ERICSSON REVIEW

RIFA – A MODERN COMPONENT MANUFACTURER
TELETRAFFIC THEORY AND ITS PRACTICAL APPLICATIONS
A DIGITAL TELECOMMUNICATION SYSTEM FOR OPERATIONAL CENTRES
A PUBLIC AUTOMATIC MOBILE TELEPHONE SYSTEM

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Contents

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COVER
Testing of hybrid circuits (speech circuits for the telephone set DIAVOX) at AB RIFA

RIFA — a Modern Component Manufacturer

Stig Larsson and Olaf Sternbeck

RIFA is a Swedish company within the Ericsson Group which manufactures components that are of great importance to the whole Group. This article gives a survey of the activities of RIFA, which will be described in more detail in a series of articles in future issues of Ericsson Review.

UDC 061.5:
621.3

RIFA was formed in 1942 by a number of major Swedish radio manufacturers in order to ensure the supply of components during the war. At the beginning of 1946 the company was taken over by LM Ericsson and ASEA, but after about a year ASEA transferred its holding to LM Ericsson. Since then RIFA has been a wholly-owned subsidiary of LM Ericsson.

The invoicing for RIFA's operations in Sweden was 5 MSKr in 1955, 175 MSKr in 1975 and 260 MSKr in 1979. Approximately half of the production goes to the Ericsson Group.

At present the company has 1600 employees in Sweden. The administration, the sales department and the monolithic and hybrid production with a total of 750 employees are situated at Kista in north Stockholm, while the capacitor manufacture with 850 employees is carried out at Kalmar and Gränna in southern Sweden. There is also a capacitor factory in France and one in Australia, with 260 and 150 employees respectively. The foreign companies are owned by LM Ericsson but are administered by RIFA in Sweden. The assembly of monolithic circuits is to a certain extent carried out by contractors in the Far East. The RIFA components are marketed by the RIFA companies and by agents and distributors around the world.

The activities of RIFA are divided up into two divisions: the IC division and the capacitor division. The IC division develops and manufactures microcircuits, such as monolithic and hybrid circuits, and resistance networks. The capacitor division develops and manufactures various types of capacitors.

Microcircuits

With a few exceptions the RIFA microcircuits are custom circuits and intended for particular purposes. The microcircuit field is undergoing rapid development and new applications appear continually. This is also the activity that is expanding most rapidly within RIFA.

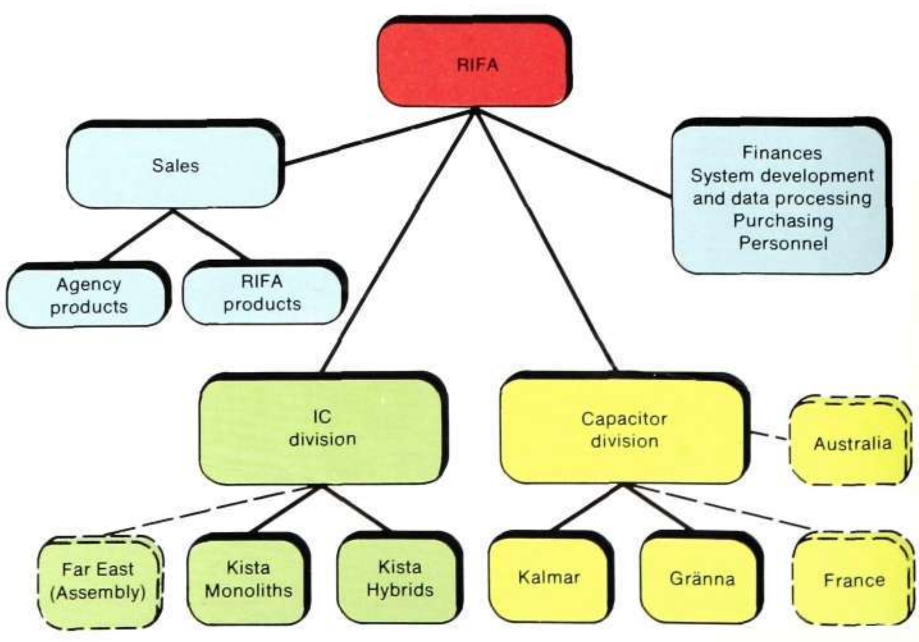

Fig. 1
The organization of RIFA

STIG LARSSON
OLAF STERNBECK
AB RIFA

Monolithic circuits

A monolithic circuit is a microcircuit that is built up on a piece of a single silicon crystal, a chip, with an area of a few square millimetres. The various circuit elements are formed by means of dopants, which change the conductivity of the silicon and which are diffused into the chip locally in different stages. The chips are manufactured on a slice of the single silicon crystal, a wafer, which is first covered with a layer of silicon oxide. Openings for the dopant are then made by means of photolithography, whereby the oxide is removed from the areas that are to be doped. This process is repeated several times, and in this way such circuit elements as pnp and npn transistors, resistors and capacitors are built up in the chip. The circuit elements are connected by evaporating a layer of aluminium, approx. 1 μm thick, on the wafer and etching out the wanted wiring pattern. The technique used permits a connector width of down to 3.5 μm. 1 mm^2 of the wafer surface can hold up to 300 logic gates.

A silicon wafer can contain several hundred to several thousand identical chips. When the chemical processes have been completed, the wafer is cut up, the individual chips are mounted on package bases, connected to the package pins and encapsulated.

RIFA apply bipolar microcircuit techniques for both linear and digital circuit functions on one and the same chip. Most custom circuits, particularly in telecommunications, are intended for circuit functions that form transitions between a central, purely digital part of a system and its environment, and which usually require linear signal processing. A monolithic circuit normally requires a quite different circuit design compared with a corresponding circuit with standard components. The translation of the customer's functional specification to an actual circuit design must therefore be carried out by RIFA, and utilize as far as possible previously defined components and be developed with the aid of circuit simulation and

Fig. 2
The plant at Kista near Stockholm

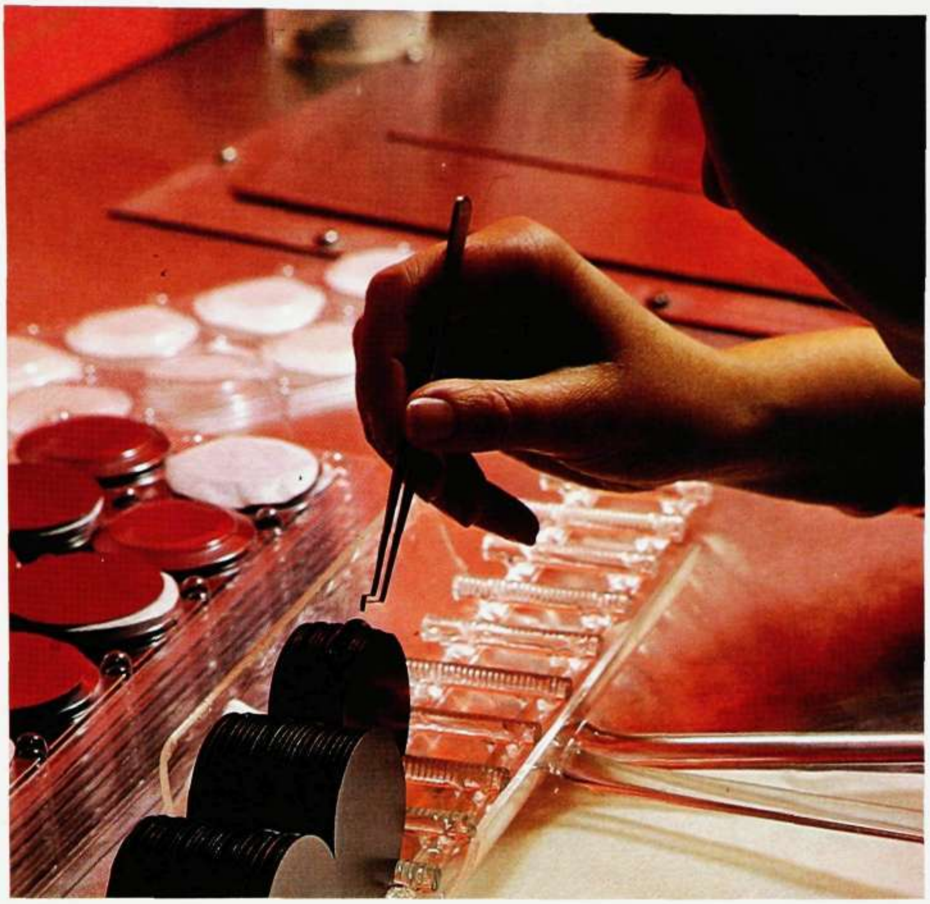

Fig. 3
A silicon wafer forms the basis for the manufacture of monolithic circuits

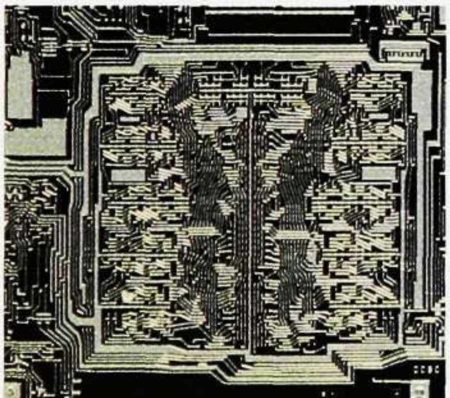

Fig. 4
A tone frequency key sending circuit for the telephone set DIAVOX

artwork construction by computer. Fig. 4 shows a two-tone oscillator for telephone sets. The circuit is controlled by a 3.5 MHz crystal and generates the required tone frequencies at the correct level and with the prescribed freedom from distortion.

The possibilities of the monolithic technique increase rapidly through the improvement of the basic technique and development of new circuit solutions.

Hybrid circuits

The RIFA hybrid circuits are of the thick film type. The base or substrate is a rectangular slice of aluminium oxide ceramic approximately 0.6 mm thick. Wiring patterns, resistance patterns and insulation layers, which can consist of metallic powder, ceramic materials or bonding agents of glass-like materials, are then screen-printed on the substrate. The printed patterns are fixed to the substrate and each other by sintering at 850° C. Wiring patterns, resistances and to a certain extent also capacitors can be manufactures direct using the thick film technique. The active elements of the circuit must be fixed and connected to the thick film curcuit either as a chip or as miniature encapsulated components. Additional components, such as miniature capacitors of ceramic or tantalum type, are connected by surface soldering.

Since several chips can be mounted on one and the same thick film circuit, the hybrid technique can be applied for larger and more complete functional units than the monolithic technique.

Thick film resistors can be trimmed to a high degree of precision using a laser ray. Trimming of functional parameters to the optimal setting can also be done. The resistors can be dimensioned to withstand high voltages, for example in units that are to be connected to the mains or to telephone lines.

The above possibilities and the freer choice of components compared with the monolithic technique means that the hybrid circuit engineering is more like that of the corresponding circuits with standard components. The circuit diagram and testing with standard com-

Fig. 5
Diffusion oven used in the manufacture of monolithic circuits

Fig. 6
Manufacture of hybrid circuits

Fig. 7
Speech circuit for the DIAVOX

ponents can to a great extent be done by the customer, but the layout and mechanical construction must be carried out by RIFA.

Thus the hybrid technique provides a wide range of possibilities. For reasons of standardization and cost the whole range of possibilities can only be utilized for circuits in which compactness and the need for complex functions are more important than the cost, for example for military and medical applications.

For ordinary applications in industrial electronics and telecommunications the costs are important and justify standardization and restrictions.

Hybrid circuits can therefore be divided into the following main categories:

- *Chip & wire: transistors and microcircuit chips* are placed direct on the substrate. This gives a compact solution but precludes capacitors.
- Soldered component technique: active components and capacitors are surface soldered to the substrate. This makes the element larger but permits the connection of capacitors of between 10 pF and 47 μF.
- Resistance networks: only resistors and wiring patterns are printed on the substrate. The method permits resistances in the range 1 ohm to 100 Mohms and tolerances of 0.5 % absolutely and 0.1 % relatively.
- Special circuits for military and medical applications.

Hybrid circuits are used where independent, complete, functional units with small dimensions are needed, and also as subunits on printed board assemblies when the demands for compactness and set module sizes make this necessary. The resistance networks replace discrete resistors, often with considerable saving of space. Moreover the resistance networks give better characteristics as regards limits and stability than the resistors generally used.

Capacitors

At present RIFA manufactures electrolytic, precision and power capacitors. The machines used for the production of

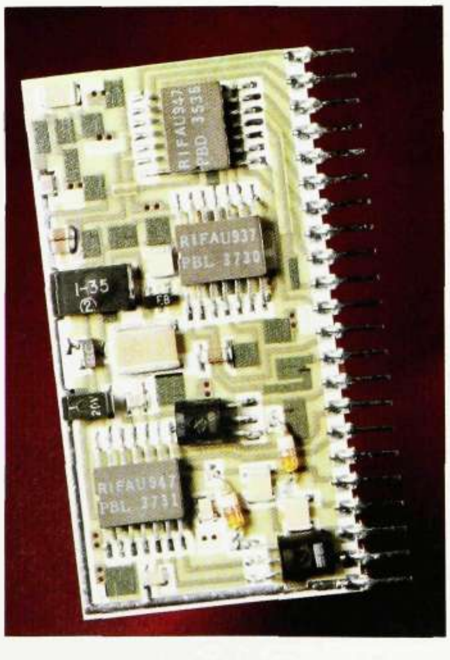

Fig. 8
A hybrid circuit

Fig. 9
Testing a hybrid circuit

Fig. 10
Winding of capacitors. The machines were designed and manufactured by RIFA

Fig. 11
Some types of capacitors manufactured by RIFA

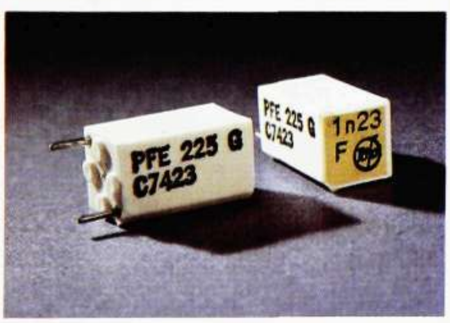

Fig. 12
Precision capacitors of the polystyrene type

capacitors are very sophisticated and in most cases designed by RIFA. The manufacturing process must be carefully controlled to give the desired product quality.

The Swedish RIFA factories produce approximately 800 000 capacitors daily.

Electrolytic capacitors

In the electrolytic capacitors the dielectric consists of a thin oxide layer, which covers the surface of a porous foil of extremely pure aluminium, the positive electrode of the capacitor. The negative electrode is in contact with the electrolyte. The electrolytic capacitors have high capacitance and cover the range 10 μF – 100 000 μF. The RIFA electrolytic capacitors are mainly of the long life type and have electrolytes that do not contain water. They are characterized by stable capacitance, long life – even in high temperatures – and low leakage current. These capacitors are used for decoupling and filtering, for example in power supply equipment for telecommunications and industrial electronics.

Precision capacitors

In precision capacitors a dielectric made of polystyrene or polypropylene film is wound, in automatic machines, to form capacitors having exactly the required capacitance. They can be made to an accuracy of 0.5 % in the capacitance range 100 pF – 1 μF. The RIFA precision capacitors are characterized by low losses, high capacitance stability and high reliability against short circuits. They are encapsulated in epoxy resin and for reasons of stability the windings are round. These capacitors are used for example in filters and in timing circuits in telecommunications.

Power capacitors

Power capacitors are used for power factor correction and motor operation, in thyristor equipment and other equipment connected directly to the mains. Paper dielectric was used earlier, but it has now been replaced by metallized polypropylene film. The advantages of this material are low heat generation and insensitivity to moisture, and the capacitors can therefore be encapsulated in plastic. Power capacitors are available in the range 1 μF – 100 μF.

Special variant MINIPRINT

By MINIPRINT is meant capacitors with a fixed dielectric of metallized paper or plastic, flatened windings and radial terminals, impregnated and encapsu-

Fig. 13
The plant at Gränna (southern Sweden)

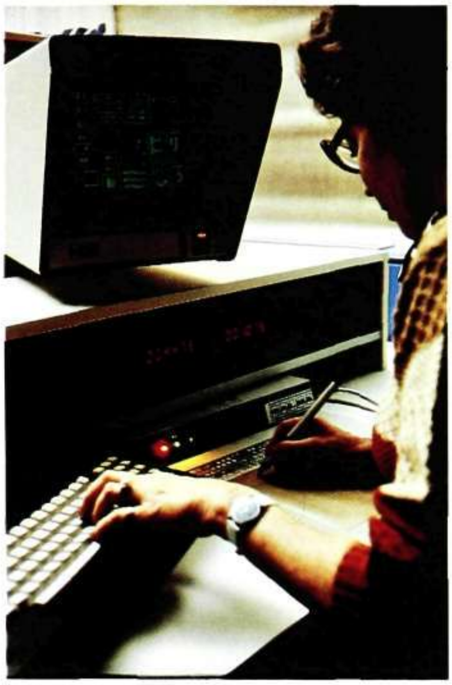

Fig. 14
The production is documented using computer-controlled construction aids

lated in epoxy resin. They cover the capacitance range 1 μF – 10 μF.

For their size, the original MINIPRINT capacitors with paper dielectric have excellent capability of withstanding high voltages and current surges of short duration. MINIPRINT capacitors with paper dielectric have become one of the major RIFA products, used predominantly to eliminate radio interference in electrical apparatus connected to the mains. They are thoroughly competitive as regards performance and size. For telecommunications applications the same basic construction is used, but with plastic film as the dielectric, which first and foremost gives better insulation characteristics and smaller dimensions with low voltages.

Characteristics of RIFA capacitors
In one or more respects all RIFA capacitors have outstanding technical characteristics. Furthermore they all meet the most stringent requirements as regards environment.

Agency

RIFA supplements its own range of components by means of an extensive agency business.

These activities, which started in 1959, now amount to 10 % of the total RIFA sales.

RIFA in the 1980s

In view of the increasing importance of electronics in society RIFA is expected to undergo very interesting development during the 1980s. The electronics companies tend to concentrate their resources on the development of systems and apparatus, and to leave the development of components, which can consist of whole subsystems, to the component companies.

RIFA has extensive development programs for new products and techniques in the field of monolithic and hybrid circuits as well as capacitors. It may be mentioned here that during 1980 – 81 the bipolar technique in the monolithic field will be supplemented by MOS technique. In the hybrid field a new construction technique will be developed that lies between monolithic and printed circuit board technique. As regards capacitors development is being concentrated on interference suppression and miniaturization.

An "LSI Design Centre" is now being built up within the Ericsson Group, with design groups placed in the various system departments in the divisions and subsidiary companies. RIFA will be manufacturing prototype monolithic circuits for these design activities. In this way the technical cooperation between RIFA and the Group will be further intensified.

Fig. 15
The plant at Kalmar (southern Sweden)

Teletraffic Theory and its Practical Applications

Christian Jacobæus

This article is a revision of a paper the author was invited to present at the Ninth International Teletraffic Congress, ITC 9. The congress was arranged by the Spanish telephone administration, Compañia Telefónica Nacional de España, in cooperation with the Spanish telephone industry and was held at Torremolinos in October 1979.

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519.87

Fig. 1
A.K. Erlang, founder of traffic research

The main aim of traffic research is to find rules for the dimensioning of telephone exchanges so that, with given service criteria, they can handle the traffic from the subscribers they serve. The research is based on observations of the nature of the traffic, including the subscribers' telephone behaviour. The rules are arrived at by means of mathematical methods from the fields of probability theory and operations research or by simulating telephone exchange functions and traffic in computers. Traffic research and its results play an important role in general system engineering in telephony. Furthermore, in their operation and administration of telephone plant, administrations make extensive use of methods and results deriving from traffic research.

The international teletraffic congresses

The first scientific contributions to traffic research came in the 1910's. In the following decades there were essential advances in several sectors. Traffic research acquired practicians in most of the industrialized countries and became an established science. In the early fifties the thought arose of arranging international congresses for this new domain. These would bring together traffic researchers for useful discussions and would, above all, be a stimulant to research. Researchers would have a forum where they could present their results. Support for the project came not only from active practicians but also, which was more important, from administrations and industry. The first congress was held in Copenhagen in June 1955 under the aegis of the Copenhagen Telephone Company (KTAS). This was natural, as the founder of traffic research, A.K. Erlang, was working at KTAS and made his investigations there. The person at KTAS who took the initiative to the congress, and was its main instigator internationally as well, was Dr Arne Jensen, later Professor at the Danish Institute of Technology.

The subject of the first teletraffic congress was defined as "The application of the theory of probability in telephone engineering and administration". Congresses have since been held every third year at different places in the world. From a rather modest start with some 70 delegates they have grown into gatherings of nearly 400.

$$E_{1,n}(A) = \frac{\dfrac{A^n}{n!}}{1 + A + \dfrac{A^2}{2!} + \cdots + \dfrac{A^n}{n!}}$$

Fig. 2
Erlang's formula published in 1917. n is the number of devices in a full availability group, A the traffic offered in erlangs, and $E_n(A)$ the probability of congestion owing to all devices being engaged

Fig. 3 (to the left)
Arne Jensen, originator of the teletraffic congresses

Fig. 4
Conny Palm – one of the pioneers of traffic research

CHRISTIAN JACOBÆUS
Telefonaktiebolaget LM Ericsson

ITC	Place	Time	Delegates		Papers	
			Number	Countries	Number	Countries
1	Copenhagen	1955-06-20--23	69	13	26	8
2	The Hague	1958-07-07--11	93	15	31	11
3	Paris	1961-09-11--16	134	20	48	12
4	London	1964-07-15--21	179	22	60	11
5	New York	1967-06-14--20	159	20	80	17
6	Munich	1970-09-09--15	310	30	108	19
7	Stockholm	1973-06-13--20	328	30	130	20
8	Melbourne	1976-11-10--17	235	27	135	23
9	Torremolinos	1979-10-16--24	392*	34*	184*	24*

* Preliminary figures

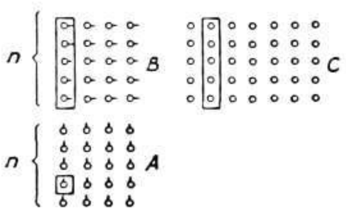
Table 1
Number of delagates and of papers read at the international teletraffic congresses

The main features of traffic research in the past 25 years

Telecommunications have undergone extensive development during the postwar period. There have been great technical advances and considerable expansion. New services have been introduced and new operational methods developed.

The events in the sphere of the congresses reflect the development of telecommunications in general, but also the advances in the purely theoretical auxiliary sciences of probability theory and operations research. Developments in the computer field have also had a great significance.

At the time of the first congress in 1955 the main interest was in the traffic-handling capacity of different groupings of switching devices and circuits. Queuing systems also played an important role. Different mathematical methods were used, mostly taken from probability theory. Most of the people engaged in these questions had an education founded on mathematics. The researchers who developed the fundamental theories were almost all mathematicians, even if some of them, like Erlang and Palm, had firm links with telephony in their daily occupation. Engineers participated as well and often made contributions of great practical value. The problems dealt with could be formulated in models which could be translated into mathematical language. In many cases, therefore, it was possible to arrive at expressions which were calculable, though often involving a large amount of work. In some cases researchers were faced with systems of equations of state which were not practically solvable with the methods of that time. As regards the basis for all investigations, namely the nature of telephone traffic, people worked entirely with idealized concepts of randomization, etc., the validity of which could be verified only in broad outline.



$$E = \frac{E_n(A)}{E_n\left(\frac{A}{b}\right)}$$

Fig. 5
Jacobæus' formula of 1950 for the calculation of congestion in link systems. E is the congestion in a two-stage link system, A the traffic offered to the framed in trunk group of the C-stage, and b the load per link in the B-stage. The numerator and denominator consist of Erlang's formula for n devices and traffic A and A/b respectively

Fig. 6
The author in an informal discussion during the teletraffic congress at Torremolinos, Spain, with (from left) Dr. J.M. Rebello, C.T.N.E., and the Spanish Minister of Communications, Sanchez Teran

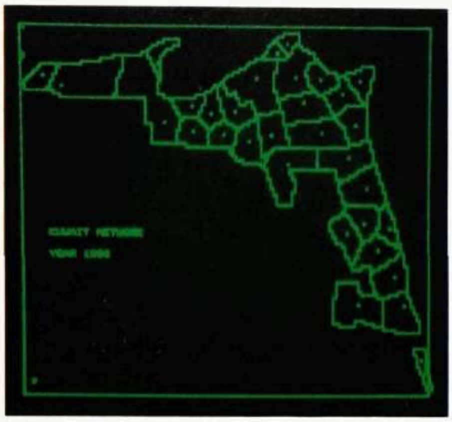


Fig. 7
In network planning exchange areas and exchange locations are optimized

Fig. 8
Did telephone traffic increase with the introduction of pushbutton dialling?

What are now the essential features in the development we have passed through? To start with, we may say that the pure *grouping problems* have fallen rather into the background. This is due to two things: one, that most of these problems have found their solution theoretically or by simulation; the other, that the modern switching systems, both with crossbar switches and with electronics, are link systems. The electronic systems often work even with negligible congestion. On the other hand it must not be forgotten that new problems have arisen. One such problem of great immediacy is the loading conditions in the computer systems for the stored program controlled telephone systems. Also different forms of alternative routing systems which constitute combinations of groupings often cause new problems.

A very striking element in the development has been an increasing emphasis on the *economic factor*. Solutions of dimensioning problems have been sought in which the controlling factor has been economy instead of solely the traffic-carrying capacity or the congestion. Both initial capital expenditure and operating costs have become parameters in the system. Network planning systems—for long distance and local networks—have essentially been treated as economic problems.

An element of great significance has been the *human factor*. Telecommunications administrations have admittedly held a special congress devoted to Human Factors, but the subscriber's behaviour in different situations also includes his telephone habits. It is therefore of direct interest to traffic researchers to observe the effect of human behaviour on telephone traffic.

New services such as data communication and telex have also, naturally, fallen within the sphere of the congresses as regards the dimensioning of networks. *Operational conditions*, too, have become a large new subject-field.

In the 25 years during which the congresses have been held the breakthrough of computers has revolutionized traffic research. Computers have permitted calculations which would earlier have been inconceivable owing to the amount of work involved. They have also made simulations of traffic systems a method with wide application.

It may thus be said that the ITC congresses have acquired an increasingly wider sphere of work, encompassing several new fields in telecommunications. One reason, of course, has been that probability theory and operations research have proved to be useful tools in increasing numbers of spheres. One consequence of this has been that the congresses have gathered a larger number of participants, representing also many different skills. The congresses have become a meeting-point for persons from different disciplines and backgrounds. It has naturally been very useful for the general development that experts from different fields have been able to meet and discuss problems relating to more than one such field. We now meet at the congresses theoreticians with training in mathematics and operations research, telephone engineers with R&D as main interest, operations technicians, behavioural researchers and administrators. It is obvious, and not merely a disadvantage, that as a rule the possibility for each participant to assimilate what is offered in papers and discussions is limited to his own speciality and surrounding subject-fields.

Problems of the future

It is naturally of great interest to consider the various subfields of traffic research from which the findings are in particular demand by industry and administrations. Traffic research here directly serves technical development. Another field of interest is purely theoretical research, which in the rather longer term may find material applications.

The nature of telephone traffic

Research on *the nature of telephone traffic* has hardly produced any very remarkable results hitherto. A certain interest has been displayed in how the volume of traffic is changed by external factors such as tariff changes and tech-

Fig. 9
How do different subscriber categories use their telephone?

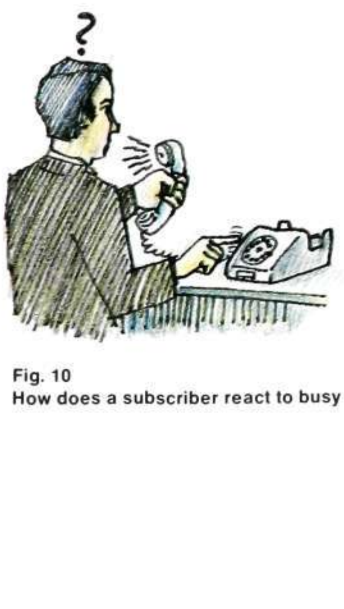


Fig. 10
How does a subscriber react to busy condition?

Fig. 11
How many people use the telephone wake-up service?

nical innovations, e.g. the introduction of pushbutton dialling. It has also been often observed that traffic increases very greatly when the grade of service is improved, e.g. through the installation of new circuits on previously underdimensioned routes. It is likewise known that the traffic increases after introduction of subscriber long distance dialling. Most administrations would undoubtedly agree that there is a slow rise of traffic over the years from existing subscribers. This is considered quite natural, as with increasing numbers of subscribers it becomes possible to communicate with more and more people. Our society seems to arrange itself in such a way that more and more matters can be settled by telephone.

It should perhaps be pointed out that this slow growth of traffic among earlier subscribers in administrations' statistics is often obscured by the fact that new subscribers have a lower average call rate than earlier subscribers. Those with greater telephoning need, of course, acquire a telephone before those with lesser need. This may face administrations with a dilemma: the new subscribers sometimes make so few calls that the amounts charged to them do not even cover the marginal costs of their subscriptions. In other cases their traffic is concentrated to particular parts of the year, which causes a skew load on exchanges and circuits. This is so in countries which, as in Scandinavia, have extensive secondary (summer) residences in the outskirts of citites. Special forms of tariff have in some cases been adopted for subscribers of this type.

Research has not come very far in revealing how the individual subscriber uses his telephone, what it is that makes him telephone or refrain from telephoning. Questions which have not been clarified are, for example:

- How do different categories of subscribers use their telephone?
- How do subscribers react to busy condition?
- How does a conversation influence the tendency for the two subscribers to make subsequent calls within a limited time?
- Is there a tendency to clustering of traffic?

The answers to these questions need not, of course, be the same for all subscribers. They may presumably also vary between urban and rural areas and between countries.

An entirely different category of questions is associated with the computer controlled exchanges. These offer subscribers new facilities: abbreviated dialling, transfer, wake-up service, to take a few examples. Measurements have been made at some places, but we do not know how these facilities affect the traffic situation in general. The traffic will presumably increase, however, through the fact that the telephone can be used for new services and that it becomes easier to use.

Dimensioning computer capacity for SPC exchanges

At a superficial glance the control computers for SPC exchanges may be regarded roughly as markers in a crossbar system. The dimensioning problems would therefore not differ greatly from those encountered in crossbar systems. The computers, however, have more complicated tasks. They represent a very strong concentration of the "intelligence" functions of the exchange, i.e. logic functions and memory.

They can also be given entirely new functions, e.g. they can change their mode of operation when overloading occurs. (In future we may have control computers which can also learn from experience!) In other ways as well they differ from ordinary markers. They perform their functions in a certain order of priority. High-priority tasks are sometimes allowed to interrupt processes with lower priority; in other cases priority gives precedence only after an ongoing process has been completed. There are usually three to six priority levels. Another complication exists in systems with several equivalent interworking computers or with super- and subordinate computers. The organization of interworking between computers has, of course, a great significance for their capacity. Special consideration must be given, to fault situations.

The problem of computer capacity can be attacked in two ways, by analytical methods and by simulation.

The analytical methods are usually based on probability theory, in particular with different applications of queue theory. The literature on this subject is considerable. Many contributions have come, too, from researchers who have studied commercial computers. Many of these studies can undoubtedly be used in SPC exchanges. The probability theory methods are usually based on very complicated mathematics. At the same time a large measure of compromise must be accepted as regards the parameters involved in order to make the problem manageable.

As in other cases where complicated processes are studied the *simulation technique* has proved to give valuable results. One can use a control computer of the type to be studied and make a full-scale simulation of an entire exchange, in which case one can get fully realistic results as regards the work of the computer. The difficulty is that this requires fairly extensive preparations and a large quantity of equipment. Furthermore alternative program principles cannot be tested.

Another way is to simulate the control computer in another computer, either all or parts of it, i.e. the functions that are relevant to the problem to be studied. This saves time but one must be careful not to carry the simplification too far.

The dimensioning of computers in SPC systems is an example of a field of traffic research where there is still much to be done. This applies, in particular, to the aforementioned complicated structures with several equivalent interworking computers or to systems with superordinate and subordinate computers.

The software plays an important part. An optimal solution requires cooperation between traffic researchers, hardware designers and software system engineers. A large measure of understanding between these three specialist groups is required if the result is to be satisfactory. It is questionable whether the development must not advance some steps further before the specialists see their own fields so clearly that the synthesis achieved by them jointly can approach the optimal. We must remember that the costs of hardware are continuously changing. Shifts of functions from software to hardware and vice versa are common. It would be desirable to have methods which allow an analysis of the consequences of such shifts.

Data traffic

When data transmission started to make its entry in earnest in the mid-1960's, the general opinion was that data traffic would be very large, even as large as telephone traffic. Later experience, however, has shown this expectation to be greatly exaggerated. It is now thought that data traffic will in due course come up to 10 % of the volume of telephone traffic. The difference

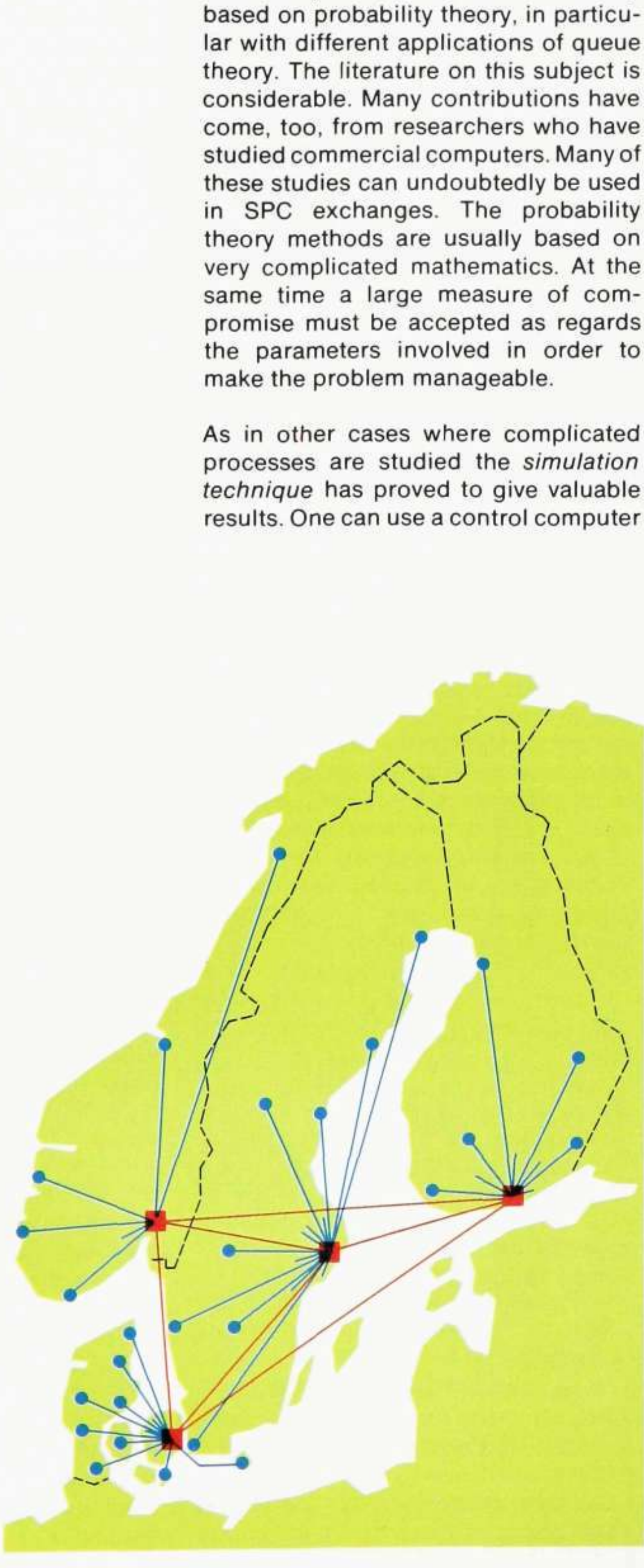


Fig. 12
Nordic data network

ion is, however, partly illusory. Data utilizes transmission media far more effectively than does speech. The amount of information transmitted as data may therefore come close to that transmitted as speech.

The technical design of data networks has proceeded along varying lines. Different solutions have been found for different types of communication. The telephone networks have served as a model only to a limited extent. No serious study has been made of data traffic. It is not known therefore whether the models used by telephone engineers apply to data traffic. This is probably not the case, at all events not when one looks at the traffic pattern of the individual data terminal.

Purely technically there would appear to be several possibilities, which complicates the picture. One can use circuit switching, which resembles ordinary telephone or telex technique, or packet switching, which involves intermediate storage of data packages with delay in the switching points; different data speeds can be chosen, etc.

At the last three ITC congresses a number of papers have been presented which deal with certain specific solutions. Another international congress, ICCC (International Conference on Computer Communication), has received a large number of contributions in this field. No overall study has been made, however, partly because of the very large number of combinations that the technique allows. Here, therefore, there is a large field for work in almost unbroken ground. The work should be directed to a deeper study both of the nature of data traffic and of dimensioning of different types of equipment. Computer and traffic experts must cooperate in this field as well in order to attain results of a universal and lasting value.

Forecasting methods

Reliable forecasts of subscriber and traffic growth would enable administrations to make extensions at the proper time. One could then be sure that investments can be optimally utilized and that the subscriber service goal can be attained. A mistake in the time of an extension may involve a delay of up to three years, depending on the planning time required and the times for delivery and installation of equipment. If there is also difficulty in financing, the times may be even longer. A premature extension or an extension at the wrong point may, of course, involve an extra cost which must be borne by the operations as a whole.

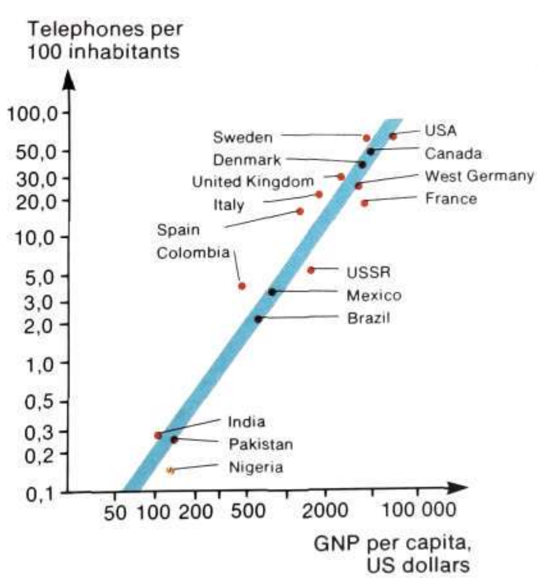
At the ITC 8 congress in Melbourne a number of papers presented the methods used by some of the leading administrations. A survey of ATT's methods was given in an invited paper. Administrations use for their forecasts large quantities of data, of trends of development in their own network, figures of the general social development, and plans for new urban and rural development with particulars of the categories of people who will live and work there. Forecasting methods can be made very sophisticated, but it is questionable whether their reliability increases in step with their complexity. ATT's representative at the Melbourne congress characterized the situation as follows:

"While it would be desirable to have an *automatic forecasting model* which would compute future telephone demand from a set of key factors, no one approach has been found that would replace or substantially reduce our reliance upon sound judgement based upon a comprehensive analysis of trends and a careful evaluation of basic assumptions and growth factors."

Traffic growth appears to be more difficult to foresee because the trends are partly obscured by seasonal variations. Traffic peaks may be caused also by chance events, e.g. a lengthy power failure. Trend methods should therefore be used with caution. All results should be considered on the basis of ordinary sound judgement. If forecast figures appear strange, the basic data should be re-examined. Experience shows that errors in this respect are not uncommon.

Forecasting methods may be expected to be of continuing importance and to be further developed to some extent. Presumably some coupling exists with other growth phenomena in the society.

Fig. 13
Relation between telephone density and GNP per capita



Technical and organizational developments in the public sector, industry and commerce will play an important part. New social patterns in the private sphere may also have an effect, particularly on traffic development. We know, for example, that in the USA and the Nordic countries the telephone is used for social intercourse much more than in other countries.

Tariffs and traffic

Among the factors which affect subscriber and traffic growth are also tariffs. In practice, however, the tariff structure is changed quite seldom, so they are hardly a significant factor in forecasts. Many administrations view tariffs as having little effect on traffic. Experience shows that a rise of tariffs has a limited and only temporary restraint on traffic. The market economy term "price elasticity" is hardly known in telephony. But as early as the ITC 2 congress in 1959 a study was presented of the relation between tariffs and traffic for tariffs made up of a monthly charge (rental) and a call charge. With data taken from many countries it was shown that the relation between call charge and rental had a decisive effect on the volume of traffic.

At the Melbourne congress a planned study in the USA was reported, with the aim of verifying the earlier findings. Unfortunately it is not known whether the study was actually made, as no results have been reported.

A Norwegian contribution also showed a distinct shift from daytime to evening traffic after a tariff differentiation in favour of the latter. The shift was, of course, more marked for residential than for business subscribers.

Studies made in the UK and the USA indicate that international traffic is comparatively insensitive to price changes. This applies only to business calls. As prices continue to fall, however, more and more people will make international calls.

Tariff issues tend to become more and more political. They are decided by governments or government-appointed bodies. The telecommunications administrations must, however, be prepared to propose tariff changes at the request of politicians (or on their own initiative). It is important to be able to foresee how a change of tariff affects traffic and subscriber growth, so that the change of revenue can be estimated. Administrations should therefore get to grips with this problem more actively than hitherto. Unfortunately this field is hardly suited for experiments, as an administration would have difficulty in assigning different tariffs to certain geographical regions or groups of subscribers.

Network supervision systems

The last three teletraffic congresses have devoted much interest to network supervision systems. This is due to a large extent to technical developments. The new SPC exchanges provide entirely other and better means for traffic supervision and traffic measurement than was earlier possible. At the same

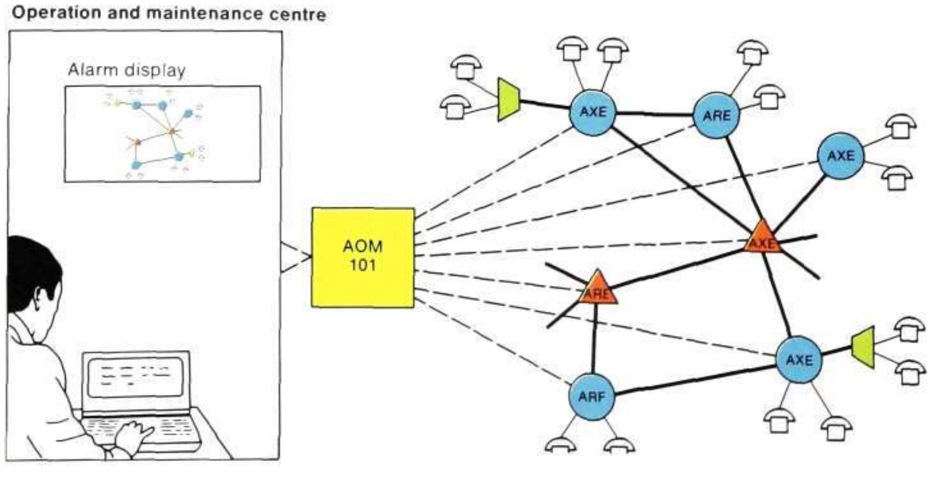


Fig. 14
SPC exchanges provide good means for network supervision

Fig. 15
The number of operators is matched to the need

time the administrative computers have permitted detailed processing of traffic data which creates a basis for more effective operation and cheaper maintenance. In older exchanges as well the attempt is being made to introduce modern supervisory and traffic measuring equipment. The development in this field has now come a bit on the way, but there is still no administration which has any lengthy experience. Some of the possibilities are discussed below.

There are four primary functions which depend upon data from telephone exchanges and network: network engineering, network administration, network management and force administration.

The role of network engineering (dimensioning) is to estimate where and how much equipment will be required in the future so that it can be ordered and installed in time to satisfy the service objectives. This has been dealt with under "Forecasts".

Network administration has the function of assigning existing equipment—lines and switching equipment—so as to obtain maximal use of it. This is more of a long-term disposition.

The purpose of network management is, from traffic data which appear at short intervals (5 minutes), to take the necessary immediate measures as regards, for example, rerouting and maintenance. These are short-term dispositions.

The object of force administration is to adapt the work-force, e.g. operators, to the current need.

The most important subfunction in a network data system is traffic measurement. The following data may be of interest for groups of devices and circuits:
- traffic flow in erlangs
- number of occupations
- mean holding time
- time congestion
- call congestion

Traffic measurements are also an aid in disturbance supervision. Disturbance supervision is affected for individual devices and for groups of devices (trunk groups). Trunks with the following disturbances can be identified:
- trunks with abnormally short holding time, "killer trunks"
- trunks which are never occupied
- trunks which are seldom occupied
- trunks which are always occupied

Since there may be computers placed peripherally in the network, the measured data can be processed close to the source. This is important, as perhaps only a small part of the primary data is of real interest. The only data which go to the central operation and supervision point are those that are needed. The computers can also be programmed so that special supervisory measures can be instituted at critical points in the network.

We shall undoubtedly see a continued development of network supervision systems in the next few years. But different administrations may be expected to have somewhat different desires. These, however, should be easy to meet with certain basic equipment together with computers programmed for the special needs in each case.

A Digital Telecommunication System for Operational Centres

Göte Brunberg and Björn Widén

LM Ericsson have developed a telecommunication system for operational centres, AXT 101. The system enables the operators at the centres to quickly establish reliable speech connections with mobile units, other operators and stationary units. The system is a new member of the well-known AX family[1, 2]. LM Ericsson's wide experience and knowledge in the fields of SPC technology and military telecommunications were utilized in the development of AXT 101. The version described in this article is intended for military operational centres.

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From a military operational centre the operations in the air, on land or at sea are controlled. The operators then continuously monitor the military situation on radar screens. The work is made easier if the operators have access to fast, reliable and flexible telecommunication equipment. Lacking such equipment, various types of point-to-point connections were often used previously. Such a system was both inflexible and uneconomical. The operators could not share the circuits, and to change a connection was a complicated and time-consuming task.

AXT 101 is used for communication with airfields and other military units, and for communication between operators. The equipment is also connected to the military and public telephone networks, and the operators can reach different stationary units via switched or point-to-point connections in these networks.

The telecommunication equipment must satisfy demands for speed, reliability and flexibility. It must also be able to handle a high calling rate, since the number of calls is large and the call duration is often short.

The function and build-up of system AXT 101 are described below, and also how the system meets the special demands made on the telecommunication equipment for operational centres.

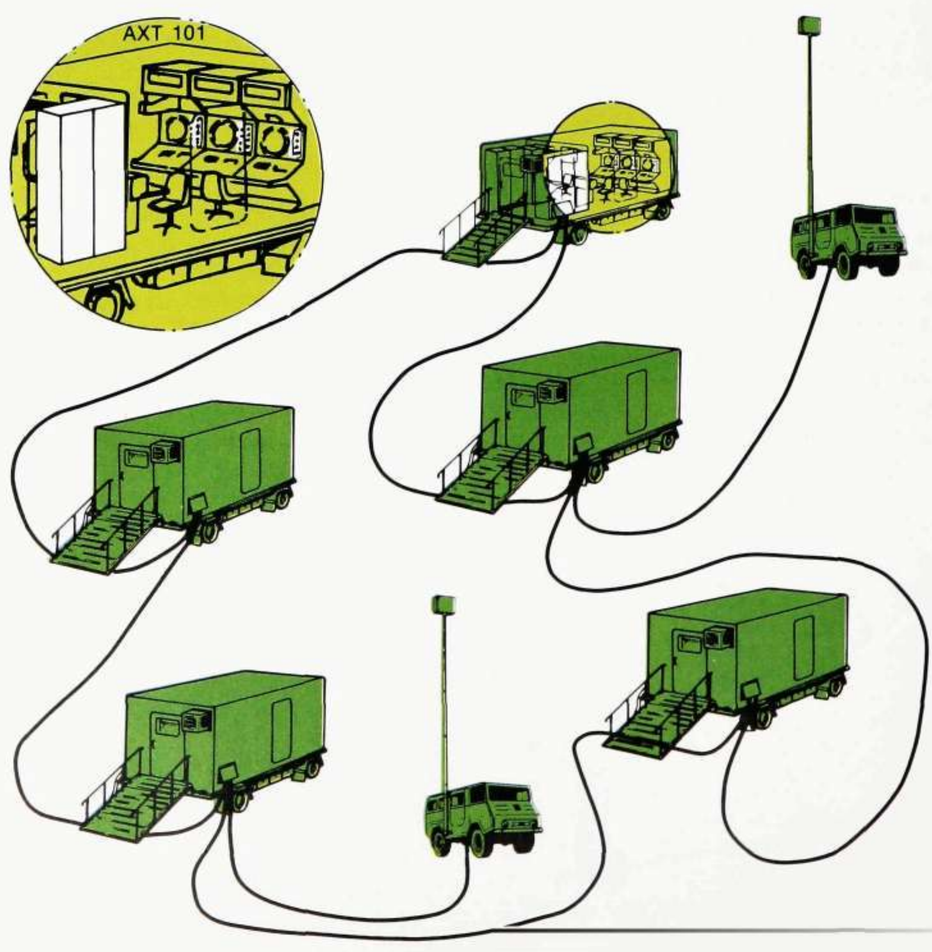

Fig. 1
A mobile version of an operation centre. The white units are AXT equipment

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BJÖRN WIDÉN
Telefonaktiebolaget LM Ericsson

Function

AXT 101 is an SPC system. It consists of a switching system with a fast and reliable digital selector stage and a data processing system with a central processor and a number of regional processors, fig. 3. The system also contains operator equipment, which comprises headsets, operator panels and control equipment. This advanced subscriber equipment makes the operators' work easier and more efficient. A connection is set up or a call is answered simply by depressing a key. For the operators AXT 101 is thus just as fast and easy to handle as a system with direct connections to different operating units.

Point-to-point connections in the military or the civil network can also be reached by all operators. Furthermore calls through these networks can be set up in the ordinary way by means of the key-set in the operator panel.

The operator panel contains a number of call keys and keys for special functions. Each call key has two light-emitting diodes, fig. 2, one for indicating incoming calls and one for indicating that the line is engaged. However, if necessary the operator can enter a call that is in progress. Each key also has a designation display, consisting of a light-emitting diode matrix, which gives the line designation in alphanumeric form. New designations are automatically indicated if the lines are redistributed.

A visual display terminal is used to allocate to the operators the lines they need to carry out their work.

If an operator has to use a new operator position, for example because of a fault in his own, he dials his own identity code from the new position. His lines will then automatically be connected to the new position.

AXT 101 can also be used to set up permanent connections between lines that would otherwise be connected via an intermediate distribution frame or a similar arrangement. One example of such lines is connections from operators to a radio station. Point-to-point connections are very easy to set up by means of

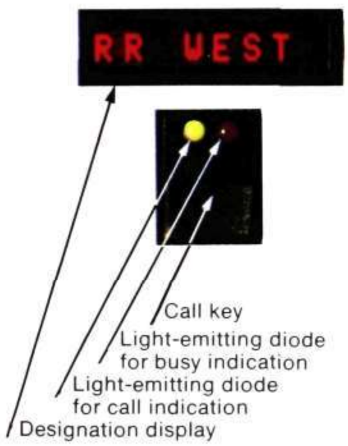


Fig. 2
Call key with its designation display

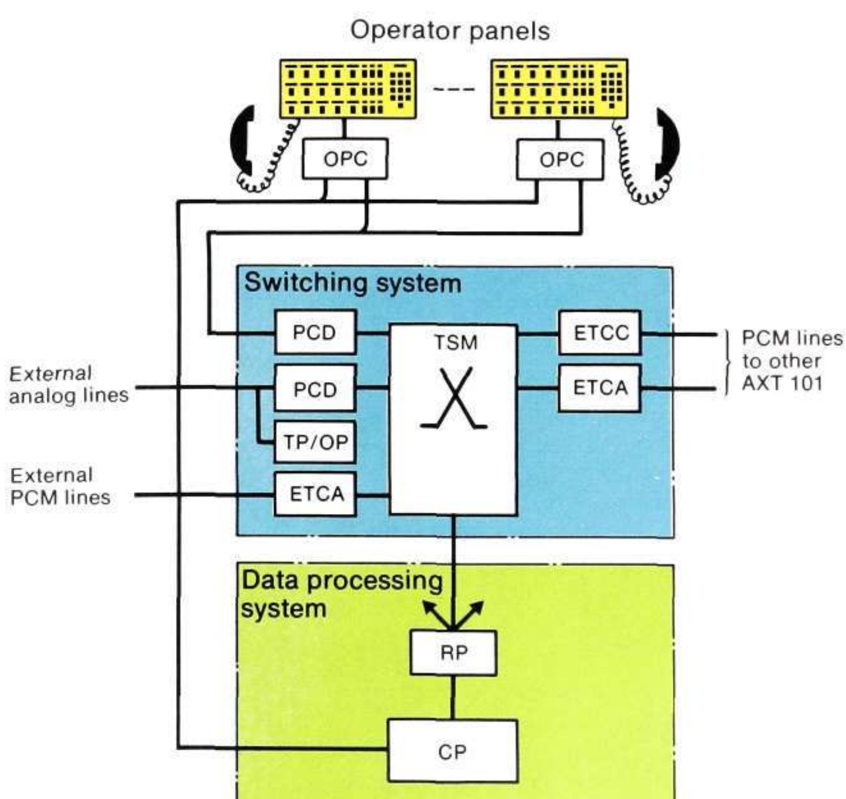


Fig. 3
A basic diagram of AXT 101

TSM	Digital selector stage
CP	Central processor
RP	Regional processor
OPC	Operator panel control equipment
PCD	Terminal device for analog lines
TP/OP	Test and operation point unit
ETCA	Terminal unit for PCM lines with channel-associated signalling
ETCC	Terminal unit for lines with common channel signalling

instructions given via a visual display terminal. They can be rearranged using the same method.

Traffic facilities

In addition to normal telephone traffic functions the system provides a number of advanced traffic facilities, which are specially adapted for operational centres. The main ones are described below.

Access to an engaged line
The operator is guaranteed access to busy lines when required. If the lamp which indicates that the line is engaged is lit, the operator can still connect to the line by depressing the call key.

Conference calls
A digital conference unit is used for conference calls. The operator initiates setting up of a conference call by depressing the call keys for the conference participants.

Long-term connections in the external automatic network
A circuit can be set up for a certain period in order to ensure immediate call connection in the automatic network even during very busy times. The circuit is then not disconnected at the end of a call. The operator is released, however, and can make other calls. He connects himself to the circuit by depressing the relevant call key.

Calling a group of operators
Operators having similar tasks can form a group with respect to incoming calls. A call to such a group reaches all operators in the group, and the first operator to become free takes the call.

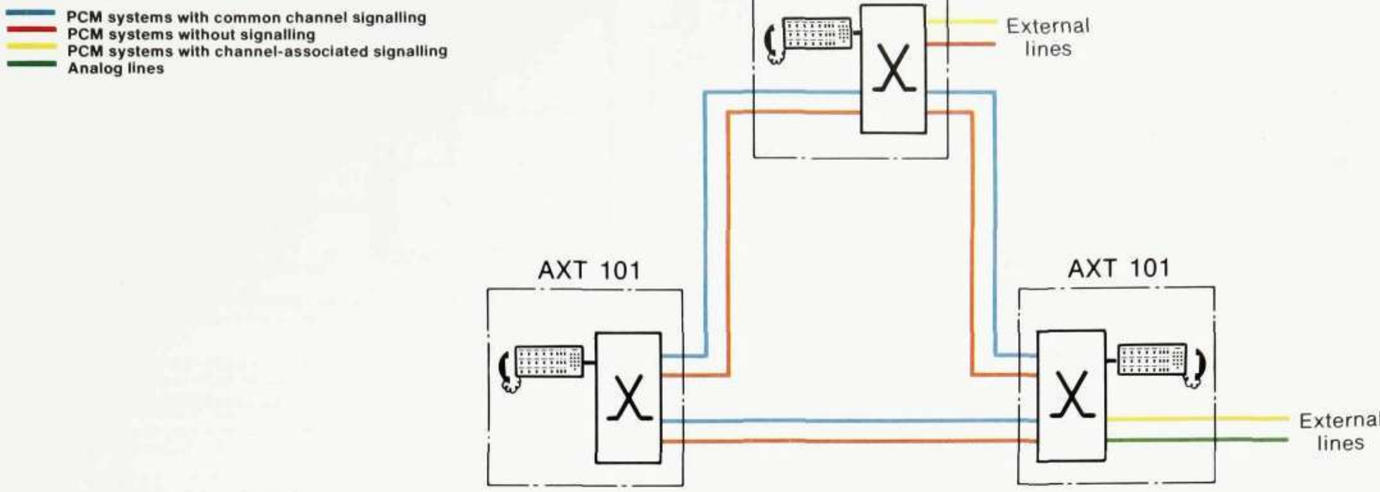
Transfer of a call to another operator
An operator can transfer a call to another operator by first depressing the call key for the other operator and then a special transfer key.

Parking of calls
If an operator has to answer or make an urgent call while engaged in another call, he can park the call in progress. When the urgent call is finished, the operator has the choice of returning to the original call or carrying out other tasks first.

Night service
When the operator hangs up his headset on a special hook or pulls out its plug, the operator equipment is automatically connected for night service. All incoming calls will then be transferred to a predetermined, manned operator posi-

Fig. 4
A central processor magazine

Fig. 5
Operational centre. The principle of connecting AXT 101 together to form one unit



tion. If this position is also connected for night service, the calls are transferred to a PABX operator or another attendant on duty.

Transfer of symbols between radar screens
Movable markers are used to identify objects on the radar screens. When an operator wants to point out a certain object to another operator, the marker is transferred to the corresponding position on the other operator's screen. This is done over a separate data channel. Since only a limited frequency band is required for the transmission, the data channel can be interleaved in the operator's normal speech channel. Special interleaving equipment is connected to the speech channels in question in order to make possible such transfer of symbols via AXT 101.

Tape recorder for continuous monitoring of speech paths
When a circuit is not used by the operator, a tape recorder which transmits a tone or a recorded message can automatically be connected. The operational unit that is waiting for an order is then kept informed that the order path remains set up.

Supervision facilities for the chief operator
One of the operator positions can be designated the chief operator position. From this position a chief operator can supervise the calls of the other operators. This can be used, for example, for training purposes.

Several AXT 101 can interwork as one unit

System AXT 101 permits the connection of several AXT 101 to form one unit, fig. 5. The characteristics of such a unit are such that it can be regarded as a single exchange. Operator positions and external lines can be connected to any AXT 101 in the unit as desired. This provides additional operational security. If one AXT 101 is knocked out or is out of order temporarily, this would not affect the remaining AXT 101 and the connections between them.

The interconnection possibility is used to create operational centres that have greater capacity than a single AXT 101 exchange can offer, or when for strategic reasons it is desired to divide the operator positions in a centre between several units, fig. 1.

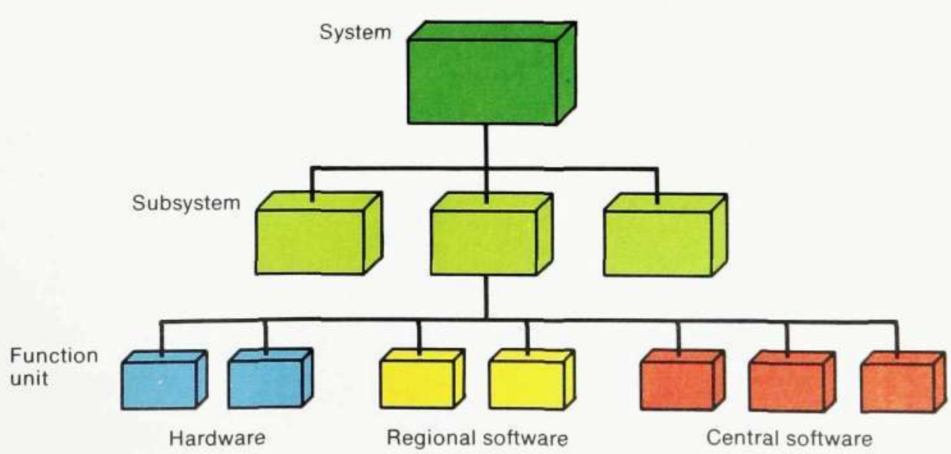


Fig. 6
The functional levels in system AXT 101

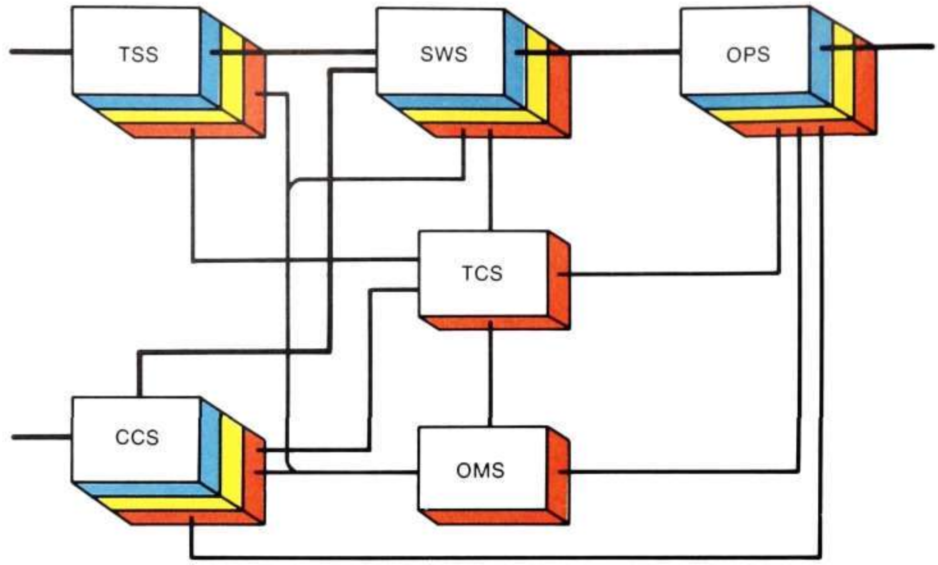


Fig. 7
Subsystems in APT 101

TSS Trunk and signalling subsystem
SWS Switching subsystem
OPS Operator panel subsystem
CCS Common channel signalling subsystem
TCS Traffic control subsystem for sending, receiving and analyzing digits, choice of route and line etc. TCS also handles the setting up of point-to-point connections
OMS Operation and maintenance subsystem for loading software, administering data changes and transmitting data between the exchanges

Hardware
Central software
Regional software

The interworking AXT 101 exchanges are connected together in a ring via one or several first-order PCM systems, fig. 5. Time slot 16 in one of these systems is used for common channel signalling. This signalling channel is used to transmit information for the setting up of connections, to order changes in data from visual display terminals etc.

System structure

AXT 101 has a modular structure with several functional levels like the successful AXE 10. AXT 101 is divided into three functional levels system, subsystem and function unit, fig. 6. The modular structure has many advantages. For example, it gives the system flexibility as modules can be added or changed to adapt the system to new requirements. This structure also makes it easier for the operators and maintenance staff to understand and handle AXT 101.

At the highest level AXT 101 consists of switching system APT 101 and data processing system APZ 101. Both these systems are divided into a number of subsystems as shown in figs. 7 and 8. The subsystems in their turn consist of function units, which comprise hardware, central software or regional software.

For the following description of APT 101 and APZ 101 reference should be made to the hardware structure illustrated in fig. 9.

Switching system APT 101
Switching system APT 101 contains six subsystems, see fig. 7. Only four of these are shown in fig. 9. The other two contain only software.

The hardware used in APT 101 is the same as that designed for the digital group selector GSS-D in AXE 10[3]. A few new printed board assemblies have been designed, for example for common channel signalling between interworking AXT 101.

Digital selector subsystem, SWS
480 speech channels can be connected to the time switch module, TSM, of the digital selector. Of these, 30 channels are required for the conference equipment MJC-D. The remaining 450 inputs to TSM are connected to PCM systems, via terminals ETCA and ETCC, and analog lines, operator equipments etc., via terminals PCD with analog/digital conversion. The switch is free from congestion. A brief description of TSM in AXT 101 is given on page 25.

The conference equipment is used both for conference calls and for the trans-

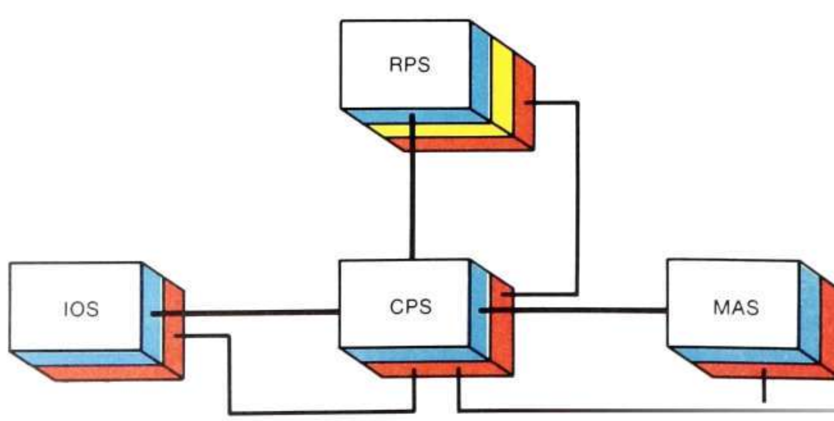


Fig. 8
Subsystems in APZ 101

CPS Central processor subsystem
RPS Regional processor subsystem
IOS Input/output subsystem
MAS Maintenance subsystem

Hardware
Central software
Regional software

mission of dialling tone, ring-back tone etc. The total number of connections with simultaneous conference calls or tone transmission must not exceed 30. This is the only restriction, otherwise the number of conference calls and participants in each call can vary as required.

The clock module CLM sends clock signals to TSM and thus controls the outgoing bit rate in the connected PCM systems. When several AXT 101 interwork via PCM systems, the clocks in question are synchronized in accordance with the master-slave method. The CLM in one AXT 101 is then designated the master clock, and the CLMs in the other synchronize with it.

Trunk and signalling subsystem, TSS
Both digital and analog lines are connected to TSS. They can be trunk lines to other exchanges as well as subscriber lines. PCM systems with channel associated signalling are connected to terminal unit ETCA. Time slot 16 is used for signalling and time slot 0 for synchronization. The remaining 30 time slots are used for speech channels.

Analog lines have six-wire connection to AXT 101. Four of these wires are used for speech and two for signalling. Thus AXT 101 meets very stringent transmission requirements.

The speech wires for 30 lines are connected to a terminal unit PCD for

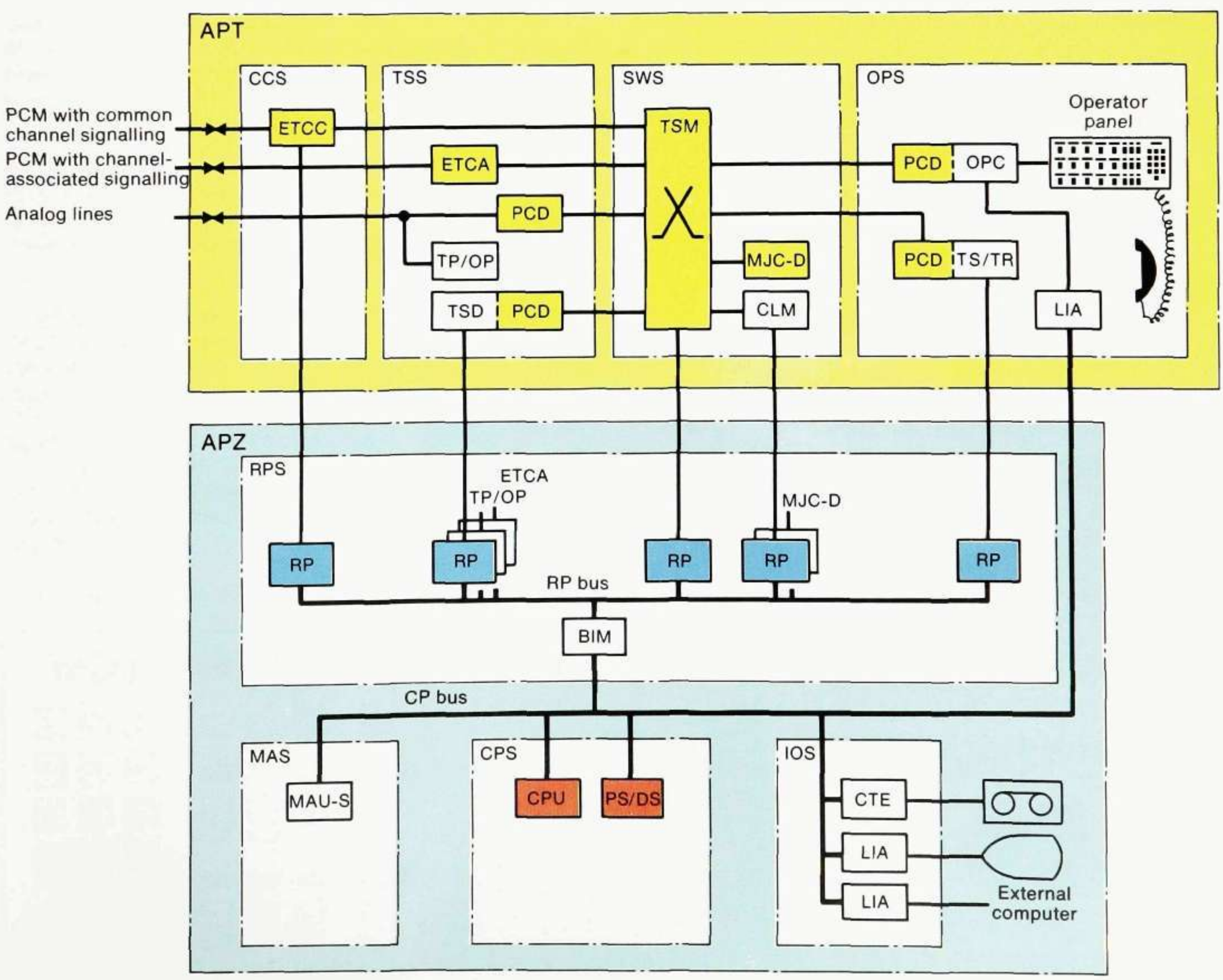


Fig. 9
The hardware structure of AXT 101

CCS	Common channel signalling subsystem
ETCC	Terminal circuit for PCM lines with common channel signalling
TSS	Trunk and signalling subsystem
ETCA	Terminal circuit for PCM lines with channel-associated signalling
TSD	Tone sender for key set tone-code sending
TP/OP	Test and operation point unit
PCD	Terminal device for analog lines
SWS	Switching subsystem
TSM	Time switch module
CLM	Clock module
MJC-D	Conference equipment
OPS	Operator panel subsystem
OPC	Operator panel control equipment
LIA	Line interface unit
TS/TR	Tone sender and tone receiver
RPS	Regional processor subsystem
RP	Regional processor
BIM	Bus interface module
MAS	Maintenance subsystem
MAU-S	Supervisory unit
CPS	Central processor subsystem
CPU	Central processor unit
PS/DS	Program and data store
IOS	Input/output subsystem
CTE	Cassette tape unit
LIA	Line interface unit

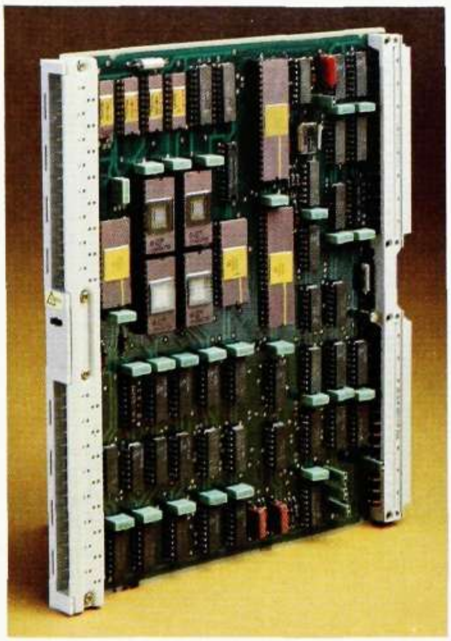


Fig. 10
Regional processor, RP

analog/digital conversion, and the corresponding signalling wires are connected to a test and operation point TP/OP for the sending and receiving of signals.

Tone sender TSD is used for digit transmission with key set tone-code sending.

Operator subsystem, OPS
OPS contains the operator panels mentioned above, operator panel control equipment OPC with line interface unit LIA and equipment for setting up long-term connections, TS/TR.

Different versions of the operator panel are available to suit different requirements. One version is illustrated in fig. 11.

OPC contains a microprocessor, which interworks with the central processor in a similar way to the regional processor. The microprocessor is used to scan the panels for depressed keys, to control the light emitting diodes in call keys and designation displays, for volume control, routine testing of OPC and the panels etc.

Physically the line interface unit LIA is placed in the central part of AXT 101. 4-wire connection is used between LIA and the remainder of the operator equipment, and the distance may be up to 1 km.

TS/TR contains the tone sender and tone receiver for signalling over the circuit when a long-term connection is set up.

Common channel signalling subsystem, CCS
When two or more AXT 101 are interworking they are connected together by means of first-order PCM systems. Time slot 16 in one of the PCM systems is used for the signalling between the AXT 101. The transmission rate is 64 kbit/s. Terminal ETCC handles this signalling. The signalling is based on CCITT signalling system no. 7.

Data processing system APZ 101
Data processing system APZ 101 consists of four subsystems:

Central processor subsystem, CPS
CPS contains a central processor unit CPU with the associated program and data stores, PS/DS.

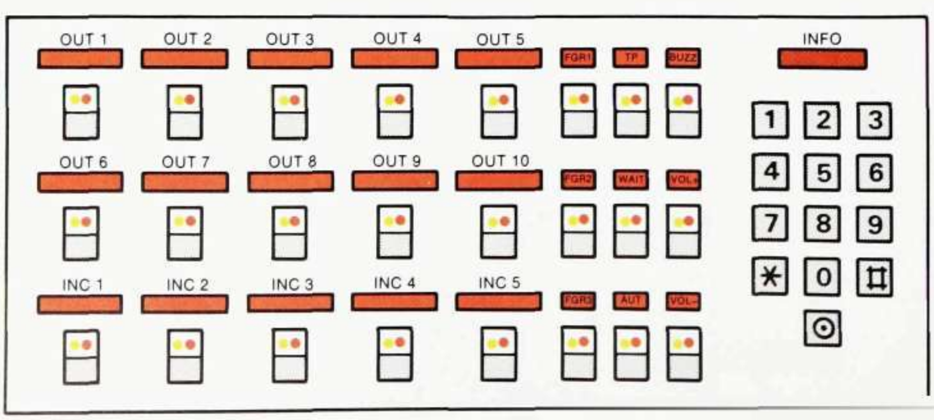
CPU is a miniprocessor, which is also used in other products made by LM Ericsson, for example the centralized operation and maintenance system AOM 101.

PS/DS is of the RAM type and has a total capacity of 176k words with a length of 17 bits. Programs and data are stored in identical memory units and the boundary between PS and DS is flexible.

Regional processor subsystem, RPS
RPS contains regional processors, RP, each of which consists of a printed board with microprocessor and the associated program and data store, fig. 10. Each regional processor controls its functional unit (TSM, CLM, ETCC, TP/OP, TS/TR or TSD), and is placed in the controlled unit. The regional processors carry out frequently recurring routines,

Fig. 11
One version of the operator panel with call keys, auxiliary keys, light-emitting diodes, designation displays and key-set

OUT 1–10	Call buttons for direct connection of calls without dialling. The associated designation strips show the designations of the lines
FGR 1–3	Keys for group selection. By using FGR it is possible to use each OUT button for several lines and thus increase the capacity of the panel
INC 1–5	Keys for answering incoming calls. All calls are put in queues on the INC lines, whose designations are shown above the associated buttons
TP	Key for transferring a call to another operator
WAIT	Key for parking the call in progress
AUT	Key for setting up connections with the aid of the key-set, for example to the military and public automatic networks
BUZZ	Key for connecting an acoustic signal for calls to the operator panel
VOL+ VOL–	Keys for increasing and reducing the sound level. The regulation range is 21 dB in steps of 3 dB
INFO	A designation strip giving the identity code of the operator using the panel



such as scanning of line states, and thus relieve the central processor of such simple but capacity demanding tasks. The program store is of the EPROM type and the data store is of the RAM type.

The bus interface unit BIM is a communication link between the central processor and the regional processors.

Input/output subsystem, IOS
IOS contains the interface units CTE and LIA for interworking with I/O units.

CTE is a unit for connecting the cassette tape recorder that is used for loading programs and data.

LIA is used for connecting the visual display terminal for various operational and maintenance purposes, and for communicating with an external computer when transferring marker symbols.

Maintenance subsystem, MAS
MAS contains a unit MAU-S, which supervises the program handling of the central processor and initiates restart in case of a fault. The function of MAS is described under "Operational supervision" below.

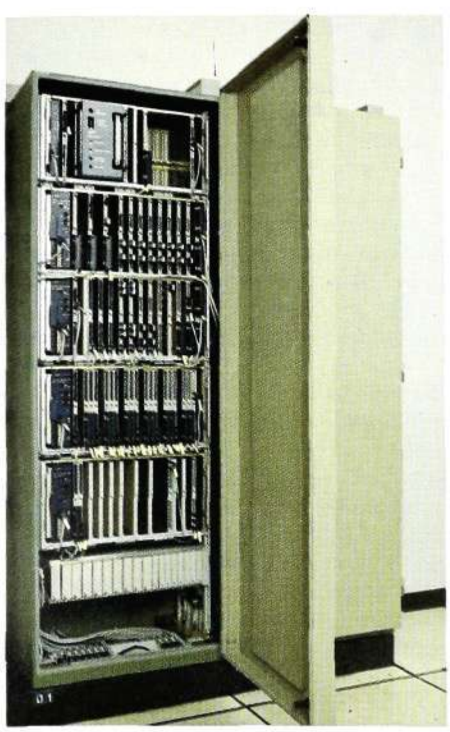


Fig. 12
Cabinet for AXT 101

Software

The central software has a modular structure. Each subsystem in APT 101 and APZ 101 contains a number of function units, which consist of one or more programs and associated data. Each program deals with one well defined function. This makes the software easier to understand and maintain.

A high-level assembler language developed by LM Ericsson has been used to design the central software. This language combines the normal advantages of an assembler language – good utilization of the store and fast program handling – with the good structural properties of a high-level language.

When an exchange is put in operation the programs and data are loaded from a cassette tape recorder. In order to prevent the spreading of faults, the parts of the store that contain programs and data that are individual to the exchange are protected against writing. Temporary data, concerning the setting up of connections etc., are stored in parts of the store that are not barred to writing of data.

The regional software is written in assembler language. In the various regional processors the programs are stored in EPROM type stores.

Mechanical construction

The function units in AXT 101 are built up on printed circuit boards, which are mounted in magazines. Each magazine is equipped with a voltage converter, which converts -48 V to the required voltages.

The magazines are mounted in cabinets, which when closed provide protection against electromagnetic interference, fig. 12. Each cabinet holds six magazines. An air conditioning system blows cool air at the bottom of the cabinets. The warm air is conducted away from the top of the cabinets.

In exchanges where special protection against interference is not necessary, the magazines are mounted in cabinets with openings for natural circulation of cooling air.

```
ALLOCATION TABLE FOR OPERATOR 004

CALL   DESTINATION
KEY    CODE

01     RR NORTH
02     AIRB. N1
03     AIRB. N2
04     MISS. N1
_05    MISS. N2

06     RR SOUTH
07     AIRB. S1
08     MISS. S1
09     RR WEST
10     OP 128
```

d. The alteration is introduced in the system by pressing the key again and acknowledged on the marked line

```
ALLOCATION TABLE FOR OPERATOR 004

CALL   DESTINATION
KEY    CODE

01     RR NORTH
02     AIRB. N1
03     AIRB. N2
04     MISS. N1
05     NAVY HQ1

06     RR SOUTH
07     AIRB. S1
08     MISS. S1
09     RR WEST
10     OP 128

05     MISS. N2
```

c. The designation of the new line is written on the alteration line

```
ALLOCATION TABLE FOR OPERATOR 004

CALL   DESTINATION
KEY    CODE

01     RR NORTH
02     AIRB. N1
03     AIRB. N2
04     MISS. N1
05     NAVY HQ1

06     RR SOUTH
07     AIRB. S1
08     MISS. S1
09     RR WEST
10     OP 128

05     NAVY HQ1
```

b. An alteration key is depressed, whereby the marked line is printed on an alteration line

```
ALLOCATION TABLE FOR OPERATOR 004

CALL   DESTINATION
KEY    CODE

01     RR NORTH
02     AIRB. N1
03     AIRB. N2
04     MISS. N1
_05    NAVY HQ1

06     RR SOUTH
07     AIRB. S1
08     MISS. S1
09     RR WEST
10     OP 128
```

a. The original table, where the line to be changed is marked

Fig. 13
Changing data with the aid of a table displayed on the screen. The example shows how operator no. 4 is allocated a new line on call button no. 5 in the operator panel

Two cabinets are required for a normal AXT 101 exchange.

Installation and testing

The installation starts with the erection of the cabinets, after which external cabling and power cables are run and connected. The magazines, equipped with printed board assemblies, are then mounted in the cabinets. The magazines are connected by means of front cables with plugs at both ends, which are plugged into jacks on the fronts of the printed boards. All cables whose length are known in advance are factorymade.

An AXT 101 in an operational centre must satisfy exacting reliability demands immediately it is put into operation. Before delivery the hardware therefore undergoes long-term testing. In connection with this the whole exchange is tested as a unit. Any faulty unit is indicated by the test functions built into the exchange. The extensive final testing greatly simplifies the installation testing.

Operation and maintenance

One of the principal aims during the development of AXT 101 was to make the operation and maintenance work as simple and efficient as possible.

Exchange data easily altered

AXT 101 often forms part of operational centres that are moved from one place to another. The exchange data must then be altered to suit the new network. For this purpose different sets of exchange data can be stored on a cassette tape. The relevant exchange data are then fed in before the exchange is put into operation in a new place.

Exchange data are often added to or changed, for example in order to allocate new lines to the operators. This process has therefore been made very simple. Current data are displayed in text en clair on the chief operator's visual display terminal in the form of clear and lucid tables, fig. 13. The chief operator can make the necessary changes and additions simply by erasing and adding to the tables, and can see in the tables on the display that the new data are correctly entered.

If several AXT 101 are connected together to form one unit, all AXT 101s must contain identical exchange data. When the chief operator changes the data in one AXT 101, the same changes are automatically made in all the others.

In the case of a mains break, the exchange data are fed out from the store to a cassette tape. If the breakdown is so long that the exchange stops, the store will be reloaded from this cassette tape at the restart.

Operational supervision

The individual function units and the PCM system connected to the exchange are efficiently supervised. When a fault is detected, an indication is obtained that specifies the type of fault. An alarm is then sent to a supervisory position. The different alarms are divided into three categories according to the degree of urgency. The alarm category and the cause of the fault are stated on a visual display terminal.

The central program handling is monitored continuously. When a fault is detected, a system restart is carried out automatically. This function is an excellent aid in maintaining the operational reliability of the system, since it limits the effects of any disturbancy.

There are two types of restart, minor and major. A minor restart is made in the case of small faults and the calls in progress are then not disturbed. A major restart is carried out when minor restarts have been made several times without any positive result, or when a serious program handling fault has occurred. A major restart means that the central processor is reloaded with programs and data, so that any degenerated software is replaced by the correct material.

Checking the operator panel

The operator equipment includes functions for testing all light-emitting diodes and designation displays. The operator initiates this test by punching a special code on the key-set.

Digital selector

The digital group selector for AXE 10 has been described in an earlier issue of Ericsson Review[3]. The article also dealt with the basic principles of PCM, time multiplex and the function of the digital selector.

The digital selector in AXT 101 consists of only one time switch module, TSM, which on the input side contains a speech store, SSA, and on the output side another speech store, SSB, fig. 14.

512 channels can be connected to SSA and SSB. This corresponds to a total of 16 first-order PCM systems and analog/digital converted 30-groups.

Since the selector consists of only one TSM there is no need for a normal space switch module SPM. However, in order to retain the well-tried design from AXE 10, a very simple space switch link module SPMS has been added.

A central store CSA(B) is used to determine which internal time slots are to be used for each call. There are as many internal time slots as there are store positions in SSA and SSB. The choice of time slot is controlled by the central software.

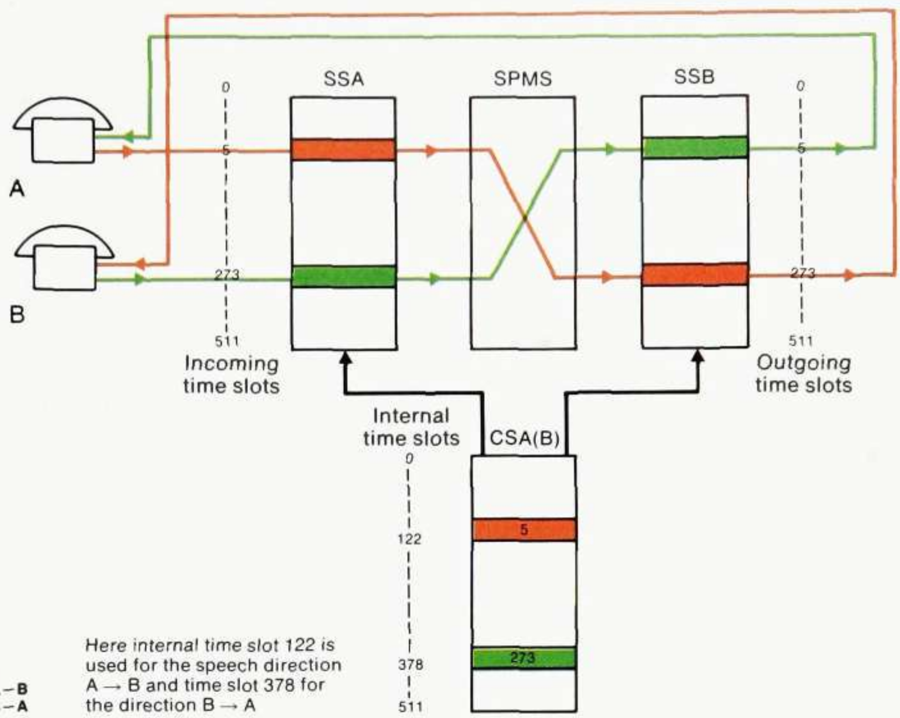


Fig. 14
The principle of the digital switch module TSM

Speech and control data for speech direction A – B
Speech and control data for speech direction B – A

Summary

Some of the most important features of system AXT 101 are summarized below:

- Each operator has an advanced subscriber equipment, consisting of headset, operator panel and control equipment, which makes his work simple and efficient.
- The system offers a number of valuable traffic facilities:
  - conference calls
  - calling a group of operators, the first free operator answers
  - transmission of markers between radar screens
  - continuous supervision of order paths.
- Two or more AXT 101 exchanges can be connected together to form one unit. Even if one exchange is knocked out, the others will still function and interwork as usual.
- Efficient testing methods guarantee AXT 101 high reliability right from the start.
- Additions to and changes in the exchange data are easily made from a visual display terminal.
- All units are continuously supervised and an alarm is given if a fault is detected. The cause of the fault is given on a visual display terminal.

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A Public Automatic Mobile Telephone System

Olle Billström and Björn Troili

LM Ericsson, together with their subsidiary SRA Communications AB, have developed an automatic mobile telephone system for connecting mobile telephones to the public telephone network. The system gives the mobile subscribers access to all facilities offered by the public network, and also to a number of new services of special value for mobile traffic.

The mobile telephone system can be given the same coverage as the country-wide public telephone network. If a neighbouring country has also installed the same mobile telephone system, telephone calls can be made to mobile units visiting that country via the telephone exchanges in the neighbouring country.

The telephone system has been designed to the sophisticated requirements set by a working party formed by the Nordic telecommunications administrations. Initially the system will be installed in Denmark, Finland, Norway and Sweden.

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The use of mobile radio communication is increasing rapidly all over the world. Transport companies, such as freight and taxi companies, industries, forestry enterprises and local authorities are some categories which have found mobile radio communication very useful. Most automatic systems of today are designed for companies and their internal needs. The public country-wide mobile telephone services that are now in operation in several countries are manual, i.e. they require the assistance of operators to establish the calls.

The development of an automatic country-wide mobile telephone system for connection to the public network has become feasible during recent years through the rapid development in the field of radio technology, for example of:

- digital frequency synthesis, which makes it possible to set the frequency for hundreds of channels from a single control crystal
- LSI circuits and microcomputers, which make it possible to construct small mobile radio equipment with complex signalling and control functions at a reasonable cost.

This article describes first the general structure and the special functions of the mobile telephone system, then the three main parts of the system, which are: exchange equipment, which is based on the normal AXE 10 system, base radio stations and mobile subscriber equipments.

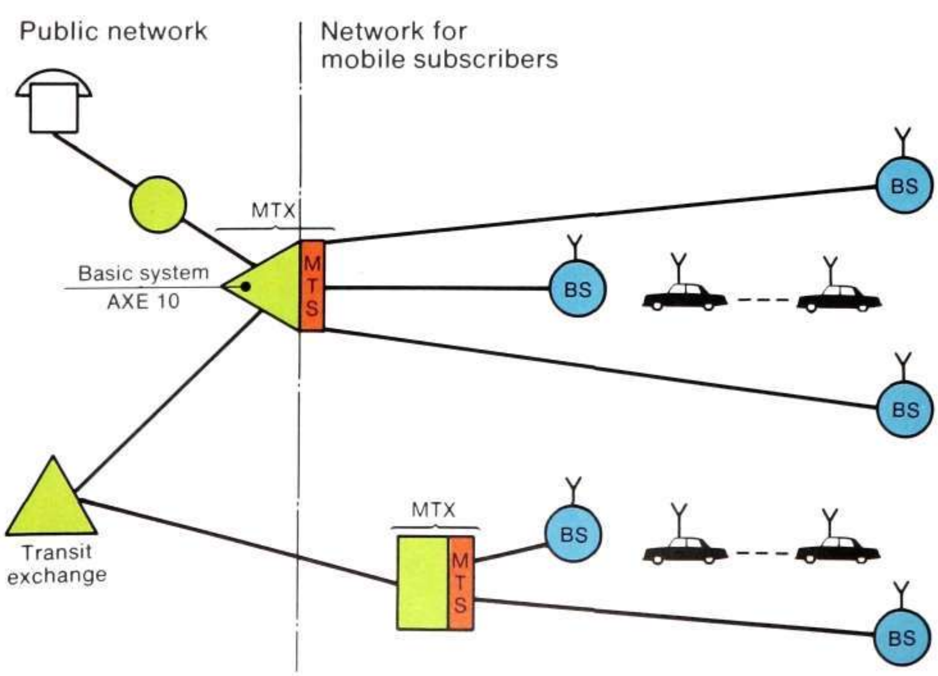
The basic elements of the system

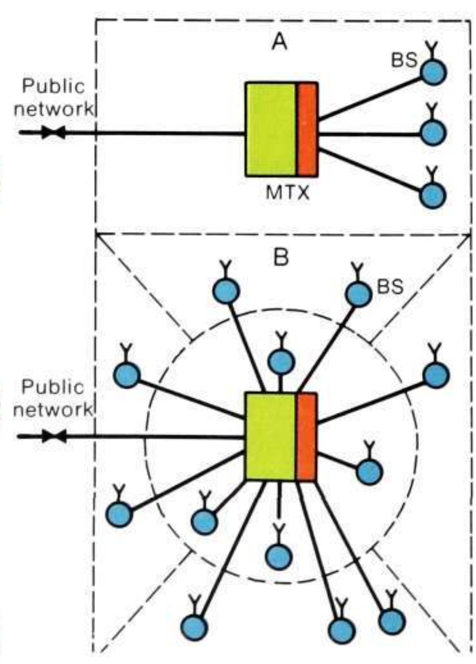
The three basic elements of the mobile system, fig. 1, consist of:

Mobile subscriber equipments (mobile stations), which are small radio stations mounted in vehicles. They are equipped with push-button sets so that the drivers can easily establish speech connections through the public network.

Fig. 1
The basic principles of a network with mobile subscribers, and their connection to the public network via AXE 10

Fig. 2, right
Two examples of the division into traffic areas:
In example A the MTX serves only one traffic area
In example B the MTX serves five traffic areas





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Base radio stations, BS, which handle the radio communication with the mobile subscribers in their own area. They transmit all signals between the radio network and the telephone exchange equipment.

The telephone exchange equipment, which consists of a subsystem, MTS, in the telephone exchange system AXE 10. The subsystem makes it possible to connect the base radio stations to AXE 10 via ordinary telephone lines. Thanks to the functional modularity of AXE 10 it is possible to use these AXE 10 exchanges either jointly for mobile and ordinary telephone traffic, or to use them only for mobile traffic. The part that is used solely for mobile telephone traffic is designated MTX.

Network structure and frequency plan

A network is built up of base radio stations, BS, the number and placing of which are dependent on the size and topography of the country, and on the number of subscribers who are to be served. The radio stations that are connected to one and the same telephone exchange form one or several traffic areas, fig. 2. Within a traffic area a call to a mobile subscriber is transmitted in parallel from all base radio stations in the area.

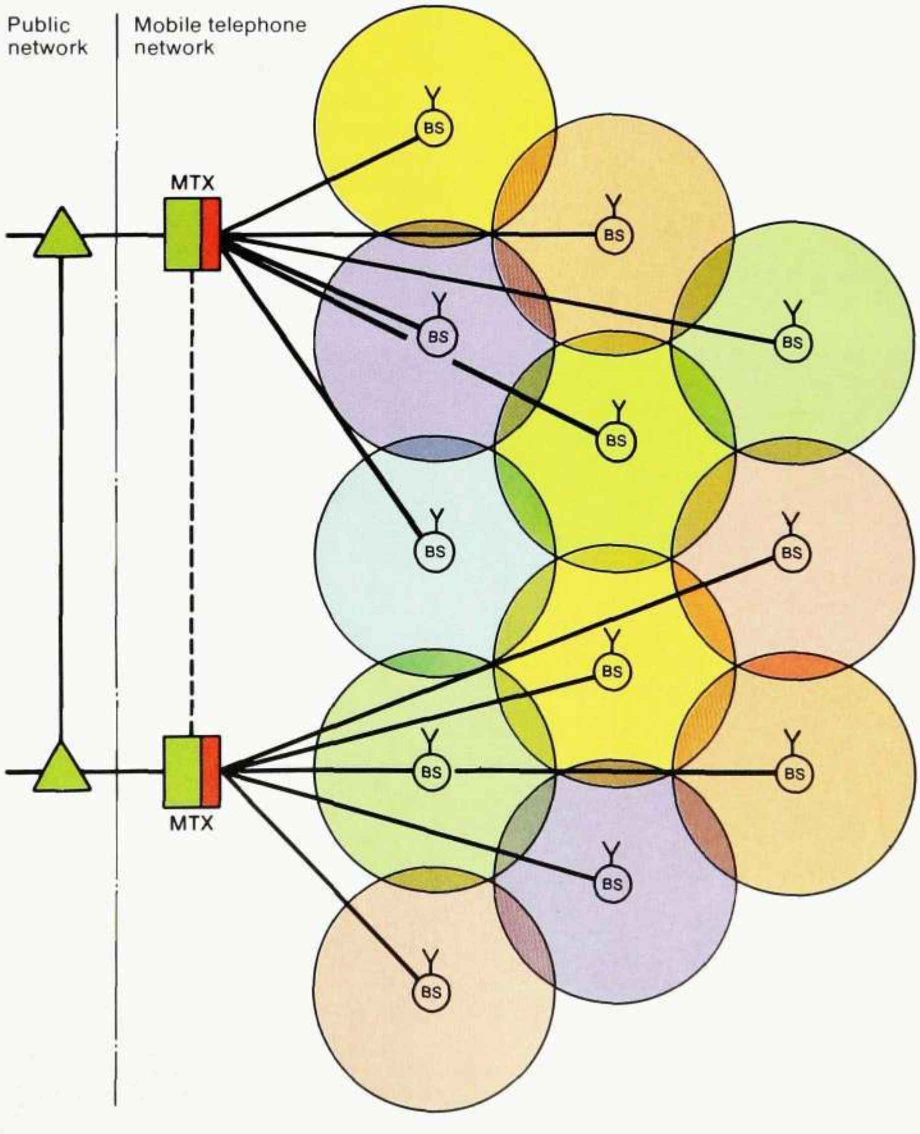


Fig. 3
A typical frequency plan. Adjoining base stations, BS, operate on different frequencies, but stations at a sufficient distance from each other can use the same frequencies. (In a typical case seven different groups of frequencies are required)

Adjacent base radio stations transmit at different frequencies, fig. 3. One channel in each base station is used as the calling channel. The others are traffic channels. The type of channel is indicated by a code in the signalling format. This arrangement is so flexible that a calling channel can be used as a traffic channel and vice versa. This is particularly useful in areas with little traffic and only a few channels per base station. Moreover the system can change channel by altering the channel marking, for example in the case of a fault on the calling channel. The range of a base station is dependent on the height of the aerial and the topography, and it is usually 20–30 km.

Each radio connection uses two channels, one for sending and one for receiving. Together the two channels form a duplex channel. The spacing between the sending and receiving frequency, the duplex spacing, is 10 MHz. The maximum number of duplex channels in the mobile station is 200 with a spacing of 25 KHz between adjacent channels. The total bandwidth required is 2×5 MHz, i.e. 5 MHz in each direction.

Since the same frequencies can be used in different geographical areas, fig. 3, the total number of channels in a country can be considerably higher than 200, with a proportional increase in the traffic capacity. For example, in Sweden it is calculated that about 250 base stations with a total of 1000 speech channels will provide sufficient traffic capacity for approximately 40–50 000 mobile subscribers in a fully extended system.

Calling methods

A call to a mobile subscriber is made in the same way as a trunk call. First the code of the service is dialled, immediately followed by the subscriber number of the mobile station. A call from a mobile station is carried out as if the station was connected direct to the public network.

Call to a mobile subscriber

The mobile telephone system constitutes one number group in the national numbering plan, and the service can be reached by one and the same code from any place in the country. Each mobile subscriber has a unique subscriber number within the number group.

A call to a mobile subscriber is made by dialling the code, which can contain 1, 2 or 3 digits, and then the subscriber number. The code and the first one or two digits of the subscriber number connect the calling subscriber to the correct telephone exchange, MTX. When the whole number has been received, MTX analyzes it with regard to validity, subscriber category (i. e. barring category) and the traffic area of the called subscriber. The exchange then

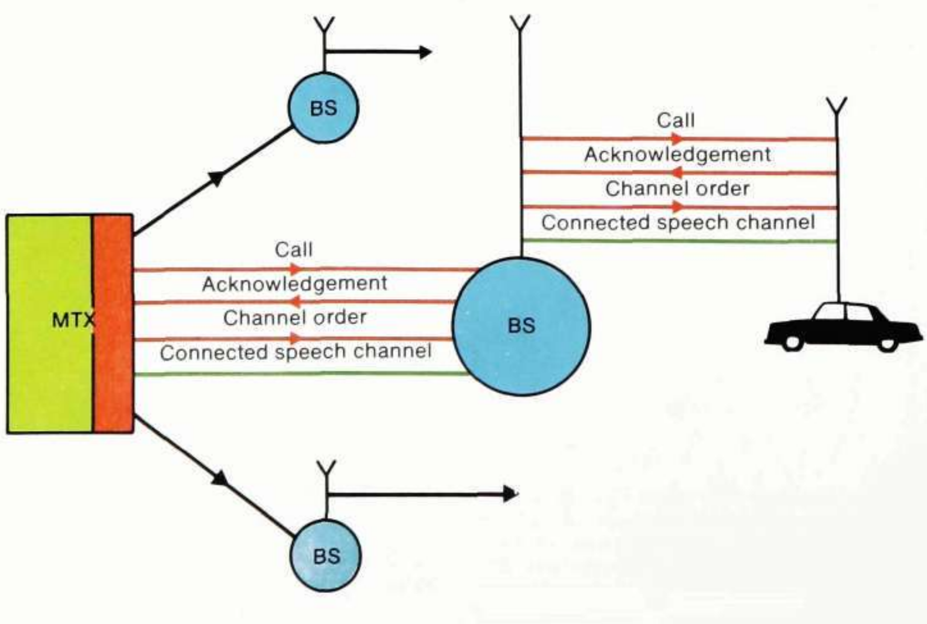


Fig. 4
Call to a mobile subscriber. Signalling takes place on the calling channel, after which a speech channel is connected in

Signalling on the calling channel

Traffic channel, which is seized by MTX and to which the mobile station switches on order transmits a calling signal over all base radio stations in the traffic area in question, fig. 4.

When the subscriber is free, his mobile station is set to the calling channel from a base station that gives an acceptable transmission quality. When the mobile station detects the call it automatically sends an acknowledgement signal on the same channel. The telephone exchange has then located the base station from which the called mobile subscriber can be reached.

The exchange, MTX, seizes a free traffic channel to this radio station and sends an order, on the calling channel, to the mobile station. The mobile station then switches over to the specified traffic channel, after which a normal identification procedure, "handshaking", takes place on the traffic channel.

Call from a mobile subscriber
A mobile subscriber who wants to make a call first dials the desired number and then initiates the call by lifting the handset. The mobile station then starts to hunt for a free traffic channel to a base station in the traffic area. When the mobile station has found a free channel and called, the normal "hand shake" takes place and the number of the caller is automatically transmitted to the exchange, MTX, which is the local exchange of the mobile subscriber. MTX analyzes the subscriber category and the dialled number, and the call is then set up.

Switch-over methods

Since the subscribers are mobile, a subscriber has to be switched over to another telephone exchange when he has left the area covered by his own exchange. If a subscriber leaves the coverage area of one base radio station during a call, he must be switched over to another station while the call is going on.

Switch-over to another exchange
Each mobile subscriber is registered in a certain telephone exchange, his "home exchange" (MTXH). When a subscriber moves to a traffic area for another exchange, "visited exchange" (MTXV), his incoming calls are automatically transferred to the latter exchange. This procedure is called roaming.

Fig. 5
An AXE 10 exchange

As soon as a mobile station enters a new traffic area, whether it is served by the same or another exchange, the mobile station detects this by identifying the traffic area code given on the calling channel. The mobile station then automatically calls the exchange, which can be MTXH or MTXV. The exchange notes which traffic area the subscriber has now entered. If a new MTXV has been called, this exchange signals to the subscriber's MTXH that the subscriber is in the new traffic area. MTXH acknowledges by sending information regarding the subscriber category to MTXV, which stores the information together with the subscriber number and the traffic area identity.

A call to a mobile subscriber is always first routed to the home exchange MTXH. When necessary, the call is rerouted to the visited exchange MTXV with the aid of the above-mentioned position information.

Switch-over to another base station during a call
When a subscriber moves out of the coverage area of one base radio station into the area of another during a call, the call is switched over from the first station to the second.

The transmission quality of every call in progress is monitored with the aid of a pilot tone (4000 Hz). The signal is transmitted from the radio station to the mobile station and back again.

When a call has to be switched over, the telephone exchange orders a field strength measurement on the relevant traffic channel from adjacent base stations. If another base station offers better transmission quality, the telephone exchange investigates whether there is a free speech channel from this base station. If so, the call is switched over to this channel.

Signalling principles

Binary signalling is used for the exchange of information between the telephone exchange and the mobile station. The same system is used for the remote control of the base station. The modulation method for signalling is frequency shift at a speed of 1200 bit/s. The shift frequencies are 1200 and 1800 Hz. The use of these frequencies means that

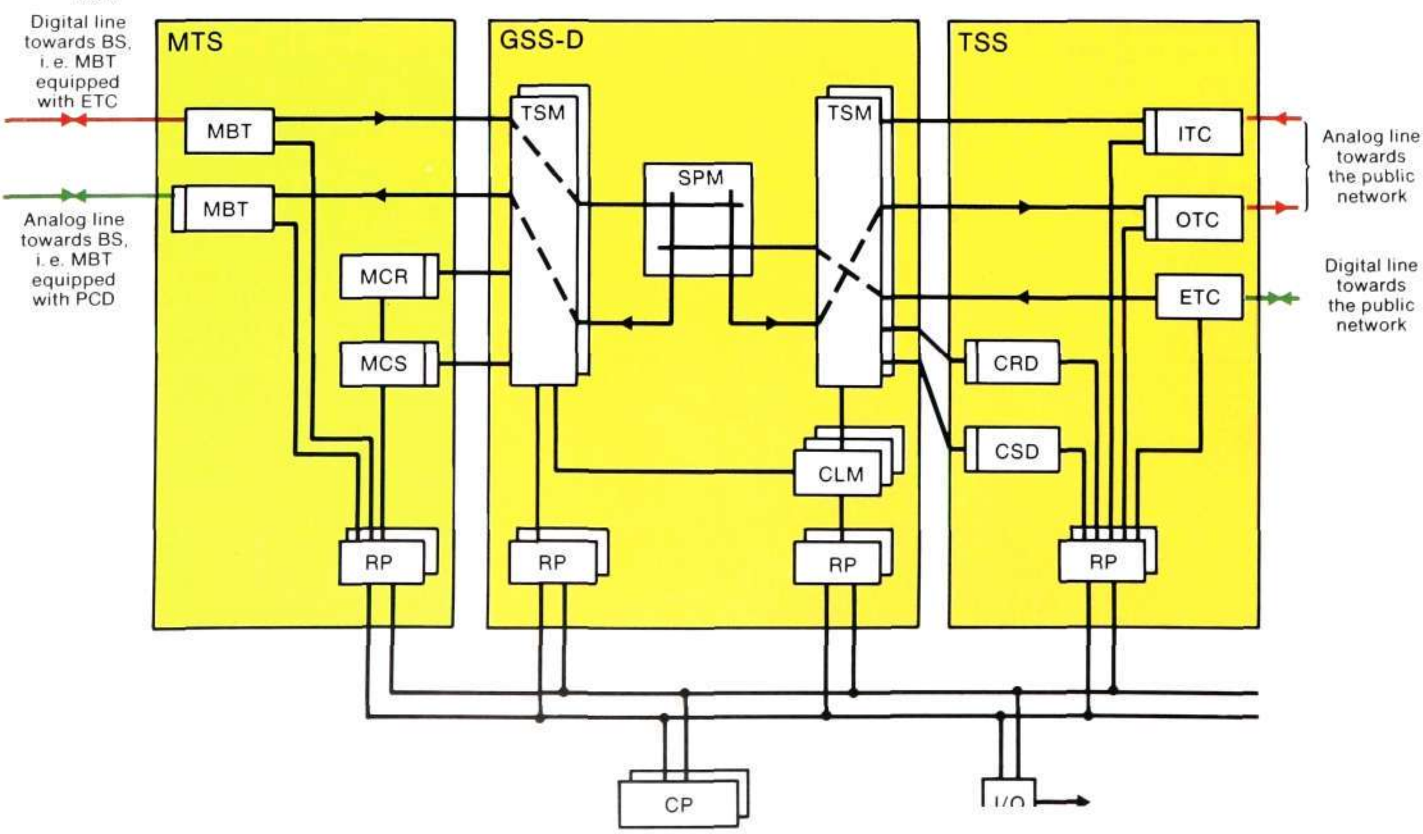


Fig. 6
Block diagram of the hardware in MTX.
The type of hardware is the same when MTX is equipped in an AXE 10 exchange that is used only for mobile telephony, as when MTS is integrated in an AXE 10 transit exchange that also handles public transit traffic

- (red line) Outgoing calls from BS, on a digital line, to the public network on an analog line
- (green line) Incoming call from the public network on a digital line, to BS on an analog line

MTS	Subsystem for matching the mobile stations to the public network
MBT	Junction line relay set block
MCR	Code receiver
MCS	Code sender
RP	Regional processor
GSS-D	Digital group selector
TSS	Subsystem for signalling towards the public network

a lower bandwidth is required than with normal CCITT standard, and higher distortion can be accepted on the point-to-point circuits between the exchange and the base stations. Disturbances caused by fading of the radio signal are counteracted by the use of an error-correcting code for the signalling. See "Fading" on page 36.

The data messages are transmitted synchronously in frames. The frame alignment is achieved with a special 11-bit sequence (Barker), which is sent after 15 bits for bit synchronization. The coded message then consists of 64 information bits and 76 check bits.

Compelled signalling, which is based on the same principles as MFC signalling, is used throughout, which makes the signalling system very reliable.

For the signalling between the telephone exchange and the remainder of the public telephone network, the existing signalling systems are used. The telephone exchange is prepared for signalling system CCITT no. 7, which can be introduced if it becomes necessary to transmit more information between the exchanges.

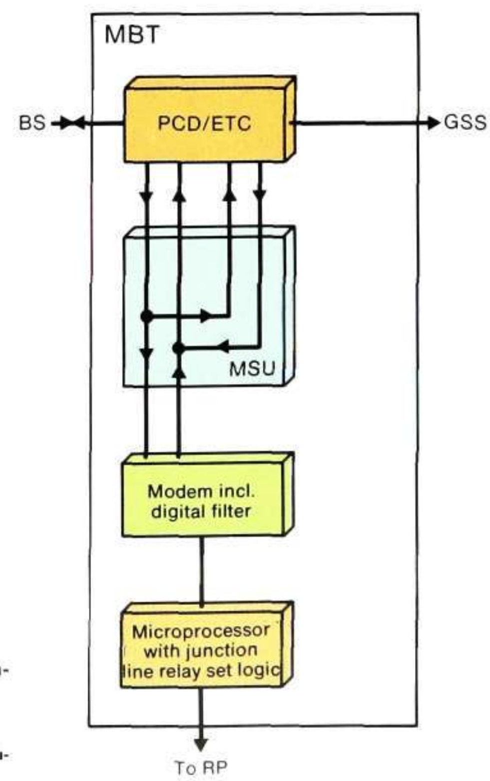


Fig. 7
Junction line relay set block MBT with level regulation, modem and microprocessor

PCD Terminal device for analog lines
ETC Terminal circuit for digital lines
MSU Unit for splitting, tone transmission and level regulation

Telephone exchange equipment, MTX

The exchange equipment consists of the public digital telephone exchange system AXE 10. AXE 10 is a modular, stored-program-controlled system, which covers the whole range of applications from local and tandem exchanges to transit exchanges. Fig. 6 shows the exchange hardware. Previous articles have described both AXE 10 in general[1] and the digital group selector in particular[2].

The use of AXE 10 as a transit exchange will be described in more detail in a later issue of Ericsson Review.

All additional functions that are required when AXE 10 is used as a mobile telephone exchange are assembled in a subsystem. Thus all other subsystems are unchanged. The functional modularity of the AXE 10 structure therefore makes it possible for an AXE 10 to
- handle both mobile telephone traffic and public transit traffic, i. e. an ordinary AXE 10 transit exchange is equipped with subsystem MTS
- handle only traffic to and from mobile subscribers.

In MTS the traffic and calling channels are connected to analog or digital transmission channels. The above-mentioned binary signalling and error correction are then used on all these channels. In MTS the level of the incoming speech signals is also measured and adjusted when required, since the junction line relay set towards the base station contains a modem and a level regulator in addition to the normal relay set functions, fig. 7. The junction line relay set block MBT is controlled by a microprocessor.

The signal to noise ratio on all channels that carry traffic is continuously measured at the base station and reported to the exchange. If this ratio falls below a certain limit value on a traffic channel for a certain time, the exchange orders a field strength measurement on this channel from the base station. The limit value can be set by means of a command from the exchange. The result of the measurement is analyzed, after which the mobile station in question can be ordered to switch over to another traffic channel, if a free one with better transmission quality is available. Such a field strength measurement and analysis, and possibly also switch-over to another channel, are also carried out during the setting up of each call to or from a mobile subscriber.

If a base station has many channels to the exchange, one of the cannels can be designated the signalling channel and used only for signalling information.

Local exchange data concerning both the registered and visiting mobile subscribers are stored in MTS, for example information regarding category, any barring for outgoing traffic or priority level. Furthermore, the geographical position of the subscriber is stored, that is to say the traffic area he is in.

Subscribers with priority always call the exchange via the calling channel, unlike the other subscribers. If there is no free traffic channel, the subscribers with priority are put in a queue. MTS also contains facilities for introducing what is called emergency traffic. This means that for each radio station a percentage of the traffic capacity is reserved for use in an emergency by subscribers with priority. This emergency traffic state in the telephone exchange is ordered and removed by means of commands.

When there is more than one MTX exchange in the country the system must permit roaming. In addition to the storing of data for "visiting" subscribers this function requires the transfer of information between exchanges. This transfer is done by means of special MFC signalling, end-to-end, over the public network. In future CCITT no. 7 can be used if it is necessary to transfer greater amounts of information. The updating traffic between MTX exchanges can also go via point-to-point connections in the

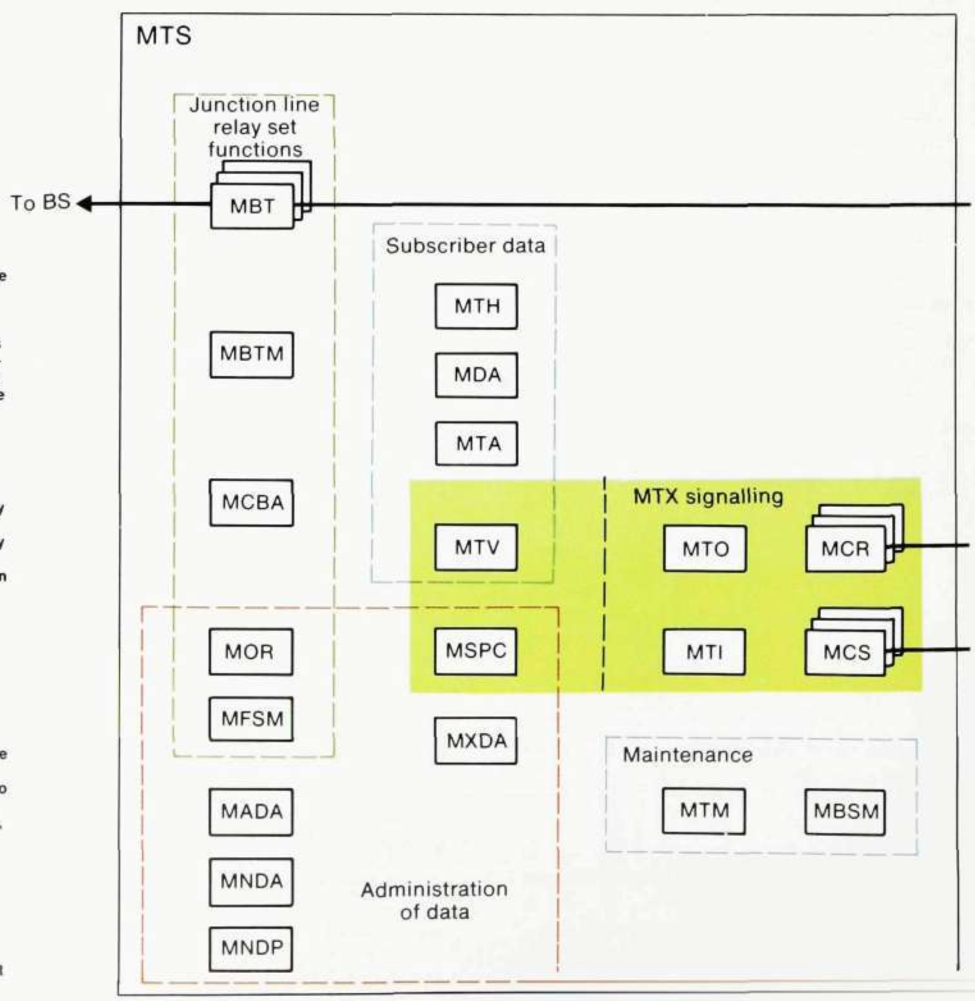


Fig. 8
The basic distribution of the functions in subsystem MTS different function blocks

Blocks required only for roaming

Junction line relay set functions
- **MBT** Signalling towards BS and mobile stations
- **MBTM** Operation and maintenance of MBT in accordance with the AXE 10 standard
- **MCBA** Checks the transmission of calls to mobile stations
- **MOR** Controls the base stations, executes commands regarding the changeover to and from the emergency traffic state. Calculates and regulates the number of traffic channels that are to be kept free for calls from mobile stations
- **MFSM** Determines the data for the supervision of call quality. Orders and evaluates field strength measurements

Subscriber data
- **MTH** Stores information regarding the barring category and traffic area for resident subscribers
- **MTV** Stores information regarding the barring category and traffic area for visiting subscribers
- **MDA** Analyzes subscriber numbers and converts them into internal numbers
- **MTA** Controls the setting up of calls

MTX signalling
- **MTO** Controls the outgoing signalling
- **MTI** Evaluates incoming signals
- **MCR** Code receiver
- **MCS** Code sender

Administration of data
- **MADA** Interprets commands for the administration of the analysis table in MDA
- **MNDA** Administers data for the traffic areas, BS and radio channels
- **MNDP** Controls the printout of data for the traffic areas, BS and radio channels and supervises the call quality when so ordered
- **MSPC** Used for the transmission of updating information over point-to-point circuits between exchanges
- **MXDA** Receives commands for data via MTX

Maintenance functions
- **MBSM** Receives alarms from BS and commands to reset alarms from BS

public network that are intended solely for this type of traffic.

Subsystem MTS in the exchanges also contains the operation and maintenance functions, including command functions, which are required for MTS, as well as functions for the transmission of alarms from the base stations. Moreover, by means of commands it is possible to indicate individual channels for testing and checking the connection with the mobile station. A block diagram of MTS and brief descriptions of the function blocks are given in fig. 8.

The normal AXE charging subsystem is also used for the mobile subscribers. Outgoing calls are charged by means of toll ticketing. If a country has more than one MTX, the charging data from all MTXs must be processed together, since a mobile subscriber can have made outgoing calls from several of them. If several countries are covered by a common mobile telephone system which permits roaming, the output data from the toll ticketing must be used in the accounting between the administrations in these countries.

If an administration so desires, the mobile subscribers can also be charged for incoming calls or charged an extra fee for calls via "visited" MTXs. Toll ticketing must then be used.

Base radio stations

The base radio stations, which are connected to the telephone exchanges via point-to-point circuits, fig. 1, handle the radio communication with the mobile stations. They function primarily as relay stations for the line signals. They also supervise the quality of the radio circuit with the aid of a pilot tone.

Magnetic AB in collaboration with SRA are developing a base radio station for the Nordic mobile telephone network. SRA is responsible for the important control and supervision parts. Otherwise the base radio station is a slightly modified version of a type that has been in operation for a number of years in manual mobile telephone systems in Scandinavia. These systems have proved to be very satisfactory. The block diagram of a base station is shown in fig. 9.

Each channel has a transmitter TX, a receiver RX and a control unit CU. The control unit matches the base radio station to the exchange. It controls the signalling between base station and exchange. It also controls the transmitter and receiver as well as the fault supervision in the base station. A message is sent to the exchange if a fault occurs in the station. The control unit also generates the pilot tone and evaluates the

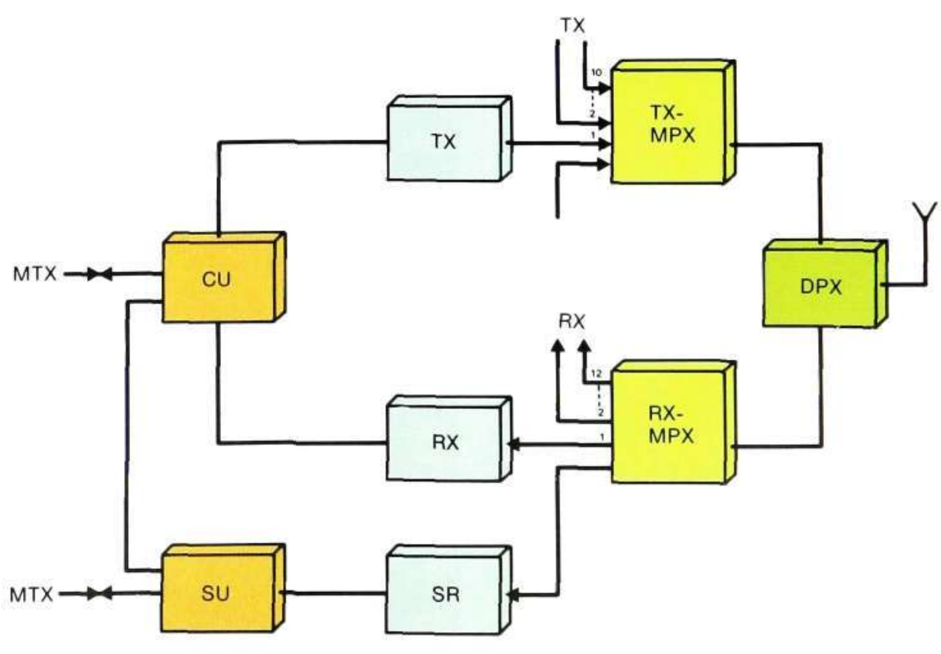


Fig. 9
Block diagram for a base station

CU	Control unit
TX	Transmitter
RX	Receiver
TX-MPX	Multiplex equipment for transmitters; enables several transmitters to be connected to a common antenna
RX-MPX	Multiplex equipment for receivers; enables several receivers to be connected to a common antenna
DPX	Duplex filter; enables transmitter and receiver to use the same antenna
SR	Receiver that measures the field strength
SU	Supervisory unit

Fig. 11
A mobile telephone with a push-button set for dialling, number panel that shows the dialled number, special key HF for changeover to the loudspeaker, on – off switch and volume control. The subscriber number is shown to the right

quality of the tone that is returned from the mobile station. The control unit is built up around a microcomputer.

The transmitter-multiplexor TX-MPX makes it possible to connect up to 10 transmitters to a common antenna. This is an extremely valuable facility, since the masts in which the antennas are mounted can be quite crowded. It is sometimes necessary to use the same mast for up to 100 channels.

The receiver-distributor RX-MPX makes it possible to connect up to 12 receivers to a common antenna. Transmitters and receivers can also be connected to the same antenna if a special duplex filter DPX is used.

The field strength receiver SR measures the field strength on any channel ordered by MTX. The result of the field strength measurement is used to decide whether the call in progress should be switched to another base station.

The supervisory unit SU controls the signalling between the field strength receiver and MTX.

Fig. 10 shows the layout of a base radio station. The station has a modular structure with the channel equipment constructed as plug-in units in cassettes. A rack holds equipment for up to 8 complete channels, with the exception of the transmitter-multiplexor. The latter, which consists mainly of cavity filters, is mounted in a separate rack, one TX-MPX for every five transmitters.

Thus the amount of space required is very small and service and maintenance extremely simple.

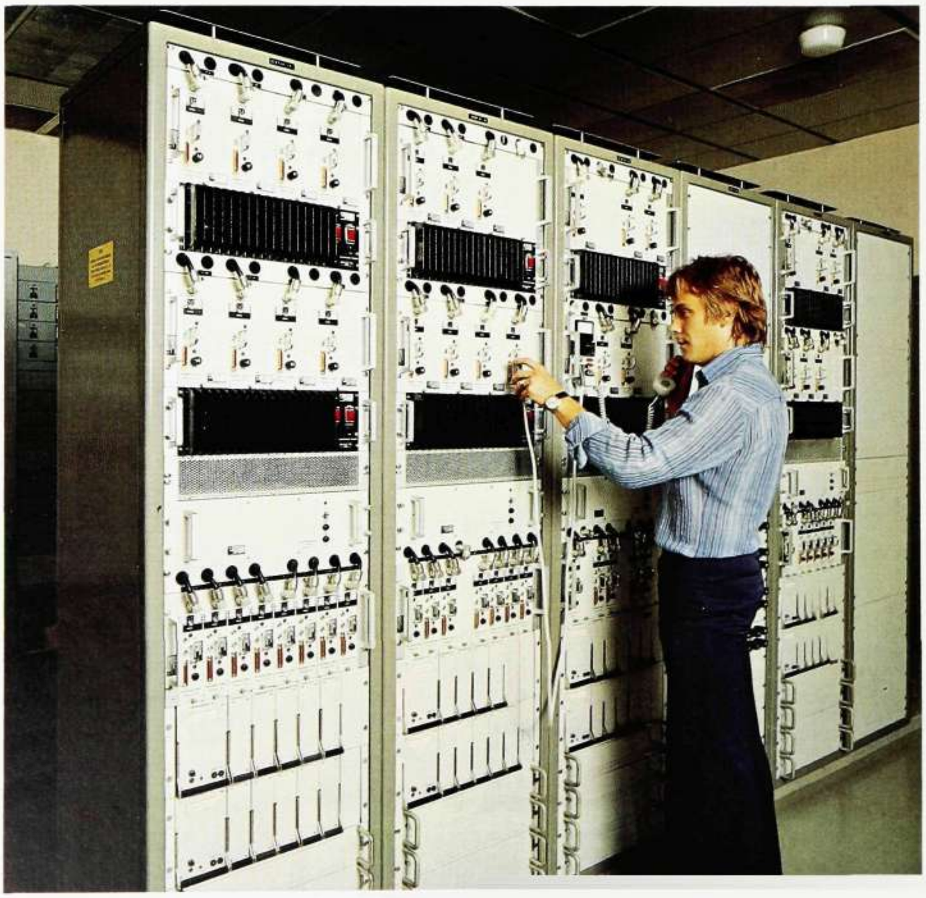


Fig. 10
The base radio station equipment without the transmitter – multiplexor.
Each rack holds four transmitters in the top shelf, a power unit beneath these, and then again four transmitters and a power unit. Below these come the receiver-multiplexor and eight receivers. The following shelves hold eight CU, one SU and one receiver for field strength measurements

Mobile subscriber equipment

The mobile subscriber equipment, the mobile station, is shown in fig. 11. It offers a number of useful facilities for mobile subscribers. A brief summary of them is given here.

- Push-button set, which gives simple and fast dialling.
- Pre-selection, which means that the dialling and checking of the dialled number on the number panel can be done before the subscriber lifts the handset. This prevents many wrong numbers. Furthermore the channel is not occupied during the time it takes to dial.
- Abbreviated dialling with one or two-digit numbers for subscribers who are often called. The number information is stored in the mobile station.
- Loudspeaking telephone, which means that the calling procedure can be carried out using only one hand. However, in this case it is necessary to operate a fixed microphone during the call, for example a microphone mounted by the steering wheel, and equipped with a special speech key, since the interference level is often high in a vehicle.
- A service indicator, which indicates when the subscriber is within reach of the base station network.
- An indicator, which gives persistent indication of incoming calls. If the subscriber has left the car temporarily, on his return he can call the person from whom he expects a call.
- Volume control, for regulating the sound level of incoming call.
- Normal subscriber facilities that are available in AXE 10.

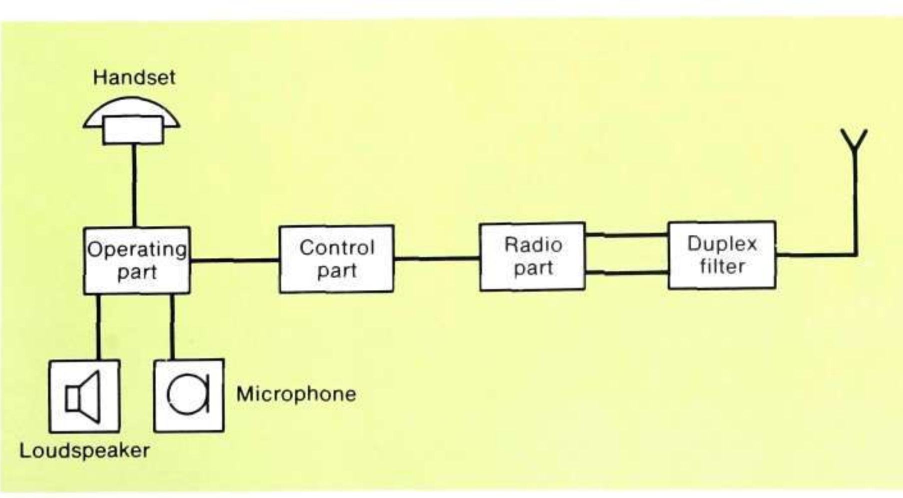
A block diagram of the mobile station is shown in fig. 12. The design is based on the latest development in digital frequency synthesis (see "What is digital frequency synthesis?" on page 36) and LSI and computer technology. The complex mobile station could not have been made so small and been manufactured at a reasonable cost if this revolutionary development had not taken place.

The control unit, fig. 12, is built up around a microcomputer. It is used for complex signalling functions, and also to provide the subscriber with extra facilities, such as abbreviated dialling, without any appreciable extra costs.

The radio part is built up of a number of MSI and hybrid circuits, a total of three monolithic and five hybrid circuits, in order to reduce its weight and volume. The frequency generator of the radio part is based on digital frequency synthesis.

The installation of the mobile telephone station is simple and flexible. It is usually mounted in a cassette, as a single unit, and will then fit in, for example, a normal car radio compartment. However, the station can also be divided up so that the control part is placed where it is easily accessible to the driver, the remainder of the equipment being placed elsewhere in the vehicle.

Fig. 12
The function units in the mobile station.
The operating part contains the push-button set and the number panel for checking the dialled number.
The control part handles the necessary signalling towards MTX, for example for setting up and disconnecting calls, and the control of the radio receiver and transmitter, for example channel selection, start of the transmitter, opening of the speech path etc.
The radio part handles the transmission to the base stations. The duplex filter makes simultaneous sending and receiving possible



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Fading

Fading of radio transmission, caused by multiple propagation as a result of reflection along the transmission path, makes special demands on the signalling system. Fading often manifests itself as large field strength variations, often 20 – 30 dB, with deep troughs for some milliseconds (depending on the frequency band and the speed of the vehicle). As regards data transmission this means that bursts of bit errors occur. Modern encoding theory provides special error-correcting codes that give protection against these error bursts. Here a Hagelbarger falting code with a span of 6 is used. This code manages error bursts of up to 6 bits, as long as the distance between two bursts is at least 20 bits. Thus the code can handle most errors caused by fading.

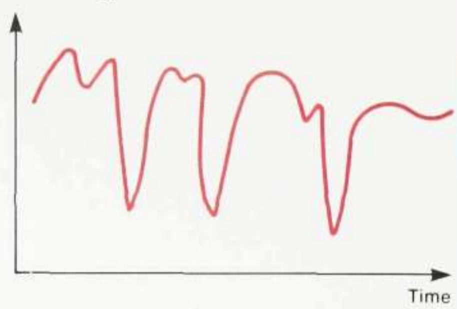

Fig. 13
Typical variation of the field strength with time, as a result of fading

What is digital frequency synthesis?

The traditional method for determining the transmitter and receiver frequency in a radio station was to use a control crystal for each channel. The number of possible channels in a radio station was then limited for reasons of space and cost. One solution for multi-channel stations was to use mixed synthesis. By using a combination of two crystal banks of *m* and *n* crystals respectively, it was possible to derive $m \times n$ frequencies. The method requires careful choice of crystal frequencies and poses many production problems if the wanted frequencies are to be sufficiently pure. Moreover it is still expensive and space-demanding.

With digital frequency synthesis, on the other hand, it is in principle possible to derive hundreds of frequencies from a single crystal using the basic diagram shown in fig. 14. The wanted frequency is obtained from a voltage-controlled oscillator in a regulation loop. The oscillator frequency is divided down in a programmable divider and is then compared, in a phase detector, with a reference frequency derived from a stable control crystal. The error signal from the phase detector adjusts the voltage-controlled oscillator until the error signal is zero. If the division factor in the programmable divider is changed, the frequency of the output signal will also be changed.

The version of digital frequency synthesis that is commonly used is slightly modified. An extremely stable oscillator with a fixed frequency is used to reduce the frequency to the programmable divider, so that the practical difficulties of high-frequency dividers are avoided, as shown in the added part of fig. 14.

The basic principle of digital frequency synthesis is not new, but it is only during the 1970s that it has been possible to put it into practice, thanks to the development of fast dividers. There are special circuits available for synthesis, which contain divider and phase detector on the same chip.

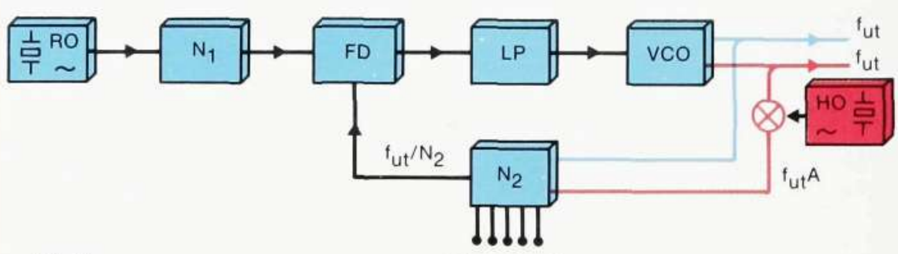

Fig. 14
The principle of digital frequency synthesis

RO	**Reference oscillator, which provides a stable frequency**
N_1	**Fixed divider, which divides down the reference oscillator frequency to a reference frequency (= the channel spacing 25 kHz)**
FD	**Phase detector, which gives an error signal when the divided output frequency deviates from the reference frequency**
LP	**Low pass filter, which filters the error signal from FD**
VCO	**Voltage-controlled oscillator, which is controlled by the error signal from FD**
N_2	**Programmable divider, which divides down the output frequency to the reference frequency. The division factor is determined by the channel setting**
HO	**Extremely stable oscillator with fixed frequency**
f_{ut}	**Output frequency**
$f_{ut}A$	**The output frequency after it has been transposed by HO so that it is matched to N_2**
(blue line)	**Basic version**
(red line)	**Addition for reducing the frequency so that it is matched to N_2**

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THE DIAVOX FAMILY
OVERVOLTAGES IN TELECOMMUNICATION NETWORKS
CTR — COMPUTERIZED TIME RECORDING
CHOICE OF MONOLITHIC TECHNIQUE
ELLEMTEL 10 YEARS OLD

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Contents

COVER
DIAVOX telephone sets in different colours and with different functions

Standard Telephone Set, DIAVOX 100

Leif Branden, Jan-Olof Hedman and Olle Larsson

LM Ericsson's new standard telephone set, DIAVOX 100, was first announced in this magazine in 1977[1]. The set was designed by ELLEMTEL for the Swedish Telecommunications Administration and LM Ericsson. Manufacture was started in LM Ericsson's factories in 1978. The set has been well received on the market. The sales during the first two years have been considerable, including 400 000 telephone sets to Saudi Arabia.

The design of the new telephone set is described in this article, and the whole family of telephone sets that has been developed based on DIAVOX 100 is described in the following article.

UDC 621.395.6

The predecessor of DIAVOX 100 in LM Ericsson's range of telephone sets was the DIALOG, which was introduced in 1963. Its design was very advanced at the time. The main components were independent units, which were combined to form the desired type of telphone set. The design was highly praised and the same principles have since been used by many manufacturers around the world.

The technology of today and tomorrow, with its integrated electronics, requires a different mechanical construction if the possibilities it offers are to be utilized to the full for the telephone functions.

One prerequisite for a rational mechanical construction is that it must be possible to mount all components, including the mechanical ones, on printed circuit boards. The development of the new telephone set therefore started with the design of the cradle switch and a push-button set for mounting on a printed board.

The position of the handset cradle, on the rear part of the cover, provides a large free area for a control panel nearest to the user. The push-button set is placed to the right on the front cover. This gives an attractive appearance and leaves a large area on the left for buttons and indicators for special functions. The internal design of the telephone set provides a large space for printed board assemblies, which is necessary if the same cover is also to be used for more complex types of telephones. From the points of view of manufacture, servicing, maintenance and investment it is an advantage that the more usual variants of the set can be obtained in this way.

The subscriber of today wants to be able to choose the colour of his telephone. Conventionally designed telephone sets in several colours entail, among other things, high stockkeeping costs. DIAVOX is designed so that the front cover can be supplied in several colours. The other details are black. This reduces the cost of providing a wide choice of colour.

The remainder of the article consists of a description of the telephone, the handset and the components included in these, and also the characteristics of the telephone set and the possibility of additional functions.

Fig. 1
LM Ericsson's new standard telephone set, DIAVOX 100

LEIF BRANDEN
JAN-OLOF HEDMAN
OLLE LARSSON
Subscriber Equipment Division
Telefonaktiebolaget LM Ericsson

Telephone set

The set consists of a base plate, rear cover and front cover, fig. 2. The standard version contains one printed board assembly.

The base plate has four polyurethane studs, which give good friction and do not mark lacquered table surfaces. The ringing device and gongs are mounted on the base. There are sound slots in the front and rear edges of the base. These slots are less than 0.5 mm wide in order to prevent insects from getting into the set.

The ringing device in DIAVOX is basically the same as the one used in DIALOG. The output level of the bell at a distance of 1 m is nominally 75 dB(A) as in DIALOG, and it can be reduced by up to 20 dB. Alternatively a tone ringer can be used.

The rear cover, where the number frame is mounted, is designed with an indentation for the fingers, which gives a good grip for lifting the telephone. Cradle switch plates and other details which transfer the movements of the cradle to the cradle contact spring set are mounted in the rear cover.

The front cover is a simple item without any special tolerance problems, which simplifies the change of cover. The front cover is manufactured in two versions, for a push-button set and for an ordinary dial. At present the front cover is available in the following colours: deep red, flame red, sand beige, camel, olive green and pearl white.

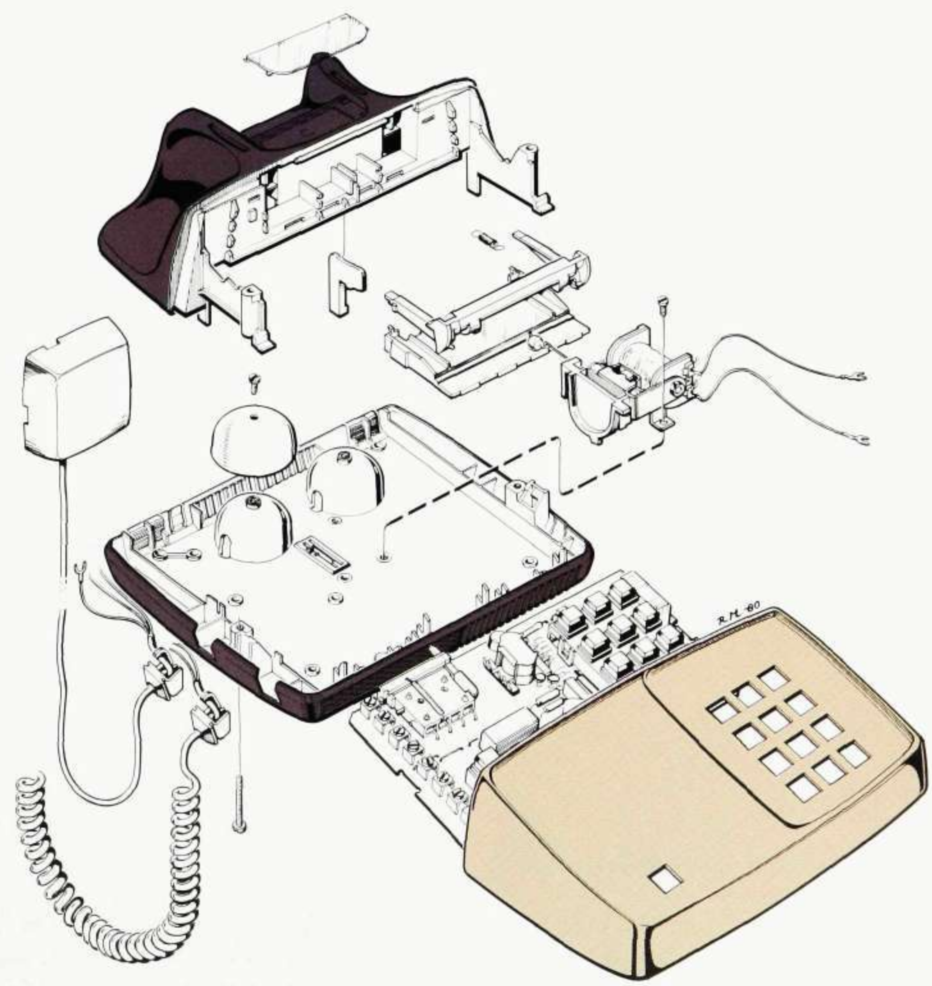
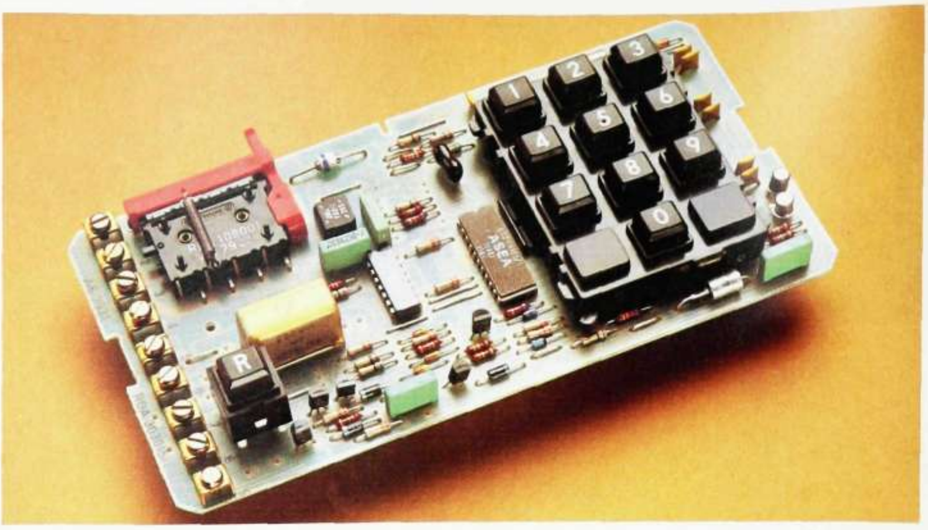


Fig. 2
Exploded view of the telephone set

Fig. 3
Printed board assembly for loop-disconnect signalling



The printed board assembly contains the impulsing device and register calling button with the associated electronic circuits, cradle contact spring set, overvoltage protection and terminal strips. The transmission circuit is placed in the handset.

Impulsing device

The telephone set can be equipped with a push-button set for tone frequency key sending or loop-disconnect dial pulsing. Alternatively it can be equipped with a dial.

Tone frequency key sending

Tone frequency key sending has long been available on the market. The traditional LC oscillator has successively been rationalized and it is still able to compete, both technically and economically, with anything that modern semiconductor technology can offer.

In the near future the possibility of having digital and analog elements in the same integrated circuit will make digital oscillator circuits competitive. Circuits are now available in I^2L technique, which divide down and combine frequencies from a crystal oscillator so that they meet CCITT recommendations. The same circuit also contains the filters and analog circuits required for matching to the line, so that the special requirements for Europe, as recommended by CEPT, are met.

Subscribers who are connected to stored program controlled local exchanges must be able to call registers to order services. CEPT have recommended that such register calling is done by means of a break of a preset length of time in the DC loop. The circuit that is to cut off the line current should be a separate circuit since it must be able to withstand high overvoltages and, during the breaks, also the exchange voltage. A circuit for this purpose is therefore included in the tone frequency key sending board, and it is controlled by the register calling button.

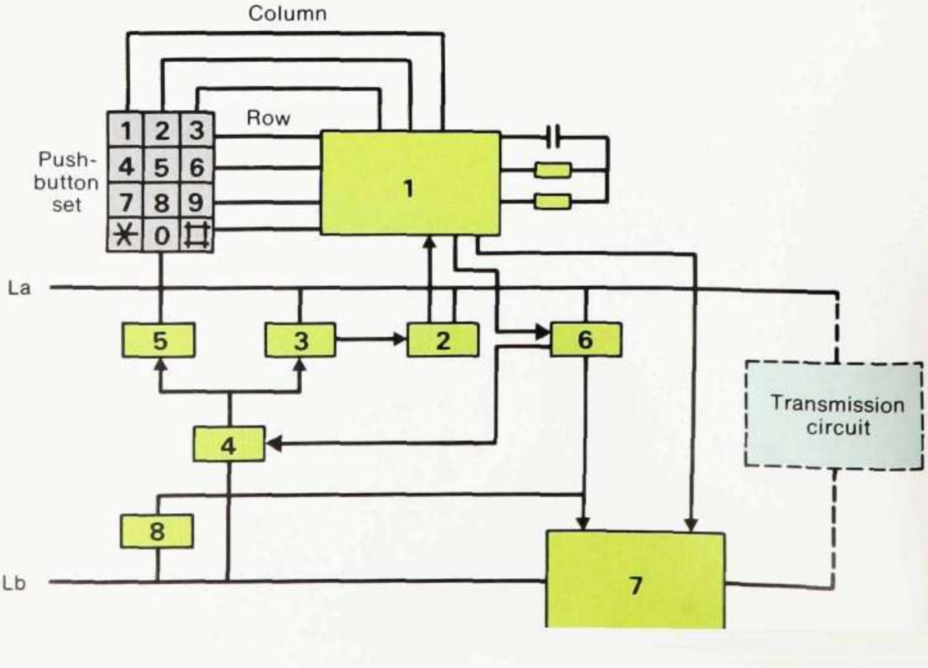
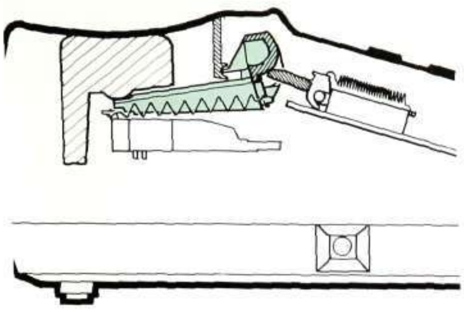


Fig. 4
Block diagram of the pulse dialling circuit

1. Control and memory circuit
2. Resetting circuit
3. Voltage regulator
4. Impulsing circuit
5. Circuit for extra voltage drop during impulsing
6. Circuit for driving the switch transistors
7. Circuit for disconnecting the transmission
8. Transient protection circuit



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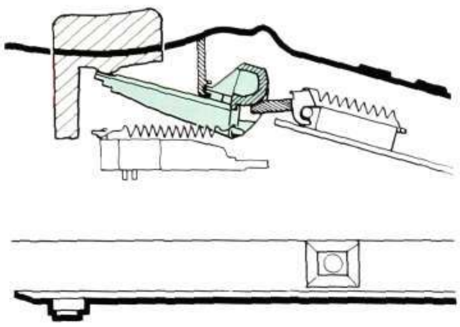

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Fig. 5
Cradle mechanism
a. Handset on
b. Handset off

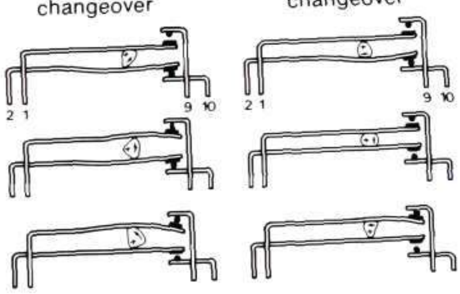


Fig. 6
The contact function of the cradle switch

Fig.7
Push-button set

Loop-disconnect pulsing
In markets where push-button sets are introduced for tone frequency key sending towards new public exchanges, there is also a demand for push-button sets among subscribers connected to exchanges of older types. A version of DIAVOX for loop-disconnect pulsing, figs. 3 and 4, is provided for these subscribers.

In this case also, development has been carried out in order to utilize new technology and meet new requirements. LM Ericsson, in collaboration with the Swedish Telecommunications Administration, have had an integrated circuit developed, which forms the control and memory part of the pulse unit. CMOS technique is used for this circuit, which operates with as little as 2 V and has very low current consumption. The pulse unit meets extremely stringent demands as regards contact function and voltage regulation. Among the characteristics that have been improved are in particular the "short circuit voltage" during impulsing, the start time and the ability to withstand overvoltages. The first two of these improvements are direct results of the lower power consumption in the control and memory circuit. The characteristics are specified in "Technical Data" at the end of the article. One factor that should be noted is the low voltage during the first half of the make time, which also gives good function towards old types of relay exchanges.

In the main version transistors are used both for impulsing and for disconnecting the transmission circuit, fig. 4. The use of transistors leads to a certain voltage drop in series with the transmission circuit. This has a marginal effect on the transmission characteristics which some administrations do not accept. For this reason an alternative version is available where a miniature relay is used instead of transistors. It is connected in such a way that the transmission circuit is short-circuited during the impulsing, and the pulse circuit is short-circuited in the speech position. In view of the power that is available the relay must be bistable, and the design therefore also incorporates a control circuit which ensures that relay always takes up the correct position.

In order to enable the pulse circuit to withstand overvoltages it has been equipped with a protection circuit. If the voltage increases, the circuit quickly cuts off this current through the transistors before the power becomes destructive. In order that the voltage across the set shall not become excessive the current must be conducted away. In DIAVOX this is done by a thyristor diode, which has been specially developed for protecting telephone sets against transients. It can withstand sufficiently high power and acts very quickly. The trigger voltage is 110 V in order not to distort the pulses during impulsing. The thyristor diode is also designed so that it is turned off immediately the current falls to less than 150 mA, i.e. it will always return to the normal state as soon as the transient has passed.

The CMOS circuit contains a memory with a capacity of 18 characters. If the administration allows the telephone set to draw a very low current from the exchange even when it is not in use, the information stored in the memory in one version of the set can be retained after the handset has been replaced. This enables the subscriber to repeat the latest dialled telephone number just by depressing a button instead of dialling the whole number again.

Cradle switch
The cradle spring set is mounted on the printed circuit board and is operated by the cradle, which is mounted in the rear cover, fig. 5. The operation is indirect. The cradle arm operates the spring set and when the handset is put down, the arm lifts. The spring set then returns to the rest position with the aid of a return spring mounted on the spring set. This protects the spring set if the handset is replaced with force.

The cradle spring set, top left in fig. 3, is characterized by small dimensions, low operating force, large overtravel before and after the actual making and breaking, and a large number of contact functions.

The spring set contains four separate break contacts and four separate make contacts, which can be paired to form changeover contacts, fig. 6.

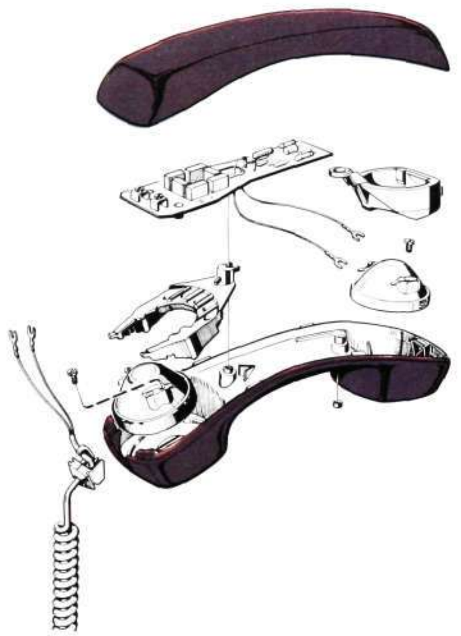
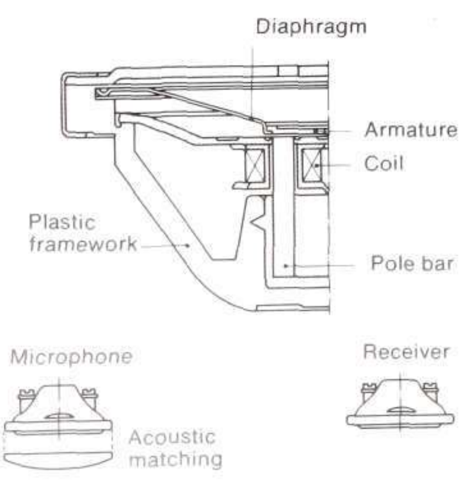


Fig. 8
Exploded view of the handset

Fig.9
Microphone and receiver



The design of the spring set, with a turning camshaft that moves the springs, permits large overtravel before as well as after both make and break, without any increase in the actuating force or stress on the spring.

The camshaft is shaped so that it gives the desired time lag between make and break.

Gold contacts are used to ensure good contact functions even with the low currents in the electronic circuits.

Push-button set
LM Ericsson's push-button set has been further developed to make it more suitable for electronic circuits. The set is small and can be mounted direct on a printed circuit board, fig. 7.

The basic function gives two individual contact closures for each button, and also operates a spring set (which is common for all buttons) having the required number of make and break contacts. The individual contact functions are obtained with the aid of two leaf springs which are operated by a wedge-shaped part of the button. The leaf springs each make contact with a contact plate. The common spring set is mounted underneath the push-button set.

All contacts consist of metal profiles with gold plating. The contacts are welded to the leaf springs and contact plates.

The push-button set is available in different versions with
- two individual contact closures per button together with a maximum of 4 closures or 4 breaks or 1 – 2 change-overs in the common spring set
- two closures per button and without any common spring set
- one closure per button and without any common spring set.

Advantages of the DIAVOX design
The telephone set has a spacious and convenient control panel with the push-button set on the right. The design of the front cover makes it easy to change the colour of the set.

All components are mounted on a printed circuit board, which simplifies the stocking of spare parts.

The design gives the set even weight distribution and makes it easy to lift.

The position and shape of the handset, together with the design of the rear cover, makes the handset easy to grip and hold.

The number frame is placed on the rear cover in front of the handset so that the subscriber number is easy to see. Thus a change of colour does not affect the number frame.

Handset

The handset in DIAVOX 100 is a complete transmission unit. In addition to the receiver and microphone it also contains a printed board assembly with the transmission circuit, fig. 8.

When the work on designing DIAVOX started, LM Ericsson already had experience of speech circuits built into the handset (DIALOG and ERICOFON 700). It was therefore possible to formulate explicit directives for the design of the handset right from the start, to give the best possible basis for and complete uniformity of the whole design work. The handset has been designed for equipping with alternative acoustic converters and speech circuits, and so that it can contain a printed circuit board which is big enough to provide a choice as regards construction practice and components.

Construction of the handset
The handset, fig. 8, consists of a two-piece case, a transmission circuit with a microphone, a receiver, a fixing device and a cord. Compared with a conventional handset with a one-piece case and microphone and receiver lids, the two-piece case has advantages both as regards design and construction. Thus the handset is attractive as well as comfortable to grip and hold.

Furthermore the two-piece handset enables the transmission circuit to be placed together with the microphone, whereby the circuit can be protected

The handset weighs approximately 180 g. The two parts of the case are held together by two screws. These also secure the receiver and transmission circuit, via a fixing device, which makes the receiver and microphone easily accessible when the case is opened.

The low weight of the telephone set and above all the handset have led to the development of a new, light cord. Both the cord and the telephone instrument cable are fixed in the standard version, but there is an alternative version with plug and jack connection.

Receiver and microphone
The receiver is of the normal electromagnetic type, fig. 9, which LM Ericsson have used since the beginning of the 1970s in DIALOG and later also in ERICOFON 700. This receiver is widely used, and its continued use ensures good reliability and delivery times.

Since the receiver is so well established with the customers LM Ericsson have decided to use it also as the main microphone alternative in DIAVOX. It has been adapted acoustically by adding a lid to give the desired frequency response.

Another microphone alternative for DIAVOX is an electret microphone. It has excellent acoustic properties and its comparative insensitivity to mechanical vibrations gives good immunity against acoustic feedback. The Swedish Telecommunications Administration have chosen to use only the electret microphone.

The electret microphone has a high impedance and therefore makes special demands on the speech circuit. It is positioned mechanically to provide simple and rational handling and also high immunity against electrical disturbances. The microphone is placed adjacent to the circuit, and the metal cover is connected to one line terminal in order to obtain good screening.

Speech circuits
The speech circuits for DIAVOX have been developed to give the best possible transmission and DC feeding characteristics.

One of the most important prerequisites for a simple, rational structure is that right from the start the circuits should be designed for the greatest possible immunity from radio interference and other external disturbances. The placing of the speech circuits in the handset is one safeguard against disturbances.

The circuit for the electromagnetic microphone is designed with balanced microphone input and balanced output to the receiver, fig. 10. Decoupling capacitors are placed so that the circuit is immune from radio interference, and thus no screening is necessary. The microphone is connected direct to the speech circuit board and thus the wiring is the shortest possible.

Most circuit components are included in a monolithic circuit, which has been developed specially for the purpose. Resistors required for adjusting such characteristics as impedance, gain and

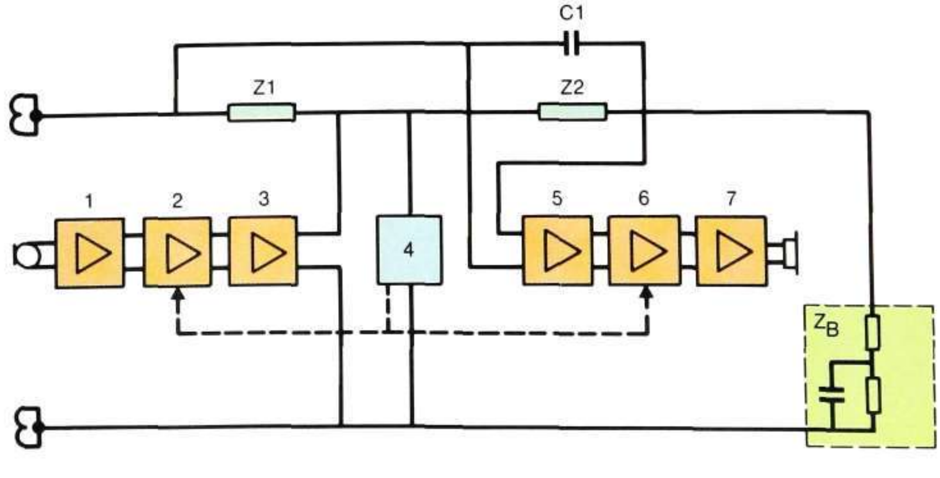


Fig. 10
Block diagram of the speech circuit

1. Input stage, microphone amplifier
2. Gain regulation, sending
3. Output stage, microphone amplifier
4. DC generator
5. Input stage, receiver amplifier
6. Gain regulation, receiving
7. Output stage, receiver amplifier

Z1, Z2 Resistive hybrid
Z_B Balance impedance
Cl Frequency adjustment

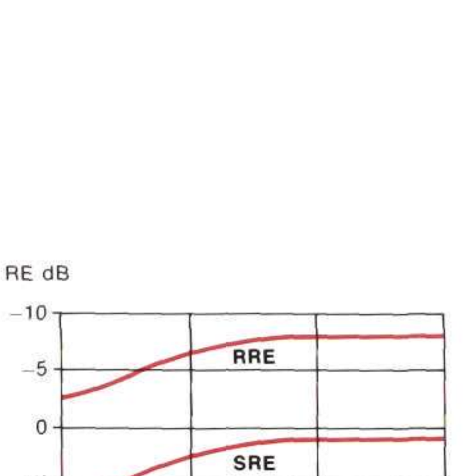


Fig. 11
The transmission characteristics of DIAVOX 100 with electronic speech circuit

Fig. 12
Frequency response curve for sending

Fig. 13
Frequency response curve for receiving

line current dependent amplifier regulation in order to meet different customer requirements, are not included in the monolithic circuit.

The circuit for the electret microphone also contains a specially developed monolithic circuit, which includes the input stage with its field effect transistor (JFET). As in the elctromagnetic circuit the resistors that are needed for adjusting the characteristics of the circuit are outside the monolithic circuit.

However, the electret speech circuit has such a high input impedance on the microphone side that it is necessary to enclose both the microphone and the speech circuit within the electrical screen. For reasons of space it is necessary to make the circuit in the form of a thick film hybrid. The screen is also a cover and the mechanical-acoustic matching to the handset.

Auxiliary equipment

In certain cases, for example in noisy environments or for people with impaired hearing, it is desirable to have extra amplification of the received speech. A special potentiometer-controlled amplifier has been designed for DIAVOX, for placing direct on the receiver. It provides a maximum gain of approximately 20 dB.

The DIAVOX handset can also be equipped with a key that connects in the microphone only during speech, i.e. press to talk. The key switch has two make-before-break changeovers, and thus other switching functions can also be obtained.

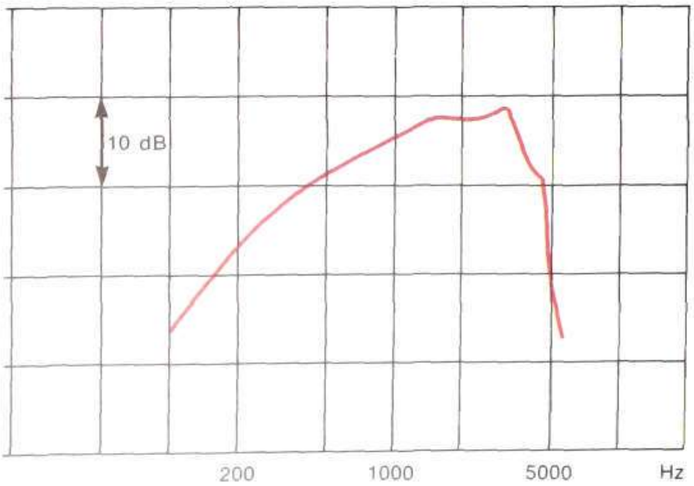
DIAVOX can be equipped with an extra receiver.

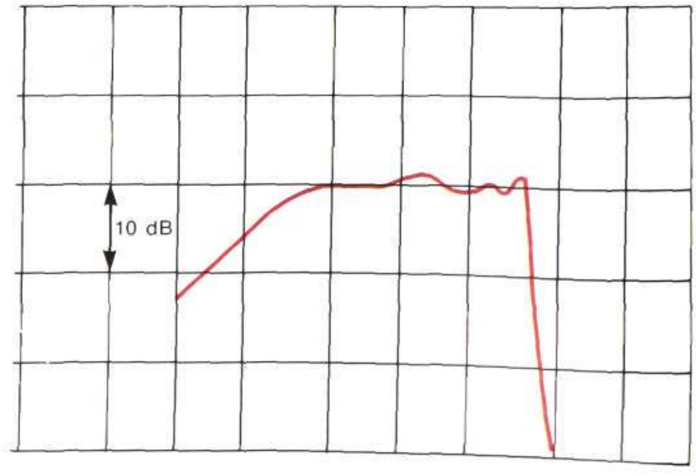
Transmission characteristics

Several factors have influenced the dimensioning of the electronic speech circuit. One example of requirements that clash is the demand for a low DC voltage drop across the telephone set and the demand for freedom from distortion for the normal speech levels. The dimensioning has resulted in the following transmission characteristics:

- DIAVOX can be connected to existing exchanges as well as the new exchanges that permit longer subscriber lines. Satisfactory function is maintained over the long subscriber lines with currents down to 10 mA.
- The transmission level regulation which is dependent on the length of the line is carried out in such a way that the demands regarding stability and echo attenuation are met.
- The transmission is free from distortion and permits send levels up to +3 dBm without clipping.
- The sidetone reference equivalent is better than 10 dB for all line lengths.
- Radio interference and disturbances caused by set noise is less than −65 dBm psophometrically weighted.

As regards disturbances the requirement concerning set noise was determined by what is permissible towards the line and what the subscriber finds





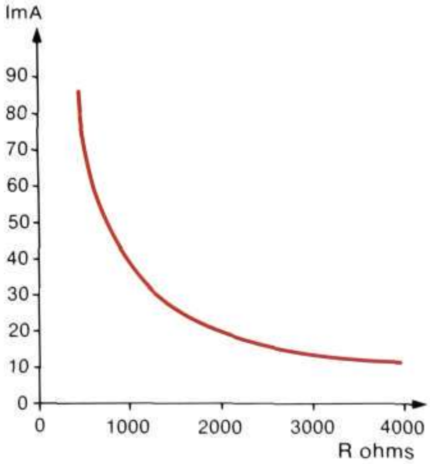


Fig.14
The line current as a function of the loop resistance (power supply circuit and line)

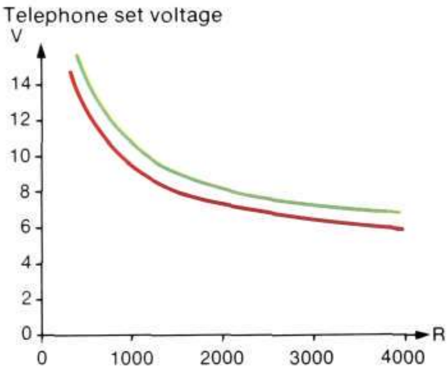


Fig. 15
The voltage across the telephone set as a function of the loop resistance (power supply cicuit and line)
Loop-disconnect impulsing
Tone frequency key sending

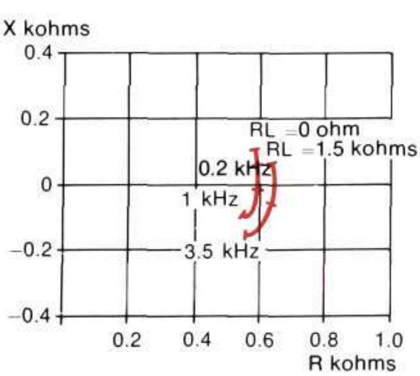


Fig. 16
Telephone set impedance

disturbing. After examination of the requirements and laboratory tests the limit was set at a maximum of −65 dBm psophometrically weighted.

Radio interference has not been a problem in conventional telephone set designs. The introduction of microphone amplification and integrated electronics for other functions of the set have meant that special attention has had to be paid to radio interference. An investigation of existing types of interference and field tests have proved that the induced radio signal between the telephone line and earth, for which protection is needed, amounts to approximately 4 V in the medium wave band with amplitude modulation.

The impedance of a telephone set is important for the whole telephone connection. Local cables with no coil loading have a capacitive characteristic. The transition points between 2-wire and 4-wire contain compromise balances, which should match the overall impedance. Hitherto most telephone set impedances have been inductive, which from the point of view of the local exchange has meant great variations in impedance depending on the distance from the exchange. From the design point of view a resistive impedance gives a rational speech circuit design and very much better characteristics than an inductive impedance. Resistive impedance has therefore been chosen for the present version of DIAVOX.

Fig. 11 shows reference equivalents for a telephone set with transmission regulation that is dependent on the line length. Sending and receiving are related to the local exchange. Figs. 12 and 13 show frequency response curves for sending and receiving with an electromagnetic receiver and microphone. Figs. 14, 15 and 16 show DC data and impedance.

Technical Data

DIAVOX 100 is designed for 20−30 years of normal use.
The telephone set withstands
- lifting and replacing the handset 300 000 times
- depressing each button in the push-button set 200 000 times
- falls from normal table height (80 cm)
- overvoltages up to 2000 V
- induced radio frequencies at a voltage of up to 4 V

The telephone set functions in accordance with the specified data
- with ambient temperatures between −15° C and +45° C
- with a relative humidity of between 5 % and 95 %

The telephone set has the following impulsing data:

Dialpulsing	Loop-disconnect
Pulse rate	10, 16 or 20 Hz ±10 %
Pulse ratio	60/40 or 67/33
Pause between digits	800 ±100 ms or 400 ±50 ms
Voltage drop with closure	≤ 7 V with 20 mA ≤ 2 V during the first half of the closure
Series voltage drop in the transmitting state	≤ 1.5 V
Pulse shaping circuit	1 μF 600 ohms

Other characteristics

In order to obtain maximum safety in cases of overvoltage between the telephone line and earth, the new telephone set with push-button dialling has been designed without any exposed metal parts. As regards overvoltage between the wires coming in to the telephone set, special protective circuits are required, as has been mentioned above. The ability of the set to withstand overvoltage and environmental stresses is shown in Technical Data.

References

1. Boeryd, A. and Wiklund, G.: *New Telephone Set.* Ericsson Rev. *54* (1977):3, pp. 112−113.

The DIAVOX Family

Leif Branden, Jan-Olof Hedman and Olle Larsson

The previous article described the design of DIAVOX 100 and how easily the construction can be adapted to give variants[1]. *On the basis of DIAVOX 100 LM Ericsson have developed a whole family of telephone sets and systems. The various members of the family are described in this article.*

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The construction of the new standard telephone set DIAVOX has made it possible to use the same cover for all the more usual variants. This is a great advantage from the point of view of manufacture and servicing.

For other designs, where the standard set DIAVOX 100 or a variant in the same cover is to be used together with other equipment, a base has been designed that takes either DIAVOX or other types of telephone sets.

On the basis of these two fundamental constructions, LM Ericsson have developed a whole DIAVOX family, which now comprises the following members:

- Loudspeaking telephone, DIAVOX 200
- Loudspeaking base, DIAVOX 250
- Telephone with abbreviated dialling, DIAVOX 130
- Telephone with headset, DIAVOX 120
- Executive-secretary system, DIAVOX 150
- Telephone set for two exchange lines, DIAVOX 125
- Telephone system for several exchange lines, DIAVOX 824

The above-mentioned sets and systems require a large space for printed board assemblies in the telephone, and an area for control buttons and indicators on the cover. The DIAVOX standard set has space for three printed board assemblies. The push-button set is placed to the right on the front, leaving room for buttons and indicators to the left.

Loudspeaking telephone DIAVOX 200

In the loudspeaking version, DIAVOX 200, fig. 1, the sending and receiving levels have been adapted to the latest CCITT recommendation proposals (SG XII 1980). This means that with normal speech the output level is the same as for an ordinary telephone. The receiving level can be adjusted with a readily accessible potentiometer, so that the desired listening level can be obtained for weak as well as strong signals. The transmitted frequency range for the loudspeaking version is shown in fig. 2.

Adjustable attenuators are used in both the send and receive channel in order to

Fig. 1
Loudspeaking telephone, DIAVOX 200

make the speech control as smooth as possible, fig. 3. The amount of attenuation is adjusted at the same time that the receive level is adjusted with the potentiometer. The total amount of attenuation that has to be switched from the receive state to the send state and vice versa is then as low as possible. This gives fast switching of the speech direction and the flow af conversation becomes natural, without any disturbing unevenness.

Another feature of the speech control circuit is that the effect of any room noise is reduced since the send amplification is decreased when the disturbing noise has a persistently high level.

In DIAVOX 200 the coupling to the ordinary (quiet speaking) part and the changeover between the loud and quiet speaking states is arranged in such a way that when the button ON is depressed the operating arm in the cradle spring set is given an overtravel. The last contact action in the spring set then takes place and the DC feeding is switched from the ordinary to the loud speaking transmission circuit.

Fig. 3
Block diagram of the speech control circuit

Send channel
D_B Microphone amplifier, controlled by B
B Regulating circuit that registers room noise
S Secrecy button
F_P, F_S Adjustable amplifiers, controlled by the comparator
F_M, F_{Mst} Fixed amplifiers

Receive channel
D_P, D_S Adjustable attenuators, controlled by the comparator
F_H, F_{Hst} Fixed amplifiers

The comparator compares the signals from the microphone, the line and the volume control

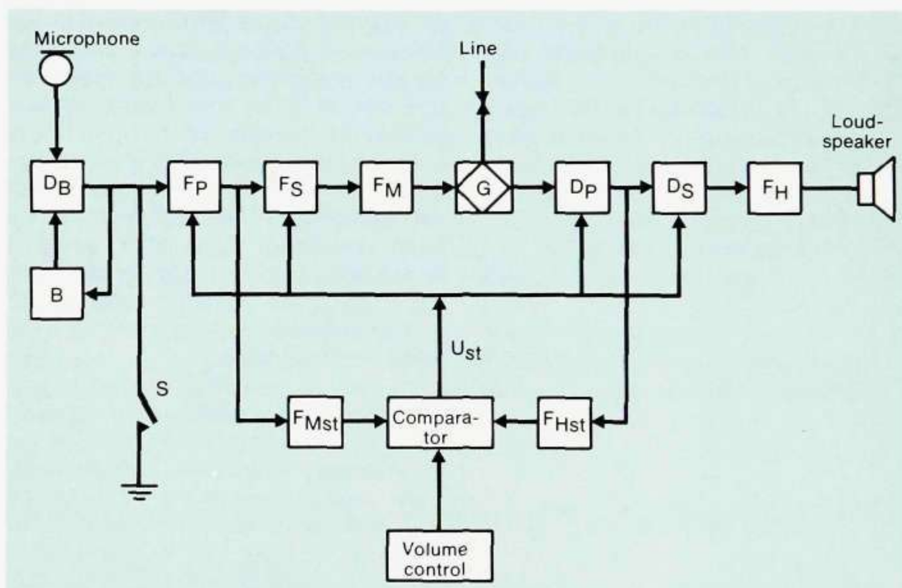


Fig. 2
Transmitted frequency range for the loudspeaking version

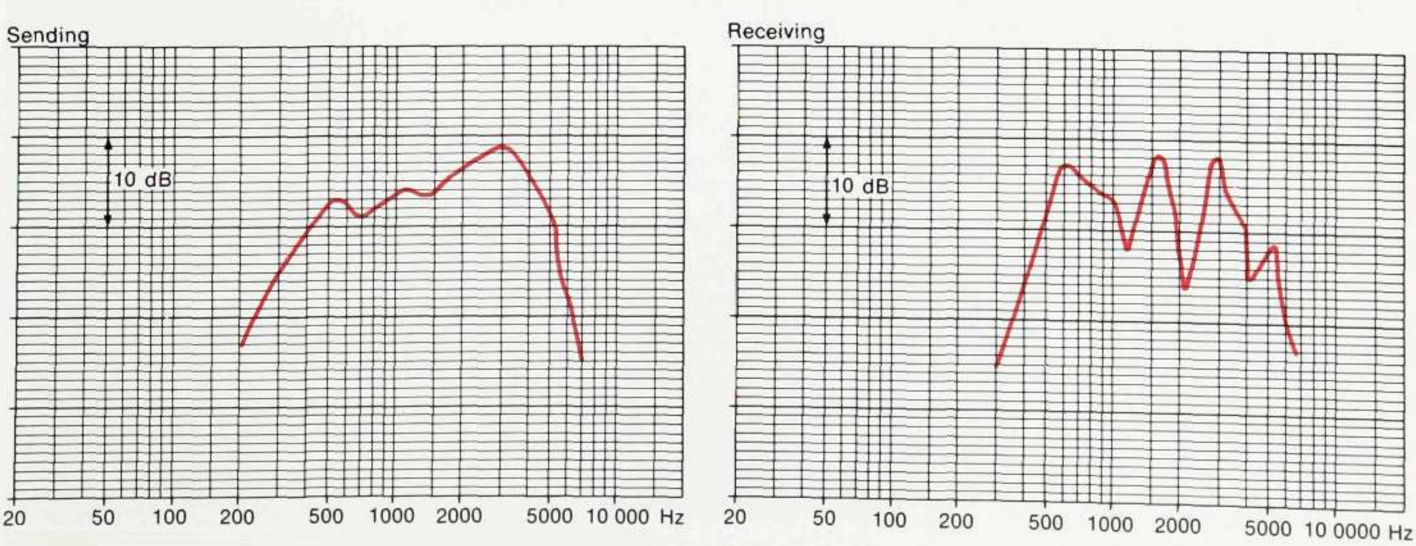


Fig. 4
DIALOG on the loudspeaking base, DIAVOX 250

Loudspeaking base DIAVOX 250

The loudspeaking base, DIAVOX 250, is designed so that also other telephones than DIAVOX can be placed on it, fig. 4.

DIAVOX 250, fig. 5, is connected to the associated ordinary (quiet speaking) telephone set either by means of parallel connection in the wall socket or via a special intermediary connection. In the former case outgoing calls must always be started by dialling the number with the combination set in the ordinary (quiet speaking) state, after which a changeover can be made to the loudspeaking state. Incoming calls can of course always be answered direct in the loudspeaking state.

The special intermediary connection is made by connecting DIAVOX 250 as the intermediary instrument and the ordinary telephone set as the extension on the same line. The tone frequency key sending circuit of the telephone set is electrically connected to DIAVOX 250. Dialling can then be done in the loudspeaking state, which makes the calling procedure more convenient for the subscriber.

The speech control circuit in DIAVOX 250 consists of standard components, fig. 6, like the corresponding circuit in DIAVOX 200.

Telephone set with abbreviated dialling, DIAVOX 130

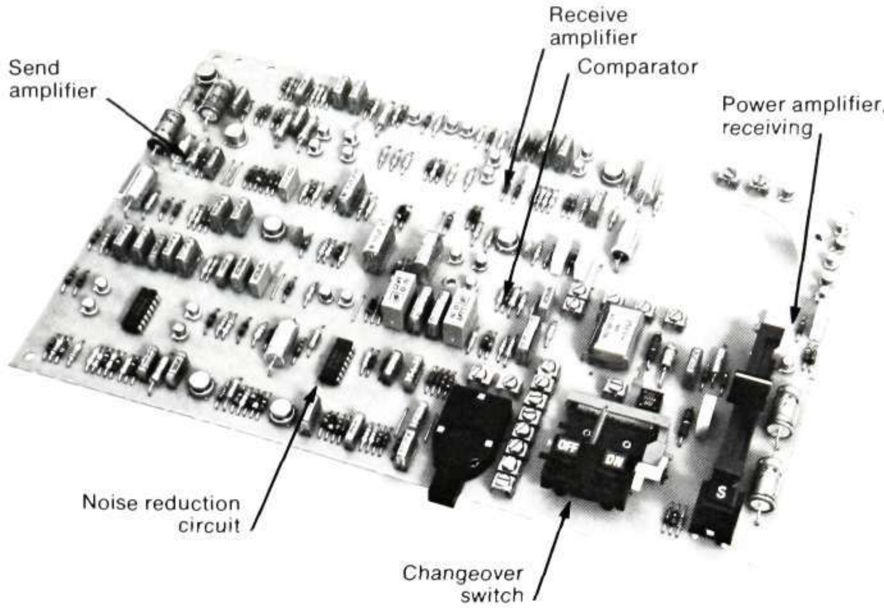
One version of DIAVOX is designed for abbreviated dialling. The abbreviated dialling circuit is controlled by a micro computer, and 9 or 27 telephone numbers can be stored. Simple procedures have been developed for the writing in and sending of numbers.

The abbreviated dialling circuit also permits repetition of the latest dialled number.

The telephones with abbreviated dialling contain a loudspeaker which is driven by a circuit with only a receive function. The subscriber can therefore dial the number and wait for an answer before having to lift the handset.

Fig. 5
Loudspeaking base, DIAVOX 250

Fig. 6
Printed board assembly for loudspeaking telephone



Telephone with headset, DIAVOX 120

DIAVOX is also available in a version with both a handset and a headset, fig. 7. This telephone is particularly suited for premises where the staff need to have both hands free during telephone calls, but where loudspeaking telephones are not suitable.

The headset is plugged into the telephone on the right-hand side.

When the handset is used, the telephone works as an ordinary instrument. The headset is connected in with the ON button. Calls exchanged via the headset are disconnected by depressing the OFF button.

Executive-secretary system, DIAVOX 150

The executive-secretary system DIAVOX 150 consists of two telephone sets which are identical, with the exception that the executive set has a button for disconnecting the bell from the exchange line. The two telephones are connected by means of an 11-wire cable and the system is powered from a 12 V battery eliminator. The executive set is connected as the intermediary instrument. Fig. 8 shows the two telephones with the secretary set on the left and the executive set on the right.

A call over the exchange line normally activates the bells in both telephones. A buzzer is used for calls over the local line.

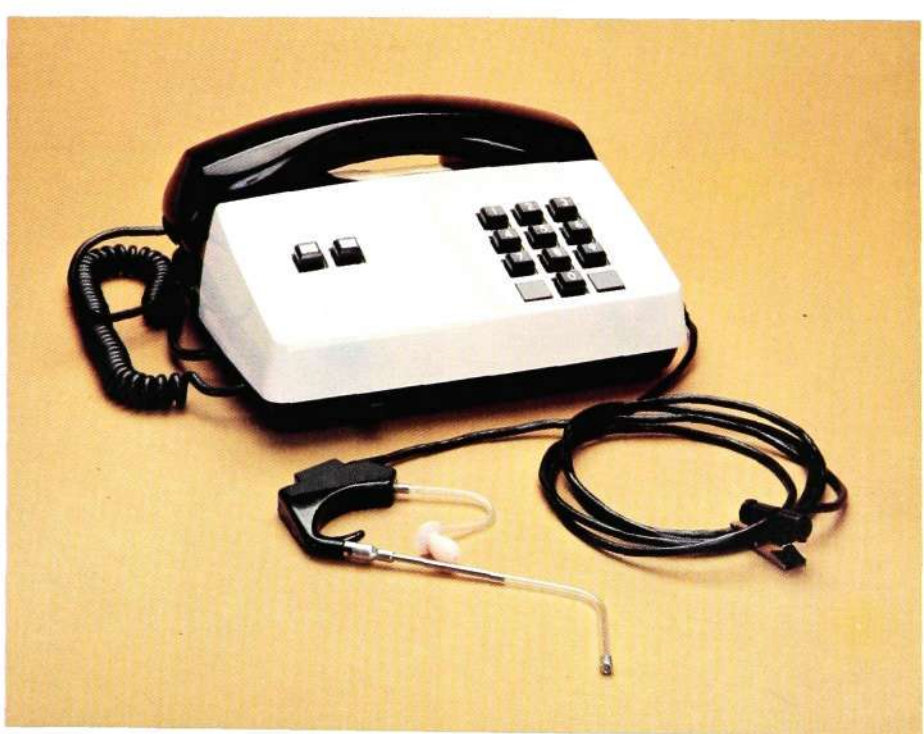


Fig. 7
Telephone set with handset and headset, DIAVOX 120

Fig. 8
Executive-secretary system, DIAVOX 150

Exchange line calls are answered or initiated by depressing button CL. Busy line is indicated by means of a light emitting diode in the other set. If a completed call is to be followed immediately by another one the handset can be left off, the clearing signal being given by depressing the OFF button.

When a local call is to be made, the local line is connected in by depressing button LL. The call is then initiated by depressing button LC. The call is answered at the other telephone by depressing button LL. The call can be terminated without having to replace the handset, by depressing the OFF button.

During a call on the exchange line a local call can be made to the other set for enquiry or notification. The exchange line call is then automatically put on hold. Return to the exchange line call also takes place automatically when the local call is completed and disconnected without the handset being replaced. Transfer of a call is carried out by depressing the CL button on the other set and then replacing the handset on the first set.

The maximum distance between the two telephones in the system corresponds to a 150 ohms cable. The range is determined by the DC feeding to the buzzer. With a wire diameter of 0.4 mm the range is 0.5 km, with 0.5 mm it is 0.8 km and with 0.6 mm the range is 1.2 km.

Telephone set for two exchange lines, DIAVOX 125

Two exchange lines can be connected to DIAVOX 125, fig. 9. Each line has its own connection button and release button. A call on one line can be interrupted

Fig. 9
Telephone set for two exchange lines, DIAVOX 125

and put on hold if the subscriber wants to answer a call on the other line or use it for an enquiry call.

One exchange line is connected to the telephone bell, and the signalling device for the other line is a buzzer.

Telephone system for several exchange lines, DIAVOX 824

DIAVOX 824 consists of a central unit, to which 8 exchange lines can be connected, fig. 10. Up to 24 telephones can be connected to the system. The system can be successively extended to this size in modules of four extensions and four exchange lines respectively.

The various exchange lines and telephones can be grouped in different ways for use as a line selector system, executive-secretary system, queue system and system with a telephone operator.

The system, which is very flexible, has been described in detail in a previous issue of Ericsson Review[2].

Fig. 10
Telephone set for several exchange lines, DIAVOX 824

References

1. Branden, L. et al.: *Standard Telephone Set DIAVOX 100.* Ericsson Rev. *57* (1980):2, pp. 38–45.
2. Jismalm, G. and Magnusson, S.: *Office Communication System, DIAVOX 824.* Ericsson Rev. *56* (1979):3, pp. 124–129.

Overvoltages in Telecommunication Networks

Håkan Mörk

A large part of the maintenance costs for both cables and terminal equipment in telecommunication networks result from damage caused by overvoltages. The costs can be reduced considerably by coordinating the protective measures, above all in the most sensitive points of the network. LM Ericsson have developed a range of hybrid protectors, which provide protection even for sensitive electronic equipment that has been designed without regard to overvoltages.

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The electrical environment in which a telecommunications plant has to operate is determined by the electrical phenomena that occur in nature and the electrical systems created by man. The electrical environment affects the telecommunication plants through resistive, inductive and capacitive coupling.

A systematic study of methods for protection against overvoltages and methods for adaptation to local conditions provides the basic data for profitable and practical solutions. Standardization of protective components, component holders and earthing material is essential for the installation and maintenance activities. Maintenance measurements and statistics concerning damage provide information about the efficiency of the protective systems and also whether they are sufficient.

Fig. 1
Sensitive electronic equipment is best protected with LM Ericsson's hybrid protector

Overvoltages

Overvoltages in telecommunication plants usually occur through electromagnetic coupling to the cable network. The main types of overvoltages are caused by

- direct contact with the low tension system
- induction from a high tension line during a fault on the line
- NEMP (Nuclear Electro-Magnetic Pulse)
- direct stroke of lightning in the telecommunication network
- induction from a lightning discharge
- electrostatic charging.

Direct contact with the low tension system means that a voltage of power frequency, and with an amplitude of up to the network operating voltage, is connected to the conductors in the telecommunication network. The size of the voltage and its duration depend on how good the contact is and on the fusing provided in the low tension system.

When a telecommunication cable is run near high tension lines attention must be paid to the risk of inductively coupled overvoltages if a fault occurs on the high tension line. Resistive coupling can also occur close to the fault. In Directives Concerning the Protection of Telecommunication Lines against Harmful Effects of Electricity Lines, CCITT have specified in detail how such overvoltages are calculated.

In a power line with directly earthed systems the fault current can amount to tens of kA, whereas in systems with the Petersen pole earthing the fault current can often be assumed to be 1 A/kV. The inductive coupling is dependent on such factors as the distance between the line and the cable, how far they run in parallel and the earth resistivity.

CCITT recommend that the induced overvoltage is limited to 430 V r.m.s. and 650 V r.m.s. respectively, depending on the type of circuit breaker. For certain types of cables it is instead recommended that the overvoltage is limited to 60 % of the dielectric strength of the cable.

Lightning is the main cause of damage

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in large maintenance costs for both cables and terminal equipment. Direct strokes, where a part of the lightning current seeks a telecommunication cable, are fairly rare. Usually it is not economically justifiable to provide the cable with overall protection against direct hits by lightning strokes. Extensive damage at the striking point must often be accepted. However, the protective system should prevent further damage.

In the area round the striking point of a lightning stroke a transitory increase in potential is obtained, which decreases with increasing distance from the striking point. If the lightning strikes near a cable with a metal sheath and insulating outer sheath there is a risk of a disruptive discharge through the outer sheath. Such disruptive discharges cause permanent damage to the outer sheath, so-called pin holes, through which water can permeate and cause corrosive damage and insulation faults.

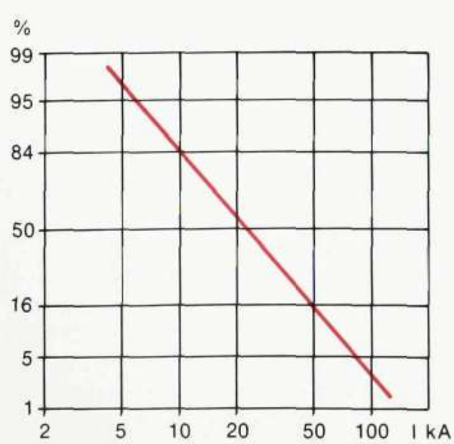
The rapid change of field and the high current during lightning discharges give rise to induced voltages and currents in conductors, even at relatively large distances. The different parameters that characterize a lightning discharge vary statistically within wide limits. The peak current in the discharge can be very high, over 250 kA has been reported. The median value is considerably lower and is often said to be around 25 kA. Fig. 2 shows a distribution of peak currents. The current in the main discharge reaches its maximum value after a few to a few tens of μs, and decreases to half the maximum value in 20−200 μs. Test pulses of the type shown in fig. 3 are used to represent the current pulse. The pulse is defined by the peak current and the pulse shape T1/T2, where T1 is the rise time and T2 the time to half value, both in μs. Some commonly used pulse shapes are 8/20, 15/50 and 10/1000.

Protection principles

The overvoltage protection for a telecommunication plant is usually built up as a combination of several measures. The screening effect of all metal in the cable sheath must be used in the most effective way in order to reduce the penetration of the overvoltage into the body of the cable. The moisture barrier, screen and armouring are connected together along the cable and earthed in the most suitable way depending on the structure of the cable.

The screening effect of a cable sheath is usually defined by means of the reduction factor, i.e. the ratio between the voltage that arises in the screened cable at a certain field strength and the voltage that would be obtained in an unscreened cable. For example, a reduction factor of 0.2 means that the voltage in the screened cable will be only 20 % of what the voltage in an unscreened cable would have been. With an increasing field strength the reduction factor first reaches a minimum and then increases again because of saturation effects in the sheath material.

The choice of sheath structure is usually determined by other factors than the consideration of overvoltages. LM Ericsson have manufactured special cables with metal sheaths consisting of



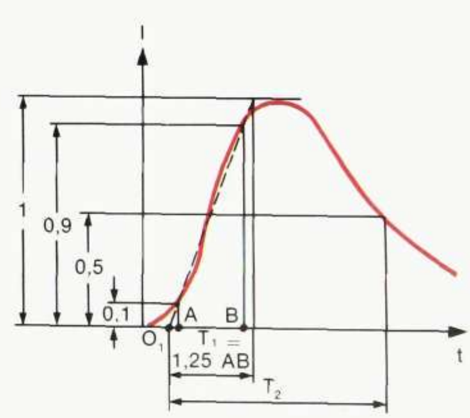


Fig. 2, left
Distribution of peak currents in lightning discharges

Fig. 3
The current pulse used for testing is defined by the peak current, rise time T1 and time to half value T2

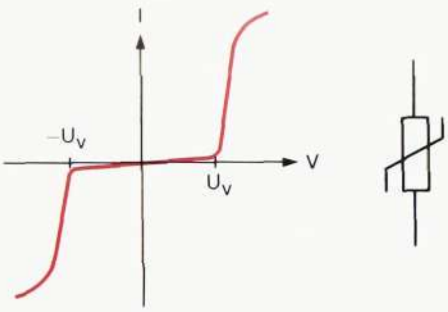


Fig. 5
Charcteristic curve of a varistor

several layers, whose reduction factor has been as low as 0.003, but the cost of these cables is too high for general use. An economical protection system uses the metal in the cable sheath for screening, but is mainly based on protective components connected to the conductors in the cable. The use of components with a pronouncedly non-linear current-voltage characteristic limits the voltage difference between conductors or between a conductor and earth. This is called, somewhat inaccurately, discharge of the overvoltages.

The basic demands made on the protective components are that they must
- limit voltage differences to a level that is not dangerous to the protected object
- withstand a large number of overvoltage occurrences, often together with high currents
- not cause transmission disturbances or problems during maintenance measurements.

It is important that protective measures are arranged at the most effective points in the telecommunication plants. Generally speaking the following points should be protected:
- Points where cables with different dielectric strengths meet, for example a joint between a cable with plastic insulation and one with paper insulation.
- Points where the cable installation method changes, for example transition between aerial cable and buried cable.
- Open ends of spare pairs and dead pairs, since these are terminated with a complete mismatch, an infinite impedance, which gives rise to voltage reflections having the same polarity as the incoming voltage and which therefore doubles the voltage in the vicinity of the open ends.
- Loading points. The loading coils act as a distributed inductance for the signals, but to an overvoltage pulse they are large impedance differences which cause reflections in a way similar to open ends.
- Terminal equipment, which nowadays is often electronic and is thus much less able to withstand high voltages than the cable network is.

A protective system for a local network can be built up as shown in fig. 4. In this system the subscriber and telephone exchange are protected as well as the distribution point, where the distribution wires are connected to the secondary cable.

In certain cases it is possible to take the risk of overvoltage into consideration when planning a telecommunication cable. Areas with high towers and masts or single high trees have a high probability of beeing hit by lightning strokes and should therefor be avoided. In the vicinity of a directly earthed high tension line the cable should only be run in parallel with the line as far as is absolutely necessary and it should then be run as far away from the line as possible. Any crossings should be at right angles to the high tension line.

Protective components

The types of components that are usually considered for protection against overvoltages in telecommunication networks are
- voltage-dependent resistors, i.e. varistors
- transient protection zener diodes
- carbon arresters and air gaps with metal electrodes
- rare gas tubes.

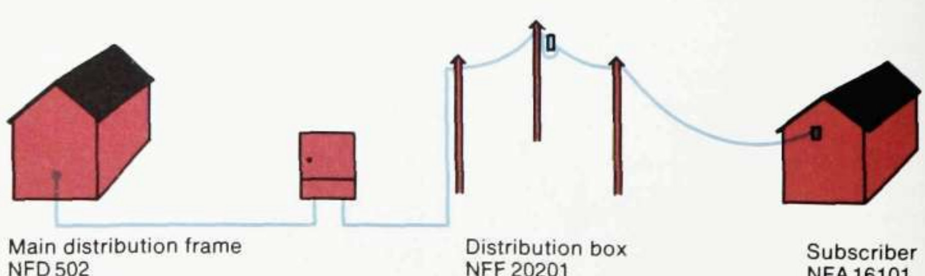


Fig. 4
Protected points in a local network and some examples of protective devices

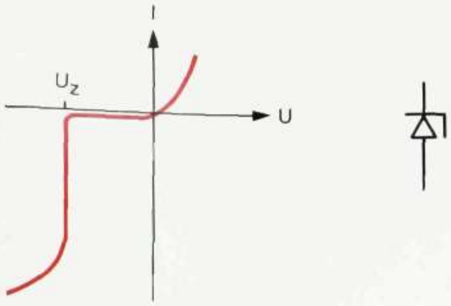


Fig. 6
The characteristic curve of a transient protection zener diode

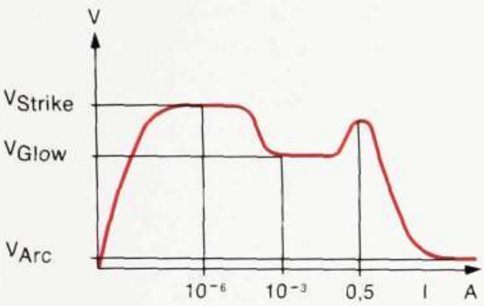
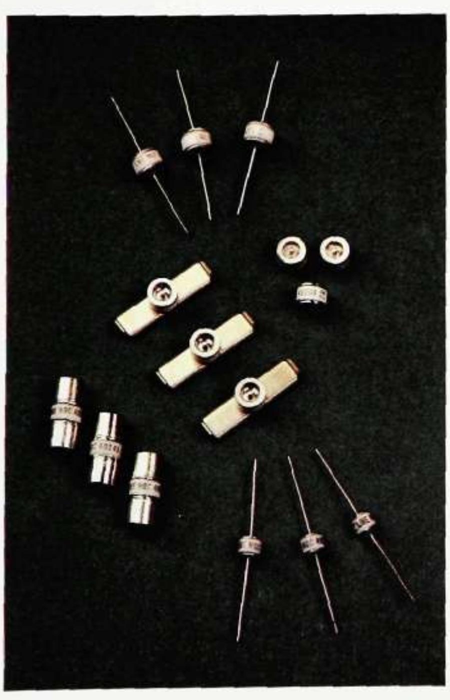


Fig. 7
The characteristic curve of a rare gas tube and an air gap

Data for NGC 40201	
DC striking voltage	280 – 600 V
Surge striking voltage with 500 V/μs	<600 V
Surge striking voltage with 3 kV/μs	<800 V
Surge current durability 10 pulses 8/20	20 kA
Alternating current durability 10x1s	5 A r.m.s.
Insulation resistance	$> 10^{10}$ ohms
Capacitance	< 2 pF

Table 1

Fig. 8
Rare gas tubes type NGC 402



In view of the fact that the overvoltage protectors function in different ways and have different advantages and disadvantages, a brief description of each type is given below.

Modern varistors are usually made of small granules of a conducting metal oxide, which are coated with a thin film of another metal oxide that is insulating at low voltages and conducting at high voltages. The varistor is bipolar, as can be seen from the characteristic curve shown in fig. 5.

Varistors are manufactured with varistor voltages from some tens of volts up to several kV. The residual voltage across the varistor is dependent on the current and can amount to twice the varistor voltage at a couple of hundred ampères. Both price and volume increase rapidly with increasing power dissipation capability.

Transient protection zener diode, TSD, is the designation for zener diodes which have been designed to withstand high pulse power. Extra large chip area and carefully constructed pn junction in order to avoid local current displacement are the means the manufacturer usually uses in order to obtain the desired result. External cooling flanges are not use in this respect since the thermic time constant from chip to cooling flange is too large. In principle the characteristic for a TSD is the same as for an ordinary zener diode, fig. 6. Since the diodes are undirectional, two zener diodes, connected in series opposition, are required for the general case.

The zener voltage is well defined and can be chosen from about one volt up to a few hundred volts. The current-depending voltage increase over the TSD is low and the time lag is very short, which means that transient protection zener diodes offer very good protection. The disadvantage is that not even the best TSD can withstand the pulse power that often occurs in connection with lightning. Good 33 V TSDs can withstand current surges in the range up to 200 – 250 A with an 8/20 pulse and in the range up to 40 – 50 A with a 10/1000 pulse. The price is then high in relation to other types of protectors.

The oldest type of overvoltage protection is the air gap, i.e. two electrodes which are mounted so close to each other that there is a flash-over between the electrodes before the equipment is damaged. The electrodes are usually made of metal or carbon. The flash-over voltage is determined by the distance between the electrodes and by how quickly the voltage increases. For slowly increasing voltage, e.g. 100 V/s, the flash-over occurs when the striking voltage has been reached. An electrode spacing of 0.1 mm gives a DC striking voltage of approximately 800 V.

Lightning overvoltages often have a very short rise time, and since it takes a certain amount of time to start and complete a discharge, the voltage has time to rise above the DC striking voltage. The concept surge striking voltage has been introduced, meaning the striking voltage with a certain leading edge slope, usually given in kV/μs. When the flash-over has taken place an arc is formed between the electrodes and the voltage falls to the arc voltage, some tens of volts. The characteristic curve is shown in fig. 7. When the overvoltage has been discharged the arc is extinguished and the protective device returns to its high resistance state. The small elctrode spacing which is required for an air gap in order to obtain a reasonably low striking voltage makes its resistance to surge currents low. Such a small gap is easily short-circuited by electrode material that is sputtered off during the discharge. Dust and sand can have the same effect on an air gap that is not encapsulated. Simple air gaps can often only withstand surge currents of up to about one kA with an 8/20 pulse. However, the low price of air gaps can justify their use in places where it is easy to change damaged ones, for example in manned exchanges. LM Ericsson manufacture both carbon arresters and air gaps with metal electrodes.

According to Paschen's law, for a given gas the flash-over voltage between two electrodes is dependent on the gas pressure and the spacing beween the electrodes. By placing the electrodes in a vacuum-tight cover, filled with gas at a certain underpressure, the spacing between the electrodes can be increased without the flash-over voltage becom-

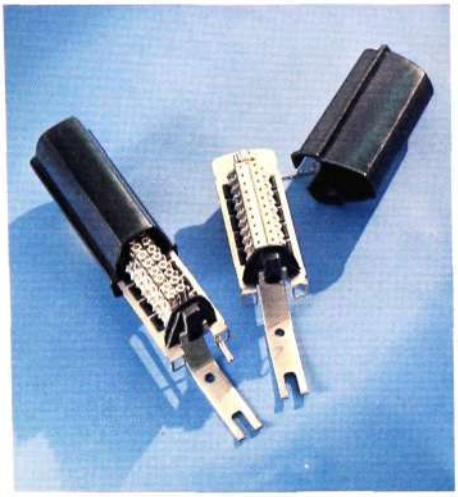


Fig. 9
Distribution points for outdoor installation equipped with rare gas tubes

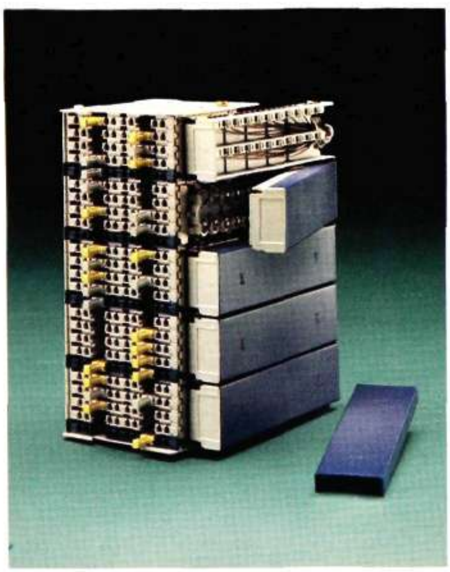


Fig. 10
The overvoltage protection in the main distribution frame BAB 340 is provided by rare gas tubes NGC 40201 in box NFD 50501

Fig. 11
Two-pair subscriber protector NFA 16101 with rare gas tubes NGC 40201

ing too high. If the cover is filled with a rare gas, which does not react with the electrodes even at high temperatures, the component is called a rare gas tube.

In principle rare gas tubes have the same characteristic as air gaps, fig. 7. It is possible to manufacture rare gas tubes with a DC striking voltage from about 90 V upwards. The DC striking voltage is of interest for protection against induction from high tension lines, for maintenance measurements and for production control. However, as regards protection against lightning overvoltage the surge striking voltage is the most important parameter. Good rare gas tubes have a low surge striking voltage, less than 1 kV at 5 kV/μs.

Modern rare gas tube can withstand high surge currents; Ten 20 kA surges with an 8/20 pulse constitute the test value for most of LM Ericsson's rare gas tubes, which are shown in fig. 8. Data for the basic type, NGC 40201, are listed in table 1. The excellent protection features and the long life of NGC 40201 makes it suitable as the general protection throughout a telecommunication network. Despite the fact that rare gas tubes cost more than air gaps, in the long run they are the cheaper alternative, since their maintenance costs are considerably lower than the corresponding costs for air gaps.

Overvoltage protection for local networks

In order to provide full protection the protective components must be able to reduce voltage differences to levels that are not harmful to the protected object. In the cable network paper-insulated cables are usually the most sensitive, with a longitudinal voltage rating of 2kV and upwards. Cables with plastic insulation are often guaranteed to withstand some tens of kV, whereas distribution lines normally can take even higher voltages. In principle either air gaps or rare gas tubes could therefore be used to protect cables. However, in view of the maintenance costs only rare gas tubes should be used. Distribution point protectors are available for both indoor and outdoor mounting. The best result is obtained with rare gas tubes NGC 40201. Fig. 9 shows protectors for outdoor installation.

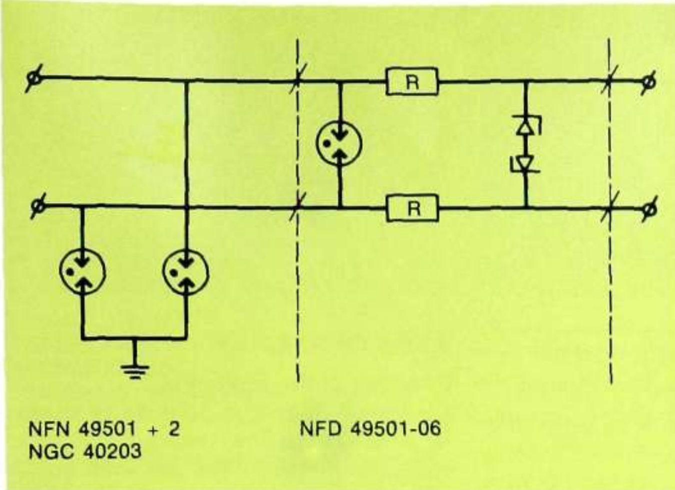
As regards the terminal equipment, i.e. the telephone sets and exchanges, it is expensive to build in high overvoltage durability. The requirement for telephone exchanges is that its own durability must be so high that no auxiliary protective components are required in areas with a low incidence of lightning, and that the addition of longitudinal protection in the main distribution frame provides very high overvoltage durability in other areas. This means that the exchange must be able to withstand 1000 V with a fairly long pulse (10/1000 pulse) and very briefly even higher voltages. With such requirements the protection in the main distribution frame can consist of either air gaps or rare gas tubes, but in this case also, rare gas tubes NGC 40201 gives the lowest overall cost. In the main distribution frame type BAB 340, cassettes with overvoltage protectors for ten pairs can be installed in box NFD 50501, which is mounted on the main distribution block in the line side, fig. 10.

The telephone set, which has no earthing, must tolerate transversal overvoltages of at least 500 V. The set can then be equipped with longitudinal protection in the subscriber protector box, which gives the set a very high ability to withstand overvoltages. If the protection is correctly earthed it will also eliminate the risk of fire caused by a flash-over between the set or instrument cable and earthed objects, such as a central heating radiator. The high cost of changing a damaged protective component makes rare gas tubes the only alternative for subscriber equipment protection. A two-pair protector box with rare gas tubes NGC 40201 is shown in fig. 11.

The holder for a protective device must not reduce the protective effect of the device. The main requirements for a good holder are that it must

- give high and even contact pressure
- give a low inductance connection between the conductor and the protective device and also between the device and earth
- give good insulation between the protective devices
- make it easy to insert and remove the protective devices.

LM Ericsson's wide range of holders for overvoltage protectors is designed to meet stringent demands.



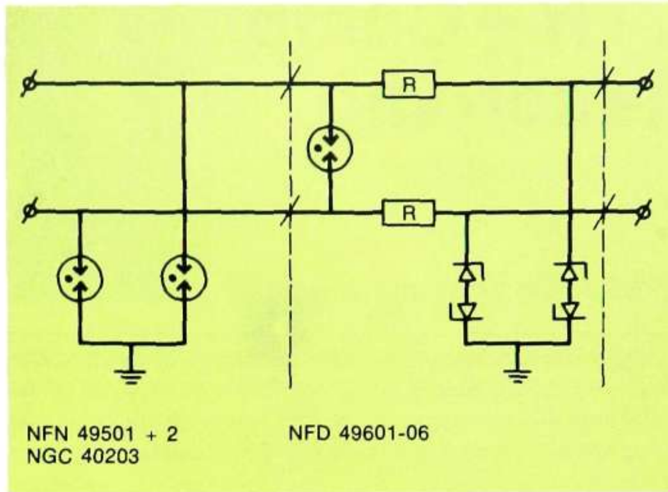


Fig. 12, left
Circuit diagram for a transversal hybrid protector

Fig. 13
Circuit diagram for a longitudinal hybrid protector

Overvoltage protection for electronics

Leased lines in public telecommunication networks, as well as private telecommunication networks, are to a large extent used for the transmission of signals between electronic equipments which have been designed without any special consideration being paid to overvoltages. This has resulted in operational disturbances and extensive repairs to this type of equipment. The voltage that electronic equipment can withstand is normally in the range 25–250 volts if no special measures are taken. This means that the ordinary overvoltage protectors used in the public networks are not sufficient.

The ideal protective component for electronic equipment is the transient protection zener diode. However, as has been mentioned above, the current they can tolerate is not sufficent to enable them to be connected directly to the telecommunication line. However, when used together with rare gas tubes in hybrid protectors the best features of both rare gas tubes and zener diodes are utilized. Diagrams for a transversal and a longitudinal hybrid protector are shown in figs. 12 and 13.

A correctly dimensioned hybrid unit provides a protector that withstands the same overvoltage as the rare gas tubes, and at the same time keeps down the voltage reaching the protected object to only a volt or two above the zener voltage of the diodes.

LM Ericsson's range of hybrid protectors has been designed to provide adequate protection and can be adapted to suit many types of electronic equipment. The hybrid protector, fig. 14, is designed as a single-pair connection block with space for the primary protection, two longitudinal rare gas tubes. The block also contains two contacts which are normally closed and which connect the line side to the telephone side. The secondary protection, the circuit with zener diodes, resistors and a transversal rare gas tubes, is designed as a plug-in unit which opens the contacts in the block and gives a connection path through the secondary protection.

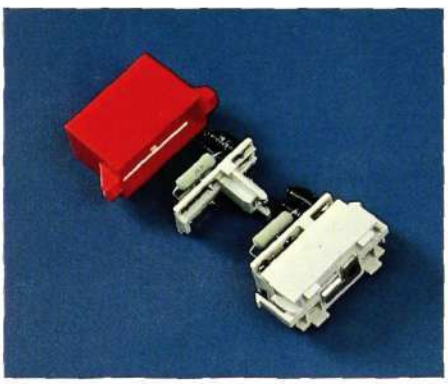


Fig. 14
The hybrid protector for electronic equipment consists of a single-pair connection block with primary protection and a plug-in unit with secondary protection

In order to obtain full flexibility the secondary protection is manufactured as both a transversal and a longitudinal protector in a number of variants, for systems with a maximum signalling voltage from 5 V to 70 V. The zener voltage is consistently slightly higher than the signalling voltage. The resistors have been dimensioned to provide sufficient current limiting for the zener diodes without attenuating the signals unnecessarily. Table 2 gives the data for a hybrid protector consisting of primary protection and transversal secondary protection for signalling voltages up to 5 V (one NFN 49501 + two NGC 40203 + one NFD 49501).

Table 2

Data for a hybrid protection consisting of one NFN 49501 + two NGC 40203 + one NFD 49501

Surge current durability with 8/20 pulse	20 kA
Maximum transversal output voltage	10 V
Contact resistance between NFN 49501 and NFD 49501	< 3 mohms
Transmission loss at speech frequency (600 ohms line)	< 0.5 dB
Return loss at speech frequency (600 ohms line)	> 24 dB
Intended for conductor diameter of	0.4 – 1.3 mm

Summary

In order to provide economical protection against overvoltages in telecommunication networks the most sensitive points in the network must be protected against the most common overvoltages. A coordinated protection system can be built up with good rare gas tubes as the basic protection, and using the screening effect provided by any screens, sheaths and armouring. LM Ericsson's hybrid protectors also provide adequate protection for modern sensitive electronic equipment.

References

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CTR — Computerized Time Recording

Endre Fabo and Ernst Höglund

LM Ericsson Telemateriel AB have developed a computerized time recording system, which has been designated CTR (Computerized Time Recording). The individual time recording is done via terminals with the aid of magnetically or optically coded identity cards. The system is characterized by the fact that it autonomously carries out all the calculations, checks and printouts necessary for reporting the time worked. The system also includes programs that enable data which affect wages to be transmitted to the pay system, either on line or via a special flexible disk store.

The system can also be used for entry control and for informing PABX operators, so that they know when staff are available.

UDC 681.1.174
621.31.681.3

CTR is a computerized time recording system which is specially adapted for companies with flexible working hours. It records and carries out all necessary calculations of the balance as regards flexible working hours and overtime. CTR also records the employee's deviations from the normal working schedule, for example business visits, leave of absence, illness, holidays, to the extent required by the company.

In addition to time recording the system can carry out other functions, such as entry control and providing PABX operaters with information regarding the presence or absence of staff.

The system contains a central unit, to which one or more registration terminals are connected. It also includes correction terminals, enquiry terminals, a console typewriter and a disk store or a flexible disk store, depending on the quantity of data that has to be processed, fig. 3.

Time recording

Function of the terminals

Equipment that must be used by all employees several times every day must be easy to operate. This was one of the main prerequisites in the development of the *registration terminal.*

Each employee has an authorization card, fig. 4, with an individual code. The card is inserted in the card reader of the registration terminal, fig. 1, for the registration of entry and departure. The card can be designed as an identity card with photograph and other identity information. The first thing the terminal does is to send the card code to the central unit for checking that the card is valid.

In the case of ordinary registrations the system is controlled solely by the authorization card, that is to say there is no need for manual input of data.

In the case of a registration that deviates from the normal work schedule, the system demands an explanation from the employee. A text, "State code", is displayed and the employee can then use the push-button set on the terminal to give the cause of the deviation, so that it is correctly processed in CTR and later in the pay routine. If the employee forgets to register, he/she will be informed of this the next time he/she registers. In this way the required information is obtained at source, which to a great ex-

Fig. 1
Registration terminal

Fig. 2
Central unit in the computerized time recording system CTR

ENDRE FABO
ERNST HÖGLUND
LM Ericsson Telematerial AB

Fig. 4
Some types of authorization cards

tent eliminates subsequent correction work.

When an employee with flexible working hours registers, his working-hour balance is immediately displayed on the terminal. The employee can also use the terminal to enquire about, for example, his *working-hour and overtime balances.*

Correction terminals (the system can contain more than one) are used by the appointed department or company time recorder. The terminal is used to correct faults in the employees' time accounts which have occurred because the employees have forgotten to register or given the wrong codes, and to supply information which the employee has been unable to enter, for example in the case of illness.

Enquiry terminals can be used to aid the PABX operator. When an employee does not answer calls on his extension, the operator can feed his telephone number into the terminal and immediately obtain information regarding
- presence or absence
- latest registration
- the cause of absence.

The operator can then see whether the person in question is ill, away on a business trip etc., or whether he is on the *premises and can be paged.*

The console typewriter is used for the
- input of specific personal and company data
- printout of lists
- listing of registrations.

All communication with the computer is carried out in text en clair. The program successively gives instructions to the operator, who therefore does not need any knowledge of programming.

Central function
In addition to the requirement for a registration terminal that had to be easy to handle there was a demand that the system should give the customer sufficiently large rationalization gains. In order to meet this demand CTR has been made completely autonomous as regards time recording and been equipped with the facility for transmitting data that affect wages direct to the pay system without any manual intervention.

A deviation check is made for each registration, that is to say the system checks whether the registration is in accordance with the person's work schedule. (There is space for 255 different schedules.)

Ordinary registrations are listed chronologically, whereas the deviations are stored in a secondary store, where *they are available for output on a printer.*

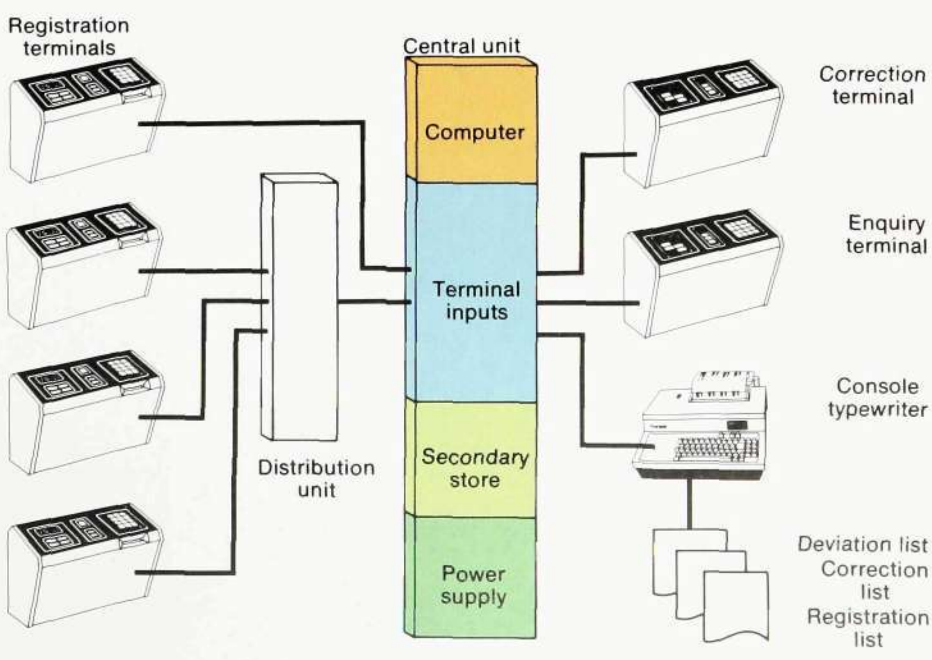


Fig. 3
System structure

At the end of a recording period the list of deviations is printed out, fig. 5, with the entries sorted according to, for example, cost centre and employee number. The printout can either be ordered when required or be done automatically at preset times. The ordinary registrations can be excluded since they have all been checked by the computer. The person in charge of the cost centre, or the employee, need only check the deviating registrations. If it is necessary to correct any item in the deviation list, this is done with the aid of a special routine. A correction list is then printed out, arranged in the same way as the deviation list, as a check that the correction has been carried out.

This completes the actual time recording procedure, but CTR also offers another facility—the transfer of data to the pay system. At the same time the deviation list is printed out, the data that affect the wages are transferred to a special flexible disk store. These data are stored in accordance with the customer's specifications so that they can be accepted by the pay system computer.

Alternatively the data can be transmitted in batches over a line to the main computer used for the pay calculations, fig. 6. This is done by means of emulation, so that from the point of view of the main computer the CTR system functions as an IBM 2780 terminal. Since most main computers of today can communicate with this type of terminal, they can also receive data from CTR into the pay system. This procedure eliminates the manual handling of CTR disk stores.

Entry control

Entry control is an additional facility offered by the CTR system. The entry control can be associated with the time registration or it can be used independently. The system can operate at any or both of the following security levels:

1. Valid card is sufficient
2. Valid card + personal security code are required.

The security levels can be time controlled so that a terminal accepts security level 1 during certain periods of the 24 hours of the day, and requires security level 2 during the remaining periods.

Function of the terminal

With security level 1 the system checks whether the inserted card is valid. If this is the case, a green light is lit, which indicates that the person may enter.

With security level 2 the text "security code" is displayed, and the employee then punches his/her personal security code on the push-button set. Thus nobody has to remember the current security level. A green light indicates that the person may enter. If the code is faulty, a new security code is demanded.

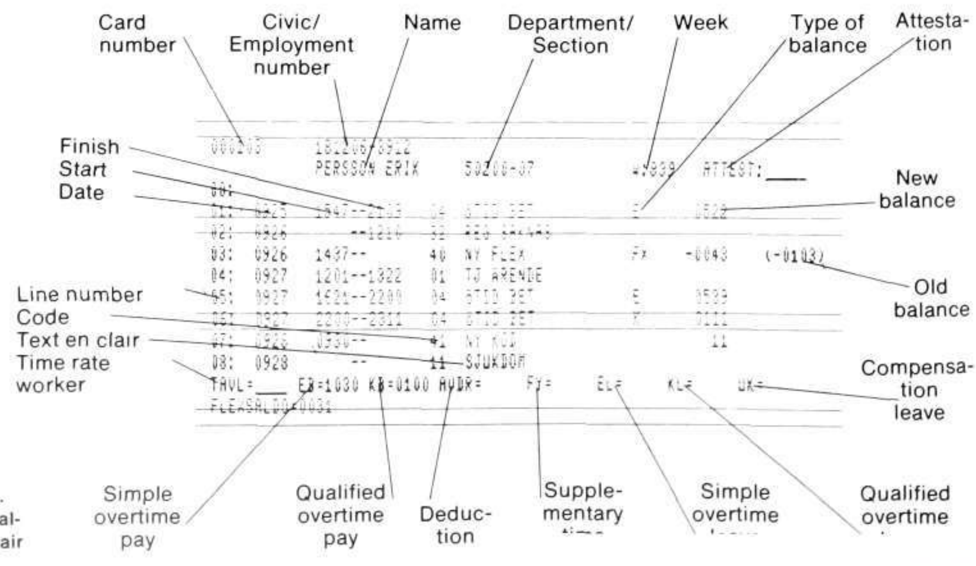


Fig. 5
An example of a deviation list for an employee. The deviation reports are arranged chronologically, with the type of deviation written in text en clair

The console typewriter is used for the input and output of information in accordance with the following program functions.

Central function

The entry control program includes the following functions:

- division into 16 geographical zones. A card can only be used to enter the zone(s) permitted for that particular card. The information regarding this is stored centrally.
- time control of security level 2 (individually via a time schedule for each person)
- listing of all registrations
- individually programmable security codes
- alarm printouts in text en clair
- automatic barring of a card after three failed attempts at entering
- fast manual barring of cards
- control of door locks, either from the terminal or from the central unit.

Technical description of CTR

Authorization card

The system can work with two types of authorization cards:

- Cards with magnetic coding. The size is 85.5×54 mm (credit card size). Both the siz and the coding are in accordance with the standards of ISO 3554. Track 2 is used. The code can contain up to 20 hexadecimal characters.
- Cards with optical coding. The size is 150×74 mm (DIN A7). The code can contain up to 13 hexadecimal characters.

The layout of the cards can be designed to suit the customer. The magnetically coded card can easily be manufactured and coded by the customer. Each card can be equipped with a photograph of the owner, his/her signature and personal information. The code consists of a part that refers to the system, the *system number*, and a personal part, the *card number* and certain *control characters*. The number of possible combinations is so large (over 10^8) that it permits individual coding of all issued cards.

In order for a registration to be accepted by the CTR program, the system number must be correct and the card number must not be barred. This is sufficient for pure time recording systems. In entry control systems, however, security is the main issue. In such systems it must be ensured that the person who registers is really authorized to pass that terminal (door) at that time.

There is a number of authorization cards available on the market, which according to the manufacturers are very difficult to falsify. Nevertheless it is wrong to rely too much on the card as the personal identification in a security system, that is to say to build the security into the card. It can be argued that any

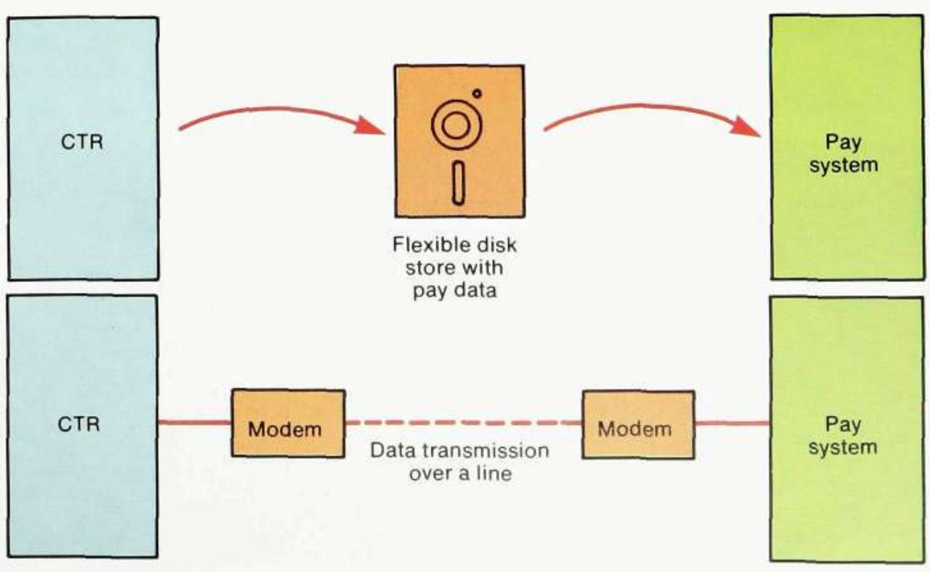


Fig. 6
Alternative methods for transmitting data from CTR to the pay system

card which can be made can also be forged. Moreover the risk of a card being lost or stolen can never be ignored. A technically complicated card is usually also expensive to manufacture and can often only be obtained from one supplier.

The aim during the development of the CTR system was instead to achieve the highest possible *overall* security. This is obtained with a simple authorization card together with an individual security code and an advanced entry control program.

System parts
The system contains a computer, a secondary store, terminals and power supply equipment. In certain cases distribution units and modems are added.

The computer, APN 144, contains a 16-bit microprocessor, LSI 11, manufactured by *Digital Equipment.* The primary store comprises 64 k bytes. The computer has 16 serial inputs for the connection of terminals.

A special input enables the system clock to be synchronized with minute pulses from an external main clock.

The secondary store can be either a disk store of 5 M bytes or a flexible disk store of 2×256 k bytes. The type of store chosen depends on how many people are to be served by the system and also the extent of the program.

A cassette tape station is used as a program standby in systems with a disk store. It is connected to the computer via a serial input.

Fig. 7
The front panel of the registration terminal

Additional secondary stores can be connected in when special program functions are required, for example the listing of registrations in a disk store or the storing of data for pay calculations.

The registration terminal, fig. 6, contains a card reader for magnetically or optically coded cards. It also includes a push-button set with 12 buttons for entering deviation and security codes. The control panel also contains a digit indicator for seven digits. The digits are shown by 7-segment light emitting diode units. The indicator is used to display the balance of flexible working hours or overtime, deviation codes etc. A number of indicator lamps with text panels provide information and instructions for the employee during the registration.

The unit cover used for the registration terminal is also used for *correction terminals* and *enquiry terminals,* but the two latter terminals do not contain card readers. Their push-button sets contain 14 buttons and the text panels for the indicator lights have different texts.

All terminals have a modular structure and contain mainly the same units. The type of terminal and function can easily be changed, which simplifies servicing and the stocking of spares. The following variants can be obtained by changing the control panel:
- Registration terminal with a magnetic card reader, for time recording and entry control
- Registration terminal with an optical card reader, for time recording and entry control
- Correction terminal and enquiry terminal.

A *typewriter terminal*, console typewriter, with a speed of 30 characters per second is used in systems for up to 600 people. In larger systems a terminal with a speed of 180 characters/s is used.

A *distribution unit* is used when more than one terminal is to be connected to one and the same serial input in the computer. It permits multipoint connection of 8 terminals, but two or more distribution units can be connected in series to one line, which enables up to 16 terminals to be connected to that line.

Technical data

Central unit

Capacity	50 terminals, 2000 people (with only entry control: 5000 people)
Computer	APN 144, word length 16 bits, primary store 64 k bytes
Secondary store	Disk store for 5 M bytes or flexible disk store for 2×256 k bytes
Environmental requirements	+15° C to +25° C ambient temperature, 20–80 % relative humidity
Power supply	220 V AC, 400–800 W depending on the equipping
Standby battery	Minimum 90 minutes (only the computer)
Cabinet	1300×800×600 mm (not including the power supply)

Terminals

(Registration, correction and enquiry terminals)

Input/output	Card reader for magnetically or optically coded authorization cards, push-button set, 7-segment digit indicators, illuminated text panels
Communication	150, 300, 600, 1200, 2400, 4800 or 9600 bauds, asynchronously with ASCII code
Interfaces	V11, RS 422 V24, RS 232 C 20 mA current loop
Signalling wires	4-wire
Environmental requirements	−15° C to +40° C ambient temperature, 20–80 % relative humidity
Power supply	24 V AC, 25 W
Dimensions	408×266×162 mm (maximum dimensions

protection circuits for each terminal line. The function of the other terminals will not be affected if a fault occurs on a line or in a terminal.

Modems can be used when the length of line between the units exceeds 1200 m. They can be connected in anywhere along the signal path between the computer and the terminal.

The power supply equipment for the computer contains standby batteries, which in the standard version are sufficient for approximately 90 minutes of operation. The other units are powered from the mains. If desired, the whole system can be provided with interruption-free power supply, which may be justified in entry control systems.

Communication between the computer and the terminals

The terminals can be either *unpolled* or *polled*.

- An *unpolled terminal* has its own serial input to the computer. This means that when the terminal has a message ready to send, for example concerning a registration, it is sent immediately, after which the computer takes care of it via its interrupt routines. In the same way any messages to the terminal are dispatched without delay. The advantage of this method is that the answering times are short, but it requires that each terminal is connected to a separate input in the computer.
- A *polled terminal* can share a serial input with up to 15 other (polled) terminals at the expense of the answering times. The computer must then ask each terminal in turn (the terminals have individual addresses) whether it has a message to send. When a terminal and the computer exchange data, all other terminals on the same line have to wait. The advantage of polled terminals lies on the installation side. For example, the number of expensive modem lines can be reduced. In addition the number of terminals in the system can be increased above the number of available inputs. The terminals are connected to the computer via the distribution unit, in the multipoint mode.

Unpolled and polled terminals can be mixed as desired in the CTR system. When the system is taken into service the program automatically determines whether a terminal is unpolled or polled, and in the latter case records its address. The computer can at any time be commanded to print out a table showing the current state of the system. It is then very easy to check that all terminals function correctly. Even if terminals are disconnected or develop a fault when in operation, the function of the system will not be affected in other respects.

The signal transmission between the central unit and the terminals is carried out in a serial asynchronous mode with ASCII code. Four wires are used. The balanced interface V11 (RS 422) is normally used, since it has much better electrical characteristics than the 20 mA current loop, which is still common in other applications. For example, V11 permits a line length of 1200 m between units over the whole speed range used. However, V24 (RS 232 C) is used when modems are to be connected.

In order to detect whether the signals are distored by interference on the line, each message is checked by the receiving unit as regards format and character parity. The transmitting unit expects an acknowledgement of each message and will repeat the latest transmission until the receiving unit has apprehended and acknowledged it.

Summary

CTR is a time recording system which meets modern demands for rationalization and flexibility. It also offers entry control,which can operate either in conjunction with the time recording or entirely independently.

The registration routines are very simple and all lists and messages to the operator are written out in text en clair.

The system carries out all calculations of balances concerning flexible working hours, overtime etc. and it can also provide data for pay calculations and personnel statistics.

The modular structure of both software and hardware makes the system extremely adaptable. It covers a wide range both as regards the size of the work force and the desired program functions.

Choice of Monolithic Technique

Per Bengtsson, Klas-Håkan Eklund and Erik Nyström

RIFA's industrial activities include the design and manufacture of integrated circuits in monolithic techniques. This article compares the various monolithic techniques and their suitability for telecommunication applications. Subsequent articles will discuss RIFA's resources and the methods used for designing and manufacturing different types of monolithic circuits.

UDC 621.3.049.774

During the 1960s and 1970s the rate of development within the field of semiconductor technology was very rapid and led to the very advanced integrated circuits in monolithic techniques that are available today. The circuits can be divided into two categories; bipolar circuits with both holes and electrons as the carriers of charges, and unipolar MOS (Metal Oxide Semiconductor) circuits with either holes or electrons as the charge carriers.

In a previous, general article on RIFA (E. R. 1/80) the manufacturing process for integrated circuits was described in broad outline, i.e. how dopants are introduced in the monocrystalline silicon wafer and affect the electrical conductivity of different parts of the wafer, which then form the base, emitter or collector of one of the many semiconductor elements. A more detailed description of the actual manufacturing process will be given in a later article. In this article some of the types of circuits that can be produced using monolithic techniques will be described.

Bipolar circuits

Most bipolar circuits are manufactured using a technique called SBC (Standard Buried Collector). The structure of such a circuit is described in fact panel no. 1 at the end of the article.

The types of components manufactured in bipolar technique are diodes, npn transistors, slow pnp transistors, resistors, ion implanted precision resistors, field effect transistors (JFET) and Schottky diodes.

Many different circuits can be manufactured in bipolar technique, e.g. analog circuits with good performance, circuits for high voltages, circuits which tolerate high currents and digital circuits. Digital functions can also be combined with analog functions in the same circuit, which is very useful for applications in the telecommunications field. The digital functions can be made very fast using Schottky technique, fact panel no. 2, and a very high packing density can be obtained with I^2L (Integrated Injection Logic) technique, fact panel no. 3.

MOS circuits

MOS (Metal Oxide Semiconductor) circuits are mainly of three types, n-MOS, p-MOS and CMOS (Complementary MOS). The manufacturing method for n-MOS and p-MOS is de-

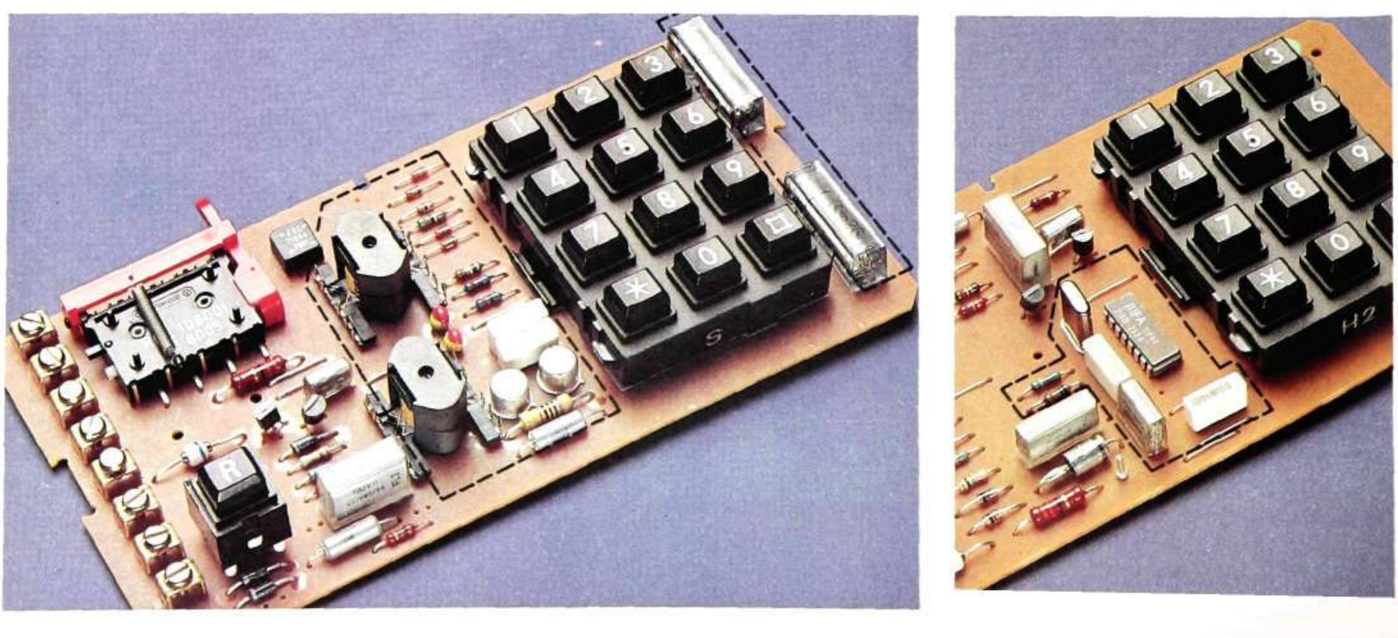
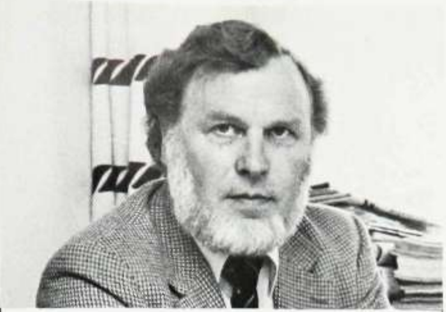


Fig. 1
Monolithic design techniques mean that large, expensive components, such as coils and precision capacitors, are replaced by cheaper and smaller monolithic circuits. The pictures show a DTMF generator (the outlined parts) for DIAVOX in the old (left) and new (right) techniques



PER BENGTSSON
KLAS-HÅKAN EKLUND
ERIK NYSTRÖM
AB RIFA

scribed in fact panel no. 4 and the method for CMOS in fact panel no. 5.

Unlike the bipolar transistors, MOS transistors do not need any space-demanding insulation barriers between the individual components. The collector is reverse biassed in relation to the substrate, which makes the component self insulating. MOS circuits can therefore be packed more densely than most bipolar circuits, with the exception of I^2L circuits, which have the same high packing density.

n-MOS circuits have better performance than p-MOS, and hence the n-MOS technique has become predominant. At present n-MOS technique is probably the most effective one for digital functions, especially for complex circuits which require high packing density, and for large manufacturing volumes.

In CMOS technique n-MOS and p-MOS transistor functions are combined. The main advantage of CMOS is the low power consumption with a low usage rate. The circuits draw very little power when idle, since it is only the changeovers that require power. This feature makes these circuits particularly attractive for telecommunication equipment that is power fed via telephone lines.

CMOS technique is increasingly being used in applications with mixed digital and analog functions. CMOS has better packing density and performance than n-MOS for such applications.

The limitations of different monolithic techniques

The possibility of manufacturing very complex circuits in monolithic technique, i.e. circuits with more than 1000 circuit functions, so-called LSI (Large Scale Integration) circuits, is limited primarily by three factors, namely the circuit surface area, power dissipation and desired performance.

Circuit surface area

Each individual element in a complex circuit must be as small as possible, otherwise the area of the circuit becomes impossibly large. Miniaturisation is not an end in itself. It affects the yield of the manufacture. A large circuit not only gives fewer circuits per silicon wafer but also a lower percentage of faultfree circuits. A reasonable basis for a comparison between different techni-

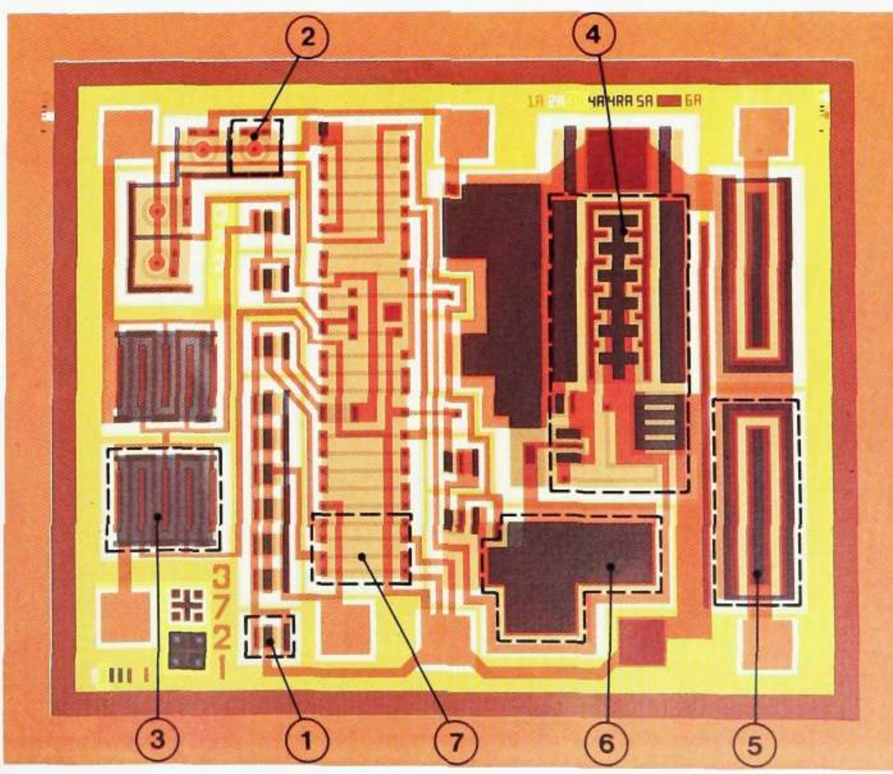


Fig. 2
Some integrated elements in bipolar technique

1. npn transistors
2. pnp transistors, lateral
3. JFET (field effect transistor)
4. Darlington transistor with an emitter resistance, 150 mA
5. Rectifier diode, 150 mA
6. Capacitor, 10 pF
7. Re

Table 1
The limitations of present-day LSI techniques

	Delay (ns)	Power per gate (mW)	Power delay product (pJ)	Packing density (gates/ mm²)	Max. number of gates per chip	Power per chip (W)	Size of chip (mm²)	LSI limitation
TTL-LS (MSI)	5	1	5	30	500	0.5	17	Power
ECL (MSI)	2	2	4	30	250	0.5	8	Power
Low voltage LS	2	0.3	0.6	60	1500	0.5	25	Power
Simple I²L	50	0.02	1	100	2500	0.05	25	Size
Advanced I²L	10	0.05	0.5	200	5000	0.25	25	Size
n-MOS	40	0.2	8	100	2500	0.5	25	Power
Advanced n-MOS	15	0.1	1.5	200	5000	0.5	25	Power
CMOS	30	0 (static)	—	50	2500	—	50	Size
Advanced CMOS	10	0 (static)	—	150	7500	—	50	Size

ques is obtained if it is assumed that the maximum circuit area is 25 mm² for bipolar circuits and 50 mm² for MOS circuits. The miniaturisation also affects the performance.

Power dissipation
Each element must develop as little power as possible in order that the total power shall not be too high. A simple package can be allowed 0.5 to 1.0 W without extra cooling being necessary. This often has the result that the possibilities of making a circuit in a certain technique are limited not by the packing density but by the power. Higher power can of course be allowed for unique circuits. In other circuits the power dissipation must be limited to values far below those given above. This is the case in circuits for telephone sets, which it must be possible to power feed over long lines.

Performance
The performance of a digital circuit is dependent on the power required per element and the delay contributed by each element. When comparing different circuit techniques it is better to use gates as the element of comparison instead of transistors, since different techniques use different numbers of transistors per gate function. In comparisons a factor of merit is often used that is called the power delay product, which is the product of the power per gate and the delay per gate.

In table 1 the characteristics and possible degree of complexity of some techniques have been compiled. As can be seen from the table, the limitations of power are often more serious than the limitations of packing density. The given values apply for the highly developed techniques of today.

The power delay product is the limiting factor for any particular technique, whereas the given values for power and delay can be modified. If the speed requirement for a certain technique can be waived, it is possible, within certain limits, to reduce the power. A more complex circuit can then be made in that particular technique if the power is the limiting factor.

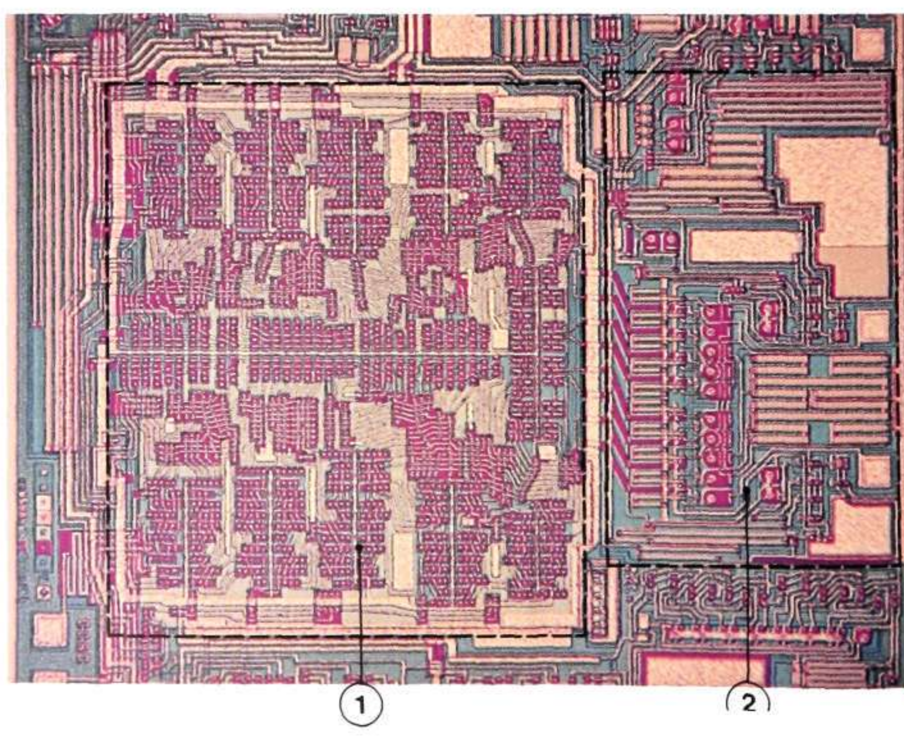


Fig. 3
A close-up of the chip for the DTMF generator in fig. 1. In bipolar technique complex digital parts in I²L technique (1) can be combined with digital/analog converters and linear amplifiers (2)

LSI technique	Linear functions, e.g. op. amp.	High voltages BV ⩾60 V	High currents I ⩾100 mA
I^2L	Yes (high performance)	Yes (worsening logic performance)	Yes
n-MOS	Yes (normal performance)	No	No
CMOS	Yes (normal performance)	No	No

Table 2
Digital techniques. Compatability with linear functions, high voltages and high currents

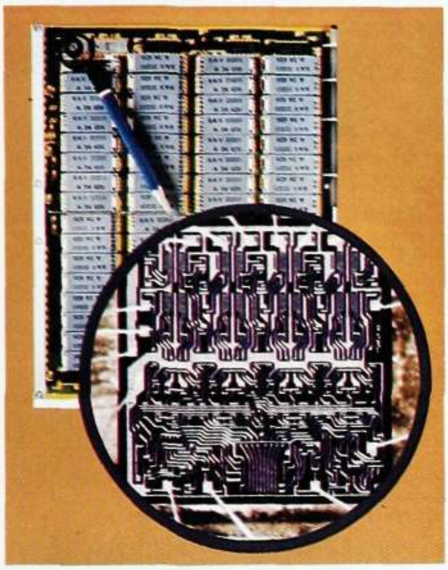


Fig. 4
Switching circuit used on the AXE analog switching circuit boards. The use of monolithic circuits, such as bus-connected relay drivers, reduces the number of contacts and also the cost

In the table the power given for CMOS circuits is zero. This needs an explanation. The CMOS gate requires only negligible power in the static state, but it draws power during the moment of switching. A CMOS circuit therefore develops a loss power that is directly proportional to the rate of use. With a system clock frequency of 1 MHz, and if approximately 25 % of the gates switch at each clock pulse, the mean power dissipation can be assumed to be 10–30 μW per gate. At 10 MHz the power dissipation in CMOS is comparable to that of n-MOS and low power Schottky circuits with small voltage swing. CMOS technique is wholly superior as regards low power consumption and speed on condition that it has a low rate of use.

Table 1 shows that n-MOS, CMOS and I^2L are the techniques that are most suitable for LSI circuits. Each of them covers several application fields. All three are likely to develop towards higher packing density and lower developed power per gate, along with the continuing development of manufacturing technique. The development will possibly favour MOS technique since it is likely that bipolar technique will encounter limitations at an earlier stage.

Choice of technique for different telecommunication applications

A circuit function can often be produced with satisfactory results in any one of several techniques. In certain cases the choice of technique is obvious. For circuits with purely digital functions n-MOS is the natural choice if the circuit is to be manufactured in large quantities and if the power dissipation does not have to be severely restricted. On the other hand, if low power consumption is a requirement, CMOS is the natural choice.

At present, analog functions with a high-level performance can only be obtained using bipolar technique. When high voltage tolerance and high current driving capability are required, bipolar technique is also the natural choice.

The problems arise when digital and analog functions are to be combined in one and the same circuit, a combination which is common in the telecommunications field. The greater the part of the system to be included in the circuit, the greater the problems. In table 2 the usefulness of the three LSI techniques is summarised as regards digital functions, analog functions, high voltages and high currents. The table shows that only I^2L meets all the demands in the table, but the performance of digital circuits is reduced at high voltages. As yet there is no optimal technique for difficult applications. This is illustrated by the fact that different manufacturers who have designed encoders and decoders for PCM (CODEC) have used n-MOS as well as CMOS and I^2L.

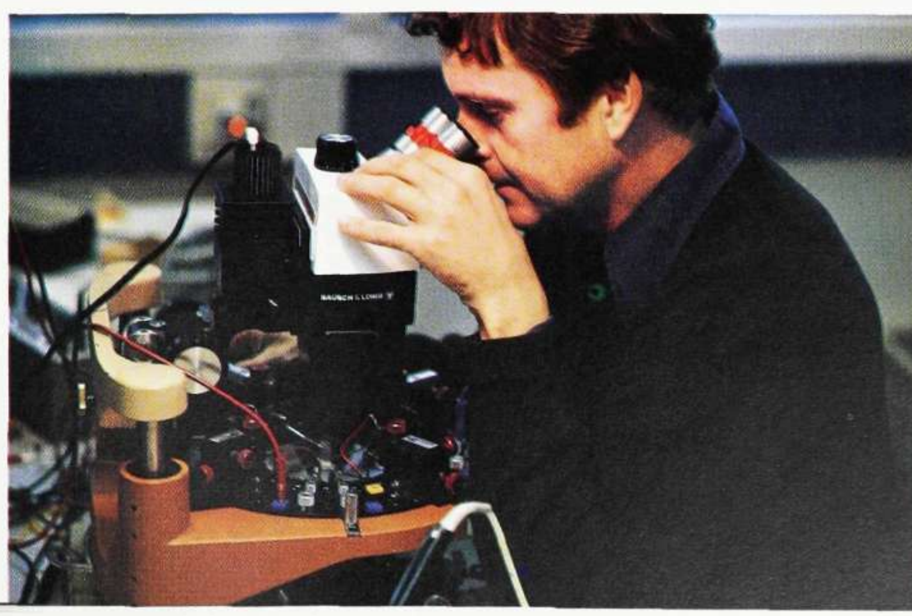


Fig. 5
The designer uses microprobes and a microscope to measure on the chip and analyze the operation of the circuit

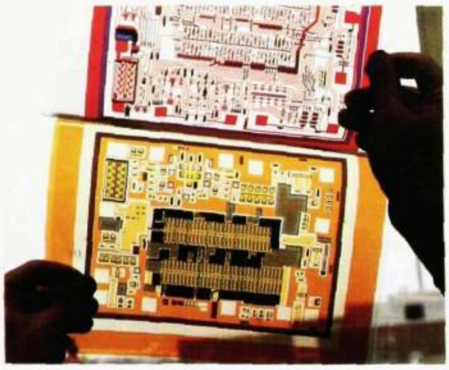


Fig. 6
The originals of the various masks, enlarged 100 times, are used to check the geometry of the elements and the alignment of the different layers

It is likely that technical development will continue and eventually provide solutions to these problems. The solutions may mean that MOS and bipolar technique will be combined, that there will be a further development of I^2L or that new technique variants will be developed that meet all demands. It is clearly the telecommunication applications which encourage this development because of the demands they make both as regards function and large production quantities.

The techniques chosen by RIFA

The choices made by RIFA as regards monolithic techniques and the company's own development work have to a great extent been dictated by the need of the telecommunication industry for customer-tailored solutions. The first generation of electronic telephone exchanges had a computer with a memory for the control function, and reed relay matrices for the switching function. The computer could be built using standard circuits, but the circuits for interfaces towards the switching equipment and the lines had to be made in a different way. What was required was a technique that could convert the fast, low-level computer signals to the high driving currents required by the relays. Moreover, adaptation to circuits driven from a 48 V battery voltage was also required. The solution was bipolar technique, further developed to tolerate high voltages. A number of circuits were developed, simple driving stages for relays with or without memory function, circuits for the selection of devices, bus connected driving stages for relays and high-voltage comparators. Analog circuits with high-level performance were required for transmission functions. In this case also, bipolar circuits were the natural choice. A number of transmission circuits were developed, for example for telephone sets, where field effect transistors (JFET) were used as the amplifier element for electret microphones. The bipolar process technique was combined with LS technique for fast digital functions. In 1972 the development of I^2L technique made possible a higher packing density for digital circuits.

The two tone oscillator for push-button telephones, figs. 1 and 3, is a good example of how several techniques are utilized to design a circuit. Other examples of circuit designs in bipolar technique will be described in more detail in a subsequent article.

A number of compatible techniques are now available to RIFA, so that it is possible to manufacture integrated circuits where one and the same circuit can contain:

- fast digital functions in LS technique
- densely packed digital elements in I^2L technique
- analog precision functions with ion implanted resistors
- amplifiers with high impedance inputs with JFET
- driving stages for high currents
- power transistors
- filters
- capacitors.

With bipolar technique the following extreme values can be obtained for different characteristics, even if it is not always possible to combine them in the same circuit:

- breakdown voltages up to 130 V
- currents up to 1 A
- absolute resistance tolerances of ± 2 %
- relative resistance tolerances of ± 0.2 %
- packing densities of up to 200 gates per mm^2 with I^2L
- clock frequencies up to 20 MHz with LS.

The developments within the telecommunications field indicate that more and more problems will eventually be solved using digital methods. As has been mentioned above, in many cases n-MOS circuits are more suitable for purely digital functions that bipolar circuits. For this reason the range of techniques in use within RIFA will in 1980 be extended to include MOS technique.

Fact panel 1
Bipolar circuits

The manufacture of bipolar circuits starts with discs of p-type silicon, *1*. The surface of the disc (or wafer) is oxidized and holes are etched in the oxide in the places where the buried collectors are to be placed, *2*. The low-ohmic n-type collectors are formed by means of diffusion. The next step in the manufacture is coating with an epitaxial layer of high-omic n-type silicon, *3*. The layer is monocrystalline and is allowed to grow over the whole wafer to the desired thickness. The wafer is then oxidized again, and in this oxide layer holes are etched for the insulation barriers between the various semiconductor elements, *4*. These barriers, low-ohmic p-type, are also diffused and form frames round each component. The n-type collector, *2* and *3*, of each intended npn transistor is surrounded by p-type silicon, *1* and *4*. *1* and *4* will afterwards be connected to the highest negative potential in the circuit, which will ensure that the components in the circuit are electrically insulated from each other. When this step is completed, the whole surface is again covered with oxide and holes are etched for the base areas of the npn transistors and for connection points to ion implanted resistors, *5*. Diffusion through these holes gives areas with relatively low-ohmic p-type silicon. In this diffusion stage it is also possible to form the emitters and collectors of lateral pnp transistors, and resistance loops that are made simply by means of base diffusion. The base diffusion is followed by the emitter diffusion, which gives low-ohmic n-type areas, *6*. The oxide layer is then restored and holes are etched for the ion implanted resistors, *7*. The wafer is exposed to an ion ray of a p-type dopant and is then heat treated in an oxidizing atmosphere so that the whole surface is again covered with oxide. Contact holes are etched for the connections to the components and the wafer is covered with a thin metal film, usually aluminium, in which the wiring pattern is etched.

The buried collector, *2*, gives the npn transistors a low collector resistance. The thickness and resistivity of the epitaxial layer can be chosen to suit different types of circuits. Typical values for the thickness are in the range 3 to 20 μm and for the resistivity in the range 0.2 to 5 ohm·cm. The characteristics of the epitaxial layer determine the breakdown voltages of the transistors, stray capacitances, the life of the charge carriers, the amplification of lateral pnp transistors and the inverse amplification of npn transistors. The last of these parameters is important for I^2L applications, where the function of the transistors is inverted.

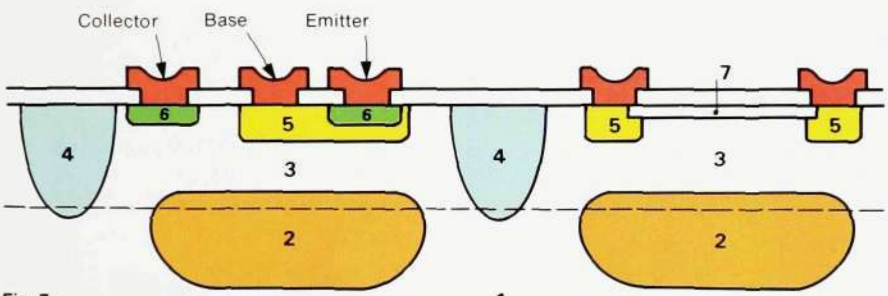


Fig. 7

Fact panel 2
Schottky circuits

The Schottky diode is a component that is increasingly being used in bipolar circuits. It is a metal semiconductor diode which has a lower voltage drop in the forward direction than a diode that consists of a pn junction in silicon. Above all, by placing a Schottky diode in parallel with the collector base diode of an npn transistor, the turn-off of the transistor is speeded up. During manufacture the metallization process for the wiring pattern is slightly more complicated if Schottky diodes are included in the circuit.

This technique is used for Schottky transistor-transistor-logic circuits, TTL-S, and the corresponding low power circuits, TTL-LS. With Schottky technique for low voltages, where the logic voltage swing is as little as 200–300 mV, very fast digital circuits can be obtained, which develop relatively low loss power and which can be packed fairly closely on the wafer, table 1.

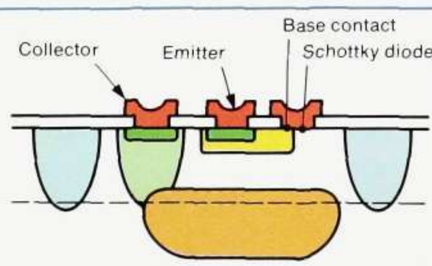


Fig. 8

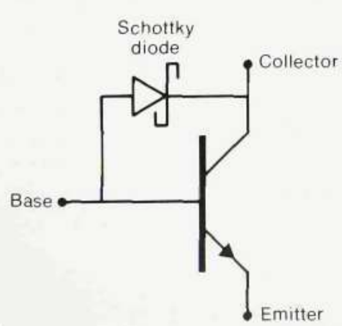


Fig. 9

Fact panel 3
I^2L circuits

I^2L circuits are inverted npn transistors. The collector and the emitter have changed function. The base is used as the input and the collector as the output. For each input there are normally several outputs which are electrically insulated from each other. Logic conditions are obtained by connecting together the relevant outputs. Outputs from one and the same transistor can form part of different logic conditions. The transistors are driven via a lateral pnp structure. A hole current goes from injectors (p) via the epitaxial layer (n) to the bases (p) of the transistors. The driving is high-ohmic. The figure shows three I^2L transistors in the same insulated n-type area. Normally several hundred transistors can be placed in the same area. Space-demanding insulation barriers are only required for insulating the I^2L part from the other circuits on the chip. The I^2L circuit can also contain normal npn transistors, to the left in the figure, pnp transistors and resistors for analog functions. In addition the circuit can contain elements for fast logic functions, such as emitter-coupled logic, ECL, or TTL-LS. The figure shows how, by means of extra deep diffusion, low-ohmic n-type areas have been created which reduce the collector resistance of the npn transistors and which screen the I^2L transistors from each other. The I^2L technique permits a very high packing density.

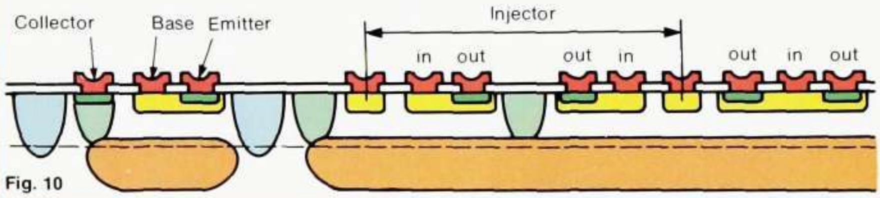


Fig. 10

Fact panel 5
CMOS circuits

CMOS circuits contain both p-MOS and n-MOS transistors. The substrate used is normally of n-type. p-MOS transistors are made in the way described in fact panel no. 4. n-MOS transistors are obtained by means of an initial diffusion of a dopant so that a p-well is formed.

The advantage of CMOS circuits is that n-MOS and p-MOS transistors can be combined in pairs to form circuits in accordance with fig. 14. The inverter shown there draws current only when changing over between the two states that the circuit can take up. If the circuit is used relatively infrequently it will consume very little power.

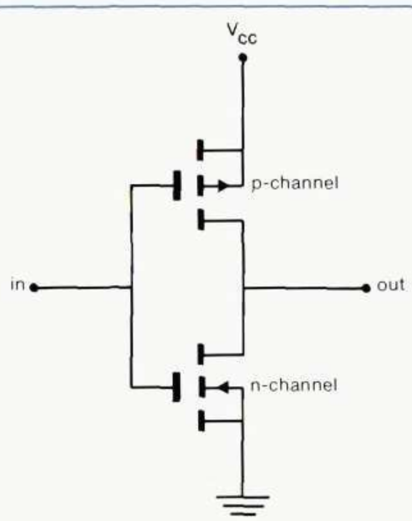


Fig. 14

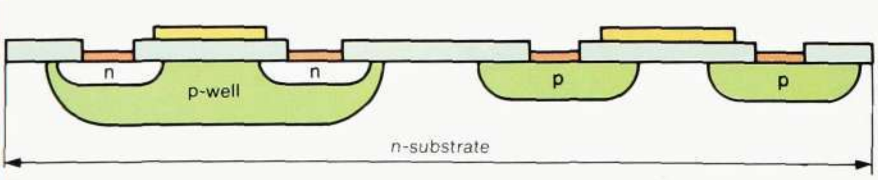


Fig. 13

Fact panel 4
MOS circuits

The figure shows a cross section of a p-MOS transistor and also the symbol for such a transistor. It is built up on an n-type silicon substrate. The areas that are to be source and drain are subjected to diffusion with p-type dopants. The gate, which is made of conducting material, is insulated from the substrate by a thin layer of silicon dioxide. By putting a voltage across the gate that is negative in relation to the substrate, the conductance of the area under the gate is changed from n-type to p-type, thus enabling current to flow from the drain to the source, and the transistor becomes conducting. The changeover to the conducting state always takes place at a certain threshold voltage. MOS circuits are therefore voltage controlled, whereas the previously described circuits are current controlled.

If instead a p-type substrate is used and the source and drain areas are doped with an n-type dopant, an n-MOS transistor is obtained. It will become conducting at a certain positive voltage.

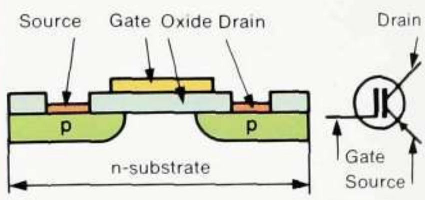


Fig. 11

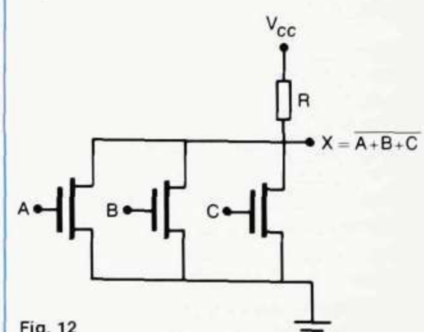


Fig. 12

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ELLEMTEL, 10 Years Old

Erik J. Eriksen

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President
ELLEMTEL

April 24, 1980, was a red-letter day for the ELLEMTEL Development Company. Exactly ten years earlier the Swedish Telecommunications Administration and LM Ericsson had made the agreement to form the company. ELLEMTEL was to be a jointly owned development company for advanced development and design work in the field of telecommunications.

When ELLEMTEL was formed, the Swedish Telecommunications Administration and LM Ericsson were faced with the task of introducing telephone exchange systems that utilized new technology.The development in the semiconductor field was rapid. New integrated circuits were continually being introduced. The price/performance ratio for these circuits was decreasing steadily. This development clearly indicated that the electromechanical telephone switching systems would soon be superseded by completely electronic systems. Stored program control had successfully been introduced for large trunk exchanges of type AKE. The introduction of stored progam control in local exchanges would necessitate further development in order to achieve rational handling when the number of exchanges multiplied.

In ELLEMTEL selected staff from the two owner companies could be brought together to form a development organization that was powerful enough to carry out the necessary renewal of the product range.

The development of telephone exchange system AXE

In the field of telephone exchanges the development work resulted in the new well-known exchange system AXE. The introduction of system AXE on the market has been exeptionally fast. Since the first exchange of 3000 lines was put in operation in Södertälje (central Sweden) in March 1977 the system, whose technical characteristics are rated very highly has had a number of successes in the international market. Hitherto 22 countries have ordered a total of around 2 million local exchange lines. The development of system AXE has been ELLEMTEL's most important undertaking, since from the point of view of cost the telephone exchange equipment is dominant in the telephone networks. However, important and in many cases pioneering development work has also been carried out in the field of telex and data networks, as well as on subscriber equipment.

Fig. 1
The ELLEMTEL plant at Älvsjö, Stockholm

Telex

In August 1977 the first fully electronic telex exchange, system AXB 20, was taken into service in Malmö in south Sweden. The same processor is used in AXB 20 and AXE. The Malmö telex exchange was the first exchange designed by ELLEMTEL where time multiplexing was used in the switching network. A complete product range for telex has now been developed, with for example multiplexors, manual operator positions and facilities for message switching.

Nordic data network

ELLEMTEL is now in the process of completing a large development project with the testing of the Nordic data network. Delivery of the first stage will take place soon. The network is of a completely new type. It was therefore possible to design all the network components, terminal equipments, multiplexors, concentrators and exchanges on the basis of digital technology throughout. The work on the data network has provided valuable experience, which will be useful for further development in the telephony field.

Subscriber equipment

Stored progam controlled PABXs with space-division switching networks have been developed. ASD 551 uses reed relays and ASB 100 thyristors as the switching element. The development and design of a new standard telephone set, DIAVOX 100, also took place within the framework of the ELLEMTEL cooperation. An office communication system, DIAVOX 824, has also been developed. The system is stored program controlled and consists of a central unit and extension sets with the DIAVOX case.

Conclusion

A look back over these ten years shows that ELLEMTEL has greatly contributed to a renewal of the products in many fields and has vitalised the development activities. In the light of today's knowledge the decision by the Swedish Telecommunications Administration and LM Ericsson to form ELLEMTEL shows great foresight.

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ERICSSON REVIEW

DEVELOPMENTS IN FIBRE OPTICS WITHIN THE ERICSSON GROUP
OPTICAL FIBRES
OPTICAL FIBRE CABLES
JOINTING OF OPTICAL FIBRE CABLES
TRANSMISSION MEASUREMENTS ON OPTICAL FIBRE CABLES
34 MBIT/S OPTICAL FIBRE LINE SYSTEM, ZAM 34-1
FIELD TRIAL WITH OPTICAL COMMUNICATION

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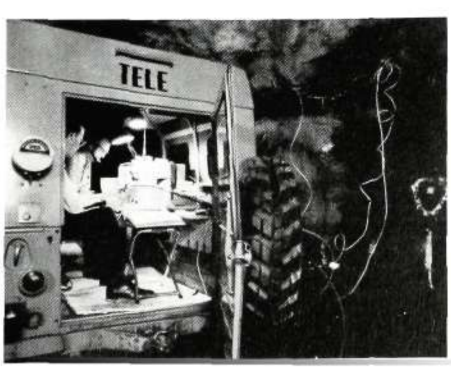

COVER
Measuring a fibre cable during a field trial with optical communication. The trial started in 1979 and was carried out in Stockholm, Sweden.

Developments in Fibre Optics within the Ericsson Group

Ulf Johansson and Gunnar Lundström

This issue of Ericsson Review is devoted entirely to the work on optical fibre carried out within the Ericsson Group. This first article gives a summary of the work, and the subsequent articles describe various aspects in greater detail.
Development in the field of fibre optics has previously been outlined in this magazine in the addresses given by the recipients of the 1979 LM Ericsson Prize, Dr Charles Kao and Dr Robert Maurer, at the award ceremony[1].

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The Ericsson Group started to work on fibre optics on a large scale in 1974. The main aim was to develop know-how and technology so that LM Ericsson would be prepared for future product development and manufacture. This preparatory work comprised the development of fibre and component technology and measurement methods. In addition, trial systems for the transmission of video and data were designed.

An important part of the know-how was obtained through research projects at the Swedish Institute for Optical Research and the Swedish Institute for Microwave Engineering. These projects were financed by LM Ericsson and the Swedish Board for Technical Development. Fundamental work has been carried out as regards measuring methods, fibre process development and laser development, and the results have been transferred to LM Ericsson.

During recent years the work on fibre optics within LM Ericsson has to a large extent been concentrated on the development work required for a large scale field trial, FOK-79 (Field Trial with Optical Communication), which was carried out in collaboration with the Swedish Telecommunications Administration. The purpose of FOK-79 was to demonstrate the possibilities of fibre optics.

Within the Ericsson Group the subsidiary cable company Sieverts Kabelverk is responsible for:
- the development and manufacture of fibres and fibre cables
- the development and manufacture of equipment for jointing fibre cables

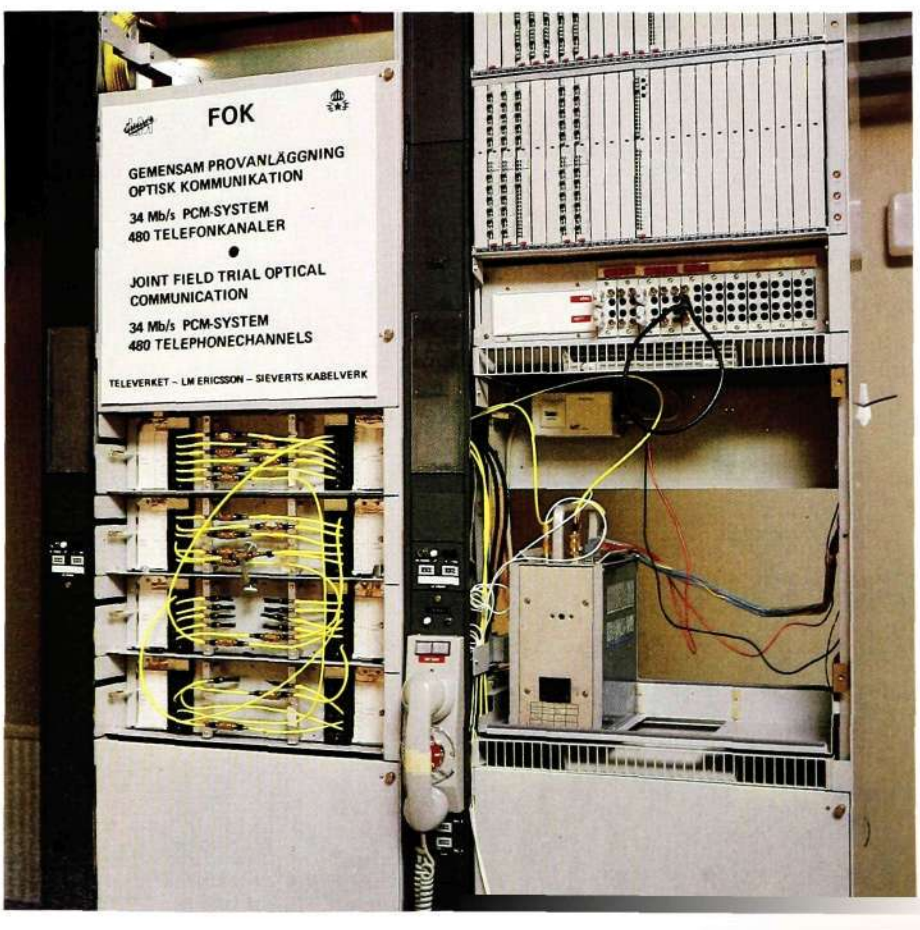


Fig. 1
Field trial with optical fibre communication equipment, carried out in Stockholm (Sweden) in 1979

ULF JOHANSSON
Transmission Division
Telefonaktiebolaget LM Ericsson

GUNNAR LUNDSTRÖM
Sieverts Kabelverk AB

- the development of measurement methods and equipment for determining the characteristics of fibres and fibre cables.

The Transmission Division of the parent company is responsible for:
- the development and manufacture of optical fibre components and systems
- the development of installation methods and installation equipment
- the installation of fibre cables and systems.

In February 1980 the Swedish Telecommunications Administration and LM Ericsson made an agreement concerning cooperation in the field of fibre optics. The agreement means that the Telecommunications Administration and LM Ericsson will be carrying out joint system development projects within the framework of the joint development company ELLEMTEL.

Optical fibre

In 1976 a fibre laboratory was set up in LM Ericsson's Materials Laboratory, for the purpose of developing fibre manufacturing methods. In this laboratory fibres are today being manufactured on a small scale. The greater part of this work is gradually being transferred to Sieverts Kabelverk, whose opto cable centre is being built up.

The development work has been carried out along two different lines[2]. A modified CVD (Chemical Vapour Deposition) method has been developed in collaboration with the Institute for Microwave Engineering. This method is now being used to manufacture fibres which have an average attenuation of less than 3.5 dB/km and a pulse dispersion of approximately 1 ns/km at a wavelength of 850 nm. This is the type of fibre used in the field trial FOK-79.

A double crucible (DC) method has been developed under licence from the British Post Office. At present this method gives fibres with an attenuation of 6−8 dB/km and a pulse dispersion of about 1 ns/km at a wavelength of 850 nm.

The development work is being continued along both lines. CVD fibres having a core diameter of 50 μm and a cladding diameter of 125 μm are expected to be predominant in telecommunication applications, whereas DC fibres having a core diameter of 100 or 200 μm are expected to dominate in industrial applications.

Fig. 2
Manufacture of optical fibres on a small scale in LM Ericsson's Materials Laboratory

Fibre cable

The development and manufacture of optical fibre cable is carried out by Sieverts Kabelverk. Machines other than those used for making conventional cables are required for some of the processes in the manufacture of fibre cables. Machines for the rewinding of fibres and laying of fibre cable have been designed by Kabmatik AB, which is a subsidiary of Sieverts Kabelverk and which also manufactures and markets these machines.

The basic development work on cables was carried out within the framework of FOK-79. The cable which was developed for FOK-79 was optimized for installation in ducts and tunnels[3]. It contains six fibres with loose secondary coating which are cabled round a plastic coated steel core and covered with a sheath containing a moisture barrier. The steel core serves to reduce the stress on the fibres. Other environments or laying methods require different cable constructions. Particular attention must be paid to the design of cables that in operation are exposed to large variations in temperature or mechanical load, so that such stresses do not cause increased attenuation or breaks in the fibres. At present a number of different cable types are under development. Prototype cables for railway and data bus applications and for military applications are being tested.

Splicing of fibres

When preparations for FOK-79 started it was considered that the technical performance of the fibre splicing equipments on the market at that time was unsatisfactory. Sieverts Kabelverk has therefore developed an equipment for splicing both CVD and DC fibres in the field[4]. The equipment has been tested during FOK-79 and has proved to be easy to handle and also to give joints of good quality. The mean loss achieved for fibre joints was as low as 0.3 dB.

Connectors

The connectors that were available on the market did not meet LM Ericsson's technical and economical requirements. Consequently connectors for telecommunication applications have been developed, and also prototypes of branching devices for data buses.

LM Ericsson's adjustable connectors have already been described elsewhere[5]. These connectors give a loss increase that averages 0.6 dB including return loss and fibre-dependent loss. The design will probably also be useful

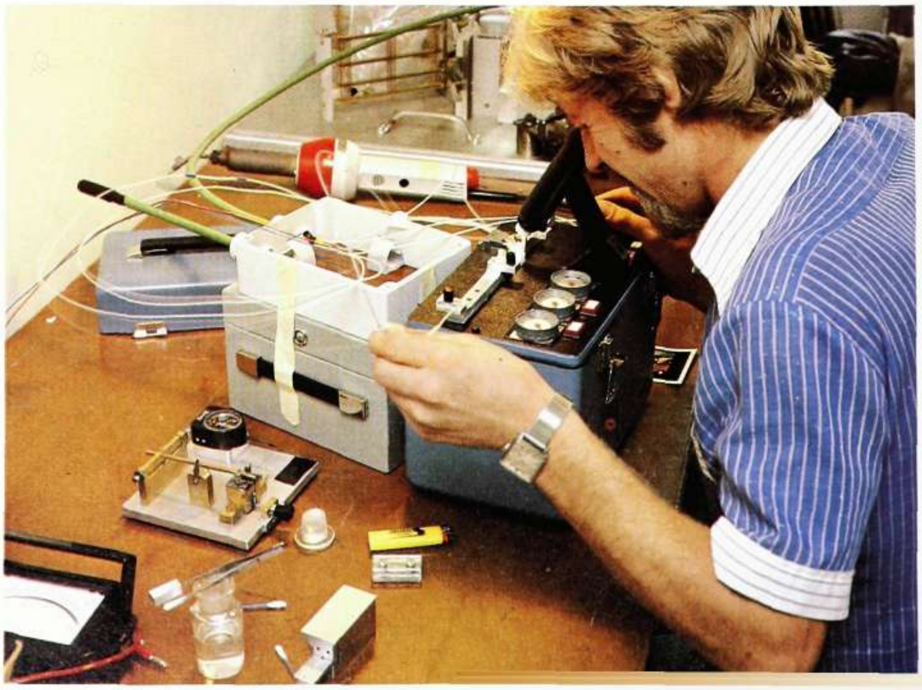
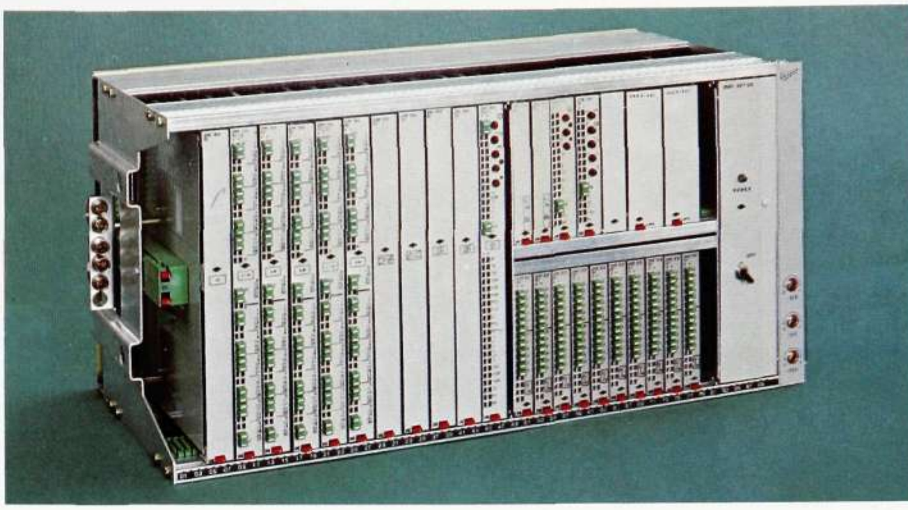


Fig. 3
Splicing of optical fibres

Fig. 5
Shelf for PCM multiplex and optical fibre line terminal, system ZAM 2 − 1



in future applications with monomode fibres.

An optical fibre connector has been designed for connecting fibres on printed board assemblies to fibres at the rear edge[6]. This connector solves the problem of handling and connecting printed board assemblies with optoelectronic components.

Optical fibre connectors are now being standardized by the International Electrotechnical Commission, IEC. In view of the fact that good quality fibres give attenuation losses of better than 3.5 dB/km at a wavelength of 850 nm, a connector for telecommunications should give a loss increase of less than 1.0 dB.

Measuring fibre characteristics

In the initial stage considerable resources were expended on the development of methods and instruments for measuring the optical, geometrical and mechanical characteristics of fibres, their ability to withstand adverse environmental conditions etc. Advanced measuring equipment has also been developed for testing fibre characteristics during the manufacture of fibres and fibre cables.

From the user's point of view, attenuation and pulse dispersion measurements are likely to be the most interesting. It must be possible to measure these parameters in the field in order to determine how they are affected by the laying and jointing of the fibre cable. Special equipment has been designed and manufactured[7] for this purpose.

Optoelectronic semiconductor components

The first generation of optoelectronic semiconductor components work at light wavelengths of between 800 and 900 nm. Light emitting diodes (LED) and laser diodes (LD), manufactured on gallium arsenide substrate (GaAs), emit light in this wavelength range which normally has a spectral width of around 50 nm and 4 nm respectively. The wavelength of the light is determined by the degree of diode doping. Photodiodes (PIN) and avalanche photodiodes (APD) are used as the receive elements.

On behalf of LM Ericsson, ASEA-HAFO, a Swedish semiconductor manufacturer, has developed light emitting diodes for both telecommunication and industrial applications. The system adaption is carried out by LM Ericsson.

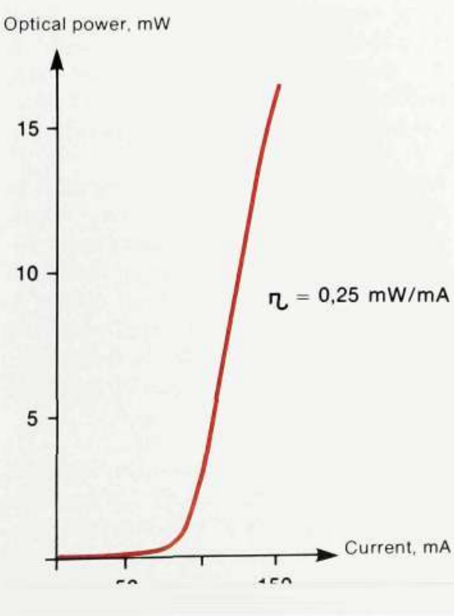
At present the reliability of laser diodes is lower than that of other optoelectronic components. Furthermore it is greatly dependent on the environment, particularly the ambient temperature. Great efforts are therefore being made to obtain laser diodes for system applications through burning-in and screening methods. A laser unit has been developed which provides a suitable environment for the laser diode[10].

A GaAlAs/GaAs laser diode with very good performance has been developed by the Institute for Microwave Engineering on behalf of LM Ericsson[8]. It has low threshold current, high output power and low distortion, and this has been achieved by limiting the width of the emitting area to 3 μm. A new soldering method has been used which gives low and stable thermal resistance. The characteristic of the laser diode is linear for an optical power of up to 15 mW, fig. 4. These laser diodes have been tested for over 2000 hours in an ambient temperature of 80° C, and show very little deterioration of performance. This test indicates that the life of the laser diode may be expected to be more than 1 000 000 hours at room temperature.

Systems

As has already been mentioned, trial systems for transmission of video and data have already been developed in or-

Fig. 4
Optical power/current characteristic for a laser diode



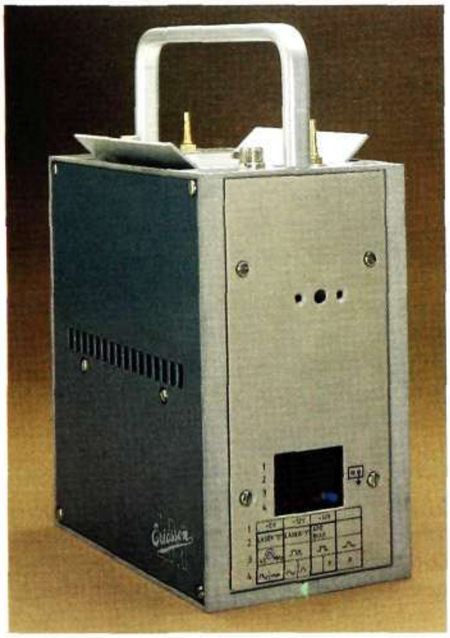


Fig. 6
A line terminal in system ZAM 34 – 1

der to gain experience of fibre optics. A data bus system has been tested in operation in an SPC exchange of type AKE 132 with very good results[9].

In the product development work the emphasis is placed on systems for telecommunication applications, particularly systems for public networks. Military systems and railway signalling systems are also being developed, among others an optical fibre link for an automatic train control system (ATC).

In the field of telecommunications two systems have so far been introduced, ZAM 2 – 1[6] and ZAM 34 – 1[10]. The systems are intended for transmission rates of 2 Mbit/s and 34 Mbit/s respectively, and both are in accordance with the relevant CCITT recommendations.

ZAM 2 – 1 has been developed primarily for use in electrically disturbed environments, where the immunity of the fibre to electromagnetic interference gives technical and economical advantages. Some fields of application are military, railway and power plant communication. The optical fibre terminals, together with a 30-channel PCM multiplexor and E/M signalling equipment, constitute a mechanical unit, fig. 5.

ZAM 34 – 1 is intended for use in public telecommunication networks, for example in junction networks between digital exchanges in an urban area. In such cases the transmission distance is seldom greather than 10 km and thus there is no need for repeaters. The system is intended for indoor installation, with local power feeding. A complete line terminal is shown in fig. 6.

The development of ZAM 34 – 1 was part of the FOK-79 programme. A great amount of work was put into the fundamental technology. The field work in connection with the installation of the system and the long-term trials now in progress have provided valuable experience[11]. ZAM 34 – 1 will also be installed by other administrations, primarily as a pilot and training system.

Extensive training material has been produced in order to meet the customers' need of training in the field of fibre optics. The wide experience of the Transmission Division as regards cable installation and construction work has been drawn upon for the designing of installation methods and equipment, as well as optical fibre cables and systems. LM Ericsson can thus offer their customers complete systems including installation.

Applications

Optical fibre systems are expected to be widely used in public telecommunication networks. The special properties of the fibre cable, i.e. insensitivity to electromagnetic interference, absence of electromagnetic radiation, no crosstalk between fibres, flexibility and low weight, make optical fibre systems an alternative to be considered also for other applications. Such systems are expected to be very economical where disturbance-free circuits are required, for example in industrial environments, in data processing centres and along electric railways. In the last case the installation costs can be very low since the cable can be suspended on existing electricity poles.

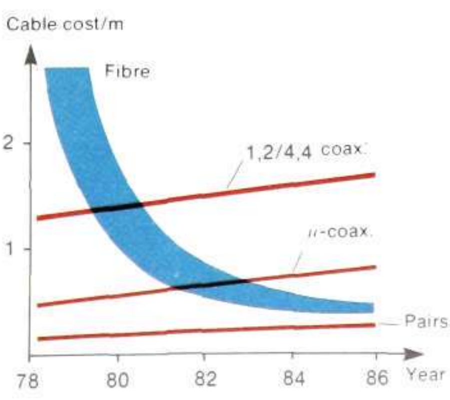
Economic gains can also be made by incorporating optical fibres in power cables. This opens up the path for the use of fibre optics for remote sensing and remote control in power networks. Such composite cables are already being tried by Sydkraft AB, electricity suppliers in south Sweden[6]. In future, fibre cables are likely to be widely used for the transmission of information in connection with power distribution.

In military applications the low weight of the cable, its flexibility and insensibility to disturbances are important properties. For example, the use of fibre cable increases the degree of security.

A fibre cable that is free from metal is an attractive alternative for lines where overvoltages occur, for example because of lightning. Several telecommunications administrations intend to install fibre cables as the lead-in to radio relay link towers in order to reduce the amount of damage caused by lightning strokes.

In public telecommunication networks the need of digital routes will increase considerably in step with the introduction of digital local exchanges. In many

Fig. 7
The cost development of fibre cable (fixed monetary value 1980)



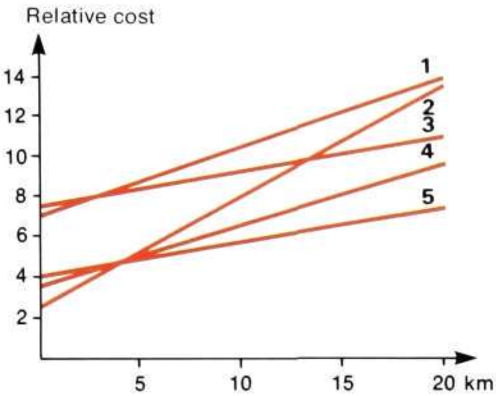


Fig. 8
Overall system cost with different cable types as a function of the length of the cable (960 channels)

1. 1×140 Mbit/s	Coaxial cable with 2 tubes
2. 32×2 Mbit/s	Pair cable with 100 pairs
3. 1×140 Mbit/s	Optical fibre cable with 2 fibres
4. 8×8 Mbit/s	Special pair cable with 20 pairs
5. 2×34 Mbit/s	Optical fibre cable with 4 fibres

not have sufficient capacity. In other cases the number of parallel 2 Mbit/s systems on pair cables can become to large to handle.

Optical fibre systems become an interesting alternative when digital systems have to be installed on new cable. Naturally they must be economically competitive. In many cases the cost of the cable is a major part. However, the cost development curve for fibre cables during the last few years shows quite a dramatic reduction, fig. 7. The cost may be expected to stabilize when the manufacture of fibres and fibre cables reaches a sufficiently large volume. It is also clear that the flexibility and low weight of fibre cable makes the cost of installation lower than for other alternatives.

An economic comparison of different system alternatives is dependent on such factors as the number of required circuits and their length. The total system cost for a typical case is shown in fig. 8, and is based on the 1980 market prices. Generally speaking 8 Mbit/s systems on pair cables are very attractive, whereas 8 Mbit/s systems on fibre cable can hardly compete because the fibre cable is not utilized properly. However, 34 Mbit/s systems on fibre cable seem to be economically competitive already. Furthermore the 34 Mbit/s systems often provide a route of suitable size for urban networks.

In the long run, optical fibre systems are likely to be economically competitive also in subscriber networks and long-distance networks.

Future aspects

So far, only the activities concerning the development of the first generation of optical fibre cables and systems have been discussed.

In future more sophisticated processes and process control methods will undoubtedly be available. Graded index fibres with larger bandwidth and lower attenuation will be manufactured and at a lower cost. Moreover the fibre characteristics will be optimized for the wavelength ranges around 1.3 and 1.55 μm, which will mean even larger bandwidth and markedly lower attenuation.

As regards optoelectronic components, light emitting diodes and laser diodes are being developed which are based on indium phosphate substrates (InP) and also PIN and APD diodes, all for the wavelengths 1.3 and 1.55 μm.

1.3 μm LED or LD systems are likely to be used for public telecommunication networks, in combination with multimode graded index fibres.

Monomode fibres will be used for optical fibre systems in long distance networks. The use of monomode laser diodes for light wavelengths around 1.55 μm gives extremely long repeater distances for systems with a high transmission rate, for example around 100 km for 34 Mbit/s systems.

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Optical Fibres

Ulf Lindborg

In the Ericsson Group two methods are used for manufacturing optical fibres. They are called the CVD (Chemical Vapour Deposition) method and the DC (Double Crucible) method. The author describes the most important fibre properties and defines the technical terms used. A brief description of the two manufacturing methods follows.

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* Light is absorbed by the glass, mainly by impurity ions, and is converted to heat.
OH ions from water which is present in the glass give absorption with maxima at 950 and 1400 nm (as well as at other wawelenghts).
Certain metal ions, such as iron, copper, chromium, manganese, nickel and cobalt, give absorption that varies greatly with the light wavelength and the composition of the glass. Even contents as low as 10 ppb (parts per billion, 10^{-9}) may give an additional loss of 1 dB/km. This content corresponds to 10 mg/ton. Many other metals, for example aluminium, give practically no absorption.

** Scattering means that light is reflected away from the desired transmission direction.
Rayleigh scattering takes place from scattering centres of the same size as the light wavelength and is caused by local variations in the composition of the glass which are very difficult to avoid. Rayleigh scattering decreases with increasing wavelength λ as λ^{-4}.
Scattering that is not related to the wavelength takes place from inhomogenities which are greater than the light wavelength for instance bubbles or effects of mechanical stresses.

An optical fibre consists of a central core which conducts the light, a cladding and a protective plastic coating, fig. 1. The double crucible method (DC) is particularly suitable for manufacturing step index fibres with constant refractive index in the core and a discrete step to the lower refractive index of the cladding. This type of fibre is suitable for transmission over short distances, up to about a kilometre.

Step index fibres give high dispersion, i.e. pulse broadening, if used for transmission over the long distances that are common in telecommunications. In such cases graded index fibres are preferable. These fibres have a carefully optimized index profile with a refractive index that gradually decreases from the centre of the core out to the cladding. Today the CVD method is considered to be the most suitable method for manufacturing graded index fibres.

Attenuation

The main prerequisite for optical communication is access to fibre material with low attenuation of light. In 1967, when development started in this field, available glasses had an attenuation of 20 000 dB/km. In 1970 research had achieved usable glass with an attenuation of better than 20 dB/km. The attenuation values achieved with modern technology are shown in fig. 2. The wavelength range of interest is 800–1600 nm, i.e. the infrared spectrum adjacent to the range of visible light.

The attenuation of a fibre is caused by *absorption** and *scattering***. Low attenuation requires an extremely high degree of purity in the fibre material and absence of virtually any type of inhomogenities. As regards CVD fibres the progress of purification has now advanced so far that scattering is the factor that has the greatest effect on the attenuation. Since the attenuation caused by scattering decreases with increasing wavelength, it is now considered that communication systems at 1.3 and 1.55 μm will be the most attractive alternatives in future. The problem will then be to develop components—laser diodes and photodiodes—for transmitting and receiving at these wavelengths. The components that are available at present operate at wavelengths around 850 nm.

Dispersion

The dispersion determines how closely pulses can be sent over an optical fibre

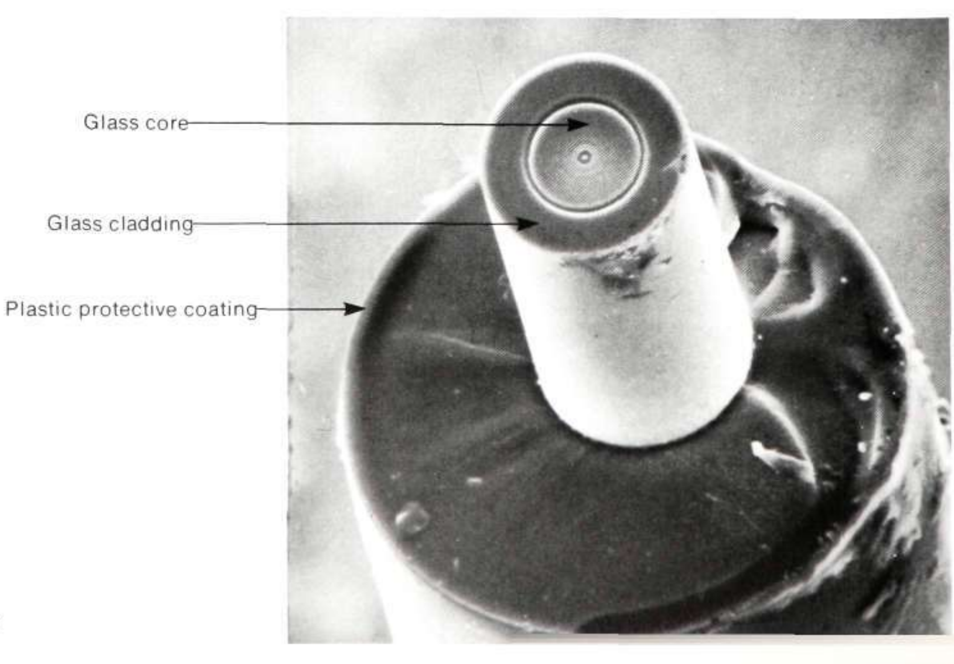

Fig. 1
Optical fibre of the CVD type. The photograph is taken through a scanning electron microscope

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Materials Laboratory
Telefonaktiebolaget LM Ericsson

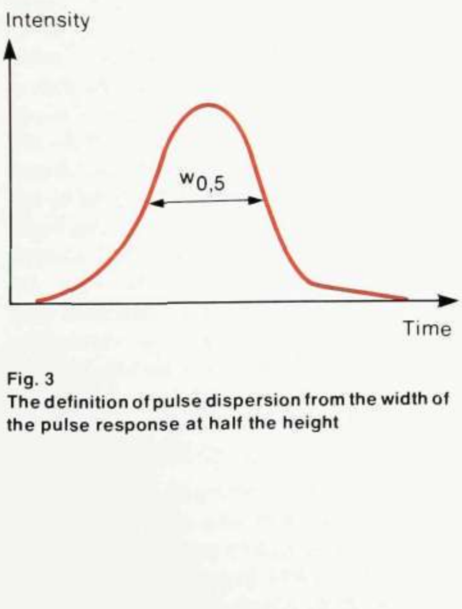


Fig. 3
The definition of pulse dispersion from the width of the pulse response at half the height

and thus how much information can be transmitted per unit of time. The dispersion is calculated from the width of the incoming and the outgoing pulse, fig. 3. The bandwidth decreases with increasing dispersion.

The dispersion contains three components: *mode dispersion*, *material dispersion* and *waveguide dispersion*.

Mode dispersion, multimode and monomode fibres

In ordinary fibres, multimode fibres, with a core of ca 50 μm, the light propagates in thousands of different modes. With a constant refractive index in the core these modes travel at slightly different speeds in the axial direction, partly because different parts of the light will travel different distances. By manufacturing fibres with a carefully controlled refractive index profile n(r) (in the radial direction), the different modes can be given almost the same transit time through the fibre, so that the mode dispersion is minimized. The resultant fibre is called a graded index fibre. A parabolic refractive index profile is often aimed at.

The refractive index is mainly determined by the chemical composition of the material. Certain process variables also affect the index, for example the cooling rate of the glass. An increase in the content of, for example, germanium, titanium, phosphorus, barium or calcium increases the refractive index of quartz and silicate glass, whereas boron and fluorine reduce the index.

The mode dispersion is reduced by mode mixing when energy is transferred between different modes at flaws in the fibre. These flaws, which give limited attenuation increases, can be advantageous from the point of view of dispersion. Fibres with extremely low dispersion and a bandwidth of over 1000 MHz·km have in practice a slightly higher attenuation than the best fibres with lower bandwidth.

In monomode fibres the light propagation is by means of only one mode (or more correctly a pair of modes) and thus without mode dispersion. In order to obtain monomode propagation the core diameter must be less than a certain critical value, which is determined by the refractive index difference and the wavelength used. In practice the core diameter is 5–10 μm. The monomode fibre is more difficult to connect up to the light source and to splice than other types, but it is potentially very interesting for telecommunication fibres with high transmission capacity and long transmission distances.

Material and waveguide dispersion

Material dispersion and waveguide dispersion are dependent on the spectral width of the light source used and the fact that light rays at different wavelengths travel at different speeds. These types of dispersion occur in both monomode and multimode fibres. Small

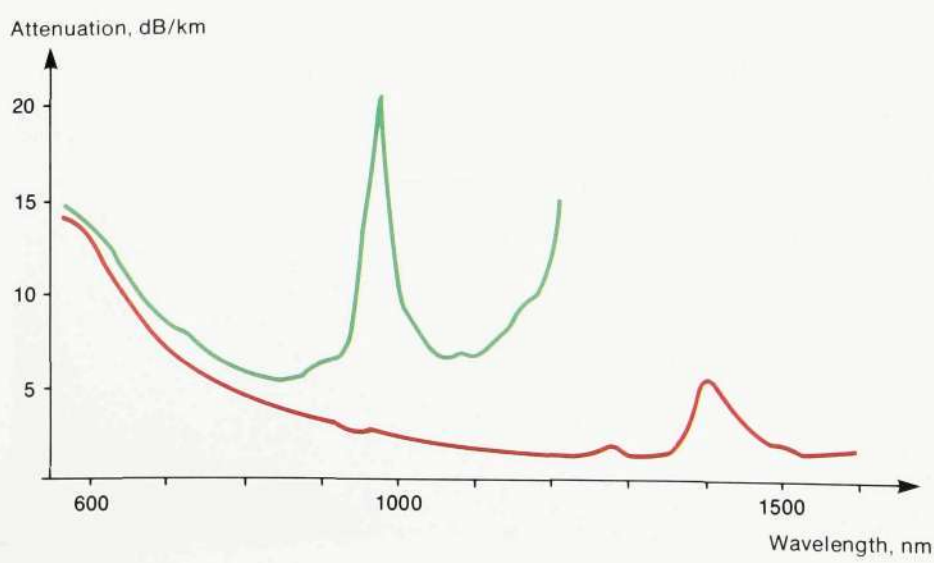


Fig. 2
Fibre attenuation curves
DC method

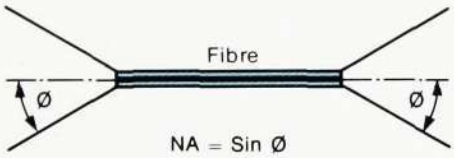


Fig. 4
The definition of numerical aperture from the largest incoming and outgoing light cone
NA Numerical aperture

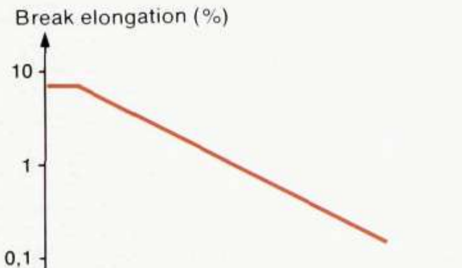
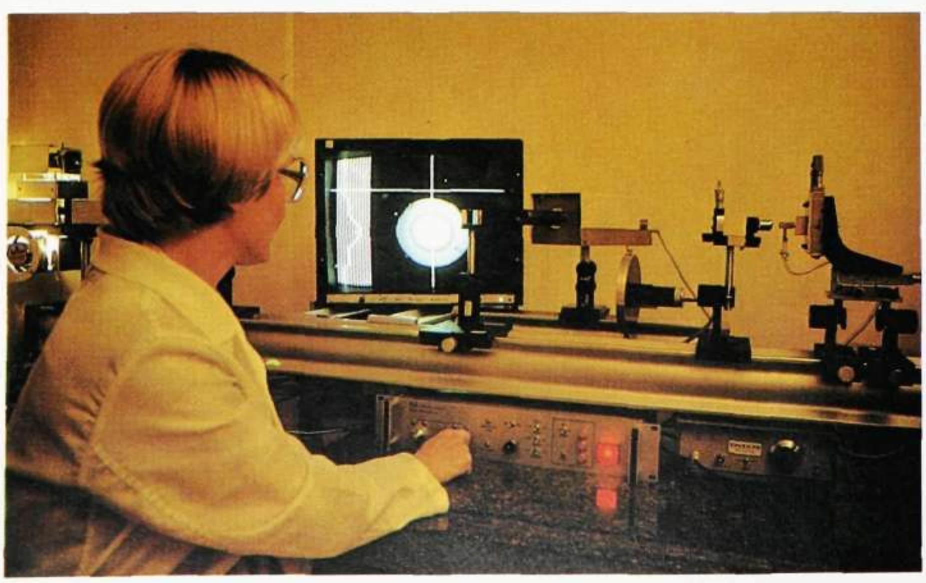


Fig. 5
The fibre strength as a function of the size of microcracks on the fibre surface

Fig. 6
Measuring the breaking profile with the aid of video equipment



pulse broadening requires a laser with small spectral width at least at 850 nm. At wavelengths near 1.3 μm the material dispersion is very small and a light emitting diode with greater spectral width than a laser can then be used without giving large pulse broadening.

Numerical aperture

The numerical aperture, NA, of a fibre is defined by the maximum angle of light that can be fed into a fibre, or the maximum angle of the cone of light that is obtained at the output end of the fibre, fig. 4.

A large numerical aperture reduces the coupling losses to the light source and detector, but it requires a great difference in the chemical composition of the core and the cladding, which usually means larger attenuation. A large numerical aperture is more easily achieved using the DC method than the CVD method.

Jointing characteristics

Low jointing losses require close tolerances in the fibres to be spliced. A relative deviation in numerical aperture has the greatest effect on the jointing losses, followed by a deviation in core diameter.

The numerical aperture and fibre geometry must be closely controlled during the manufacture of fibres.

General fibre data

CCITT Study Group XV is working on the international standardization of fibre characteristics for telecommunication applications. In a draft recommendation the Study Group has proposed that gradient index fibres should have a core diameter of 50 μm, a cladding diameter of 125 μm and a numerical aperture in the range 0.19–0.24.

For the time being the Ericsson Group have chosen two step index fibres to be used for short-distance applications, one with a 100 μm core, 140 μm cladding and a numerical aperture of 0.3 and the other with a 200 μm core, 280 μm cladding and a numerical aperture of 0.3–0.4.

The transmission capacity of step index fibres is considerably lower than that of graded index fibres, but in most cases the bandwidth 20–50 MHz·km is sufficient for short distances. The step index fibre is used in industrial applications for signal, data and video transmission. It gives smaller coupling losses than the gradient index fibre. In short-haul applications it is important to be able to reduce the coupling losses to the light source and detector so that simple optoelectronic components can be used. A large numerical aperture and large core diameter are desirable, whereas the attenuation per kilometre is less important.

Mechanical properties

Glass is usually considered a fragile material which breaks easily. Nevertheless it is possible to manufacture glass fibres that have greater strength than steel. In tensile tests the breaking stress of optical fibres is normally as high as 3 000 MN/m² (DC) and 5 000 MN/m² (CVD), corresponding to 4 and 7 % elastic elongation. A 125 μm CVD fibre can carry a load of 5 kg without breaking.

A prerequisite for high fibre strength is the absence of microcracks and other defects on the surface and inside the glass, fig. 5. Ordinary glass has many such flaws, which give concentrations of tensile stress and reduce the strength. Internal flaws are uncommon in the fibres, but surface flaws occur. The classic fracture mechanics apply for

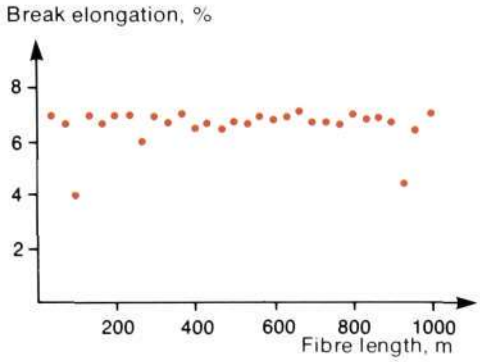


Fig. 7
The diagram shows how the strength can vary along a fibre. In this case the weak point is situated 100 m from the beginning of the fibre

Surface flaws on a fibre are statistically distributed along the fibre as regards size and position. A certain length of fibre which is under load breaks at the weakest point, i.e. the largest surface flaw. If the length of the fibre increases, the probability will also increase of meeting a surface flaw that is large enough to cause a break when a certain load is applied, fig. 7. Long fibres therefore have lower strength than short fibres. The length dependence often follows a distribution function formulated by the Swedish scientist Weibull[1] in the 1930s.

Great care must be taken in the production of glass preforms and fibres and the handling of finished fibres in order to avoid surface flaws. Optical fibres are given a protective coating as soon as the fibre is drawn, in order to reduce external damage. Uncoated fibres would be seriously affected by physical contact and moisture.

Tensile tests are used to ensure that very long fibres have a strength that exceeds a certain minimum value. The whole length of the fibre is tested when the fibre is respooled from one drum to another. A typical tensile test force is 350 MN/m^2, which corresponds to 0.5 % elastic elongation.

The tensile test force is considerably higher than the forces that are expected to affect the fibre during cable manufacture and installation.

The fibre should not be exposed to large mechanical loads for long periods. A certain weakening with time must be expected if the fibre is under tension. An extrapolation of the available data indicates a life of 100 years with a tensile stress that corresponds to 25 % of the tensile test force.

Fibre manufacture

The two manufacturing methods used in the Ericsson Group, CVD and DC, both give fibres with core and cladding made of glass. With CVD the fibre material is produced using a gas reaction, whereas with the DC method melting processes are used that are similar to those of conventional glass manufacture. The early research work at Corning Glass Works, USA, has been of fundamental importance for the manufacture of fibres by means of gas reactions of type CVD[2]. The DC method is based on pioneering work by the British Post Office[3].

As regards the CVD process the Ericsson Group collaborate with the Institute for Microwave Engineering and the Institute for Optical Research at the Royal Institute of Technology, Stockholm, Sweden.

CVD fibres

Manufacturing the glass preform
The material used in the CVD method is a quartz tube, usually with an outer diameter of 20 mm and a length of 1 m. Inside this tube, glass is deposited from vapour chemicals. The tube will form the cladding and the deposited glass the core of the fibre,

The deposition is obtained by fixing the quartz glass tube in a glass lathe and heating it with an oxygen-hydrogen burner that is moved forwards and backwards along the tube. Oxygen is passed through bubble vessels containing

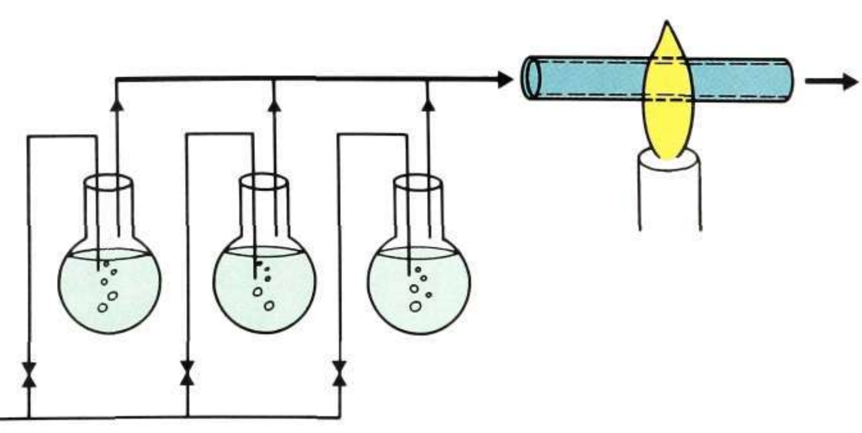
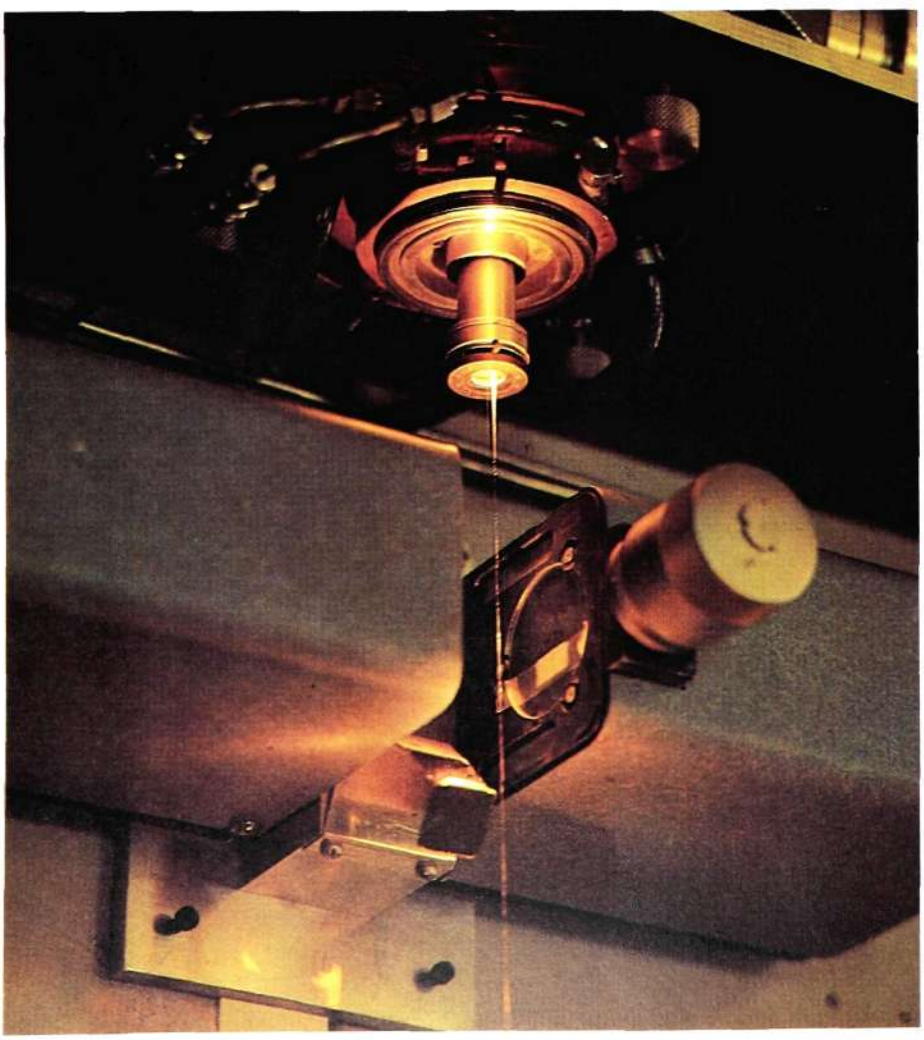


Fig. 8
Basic diagram of the CVD process. Oxygen is saturated with the desired chemicals in the bubble vessels. The gas mixture reacts in a quartz tube a

chemicals, fig. 8. The resultant gas mixture is fed through the glass tube and reacts chemically in the hot burner zone, forming thin glass layers on the inside, whose refractive index can be either higher or lower than that of the quartz tube. A refractive index profile of the graded index type is built up by varying the composition of the gas mixture fed into the tube. About 50 thin deposited glass layers are needed to give the fibre a sufficiently smooth index profile.

When the deposition process is completed, the burner temperature is raised and its speed along the tube is reduced, so that the tube contracts because of the surface tension and fuses into a solid preform with the deposited glass in the centre. This preform can then be drawn into a fibre.

Fig. 9
Drawing a CVD fibre from a graphite furnace. The fibre diameter is measured using the photo diode in the centre of the picture



Drawing the fibre
The preform is fixed in a chuck above a high temperature furnace and lowered into it at a constant speed. The furnace is resistance heated with a graphite element and has a maximum temperature of around 2400 °C. A protective gas atmosphere is required to prevent the graphite element and oxygen in the air from forming carbon dioxide at these temperatures. The protective gas used is argon. The part of the glass preform that is in the hot zone of the furnace softens, and from this part a fibre is drawn that has an outside diameter of $125 \pm 1\,\mu m$, fig. 9.

The fibre diameter is measured during the drawing with the aid of a laser, continuously and without physical contact. A first protective coating is applied to the fibre by feeding it through a silicone rubber tank. This primary coating is cured in a furnace, after which the fibre is wound on a drum with 1 m diameter. There is feedback between the diameter measuring and the winding, so that the winding speed is automatically adjusted if the fibre diameter deviates from the correct value.

One preform usually gives 3–4 km finished fibre, which is wound on one or several drums.

DC fibres

Glass composition
The glasses for double crucible fibre consist of sodium oxide, boron trioxide and silicon dioxide, with additions of other oxides. The types of glass for core and cladding are chosen to give a refractive index difference that provides the desired numerical aperture. Another objective is to obtain similar thermal expansion coefficients in the two glass types in order to reduce internal stress. There are certain restrictions: high silicon dioxide content gives too high a melting temperature, high sodium oxide content gives crystallization, and certain compounds with low sodium oxide content give a phase separation with unstable glass which tends to separate into areas that are rich in either silicon dioxide or boron trioxide, which naturally has a destructive effect on attenuation

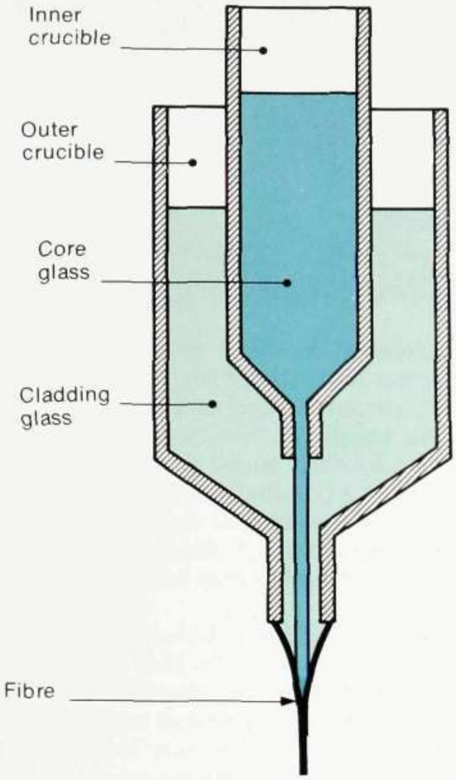
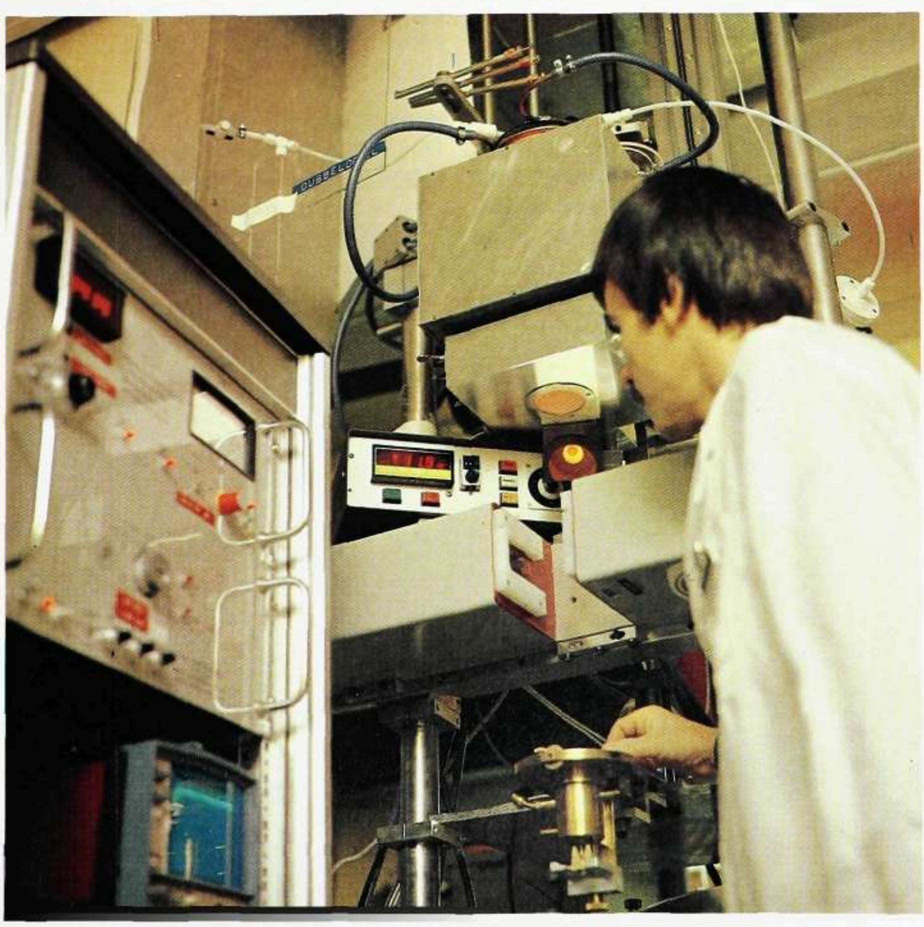


Fig. 10
Diagram of a double crucible

Fig. 11
Equipment for drawing DC fibre



Manufacturing glass rods

The basic ingredients of the glass are sodium carbonate, boric acid and silicon dioxide in the form of high-purity powders. The raw materials are weighed, mixed and melted to glass in a crucible of pure quartz under meticulous atmospheric control. The temperature is 1100–1300°C. The sodium carbonate gives off carbon dioxide and the boric acid gives off water.

It is important that air with its content of moisture is excluded, and also that water is dried out of the glass melt by bubbling with dry gas.

When the glass has been prepared it is drawn out in the form of rods at a temperature of 850–950°C.

Drawing the fibre

Two different melts are required for each fibre: one with a high refractive index for the core and one with a lower refractive index for the cladding.

The rods of core glass and cladding glass are fed into a double crucible, which consists of two concentric metal crucibles, fig. 10. The glass flows slowly out of the nozzle at the bottom of each crucible. The core glass first passes through the cladding glass. The speed is determined by the viscosity of the two glasses and the temperature, which is about 1000°C. The temperature is considerable lower than with the CVD method, and the furnace design can therefore be simpler.

The glass is drawn from the cladding nozzle into a fibre, fig. 11. Plastic coating, winding and quality control are then carried out as in the CVD process.

The DC method usually gives step index fibres. However, there is a certain amount of diffusion of core and cladding glass in the nozzle. Gradient index fibres can thus also be manufactured in this way by using certain glass compounds[4].

Conclusions

A large number of fibres have been manufactured using both the CVD and the DC method. The attenuation of the fibres produced for telecommunication applications is approximately 3 dB/km for CVD fibres and about 6 dB/km for DC fibres. Bandwidths of about 700 MHz · km have been obtained for both types. Short-distance fibres for industrial applications, manufactured using the DC method, have a numerical aperture of 0.3, an attenuation of 7–10 dB/km and a bandwidth of 20–50 MHz·km.

The Ericsson Group is now well prepared with equipment and know-how for the manufacture of large quantities of the desired fibre types. It has also been proved that the manufacturing processes can be consistently reproduced.

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Optical Fibre Cables

György Endersz

Sieverts Kabelverk, the cable manufacturing company of the Ericsson Group, has acquired the necessary resources and know-how for the design and manufacture of optical fibre cables. Different types of cables have been designed and manufactured. Two of these are described in this article. One cable contains six optical fibres of the CVD type and was designed for FOK-79, the field trial with optical communication in Stockholm, Sweden. It is intended for telephony. The other cable contains only one optical fibre, of the DC type, and is intended for data links. The work on these cables has given Sieverts Kabelverk the experience and know-how to design and manufacture the desired types of cables for optical communication.

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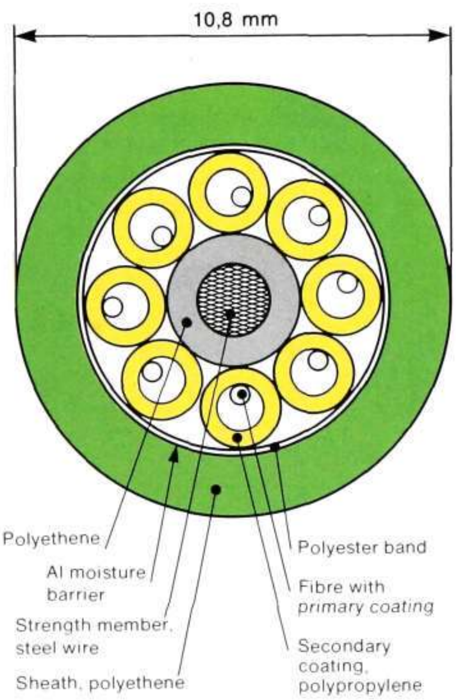


Fig. 1
Cross section of a cable with 8 fibres for telephony

The use to which an optical fibre cable is to be put determines the number of fibres in the cable and the choice of fibre type. The installation design sets the requirements as regards the mechanical properties of the cable and its ability to withstand adverse environmental conditions. The cable is optimized with regard to these factors, the available technology and production economy.

This article deals with two cable types, one for telephony and the other for data transmission. The basic requirements, and the design, manufacture and performance are described for each type of cable.

Cable for telephony

Requirements, choice of fibre

The cable for FOK-79 had to be suitable for installation in an urban network and was to be run in tunnels or ducts. It was to be used for 34 Mbit/s line systems, with a transmission capacity of 480 PCM coded telephone channels. Another requirement was that it should be possible to use the cable for line systems with a transmission speed of 8 or 140 Mbit/s. The attenuation had to be so low that large repeater spacings, at least 8 km, would be possible. The aim was to do without intermediate repeaters for normal applications, in view of the cost and the problem of remote feeding.

The transmission requirements can be met with graded index CVD fibres with low attenuation, on condition that the manufacturing tolerances are so small that the losses which occur in joints are also low. Furthermore the manufacture of the cable and the installation of cables must give only insignificant increases in the attenuation.

The suitable number of fibres per cable was considered to be 6 – 12 for the application in question. The cable specification and fibre parameters are given in table 1 (last page of the article). The cable manufactured for the field trial is in accordance with table 1, but this type of cable is now made with somewhat modified fibre parameters, in accordance with a recommendation by CCITT in July 1979[1].

Cable design

The cable is built up concentrically round a central strength member, a steel wire with a diameter of 1.6 mm, coated with polyethene to a diameter of 3.1 mm, fig. 1. The steel wire not only takes the strain but also counteracts the tempera-

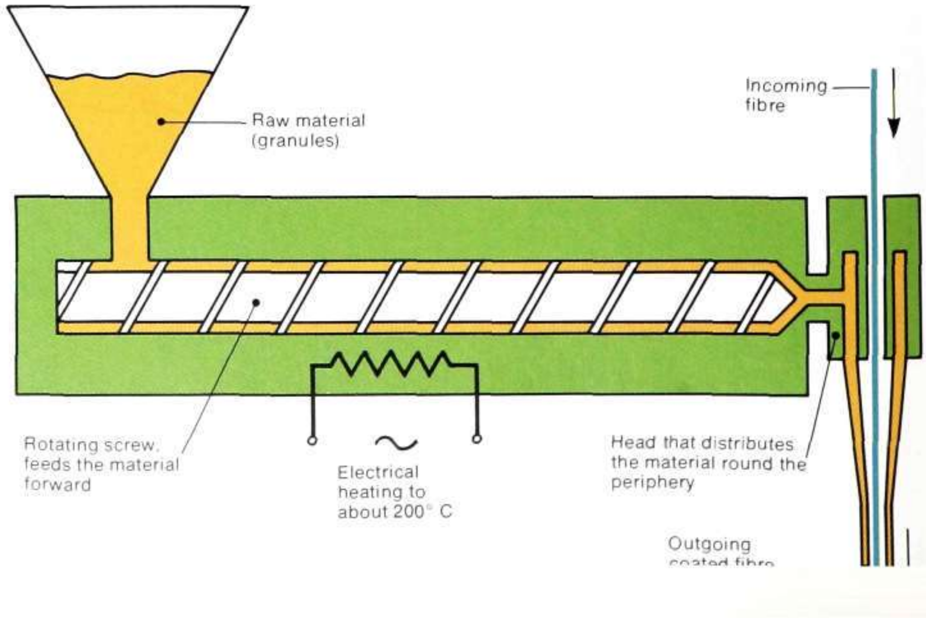


Fig. 2
Cross section of extruder for applying the secondary coating

GYÖRGY ENDERSZ
Sieverts Kabelverk AB

ture-dependent linear expansion of the plastic parts. Table 2 gives the temperature coefficient and relative linear expansion of the different materials normally used in optical fibre cables.

Each fibre, with its primary coating, is protected further by a secondary coating in the form of a loose plastic tube. The fibres in their secondary coatings are cabled in a spiral round the steel wire. The largest possible number of fibres in a layer is determined by the relationship between the outer diameters of the strength member and the secondary coatings. Polyester tapes are wound round the fibre layer and the cable is covered by a polyethene sheath. The sheath, which also contains aluminium foil, constitutes a moisture barrier and also helps to stabilize the temperature in the cable.

The choice between a tight or loose secondary coating affects the cable properties and the manufacturing method. A loose secondary coating was chosen for the cable discussed here, with the task of
- protecting the fibre during the cable manufacture
- protecting the fibre in the cable during installation and operation
- providing space for extra fibre length in the cable without the fibre suffering sharp bends.

Fig. 3
Line for applying the secondary coating, with extruder and control unit

Mechanical or thermal longitudinal variations in the cable body are transmitted to the secondary coating of the fibre. However, the coating can be slightly longer or shorter than the fibre without mechanically influencing the fibre. The tolerances are dependent on the inner diameter of the secondary coating and the lay length round the cable core. If the limit is exceeded and the tube is too short, the fibre takes up an irregularly bent shape and is pressed against the inner wall of the tube. Microbending then occurs, giving increased attenuation and in extreme cases fibre breaks. If instead the tube is too long, the fibre is stretched. If static fatigue is to be avoided, any persistent stretching of the fibre or any stretching over a long period must not amount to more than a small part of the stretching to which the whole fibre is exposed during the manufacturing testing. Any bending of the cable also leads to stretching of the fibre. With a 50 mm bend radius the outer side of fibres with 125 μm outer diameter is stretched approximately 0.12 %. Sharp bends should therefore be avoided when installing the cable.

A correctly dimensioned cable containing fibres with loose secondary coating has a low and stable fibre attenuation and can with advantage be used both at 850 nm and in applications with longer wavelengths, for example 1.3 μm.

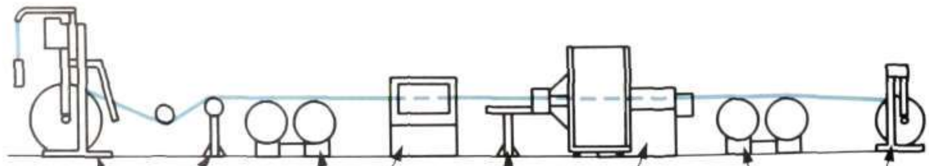
Manufacture

The cable, fig. 1, is manufactured in three stages: secondary coating of the fibres, laying up the cable and applying the sheath.

As has already been mentioned, the tensile strength of the fibre is tested along its whole length during manufacture. The dynamic stresses to which the fibre is afterwards exposed during handling and cabling must be well under the earlier testing level, and residual tensile and torsional stresses must have even lower values.

The permissible increase in attenuation caused by the cable manufacture is less than 0.5 dB/km in present applications, if the maximum repeater spacing is required. In future applications, at a wavelength of 1.3 or 1.55 μm, where the

Fig. 4
Cabling line for optical fibre cable



fibre attenuation is calculated to be less than 1 dB/km, the requirements as regards attenuation increase caused by the cable manufacture will be even more stringent.

The secondary coating of the fibres consists of a loose cover made of polypropylene (PP). The coating is applied in an extruder which provides a tubular coating. Fig. 2 shows a cross section of the extruder and fig. 3 a part of the extrusion line. The temperature of the plastic in the extruder is around 200° C. The plastic tube shrinks longitudinally in the subsequent cooling process. The process parameters, such as the temperature profile along the extrusion line and take-up, are carefully monitored to ensure that the desired excess length of fibre is obtained in the tube. The friction between fibre and tube must be so low that the excess fibre length can be utilized.

The cabling line for optical fibre cable has been designed by Sieverts Kabelverk, and is manufactured and marketed by Kabmatik AB. The layout is the conventional one for concentric cables, fig. 4. However, the stranding of optical fibres poses a number of problems which are best solved by a specially designed cabling machine.

The fibre, even with a secondary coating, is mechanically sensitive compared with copper wire. Even and gentle monitoring of the fibre tension during the stranding, and good balance and symmetry in the movements of the machine are absolutely necessary if an economic stranding speed is to be achieved without any reduction in quality. The Kabmatik machine strands up to 18 fibres at 15 metres per minute if the cable lay length is 150 mm per turn. The fibre drums are mounted on the cabling machine cage, which rotates round the cable axis, fig. 5. The drums are turned in the opposite direction, so that their angular position is fixed relative to the observer and thus twisting of the fibres is avoided.

The longitudinal moisture barrier of aluminium foil is applied in conjunction with the extrusion of the polyethene sheath in a conventional sheathing line. Fig. 6 shows the completed cable.

Performance

The cable manufactured for the field trial in Stockholm consisted of five 1 km lengths, each containing six fibres of Sievert's own make and two filler strands. An extensive measuring program was carried out which documented, for example, the attenuation and dispersion of

- fibres with primary coating
- cable on a drum
- cable laid in a tunnel
- jointed cable sections.

Valuable statistical data were obtained for the attenuation increases caused by cable manufacture, installation and jointing, and as regards the transmission characteristics of long cable sections, up to 14 km. The measured data are now being evaluated, and the following preliminary results have been obtained. The increase in attenuation caused by cable manufacture and installation was on average less than 0.2 dB/km. Fig. 7 shows the distribution of the fibre attenuation for 24 of the fibres in the trial. The attenuation is not very dependent on temperature. Measurements in a climatic test chamber show that the specification is met with a good margin over the temperature range −10° to +45° C. The bandwidth is only

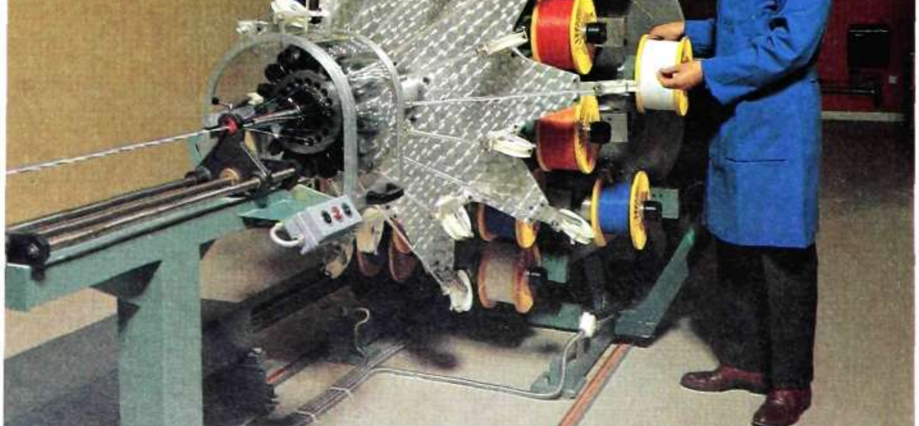


Fig. 5
Cabling machine

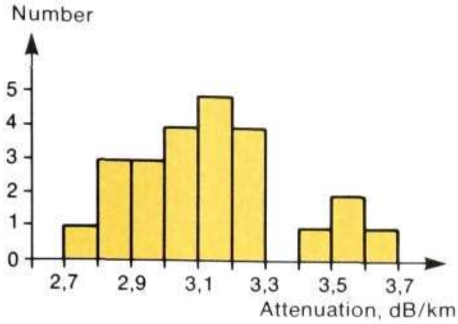


Fig. 7
Diagram over the distribution of fibre attenuation measured on a cable wound on a drum

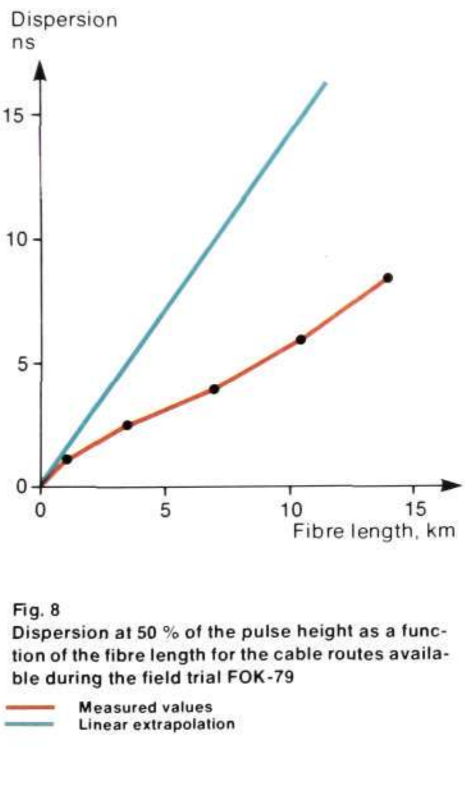


Fig. 8
Dispersion at 50 % of the pulse height as a function of the fibre length for the cable routes available during the field trial FOK-79

Measured values
Linear extrapolation

variations. A certain increase can take place at low temperatures. Microbends can then occur and cause increased mode mixing and propagation time equalisation. Table 3 gives a comparison between the specification requirements and the measured results for cable in delivery lengths.

Deviations in fibre geometry and numerical aperture affect the jointing loss. This problem is discussed in greater detail in the article on the jointing of fibre cables[2]. The mean value of the part of the jointing loss that relates to the fibre is given there as 0.15 dB, which agrees well with the values calculated on the basis of the fibre geometry and numerical aperture data.

When dimensioning optical transmission systems it is essential to know the transmission characteristics of long cable sections. The fibre attenuation and bandwidth are given in the cable data for delivery lengths, which are usually up to 1 km, and the values for a whole section have to be calculated on the basis of these data. The attenuation, including the jointing losses, can easily be added up regardless of other fibre characteristics. However, it is essential that the manufacturer has used the correct measuring method[3]. The overall bandwidth and dispersion of the cable section cannot be calculated unambiguously on the basis of the data for the individual cable lengths in the section. The fibre characteristics and the jointing characteristics together determine the total bandwidth and dispersion. The dispersion as a function of the lengths of the section is shown in fig. 8. The given values are the mean results of the measurements made on two different fibre sections. For comparison purposes the values obtained by linear addition are also shown in the figure. The inclination of the line corresponds to the mean value of the dispersion for 24 delivery lengths. However, the results obtained vary slightly with the measuring method and measuring equipment used[1,3].

Metal-free cables

Urban networks do not usually require cables that are free from metal components. However, such cables are preferable for installation in areas that are subject to lightning strokes, particularly if the ground resistance is high. Some examples are buried or aerial cables in rural networks and the lead-in cables to radio relay link stations. Metal-free cables are also required for telephone lines to power plants and high-voltage switch gear.

In these cases also, the cable construction must meet the requirements regarding strain relief, temperature stability and moisture protection. A metal-free optical fibre cable, fig. 1, can have a glass fibre rod as the strength member and a suitable filling, consisting of a water-repelling material with low viscosity, between the fibre and the secondary coating.

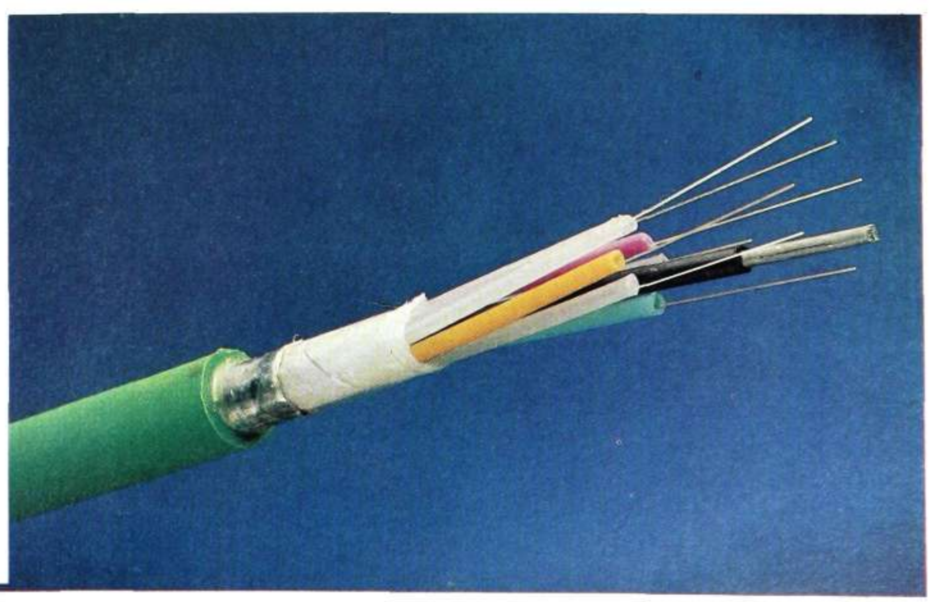
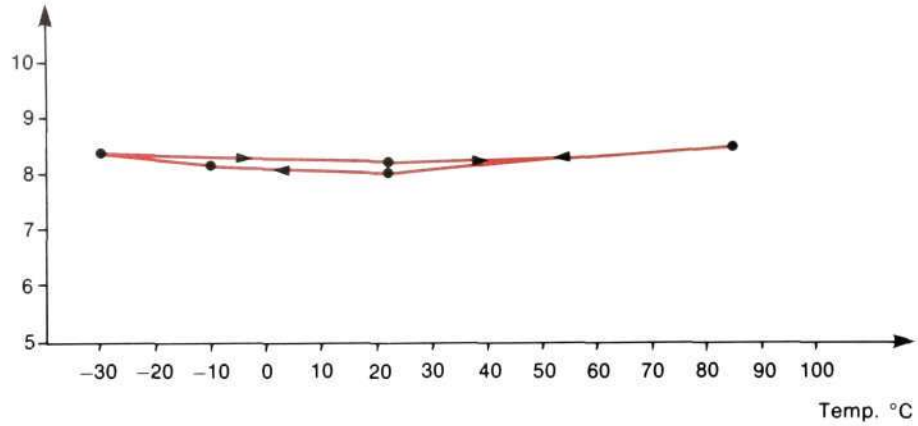


Fig. 6

Fig. 10
Attenuation of data link cable as a function of the temperature



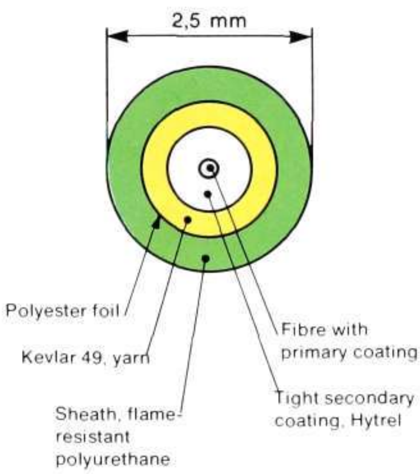


Fig. 9
Cross section of a cable for data links

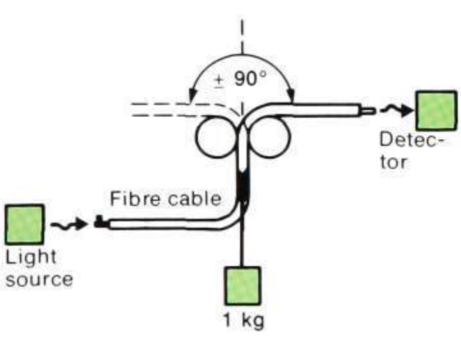


Fig. 11
Bending test on data link cable

Cable for data links

Requirements, choice of fibre

The cable for data links should be flexible and compact, contain a single fibre and have no metal components. The cable should be suitable for simplex or duplex data transmission of up to 20 Mbit/s or 10 MHz video transmission over a distance of a few kilometres. It should be possible to install the cable indoors in industrial or similar environments and in protected outdoor environments. It should also be possible to include the cable in power cables during manufacture.

The fibre in the cable should be strong enough to allow a relatively small bending radius, i. e. 25 – 50 mm. In view of the transmission requirements a DC fibre was chosen . It has larger core diameter, larger numerical aperture and greater attenuation than the CVD fibre for telephony. Technical data for the cable and the fibre are given in table 4. Adaption to other transmission requirements is possible by substituting another fibre.

Cable design

Fig. 9 shows a cross section of the cable. The chosen design meets the requirements for a light, compact and flexible cable with fairly high mechanical strength.

The fibre has a tight secondary coating of polyester (Hytrel), which gives small dimensions and also makes the fibre less sensitive to microbending and vibrations. The Kevlar yarn, which is wound along the fibre, reduces tension and gives protection against radial pressure and impacts. The sheath is made of soft but tough and flame-resistant polyurethane, three properties which are all advantageous for installation in an industrial environment. The fibre itself serves as armouring against shrinkage at low temperature.

Manufacture

The performance of the cable is to a great extent dependent on how good the secondary coating is, and the extrusion process parameters must be optimized. The secondary coating must be symmetrical and adhere well to the primary coating of the fibre. Good circular symmetry and even geometry are prerequisites for the structure of the whole cable. The mechanical stress during the extrusion is greater if the secondary coating is tight than if it is loose, and this must be taken into consideration during manufacture.

The whole length of the fibre is tested for more than 0.5 % elongation before cabling. When the Kevlar yarn is being applied the fibre in its plastic coating can only take very little mechanical strain compared with an insulated copper wire with the same external diameter. With the Kevlar yarn applied, however, the structure is fairly strong and easy to handle. The sheath is then added in an ordinary insulation line.

Performance

The most important characteristics of this cable are temperature stability and resistance to mechanical stresses. Three important stages in the type testing which concern these features are described below, namely:
- temperature cycling
- bending test
- impact test.

The diagram of fig. 10 shows the variation of the attenuation with temperature. The total attenuation variation between −30° and +85° C is less than 0.5 dB/km. The measurements were carried out with the cable loosely wound on a drum having a diameter of 300 mm.

In the bending test the cable was bent 50 000 times at the same place in the way shown in fig. 11. The cable was not deformed and did not display any weaknesses. The fibre attenuation remained unchanged.

An impact test was carried out in accordance with fig. 12 at randomly selected places along the cable. The number of

		FOK-79	CCITT
Fibres in cable			
Diameter, core	µm	50±4	50±3
Diameter, cladding	µm	100±4	125±3
NA (99 %)		0.21±0.02	(0.15–0.25)* ±0.02
Attenuation (850 nm)	dB/km	≤5	≤3; 4,5; 6; 10
Dispersion (50 %)	ns/km	<3	
Bandwidth	MHz·km		≥200, 500, 1000
Cable			
Temperature in service	°C	−10 to +35	
during transport and storage	°C	−25 to +50	
Maximum permissible tensile force during installation	N	1000	
Minimum bending radius	mm	10	
External diameter	mm	11	
Weight	kg/km	ca 100	

* The nominal value can be chosen within the given range

Table 1
Data for optical fibre cable for telephony

Material	TC 10^{-6} °C	Relative expansion at ΔT=50°C %
Quartz	+0.5	0
Plastics*	ca +100	0.5
Steel	+12	0.06
Kevlar 49	−0.6	0
Glass fibre rod	ca +20	0.1

* The TC for plastics varies considerably depending on orientation, filling etc

Table 2
Temperature coefficient, TC, and relative linear expansion coefficient for material in fibre cables

		Spec.	Measured
Attenuation (850 nm)	dB/km	5.0	3.1
Dispersion (50 %)	ns/km	1.5	1.24
Jointing loss	dB	0.5	0.3

Table 3
Comparison between specifications and measurement results from FOK-79 (mean values on drums)

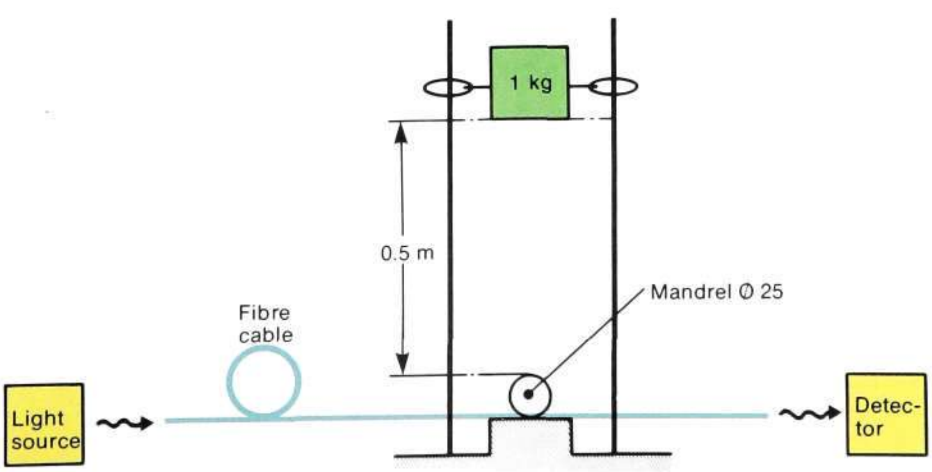
Fibre in cable			
Diameter, core	µm	100	200
Diameter, cladding	µm	140	280
NA (99 %)		0.3	0.3
Attenuation (850 nm)	dB/km	≤10	≤13
Bandwidth	MHz·km	≥20	≥20
Cable			
Temperature range, in service	°C	−20 to +85	
Maximum permissible tensile force	N	300	
Minimum bending radius	mm	25	50
External diameter	mm	2,5	
Weight	kg/km	6	

Table 4
Data for optical fibre cable for data links

Multifibre cables

Light and compact multifibre cables can also be constructed using tight secondary coating. Cables without metallic parts can be constructed so that the attenuation variations remain small even over a large temperature range.

Fig. 12
Impact testing of data link cable



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2. Böttcher, U.: *Jointing of Optical Fibre Cables.* Ericsson Rev. 57 (1980):3, pp. 92–96.
3. Endersz, G. and Rodhe, P.: *Transmission Measurements on Optical Fibre Cables.* Ericsson Rev. 57 (1980):3, pp. 97–103.

Jointing of Optical Fibre Cables

Uwe Böttcher

In conjunction with the development of manufacturing methods for fibre cable, Sieverts Kabelverk has also developed methods and equipment for splicing optical fibres. The two splicing methods that give the best results are fusing and glueing. Prototype equipments have been developed for both methods, and the fusing equipment is now in series production. The method also includes the restoration of the primary and secondary coatings at the joint. The methods used for jointing the cable sheath and restoring its tensile strength at the joint are the same as are used when jointing conventional cables.

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Although both fibres and fibre cables are manufactured in lengths longer than 1 km it has proved to be practical from the handling and installation point of view to deliver optical fibre cable in lengths of 1 km. The fibre attenuation is so low, 3–4 dB/km, that a repeater spacing of around 10 km is feasible for fibre cable systems. It is then essential that the increase in attenuation caused by the necessary splices is so small that the splicing is not a limiting factor.

Jointing done in the field, and using either of the two developed splicing equipments, gives joints with similar losses, approximately 0.3 dB per joint. The fusing equipment was used in the field trial FOK-79 in Stockholm, Sweden, fig. 1. The jointing was carried out by the Swedish Telecommunications Administration's ordinary field personnel, who after a week's training had mastered the splicing technique and made good joints all along the route in question.

When making a joint it is essential that the primary coating is restored, and that the part of the fibre that has been bared is relieved of any tensile stress, since its strength is reduced. The fusing point itself can also be a weak spot. It is calculated that the tensile strength around a joint is reduced to 50–80 % of the original value for the fibre.

Optical losses

The optical loss in a joint can be divided up into the loss caused by the fibre and the loss caused by the splicing method.

The fibre-dependent loss is mainly due to differences in
- numerical aperture
- core diameter
- external diameter if used for aligning.

The method-dependent jointing loss is caused by
- parallel displacement of the fibre axes
- angular displacement of the fibre axes
- distance between the fibre end faces
- the appearance of the faces
- Fresnel reflections from the fibre faces
- dirt on the fibre faces.

A prerequisite for low jointing loss is that the fibre-dependent loss is small. Today the fibres are manufactured with such high precision that on average this is less than 0.15 dB.

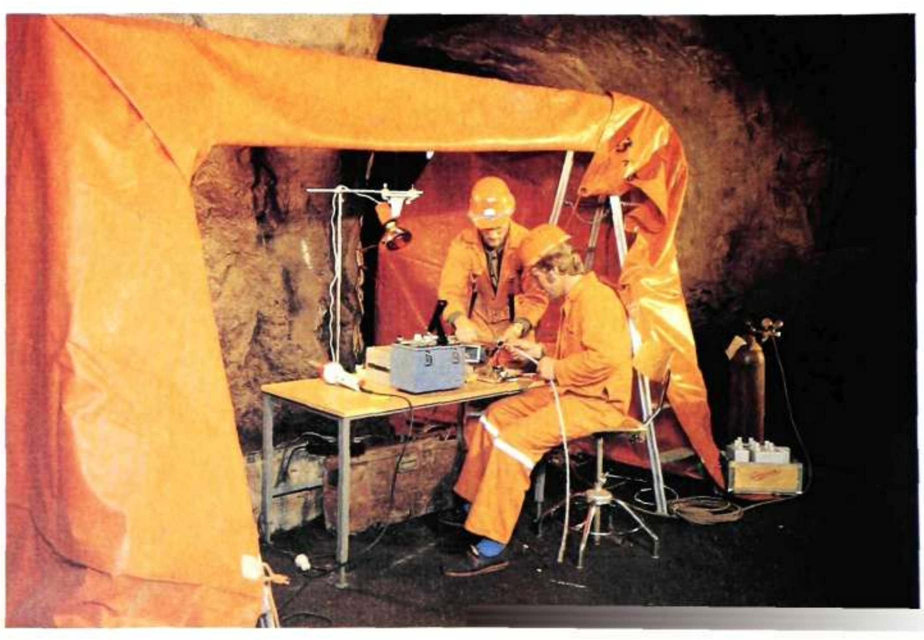

Fig. 1
Jointing of optical fibre cable should be done in a tent. A heating lamp is used in the tent in order to avoid condensation on the splicing equipment.

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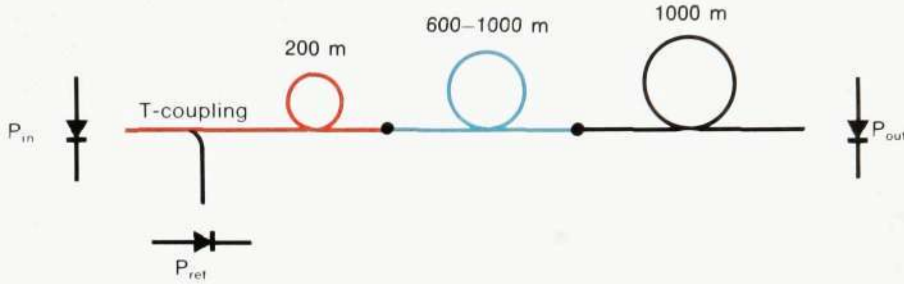


Fig. 2, right
Jointing losses are small and difficult to measure. The figure shows the principle of the measuring method used by Sieverts Kabelverk. The light source is a high radiance light-emitting diode with a pigtail fibre. The T-coupler makes it possible to get a reference signal. The launching fibre consists of approximately 200 m fibre with lower numerical aperture and smaller core diameter than the object being measured. The fibre to be measured is welded to the launching fibre. The fibre is cut at the joint and then spliced again. The part of the loss that is dependent on the splicing method, A, is calculated as

$$A = 10 \log \frac{P_{out0}}{P_{ref0}} \times \frac{P_{ref1}}{P_{out1}}$$

where 0 refers to the measurement before splicing and 1 refers to the measurement after splicing

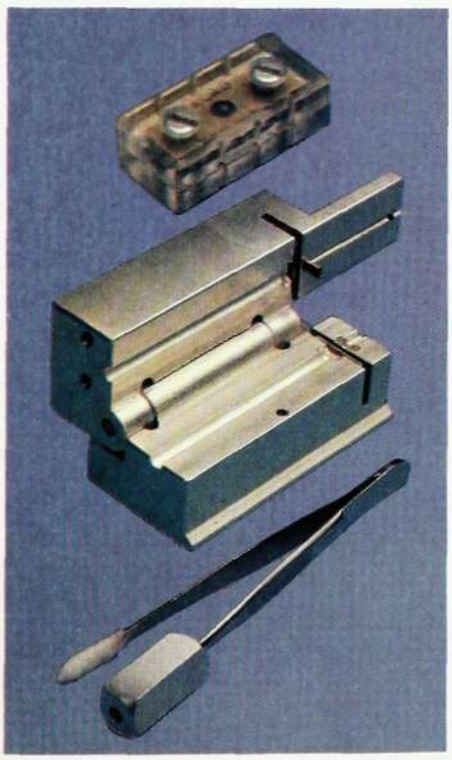


Fig. 3, above
Tools for removing the secondary and primary coatings. The top tool contains a razor blade which is used to cut the secondary coating. The tool in the middle is shaped as a pair of tongs with two semicircular blades which grip and pull off the primary coating. The tweezers are used to remove dirt and any residue of the primary coating. One leg holds a piece of aluminium and the other a cottonwool wad soaked in alcohol

The method-dependent part of the loss is approximately the same for both methods, and on average around 0.12 dB for fibres with 50 μm core diameter and 100 μm cladding diameter, fig. 2.

In the field trial the average total attenuation increment per joint was approximately 0.3 dB.

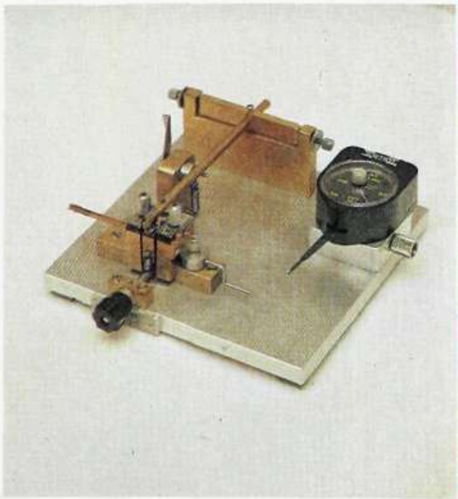
Preparing the fibres

Preparation of the end faces of the fibres is an important element in the jointing work as well as when making measurements on the fibres.

In order to be able to splice fibres it is first necessary to remove both the secondary and the primary coating. The surface of the cladding must be very clean so that the fibres can be properly aligned for the splicing. Any coating residues or dirt can cause an alignment fault.

The secondary coating is cut using the top tool in fig. 3. The tool contains a razor blade. The coated fibre is put in one of the semicircular cutouts, is kept in place with the thumb and turned round. The secondary coating, which is not adhering to the primary coating, is cut off and can then easily be removed. The primary coating is removed with the middle tool. Two edges cut into the primary coating, which is then pulled off. Any residue of the primary coating is removed with tweezers. One leg of the tweezers holds a cottonwool pad soaked in alcohol and the other holds a piece of aluminium.

The cleaned fibre is placed in the cutting tool, fig. 4, and is cut to the correct length, about 30 mm from the secondary coating. The cut face must be even, clean and at right angles to the fibre axis. The cutting is simple and efficient. In the cutter the fibre is tightened over a curved surface. A nick is made in the bent part of the fibre with a cutting edge and the fibre is then tightened further until it breaks. This method gives a fracture like the one shown in fig. 5.



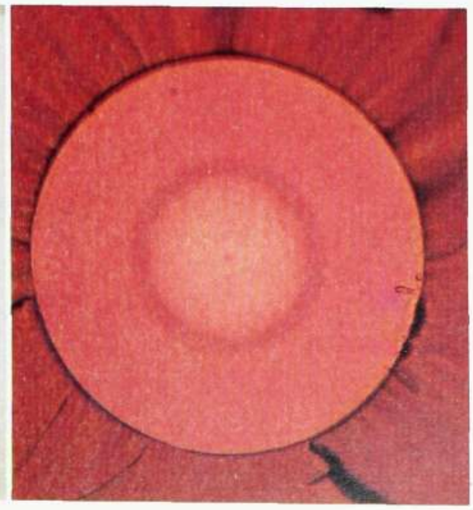
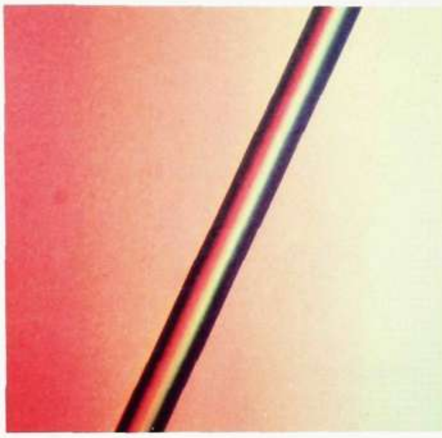
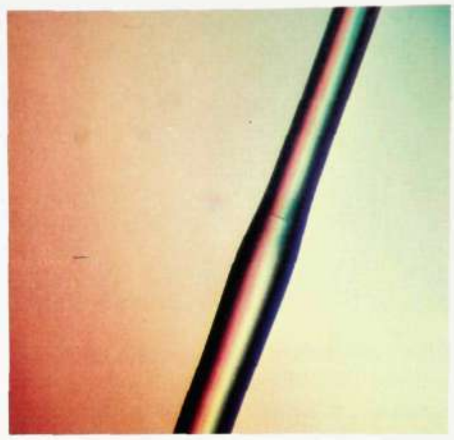


Fig. 4
Fibre cutting tool

Fig. 5
A [illegible] with the nick clearly visible

Fig. 6
To the left a joint in which the fibres have the same diameter and to the right a joint in which the fibres have different diameters





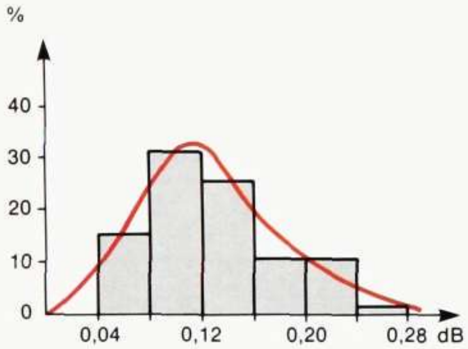


Fig. 7
A histogram showing the part of the loss in fused joints that is dependent on the method used

Fusion splicing

Fig. 8 shows the splicing equipment developed by Sievert Kabelverk for fusion splicing of optical fibres. It is intended for use in the field, and it incorporates all the functions that are necessary for the splicing of the fibre. The joint is made in a recess on a v-block, a steel block with a v-shaped groove, in which the fibres are fixed by suction. The block is manufactured with such a high degree of precision that the alignment fault is less than 1 μm. The fibres will then not need adjusting radially, fig. 9.

On each side of this v-block there is a fibre holder, movable in the axial direction and carrying a similar v-block for the fibre and clamps gripping the secondary coating. The holders are mounted on motor-driven slideblocks. The v-blocks of the holders are in contact with the fibre over a longer distance in the axial direction than in the central v-block. With the same amount of suction the fibre will therefore slide over the central block if the slideblocks move. The slide motors can be operated individually in the desired direction at one of two speeds. The gap between the fibres is adjusted by moving the fibre end faces to the correct positions relative a cross hair in a microscope mounted on the splicing equipment. The microscope is also used for checking the cut faces and the finished joint. Before the fibre faces are brought into contact with each other they are rounded off with the aid of a brief arc, of about 0.5 s. This prevents the formation of gas bubbles during the actual fusion.

When the end faces have been rounded off they are brought together and the arc is again ignited, this time for about 5 s. At the start of the fusion the two fibres are automatically fed a preset distance, about 10 μm, towards the fusion spot. If fibres having different diameters are fused together, or if the fibres are not exactly aligned, they will nevertheless automatically become concentric, fig. 6, as a result of the effect of the surface tension of the molten glass. In this way alignment faults up to about 15 μm are compensated.

The method described above was developed primarily for the jointing of CVD glass. Fig. 7 shows, in the form of a histogram, how large the method-dependent part of the jointing loss is. The method also gives good joints if used on DC fibres. The DC glass has a lower fusing point than the CVD glass. This fact makes the rounding-off process unnecessary for DC fibres. Moreover the required fusion time is much shorter and the power of the arc discharge must be much lower. A normal value for the method-dependent part of the loss in a

Fig. 8
Equipment for fusion splicing

Fig. 9, right
A close-up of the fusing equipment

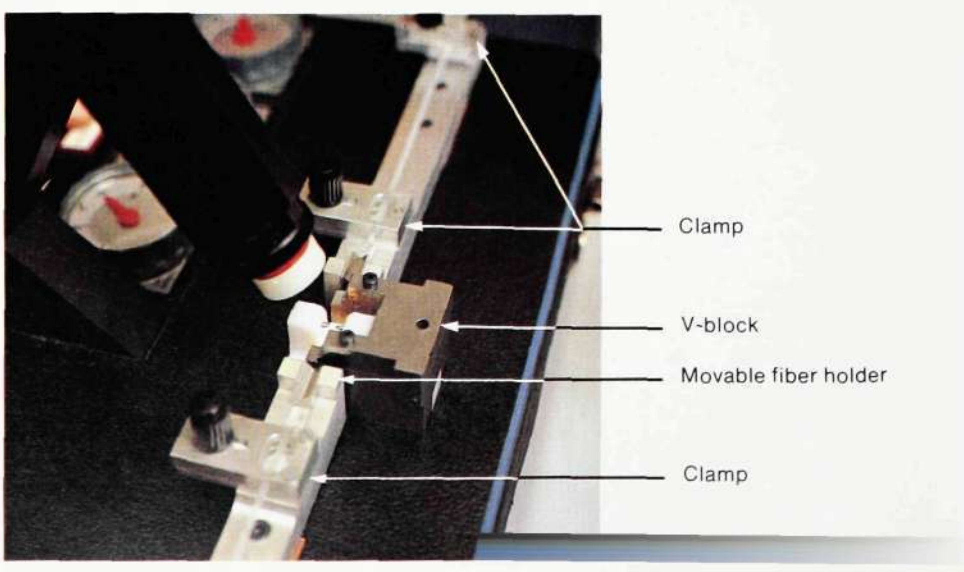
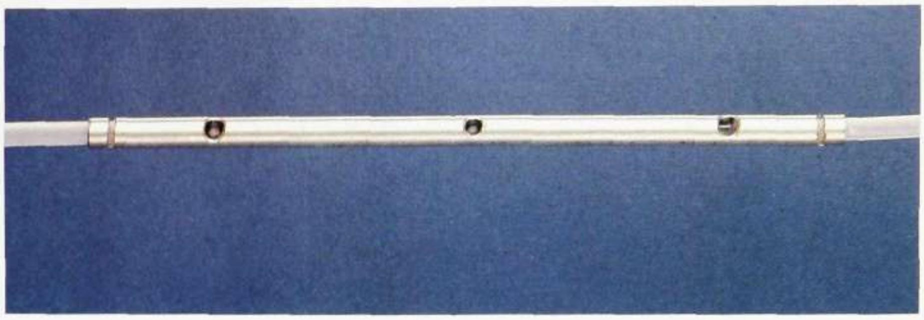


Fig. 10
A fused fibre joint with the secondary coating restored



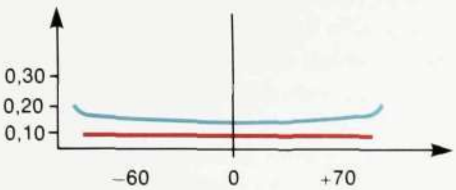


Fig. 11
The jointing loss as a function of the temperature
Top: Glued fibre
Bottom: Fused fibre

Fig. 12
New fusing equipment in series production

joint between two DC fibres with 100 μm core and 140 μm cladding is about 0.18 dB.

When the fibre has been spliced, both the primary and the secondary coating must be restored. The secondary coating is jointed with a stainless steel sleeve, which is put over the secondary coating of the left fibre before the fusion. The sleeve is approximately 100 mm long and after the fusion it is slid over the joint and the right-hand secondary coating. It is then tightened against the secondary coating with the aid of conventional shrinking tools. The sleeve is then filled with silicon rubber through a centre hole, so that the primary coating is restored, fig. 10. It is important that the compound is soft and the fibre is straight, so that unnecessary stresses, in the form of bends caused by temperature changes, are avoided. Fig. 11 shows the temperature dependence of the jointing loss. The available measuring methods do not show any variation of the loss with temperature for a fused joint. Type testing has also shown that the loss of the joint does not change after temperature cycling some 30 times between −60° and +70° C.

The fusion equipment that is now in series production has a yoke that connects the two fibre holders fig. 12. With the aid of this yoke the joint and the adjoining coated fibre can be moved intact from the fusion site to a working position for the application of the protections. A U-shaped profile is then used instead of a tubular sleeve. The joint is placed in the profile, which is then filled with silicon rubber and closed to form a tube.

Glueing

The other splicing method for optical fibres consists of aligning the fibres in a v-shaped groove and glueing them to the groove. The method is very simple and gives good joints. Since the glue is to fill the space between the fibre end faces it must have approximately the same refractive index as the glass. This method requires a high degree of cleanliness of the groove and the cylindrical fibre surfaces, and it can only be used for concentric fibres with the same cladding diameter. One problem is how to position the fibres correctly in the groove. The glueing method has been developed and patented by Sieverts Kabelverk, and a splicing equipment for this method has been designed, fig. 13, which operates as follows.

Each fibre end is fixed in a suction clamp, mounted on a slide block, which is movable in the axial direction. A jointing piece with a v-shaped groove is placed between the clamps. The jointing piece can be made of plastic or aluminium. In the latter case the groove is formed between two cylindrical steel pins placed side by side in a rectangular channel in the aluminium piece. The dimensions are such that an air gap of approximately half the fibre diameter is formed between the steel pins. A pump sucks the fibres into the groove, fig. 14.

The fibres are brought into contact with each other in the middle of the jointing piece with the aid of the movable slideblocks. Their positions can be observed with the naked eye or a magnifier. The positioning is facilitated by feeding light at an angle into the fibre through the cladding. The light emerges at the cut face. When the fibre faces

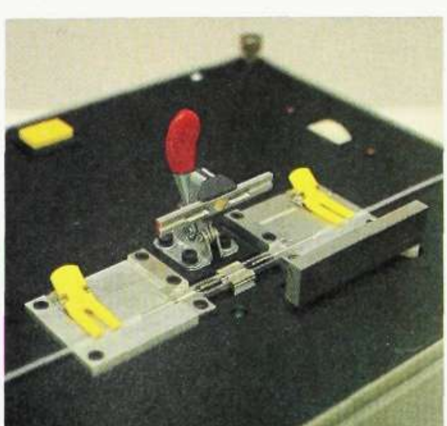


Fig. 13
Equipment for glueing joints

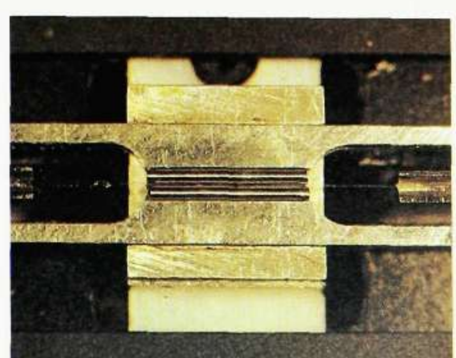


Fig. 14, right
The v-shaped groove is formed by two cylindrical

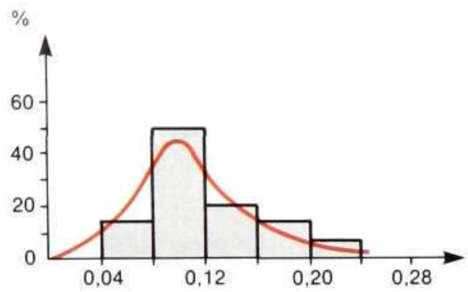


Fig. 15
A histogram showing the part of the loss in glued joints that is dependent on the method used

Fig. 16
Glued fibre joints. The jointing pieces can be stacked on top of each other

come into contact with each other the intensity of the escaping light is reduced.

The lid, which forms the top part of the jointing piece and which has been coated with glue in advance, is placed in a holder and positioned on the base piece, fig. 13. The glue is hardened by heating for a certain time at a controlled temperature. The hardening time is 5–15 minutes depending on the type of glue. Type tests have shown that this type of joint can also stand repeated cycling between −60° and +70° C without the loss value changing, fig. 15. The epoxy glue used is of the two component type. At room temperature it remains usable for several weeks after mixing. The lids can therefore be prepared in advance in a suitable environment and the sanitary problems of the epoxy glue are minimized at the jointing site.

The jointing pieces are constructed so that when the lid is fastened to the base, the secondary coating is also clamped between the two halves. The cavities in the jointing piece are then filled with silicon rubber, and thus the primary coating is restored in the same process, fig. 16.

Transmission Measurements on Optical Fibre Cables

György Endersz and Peder Rodhe

The work on fibre optics in the Ericsson Group includes studies of methods for measuring the transmission characteristics of fibres carried out by Sieverts Kabelverk, who have also developed instruments for such measurements. In this article various technical measurement problems and the requirements as regards measuring equipment are first discussed. This is followed by a description of the developed measuring equipment and the results and experience obtained, partly during the field trial with optical communication in Stockholm, Sweden, FOK-79.

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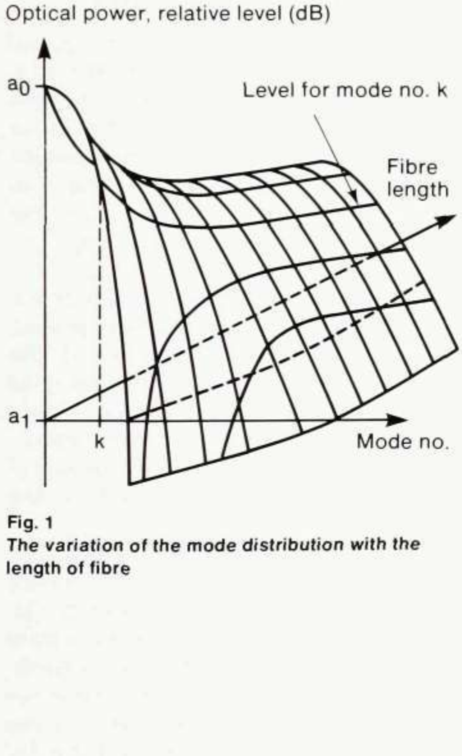

Fig. 1
The variation of the mode distribution with the length of fibre

It is essential that the transmission characteristics of the fibres in the cables used in optical transmission systems are known. The most important characteristics are the fibre attenuation and the dispersion, i.e. the broadening of light pulses during transmission. It must also be possible to determine the position of any fault in the fibre. Sieverts Kabelverk routinely check the fibre characteristics during the manufacture, installation and maintenance of fibre cables. The problems discussed in this article mainly concern measurements in the field during installation and maintenance.

Guidelines for methods of measurement

A study group within CCITT, which includes representatives of the Swedish Telecommunications Administration and LM Ericsson, is working on recommendations for fibre in cable and proposals for suitable measuring methods for different fibre parameters[1]. These proposals contain the following basic conditions:

- the transmission measurements must be easy to carry out and the methods must give reproducible results
- it must be possible to use the results for the dimensioning of systems
- the measuring methods must be non-destructive.

A fibre functions as a waveguide for the transmission of optical signals. The characteristics of the waveguide are determined primarily by the diameter and refractive index profile of the fibre core. These parameters decide the number of possible modes for the propagation of the light through the fibre. The light in each mode passes the fibre axis at a certain angle and at a certain distance. Each mode is characterized by the attenuation factor and its propagation speed. The attenuation and dispersion of a certain fibre route will therefore depend on the amount of optical power provided for each mode from the start, i.e. the mode distribution. Mode mixing occurs at irregularities in the fibre. If these irregularities are evenly distributed along the fibre, the mode distribution after a certain length of fibre will take up a characteristic, stable form, fig. 1. For even greater lengths of fibre the variation of the attenuation with length is linear and the pulse dispersion becomes more regular.

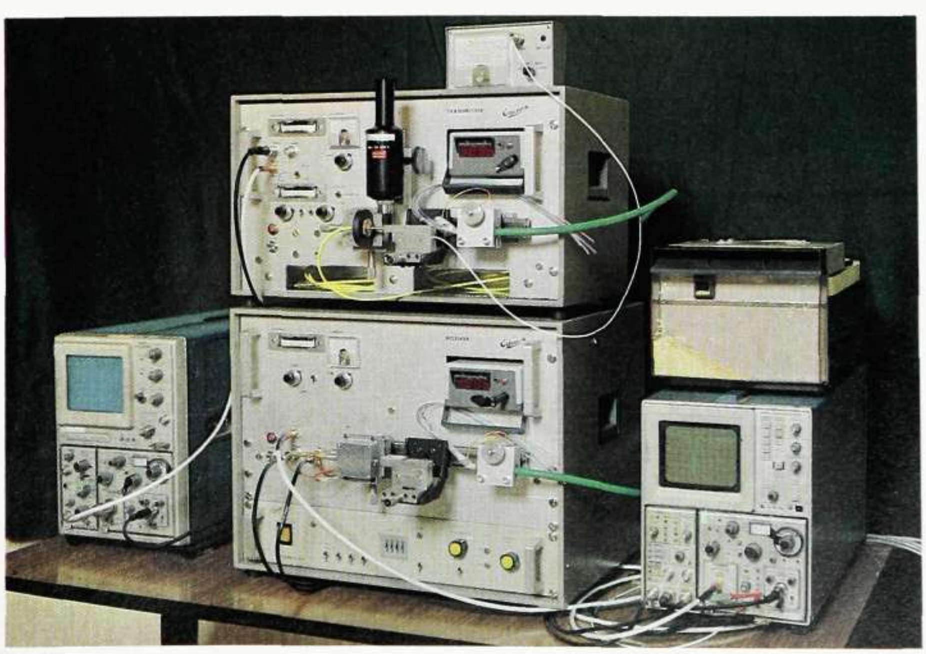

Fig. 2
Complete equipment for attenuation and dispersion measurements

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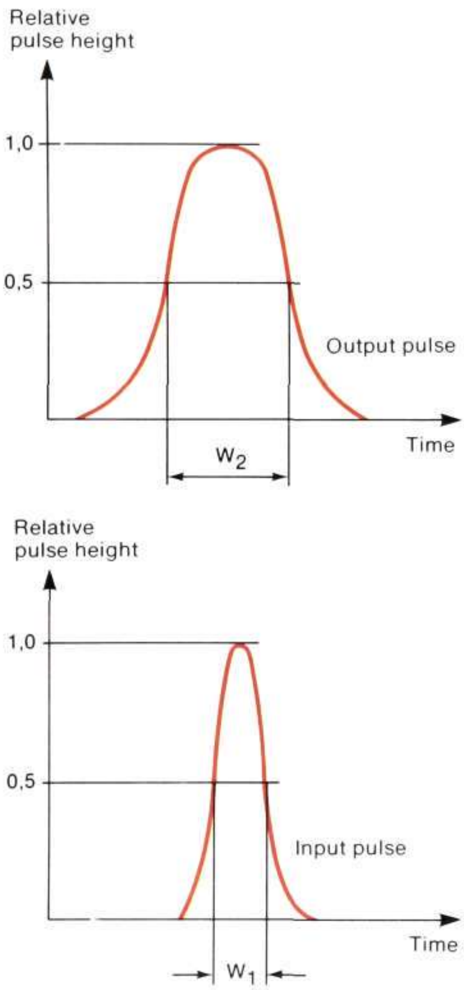


Fig. 4
Determining the pulse dispersion by direct measurement of the width of the input and output pulses at 50 % of the pulse height.
The dispersion is calculated as $\sqrt{W_2^2-W_1^2}$ and is given in ns

Thus in order to satisfy the two first conditions in the list above it is important to aim for such a stable mode distribution from the very beginning. This can be achieved by using a fibre of sufficient length between the light source and the fibre to be measured. This launching fibre must have approximately the same dimensions and characteristics as the fibre to be measured, so that the stable mode distributions of the two fibres will be similar. The launching fibre needs to be between 100 and 1 000 m long, depending on the fibre characteristics.

By using a launching fibre it is easy to measure the attenuation of delivered cable lengths and get results which, when added, amount to the attenuation *of the whole, jointed cable. Attention* must then be paid to the extra attenuation caused by the joints.

One advantage of the attenuation measurement method described here is that the amount of fibre used up is very low. Before measuring, the fibre must be cut so that well defined end faces are obtained, but the fibre lengths used up by this procedure are negligible. With another attenuation measurement method the light source is connected direct to the fibre. The whole fibre length is measured first, then the 5–50 metres next to the light source. This method uses up so much fibre that it cannot be recommended for use in the field.

The dispersion is also measured with a launching fibre inserted between the source and the fibre to be measured. However, if the results from the individual lengths are added, the value obtained for the total dispersion of the jointed cable will be too high. The reason for this is that the dispersion consists of several components, the largest being mode dispersion and material dispersion. The material dispersion increases linearly with the fibre length, but the relation between the mode dispersion and the fibre length is more complicated because of the mode mixing, particularly that caused by the joints. Measurements must be made on different fibre lengths, with and without joints, and then an evaluation can be made of the variation of the dispersion with the fibre length, which makes it possible to make estimates for the dimensioning of systems.

Technical requirements

Measurements in the field pose special *problems. The measurement transmit*ter and receiver must be placed far from each other. There are difficulties in transmitting the test results between measuring equipments, and in synchronizing the receiver with the transmitter when measuring pulses.

The maximum permissible attenuation of a cable section requires big dynamic range of the measuring equipment. The desired measuring accuracy depends on the linearity, short and long-term stability and calibration of the measuring equipment. In addition the quality of the fibre end faces greatly affects the accuracy.

The sensitivity of opto-electronic equipment to various environmental factors, such as humidity, temperature and vibrations, is another major problem. Furthermore, both the time required for the measurements and the possibility of obtaining reproducible results are greatly dependent on rational handling of cables and fibres. Simple

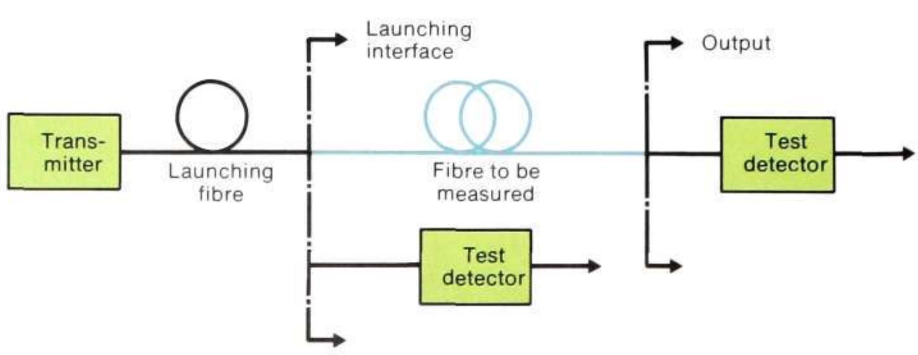


Fig. 3
The basic method for measuring attenuation and dispersion

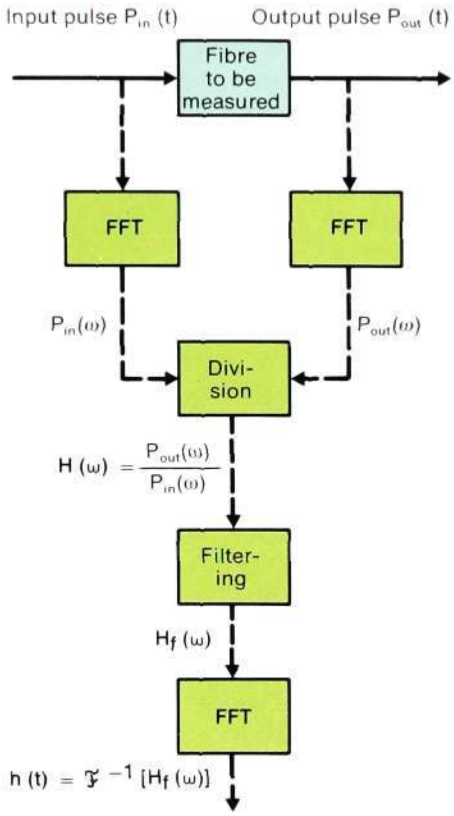


Fig. 5
Calculation of transfer function and pulse response
FFT Fourier transform

and reliable methods and equipment for fixing and aligning the fibres when connecting them to the transmitter and receiver must be available.

Measuring methods

A block diagram of the set-up for transmission measurements on fibre cables is shown in fig. 3. The excitation of the fibre to be measured must be well defined in order to get unambiguous results for attenuation and dispersion. A launching fibre of a suitable length is inserted between the transmitter and the fibre to be measured.

The measuring detector must sense the total optical power in the observed fibre cross section, and also give a photo current that is directly proportional to the optical power. The detector is first connected to the launching fibre for the calibration, and then to the output of the fibre to be measured for the actual measurements. When measuring dispersion the detector (like the transmitter) is connected via a fibre that has a larger effective area and larger acceptance angle than both the measured fibre and the launching fibre. This makes the insertion loss almost the same for both calibration and measurement. The difference is so small that it can be disregarded. When measuring the attenuation, the launching fibre and the fibre to be measured are connected direct to the detector, without any intermediate fibre, and the insertion loss between the launching fibre and the measured fibre must be determined. This can be done in a preliminary measurement by replacing the fibre to be measured with a short piece of the same type of fibre, the attenuation of which is negligible.

The pulse dispersion is most easily determined by comparing the pulse width of the input and the output signal. The dispersion is usually given at both 50 % and 10 % of the pulse height, fig. 4.

A more exact method of determining the dispersion is to measure the input and output pulse amplitude as a function of time in several equidistant points. Using Fourier transformation, this time function is converted to the frequency domain, after which the transfer function is calculated by dividing the output pulse spectrum by the input pulse spectrum. After suitable filtering of the transfer

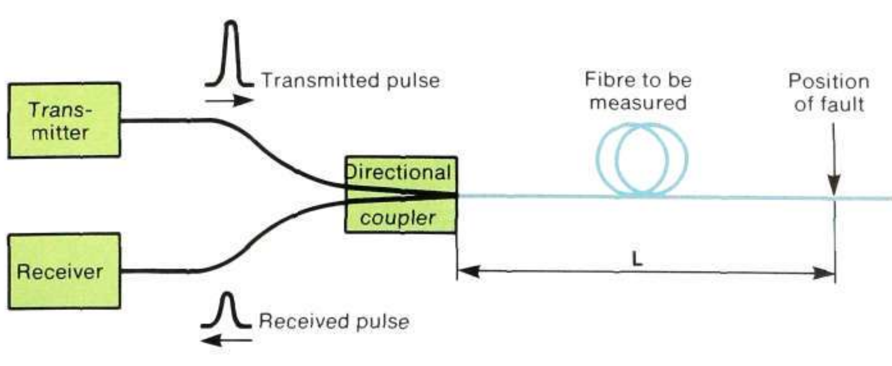


Fig. 6
Fault localization. The distance to the fault
$L = \frac{ct}{2n}$

c The speed of light in vacuum
n Effective refractive index
t [illegible]

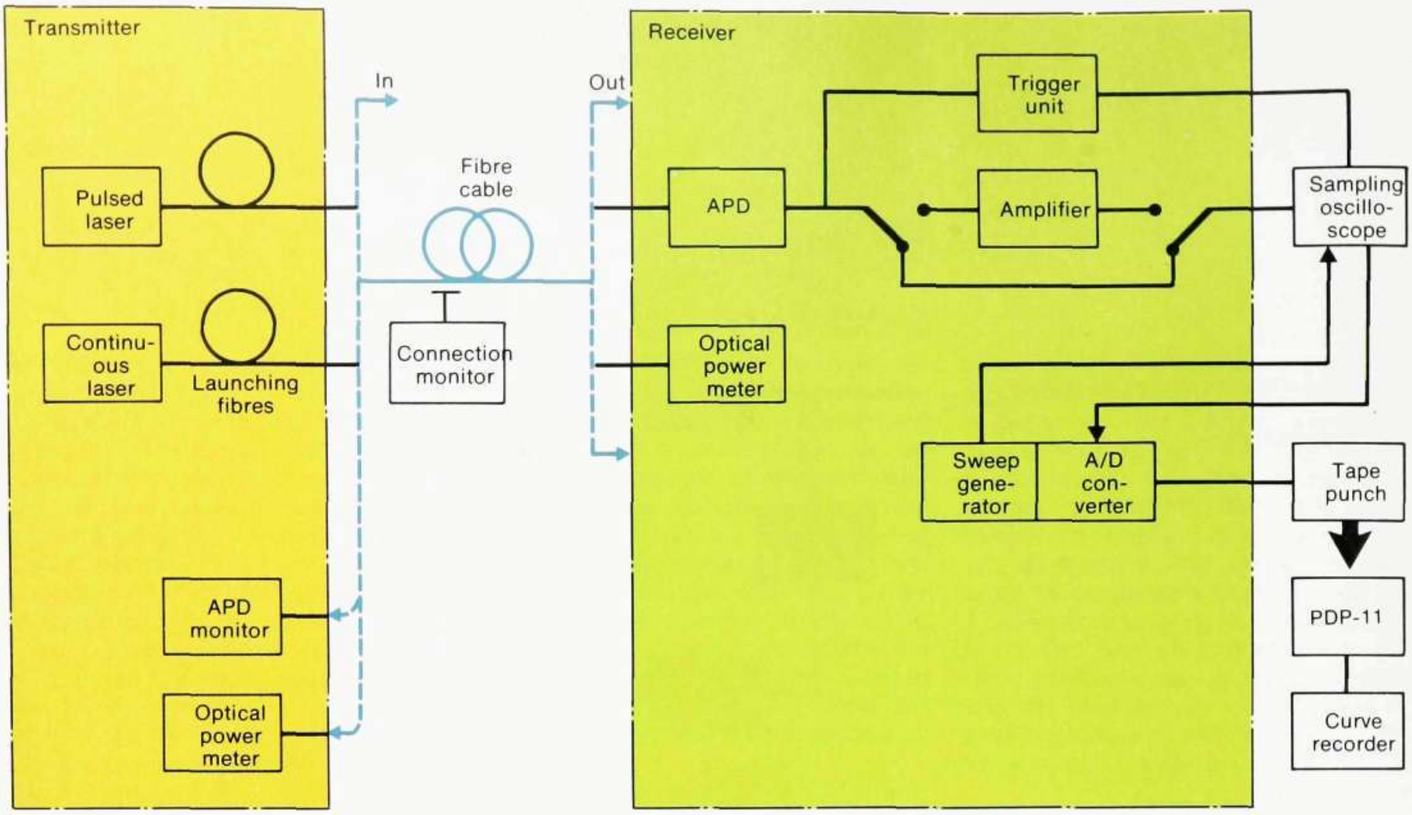


Fig. 7
Block diagram of the equipment for measuring attenuation and dispersion

function another Fourier transformation is made back to the time domain in order to determine the pulse response, fig. 5.

Faults in a fibre are located using a pulse echo method. The transmitter and receiver are then placed at the same test point. The propagation time from transmitter to receiver is measured for a light pulse that is reflected at the fault. The distance to the fault can then be calculated with the aid of the refractive index of the fibre, which gives the speed of light in the fibre, fig. 6.

Measuring equipment

Block diagrams of the equipment that has been constructed for field measurements of attenuation and dispersion are shown in fig. 7. An oscilloscope is connected to the transmitter, and both an oscilloscope and a data storage unit are connected to the receiver, figs. 2 and 8. On the front of the units there is a small optical bench for fixing cables and fibres and easy aligning of the fibres. The positions and end faces of the fibres can be checked with a microscope. Both the transmitter and the receiver are fitted with an optical power meter, accessible from the front, for measuring the attenuation.

The light sources in the transmitter consist of laser diodes. One gives continuous light and is intended for attenuation measurements. It is equipped with feedback for regulation to constant optical power[2]. The other, which is pulsed, can be switched to give long or short pulses. The choice of pulse duration depends on the attenuation and dispersion of the fibre to be measured.

The launching fibre is 250 m long. Its data are very similar to those of the fibre to be measured, but it has a slightly smaller core diameter and acceptance angle, in order to reduce the insertion loss as much as possible. A photocell with a large area is used on the send side

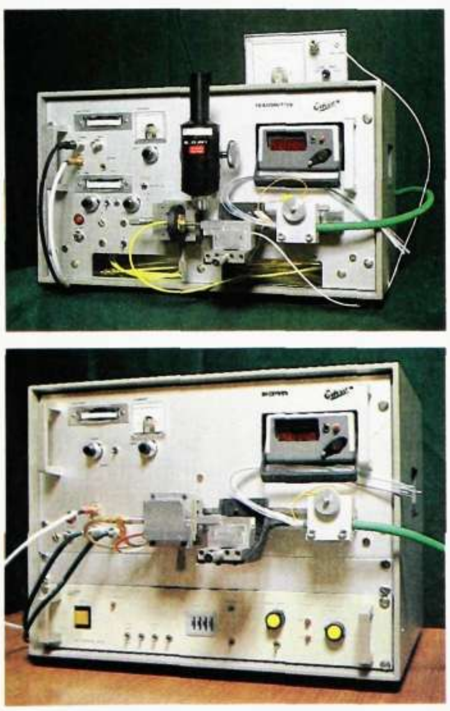


Fig. 8
Equipment for measuring attenuation and dispersion
Top: Transmitter
Bottom: Receiver

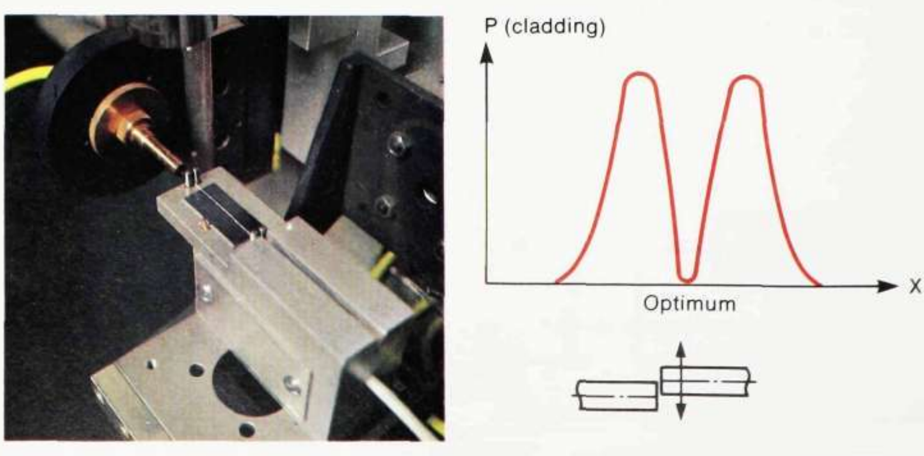


Fig. 9
Optimizing the light coupling
Left: Fibre clamp with connection monitor
Right: The optical power in the fibre cladding

for the optimization of the light coupling. The photocell detects the light that goes out into the fibre cladding when the fibres are not properly aligned, fig. 9. The coupling is optimal when the light from the cladding is at a minimum. This method is used to avoid having to transmit measurement data from the receive side to the send side for adjustment of the coupling.

The wave shape of the pulsed laser is checked at the output end of the launching fibre by a fast photo detector, an avalanche photodiode (APD), connected to a sampling oscilloscope.

On the receive side pulse detection is carried out using the same type of photo detector. A part of the photo current is taken out via a test channel, either direct or via a wideband amplifier, to a sampling oscilloscope. Another part of the photo current is coupled via a delay and trigger unit to the trigger input of the oscilloscope. The pulse shape is digitized in 256 time slots, which are scanned in turn with a separate scanner. Several pulses are digitized in this way so that a mean value can later be obtained. This reduces the effect of noise superposed on single pulses. The measurement results are output on a punched tape. Each result is stored on the tape as a 12-bit word. The tape is later read into a minicomputer for processing of the data.

Fault localization is carried out with pulse echo equipment from Felten & Guillaume. The propagation time is measured with an oscilloscope with a built-in counter for digital time indication.

Technical data for the measuring equipment are given on the last page of the article.

Processing of the measurement data

Pulse data are processed in a minicomputer of type PDP-11 and output is obtained on a Versatec curve recorder. A program controls the input of pulse data from the punched tape in sequences of 256 measurement values. After the input of each sequence a Fourier transformation to the frequency domain is carried out, and the result is accumulated in the computer disc store. This accumulation corresponds to the calculation of the mean value. The signal-to-noise ratio increases in direct proportion to the number of accumulated sequences.

Fig. 10
Transmitter position when measuring in a cable tunnel

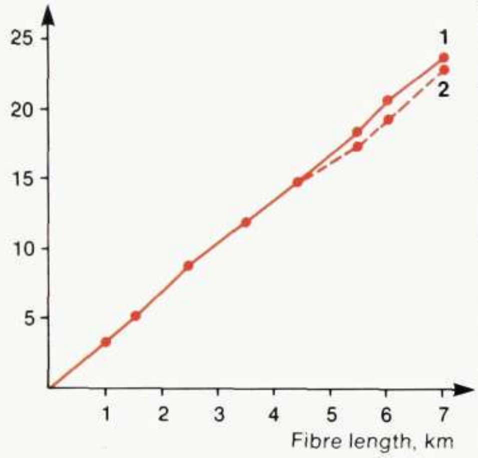


Fig. 12
The variation of the attenuation with length for a cable with seven joints
1. Calculated result
2. Measured result

When the input of measurement results and the Fourier transformation have been completed, the quotient between output and input spectrum is calculated. This gives the amplitude and phase of the transfer function. Certain quotient values may be incorrect because they were obtained by division of spectral components that had a low amplitude, and which might also have been incorrect because of noise. A weighting procedure reduces or removes the effect of such incorrect values. A new Fourier transformation is then carried out to obtain the impulse response. The program also contains routines that control the curve recorder for displaying the calculated results in the time and frequency domains.

Results and technical experiences

The measuring equipment was tested in the field during the optical communication field trial carried out in Stockholm, FOK-79. Figs. 10 and 11 show the equipment in use in a cable tunnel.

The power meters used for attenuation measurements have a measuring range of more than 60 dB. This is more than sufficient for measurements on fibre sections for line systems. The measured attenuation values must be reduced by the insertion loss between the launching fibre and the fibre to be measured.

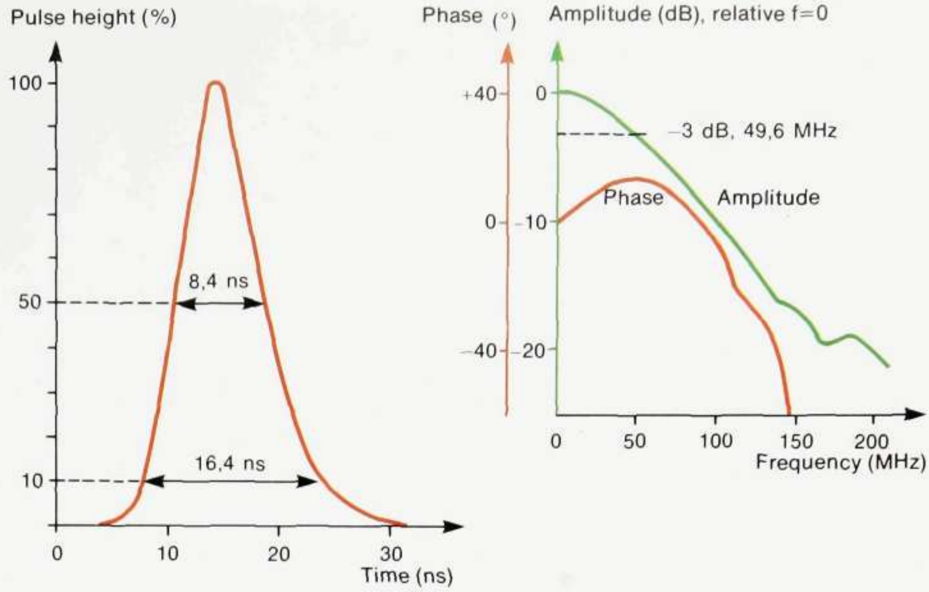
Measurement errors were estimated to be of the order of ±0.2 dB. Such narrow limits presuppose successful cutting of the fibres giving well defined end faces. If very high accuracy is desired, repeated cutting and measuring has to be carried out. When, after a series of measurements, the lowest attenuation value is reproduced, the series is usually discontinued. The last cutting faces are then also used for the subsequent measurement of the dispersion.

Fig. 12 shows the attenuation of a successively increased fibre section. Curve no. 1 shows, for different section lengths, the calculated attenuation, i.e. the sum of the attenuations of the cable lengths in the section, adjusted to take into account the insertion and jointing losses. The measured attenuation is shown in curve no. 2 and conforms well with the calculated result.

The effect of arc-welded joints and of connectors was also evaluated during the field trial FOK-79. The attenuation of a certain fibre section was measured

Fig. 11
Receiver position when measuring in a cable tunnel

Fig. 13
The measurement results for a fibre route of 14 km
Left, pulse response
Right, transfer function

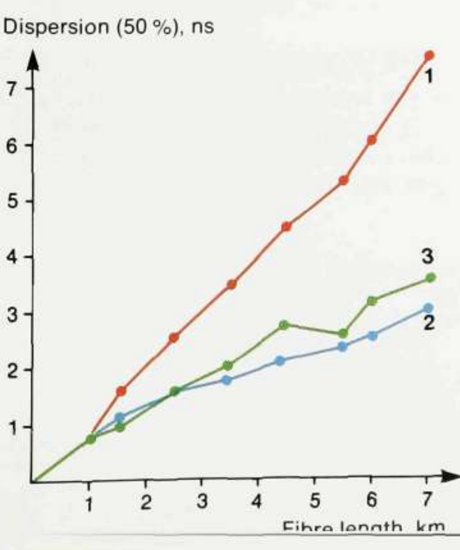


Technical data

Attenuation measurements	
Wavelength of the light source	877 nm
Spectral width of the light source	<5 nm
Optical output power of the light source (after 2 m of fibre)	>0 dBm
Measuring range	>53 dB
Dispersion measurements	
Wavelength of the light source	850 nm
Spectral width of the light source	<3 nm
Optical output power of the light source, instantaneous value (after 2 m of fibre)	
short pulse	>20 dBm
long pulse	>23 dBm
Pulse duration of the light source	
short pulse	0.4 ns
long pulse	4 ns
Receiver bandwidth	
without amplification	2 GHz
with amplification (filter)	0.9 GHz
Pulse repetition frequency	50 kHz
Measuring range	0.5–30 ns
Maximum permissible attenuation for the route	55 dB
Number of samples per data sequence	256
Time for storing a sequence on tape	4 s
Number of accumulated sequences	1–9999
Word length per sample	12 bits
General	
Launching fibre	
Length	250 m
NA (99 %, short length)	0.20
Core diameter	48 µm
Fault localization	
Wavelength of the light source	904 m
Pulse duration of the light source	10 ns
Maximum one-way attenuation over the test route	20 dB

Fig. 14
The variation of dispersion with length for a cable with seven joints

1. Calculated result with negligible mode mixing
2. Calculated result with considerable mode mixing
3. Measured result



without and with connectors installed, and the results were compared. This comparison was repeated for different fibre sections with a varying number of fused joints and connectors. The results from these comparisons were then compiled so that mean values could be calculated for the attenuation caused by fusion joints and connectors. The insertion loss between the launching fibre and the fibre to be measured could also be estimated. The value obtained for fused joints was 0.3 dB, for connectors 0.6 dB and for the insertion loss 0.2 dB.

The accuracy of the dispersion measurements depends on the synchronization sensitivity and linearity of the pulse receiver. Occasional measurement errors are estimated to be ±4 % and systematic measurement errors ±2 %. The material dispersion of the fibre contributes to the pulse dispersion to a lesser or greater degree depending on the wavelength spectrum of the transmitting laser diode. This relationship is now being studied. On one occasion during the field trial the dispersion was measured on a 14 km long fibre route that had an attenuation of 54 dB. The dispersion at 50 % of the pulse height was then 8.5 ns, and the transfer function had a greatest signal-to-noise ratio of 20 dB, fig. 13.

Fig. 14 shows the dispersion for a successively increased fibre section. Curves nos. 1 and 2 show two different theoretical calculations of the variation of dispersion with fibre length, where consideration has been paid to the material dispersion. In curve no. 1 the mode mixing has been neglected and the measured pulse dispersion values for the cable lengths in the section have just been added. In curve no. 2 considerable mode mixing has instead been assumed. Curve no. 3 shows measured variation with fibre length. The effect of joints sometimes gives this curve a downward trend. However, curve no. 2 constitutes a good approximation of the real values.

The instrument used for fault localization permitted a distance to the fault that corresponded to 20 dB attenuation. Increased sensitivity could be obtained by using a method with sampling and calculation of mean values like the one used for measuring dispersion.

In conclusion it may be said that the chosen measuring methods and the constructed measuring equipments certainly meet both the general requirements formulated by CCITT and the technical demands made during the field trial FOK-79. The experience gained from this field trial will simplify measurement work and instrument construction.

References

1. CCITT, COM XV, No. 314-E.
2. Endersz, G.: *Laser Module for Fibre Transmission and Measurement Purposes.* Fourth European Conference on Optical Communication, Genova, 1978.

34 Mbit/s Optical Fibre Line System, ZAM 34-1

Hans Giertz and Viesturs Vucins

An optical fibre line system, ZAM 34-1, for third order PCM is introduced in this article. The line system has been developed as a part of LM Ericsson's program for optical fibre communication. The system is primarily intended for use in urban networks as a link between local exchanges, between concentrators and the exchange or for connection to radio relay link equipment where insensitivity to disturbances is required. In these applications the transmission distance seldom exceeds 10 km. The system is dimensioned for transmission over 10 km without intermediate repeaters. However, intermediate repeaters are available for longer transmission distances.

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Fig. 1
Line terminal equipment ZAM 34-1 with the cover plate removed from the laser transmitter

The optical fibre line system ZAM 34-1 is intended for digital transmission of 480 PCM coded telephony channels at 34.368 Mbit/s over optical fibre cable. The system comprises line terminal equipment and intermediate repeater equipment and permits a repeater spacing of up to 10 km. In its present version the intermediate repeater equipment is designed for installation in an exchange with local power feeding. The equipment that has hitherto been manufactured is intended for field trials in different markets.

The system utilizes a laser diode as the light source and an avalanche photodiode as the light detector. The transmission medium is a graded index fibre with low attenuation. ZAM 34-1 operates at light wavelengths around 820 nm, where the optical attenuation of the fibre is 3 – 5 dB/km.

Line system ZAM 34-1 has the following advantages:
- large repeater spacing
- high reliability
- simple cable installation
- very little maintenance.

System structure

The optical fibre line system ZAM 34-1 consists of line terminal equipment and two-way intermediate repeater equipment for transmission over optical fibre cable. The line system has to a large extent the same mechanical construction and system structure as LM Ericsson's transmission for metal cables. The structure of the digital optical fibre line system is shown in fig. 2.

Connection to the line system is made via the 34 Mbit/s coaxial interface (D3) recommended by CCITT (G.703). This means that the line system can be connected to multiplex equipment, radio relay links or line equipment for coaxial cable.

The line terminal equipment and intermediate repeater equipment are supervised in the same way as LM Ericsson's systems for metal cables.

Connection in the optical interface (F3) is made with a low-loss fibre connector, which permits the connection of line fibres of different dimensions to the fibres in the optical interface in the equipment. On the send side a fibre with 50 μm core is used and on the receive side a fibre with 200 μm core. The core diameter 50 μm and the cladding diameter 125 μm are recommended by CCITT as the standard for line fibres in optical fibre line systems.

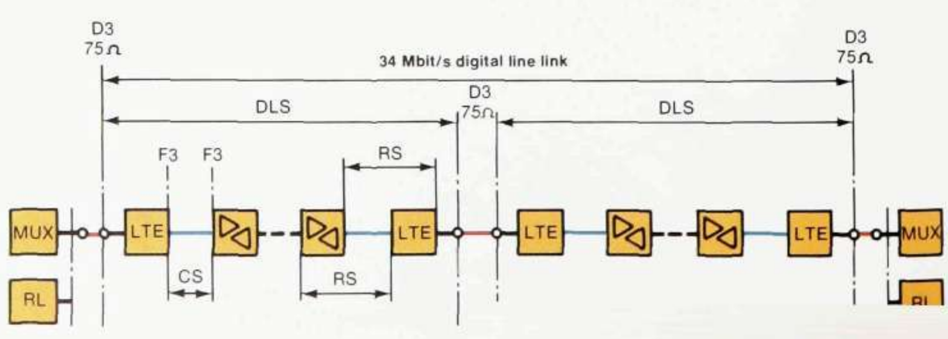
The small spectral linewidth of the laser, together with the large bandwidth of the graded index fibre, mean that the material and mode dispersions are negligible in this system. The repeater spacing for the system as a function of the fibre cable attenuation is given in fig. 3.

Line terminal equipment

In the line terminal equipment the signals in the send and receive directions are converted between the electrical digital interface (D3) and the optical fibre

Fig. 2
Block diagram and interfaces for the digital, optical fibre line system ZAM 34-1.

MUX	Digital multiplex equipment
RL	Radio relay link equipment
LTE	Line terminal equipment for one system
DLS	Digital line section
D3	Digital link interface, 34.368 Mbit/s (CCITT G.703)
F3	Optical fibre interface, 45.824 Mbaud
RS	Repeater section
CS	Cable section
(red line)	Interface cable, coaxial, 75 ohms
(blue line)	Optical fibre cable
(symbol)	Two-way intermediate repeater equipment



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interface (F3). The terminal repeater equipment also supervises the signal transmission and gives alarms if error limits are exceeded.

The line terminal equipment is built up on printed circuit boards mounted in a cast aluminium box. The construction practice is the same as that used for LM Ericsson's terminal repeaters for coaxial cable. The line terminal is shown in fig. 1 and the block diagram in fig. 4.

Send side

The bipolar HDB3 signal from the digital link interface (D3) is not suitable as the modulating signal in the optical system. The HDB3 signal is therefore decoded in the line terminal equipment so that the original binary signal is reconstituted. Groups of three bits from this signal are recoded to a new binary signal, the line signal. A 3B4B code has been chosen for the encoding of the line signal. This gives the line signal a symbol rate of 45.824 Mbaud. The coding table is shown in fig. 1.

This code gives the line signal the following desirable characteristics:
- unipolar signal
- high energy at the timing frequency
- limited spectrum
- constant mean value
- the possibility of transmitting alarm signals (AIS)
- the possibility of error supervision of the signal
- simple encoder design.

In the laser transmitter the line signal is converted to the corresponding optical signal. The laser transmitter contains a modulator, regulating electronics and a semiconductor laser with fibre connection to the optical interface (F3). The transfer characteristic of the semiconductor laser has a threshold above which the laser emits light, fig. 5. The line signal modulates the laser over the steep part of the characteristic. This is done by superposing the modulating current on a bias current which lies close to the threshold current. The amplitude of the modulating current and the bias current are automatically regulated in order to compensate for variations in the transfer characteristic. A beam from the rear mirror surface of the laser is detected by a PIN photodiode and is used as the regulation signal. A fibre, which is equipped with a lens to increase the coupling factor, couples the radiation from the front end mirror surface to the optical fibre contact in the interface (F3). The laser diode, fibre connector and photodiode are assembled in one mechanical unit. The function of the

Binary data	Mode no.1	Mode no. 2
000	1100	0011
001	1011	0001
010	0110	0110
011	1110	0100
100	1001	1001
101	1101	1000
110	0111	0010
111 (AIS)	0101	1010

Table 1
Coding table for the line code, 3B4B (mode change takes place when the previous 4-bit word is unbalanced)

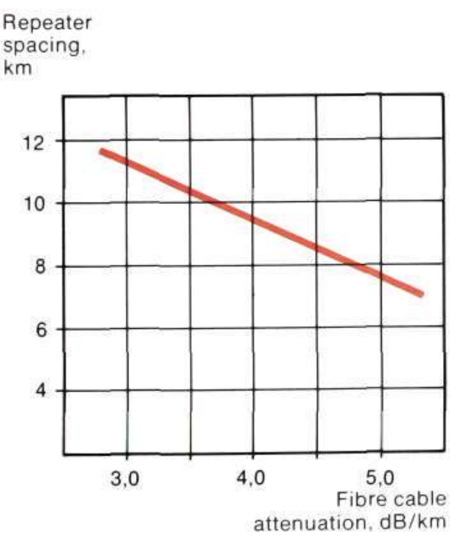


Fig. 3
Repeater spacing as a function of attenuation of the optical fibre cable including system margin. The system margin comprises a reserve for repairs (3 joints per km) and a reserve of 3 dB for degradation

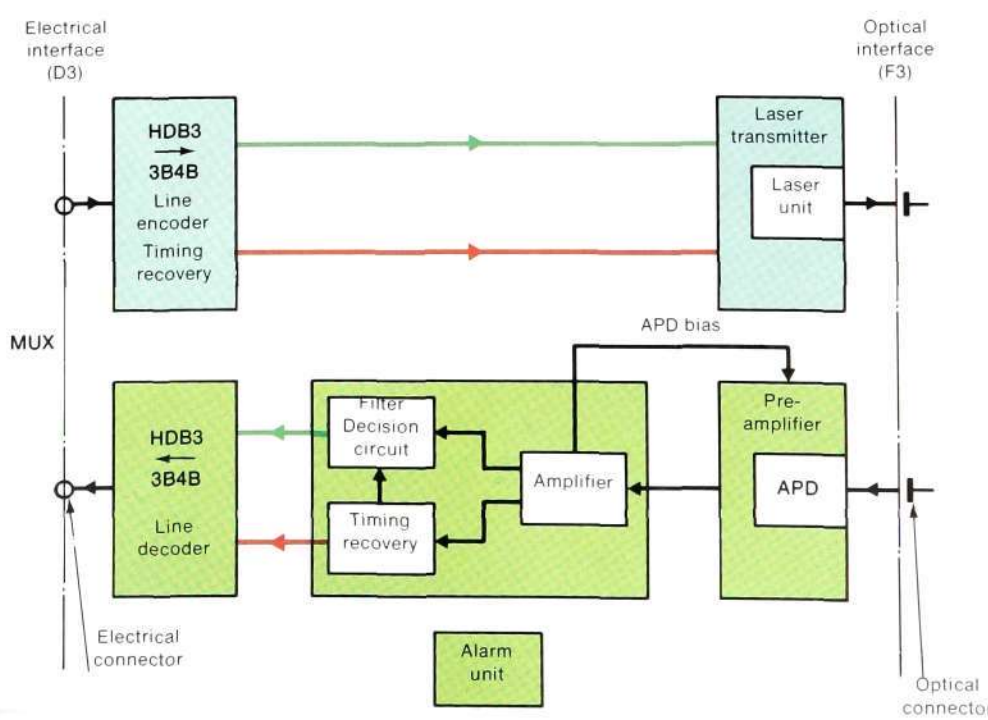
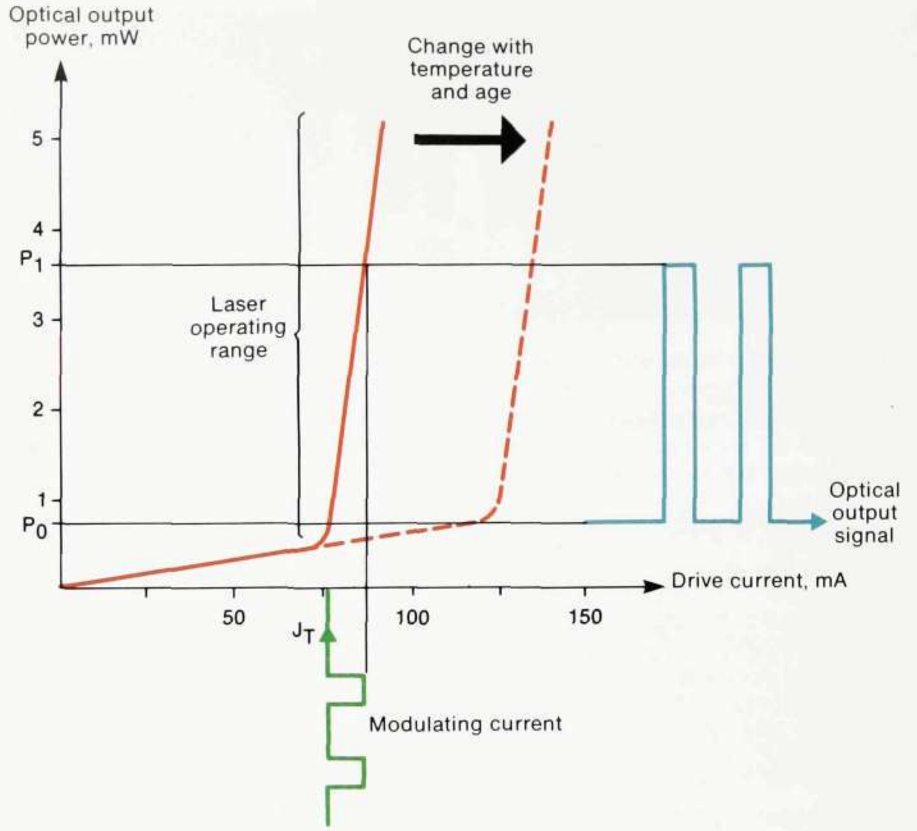


Fig. 4
Block diagram of the line terminal equipment

Information signal
Timing signal

Fig. 5
The transfer characteristic of the laser

J_T Threshold current
P_0 "Zero" light
P_1 "One" light



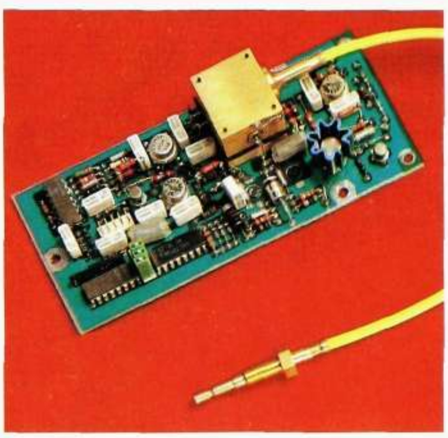


Fig. 7
The transmitter printed board assembly with laser unit and fibre connector

laser transmitter is shown in fig. 6 and fig. 7 shows the send side printed board assembly.

Receive side
The opcital signal received at the connector in the optical interface (F3) goes through a fibre to an avalanche photodiode, in which the optical signal is converted to an electrical signal. This signal is amplified, filtered, regenerated and recoded back to the original HDB3 signal.

The detector diode and components in the receiver input stage determine the sensitivity of the receiver. The use of an avalanche photodiode, APD, increases the sensitivity through internal multiplication of the primary photocurrent. Thus the receiver sensitivity is 10−15 dB higher with an APD than with a PIN photodiode. The multiplication process is random and introduces a noise that increases with the amplification. This means that there is an optimum amplification value, fig. 8. The equipment automatically regulates to the optimum value by varying the reverse bias to the avalanche photodiode.

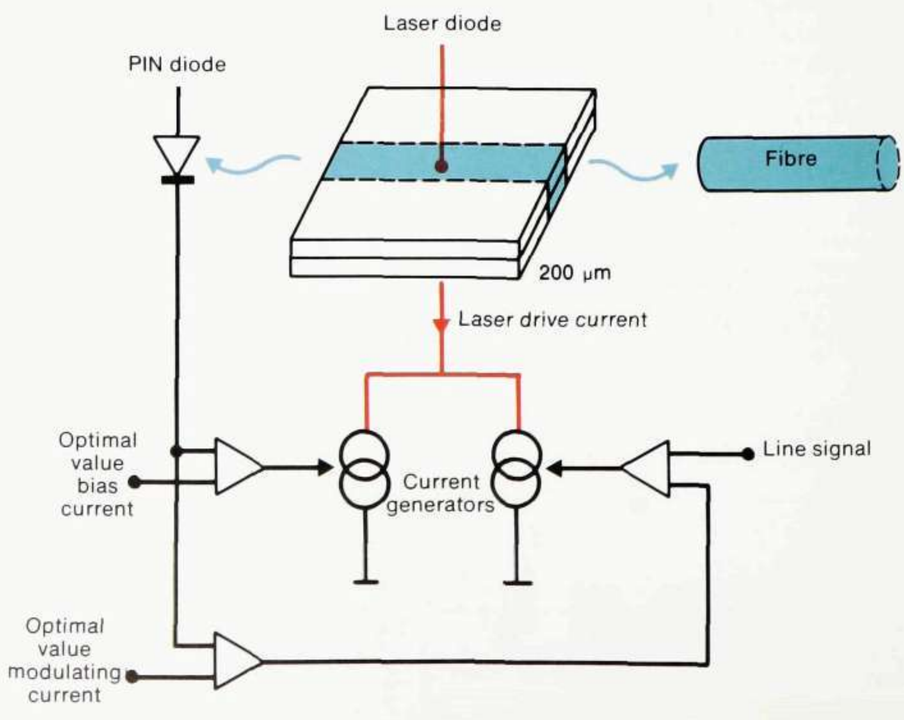


Fig. 6
The function of the laser transmitter. The light from the laser front end mirror is led via a fibre to the optical interface. The light from the rear mirror is detected and regulates the bias current and modulating current

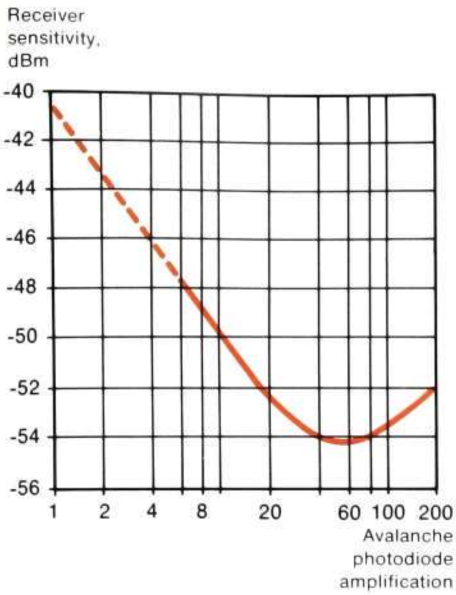


Fig. 8
Receiver sensitivity as a function of the amplification of the avalanche photodiode

- - - Thermal noise
—— Multiplication noise

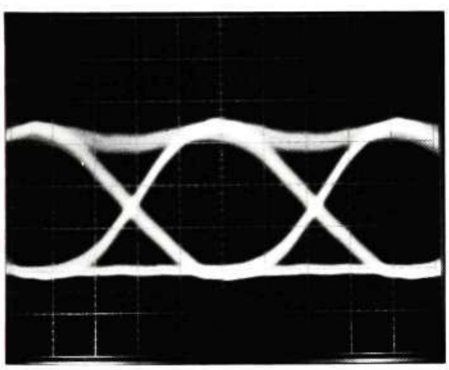


Fig. 9
The receiver eye diagram at the sampling point after 10 km of fibre cable (40 dB attenuation)

The detected signal is amplified in a low-noise input stage. The amplification method used means that the signal is first integrated and then differentiated in a succeeding amplifier stage, what is called integrating front-end. High reception dynamics are obtained by reducing the amplification in the avalanche photodiode and the subsequent amplifiers when the input signal is high. The amplified signal is filtered in a lowpass filter so that the highest possible signal-to-noise ratio is obtained in the decision point. The filter also compensates for the dispersion in the fibre. Fig. 9 shows the eye diagram at the decision point measured after 10 km of fibre cable (40 dB attenuation).

The timing signal for sampling and recoding is recovered from the received signal, which contains a frequency component at the clock frequency 45.824 MHz. The timing signal is filtered out in a bandpass filter and is then used for phase locking of an oscillator.

The information signal is sampled in the receiver synchronously with the timing signal. The information signal is regenerated and then recoded from a 3B4B line signal (45 Mbaud) to a binary signal (34 Mbit/s). The binary signal in its turn is recoded to an HDB3 bipolar signal which gives it the correct form for the digital interface (D3), fig. 2.

Intermediate repeater equipment

The optical signals are regenerated in the two-way intermediate repeater equipment. A block diagram of the equipment is shown in fig. 10.

Fig. 12 shows the two-way intermediate repeater. In each direction the signal is detected by an avalanche photo diode, amplified, filtered, regenerated and then converted to light pulses in the laser transmitter. The components and units in the intermediate repeater equipment have the same functions as the corresponding parts in the line terminal equipment. In the intermediate repeater the fibre cable is connected to the optical interface (F3, two inputs and two outputs) by means of the same type of connector as is used in the line terminal, fig. 11.

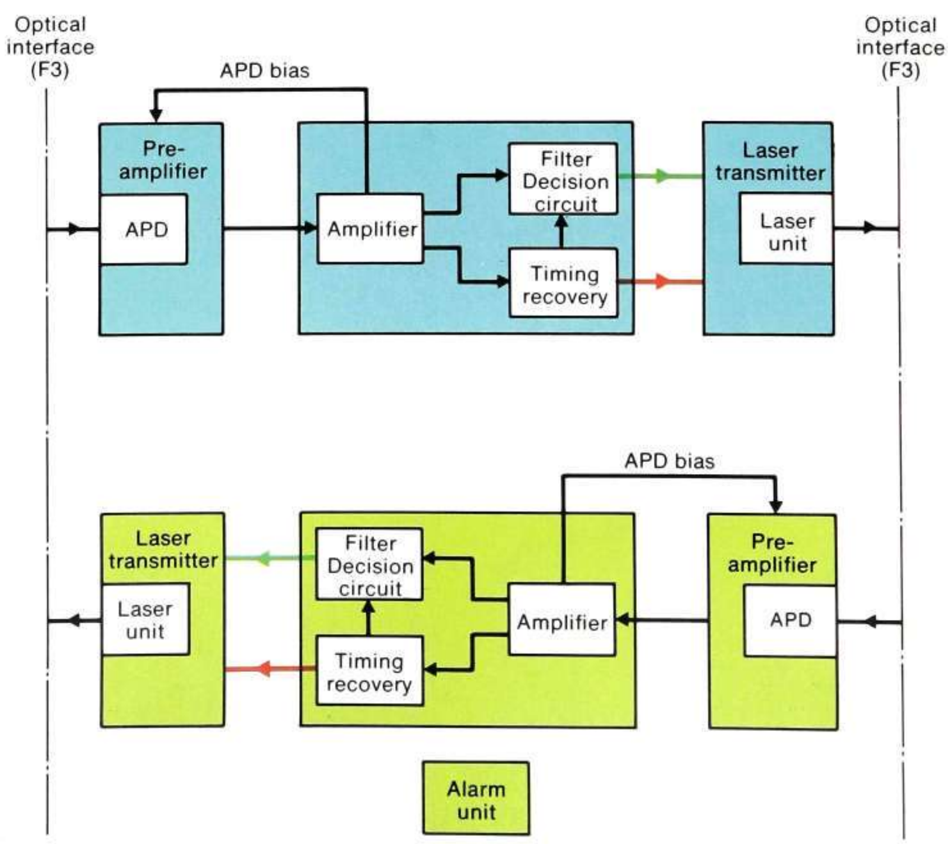


Fig. 10
Block diagram of the two-way intermediate repeater equipment

Information signal
Timing signal

Technical data for ZAM 34-1

Digital interface (D3)	
Bit rate	34.368 Mbit/s
Line code	HDB3
Impedance	75 ohms, unbalanced
Pulse amplitude	±1 V
Permissible cable attenuation at 17.184 MHz	12 dB
Optical interface (F3)	
Symbol rate	45.824 Mbaud
Line code	3B4B-LME
Fibre core diameter	50 μm transmitter 200 μm receiver
Numerical aperture (99 %)	0.21 transmitter 0.30 receiver
Output power	−2 dBm
Wavelength	820 nm
Spectral linewidth (3dB)	4 nm
Input sensitivity at an error rate of 5×10^{-10}	−53 dBm
Dynamic range	28 dB
Fibre connector type	LME
Repeater spacing	Up to 10 km, corresponding to a total attenuation of about 40 dB
Power supply	
Voltage	+5, +12 and −12V
Power consumption	
Line terminal equipment	18 W
Intermediate repeater (two-way)	12 W
Ambient temperature	
Normal operation	0° to +30° C
Limits for operation	0° to +45° C
Limits for storage and transport	−40° C to +70° C
Mechanical data	
Dimensions	310×130×210 mm
Weight	2 kg

The intermediate repeater equipment is intended for installation in an exchange and requires local power feeding. It includes equipment for fault detection and alarm indication. The mechanical construction is the same as for the line terminal equipment, figs. 12 and 1.

Alarms

A number of alarm functions are provided for the supervision of the system performance in the line terminal and intermediate repeater equipments. The primary alarms are indicated by diode lamps on the front of the equipment and can, via a strapping panel on the alarm supervision boards, be combined to derived alarms, both urgent and non-urgent (A and B alarms), and system alarms. The derived alarms and reminder (P) indication can be connected via an electrical connector to the rack alarm units and, as system alarms, to the central alarm equipment in the exchange. Power supply faults are detected and indicated separately.

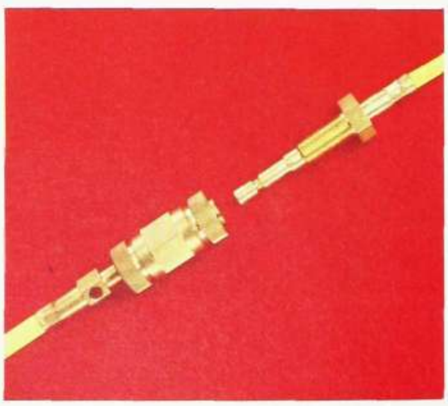
The following functions are monitored in the line terminal equipment:
- high bit error rate ($>10^{-6}$) in the incoming electrical signal (send side)
- absence of the optical output signal (send side)
- high bit error rate ($>10^{-6}$) in the received optical signal (receive side)
- no outgoing electrical signal (receive side).

The following functions are supervised in each direction in the intermediate repeater equipment:
- high bit error rate ($>10^{-6}$) in the received optical signal (receive side)
- absence of the optical output signal (send side)

The equipments are provided with a number of test points, which are easily accessible through holes in the cover plates and which simplify installation and maintenance.

Fig. 12
Two-way intermediate regenerator equipment, ZAM 34-1. The cover over the alarm generation and amplifier printed board assemblies has been removed

Fig. 11
Low-loss adjustable fibre connector. The connector plug on the right is intended for mounting in the equipment framework



Field Trial with Optical Communication

Gerhard Gobl and Sten Högberg

The Swedish Telecommunications Administration and the Ericsson Group have carried out a joint trial to test optical fibre transmission in the field.
The field trial, designated FOK-79, was implemented in the Stockholm telephone network between the exchanges Fredhäll and Äppelviken. The equipment was taken into service on October 26, 1979. In this article preconditions and aims of the trial are discussed as well as the components used, the cable laying, jointing, measurements and the resulting operational experience.

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FOK-79, a field trial with optical communication, was carried out jointly by the Swedish Telecommunications Administration and the Ericsson Group. The optical line system ZAM 34-1, intended for a transmission speed of 34 Mbit/s, was developed by LM Ericsson's Transmission Division. Two different optical fibre cables were used for the 3.5 km long trial route. One cable was manufactured by Sieverts Kabelverk, SKV, the other purchased from Northern Telecom, NT.

Both fibre cables were laid and jointed by the field personnel of the Swedish Telecommunications Administration. The fibres were spliced by means of arc-welding. Splicing equipment designed and manufactured by Sieverts Kabelverk was used for the SKV cable. The NT cable was jointed with the aid of equipment purchased from Northern Telecom.

The optical fibre parameters were carefully measured before, during and after the installation of the cables. The equipment used for the measurements had been designed by Sieverts Kabelverk. The fibre parameters, as well as the operating parameters of the line system, are now undergoing long-term measurements. The system will be used for regular traffic at a later stage.

Project goals and coordination

In september 1977 the Swedish Telecommunications Administration and LM Ericsson set up a joint working group with the task of preparing a proposal for a field trial with optical communication. The working group presented its proposal one month later. The proposal was accepted and the project initiated.

Fig. 1
The tunnel in Stockholm where the field trial FOK-79 was carried out

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The main purpose of the field trial was to gain practical experience of optical transmission and the possibilities it offers. LM Ericsson and Sieverts Kabelverk had a common interest in

- developing a digital line system for optical fibres and verifying its performance
- developing optical fibres and fibre cables and verifying their characteristics in the field.

The Swedish Telecommunications Administration, LM Ericsson and Sieverts Kabelverk had a common interest in

- developing methods for the laying, jointing and measuring of optical fibre cable
- training field personnel in the handling of optical fibre cables and systems.

In order to carry out the project, a project group was formed with staff from the Swedish Telecommunications Administration's Development Department, LM Ericsson's Transmission Division and Sieverts Kabelverk's Telecommunication Cable Division. The group was responsible for the planning and coordination of the project. Under the project group three working groups were formed in charge of system, cables and transmission measurements respectively. The tasks were divided as follows:

LM Ericsson developed and manufactured the terminal and intermediate repeater equipment for the optical fibre line system. Sieverts Kabelverk developed and manufactured fibres and fibre cables and also the jointing and measuring equipment for these.

The Telecommunications Administration carried out the installation and jointing of the fibre cables in collaboration with Sieverts Kabelverk.

The measurements in connection with the installation of the cables and commissioning of the system were carried out jointly.

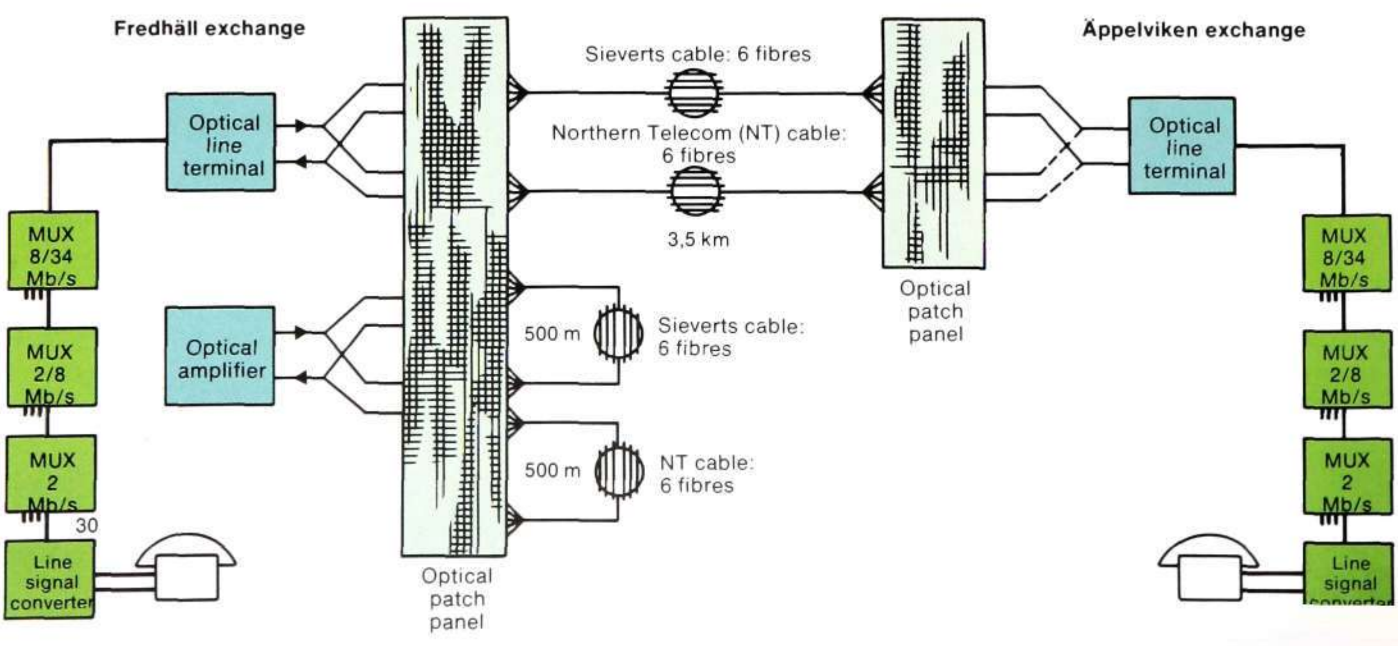
Choice of trial route

The possible trial routes in the Stockholm area were assessed and a tunnel between the Fredhäll and Äppelviken exchanges was chosen. The route is 3.3 km long. Fredhäll was designated the main exchange.

Installation in a tunnel was chosen because a first field trial requires extensive measuring during the installation stage. The ends of the individual cable lengths are easily accessible in a tunnel, and measuring stations can be arranged there without difficulty.

Different transmission distances are obtained by connecting several fibre lengths in series.

Fig. 2
Block diagram of the FOK-79 installation



Parameters at 826 nm		Planned in 1977	Measured in 1979
Optical output power in the fibre	dBm	−2	−2
Cable attenuation	dB	42	30
Jointing losses, 10 joints	dB	5	3
Connector losses, 7 connectors	dB	3	4
Optical power at the receiver	dBm	−52	−39
Receiver sensitivity	dBm	−53	−54
Margin	dB	1	15

Table 1
Planned and measured system values for a transmission distance of 8 km

		Sieverts Kabelverk	Northern Telecom
Graded index fibre Core/cladding diameter	μm	50/100	54/122
Cable with 6 fibres			
Outer diameter	mm	11	12
Weight	kg/km	95	140
Smallest bending radius	mm	300	300
Permissible tensile load	N	1000	2000
Factory length	m	1000	1000
Sheath colour		Green	Black
Attenuation at 850 nm	dB/km	3.3	3.0
Dispersion at 850 nm	ns/km	1.4	1.3
Numerical aperture with short fibre length and 99 % optical power		0.22	0.16

Table 2
Cable data for FOK-79

The field trial

The FOK-79 installation, fig. 2 comprises two cables of 3.5 km and two cable loops of 500 m each. The latter are placed in the tunnel under the Fredhäll exchange. All cables contain six fibres. The fibres from all the cables are terminated on patch panels in each exchange. Transmission distances from 3.5 km to 12.0 km can be arranged by connecting fibres together.

The installation also includes two line system terminals and one intermediate repeater equipment for the optical fibre line system, and a multiplex equipment at each terminal.

The system performance can be evaluated for different route lengths between 3.5 km and 24 km. An intermediate repeater is used for routes of more than 12 km.

The experience from the installation and operation of the system has been wholly positive. The fibre cable is superior to conventional cable in many respects. The cable drums are smaller, lighter and fewer. The cable is thinner and easier to handle. The number of working hours required for the installation is considerably less.

After a brief training period the Swedish Telecommunications Administration's field personnel were able to install and joint the cable without any major problems. The fibres were spliced by arc-welding, which gives low jointing loss.

The important operating parameters of the system are now being continuously recorded. At a later stage regular telephone traffic will be introduced on some of the fibres while measurements continue on the others.

The system requirements were set two years ago, and the system meets them with a very good margin, table 1. It was possible to increase the nominal repeater spacing for the system from 8 to 10 km, an improvement of 25 %.

OPTICAL FIBRE LINE SYSTEM ZAM 34-1

The line system for optical fibre, ZAM 34-1, used in the field trial has been described in detail in a separate article[1].

In the line system terminal equipment the opto-electronic conversion is carried out by a laser diode in the transmitter and an avalanche photodiode in the receiver. An encoder in the transmitter and a decoder in the receiver carry out the conversion between the 34.368 Mbit/s HDB3 signal and the 45.825 Mbaud binary pulse train on the fibre. The receiver also contains a timing recovery circuit and decision circuits. The systems is also equipped with error detection and alarm functions. The intermediate repeater is housed in the same type of mechanical structure as the line terminal equipment and consists of two transmitters and two receivers, one for each direction. Encoder and decoder are not required in this case.

OPTICAL FIBRE CABLES

As has been mentioned above, two fibre cables, each with six optical fibres, were used in the field trial. One cable was designed and manufactured by Sieverts Kabelverk[2], and the other was purchased from Northern Telecom, Canada. The latter cable was used for comparison purposes.

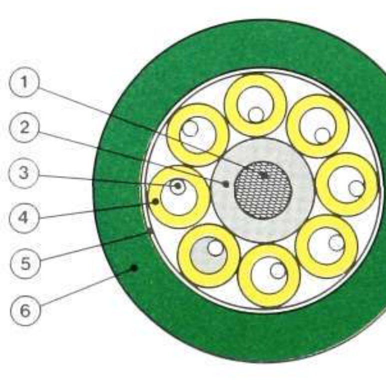


Fig. 3
The cable from Sieverts Kabelverk

1. Steel wire
2. Black polyethylene
3. Fibre
4. Polyethylene tube
5. Polyester tape
6. Aluminium and polyethene sheath

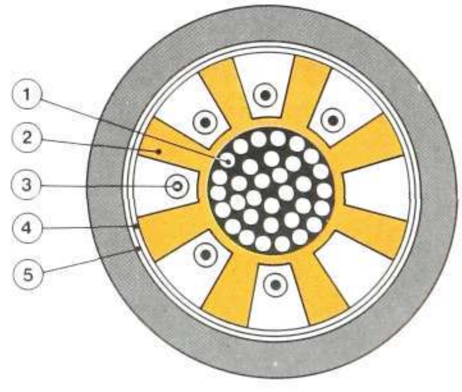


Fig. 4, right
The cable from Northern Telecom

1. Steel wire
2. Plastic core with grooves
3. Fibre
4. Polyester tape
5. Aluminium and polyethylene sheath

Type of cable	Number of joints	Number of work days: Cable laying	Jointing	Total	Number of drums	Cable length per drum, m	Weight/drum: Cable kg	Drum kg	Total handling weight kg	Drum dimens.: Diam. mm	Width mm
Paper insulated, lead sheathed cable with 1200 pairs	19	35	65	100	18	200	2200	483	47194	2000	1190
Paper insulated, plastic sheathed cable with 1200 pairs	19	35	65	100	18	200	1180	483	29344	2000	1190
Lead sheathed cable with 6 normal coaxial tubes	13	30	20	50	12	300	1596	307	22304	1800	1016
Aluminium sheathed cable with 6 normal coaxial tubes	13	30	20	50	12	300	627	483	13111	2000	1190
Optical fibre cable containing 6 fibres	5	6	5	11	4	1000	100	73	642	1000	710

Table 3
Comparison of some installation parameters for conventional cables and fibre cables

The project group prepared a specification which formed the basis for the development and construction of the cable by Sieverts Kabelverk. The same specification was used when purchasing the Canadian cable. It specifies the requirements as regards optical parameters, mechanical properties, fibre dimensions and cable dimensions.

The trial cables have a central strength member consisting of a steel core. The fibres are loosely cabled around the core and mantled with a plastic sheath with a moisture barrier of aluminium foil on the inside, figs. 3 and 4. Table 2 gives some data for the two cables.

CABLE INSTALLATION

Before the cables were installed a great amount of work was carried out to find the best installation method and the most suitable method for splicing the fibres and resealing the cable sheath.

Fig. 5
Jointing work station for fibre cable set up in a van

Cable laying

The simplest and least damaging method of laying cable in a tunnel is from a cable trolley. The tensile stress is low and the cable can be supervised continously. Two cable lengths were also run out direct on the tunnel floor in order to get an idea of the stresses that would affect the cable if it had to be laid in ducts or other places where a cable trolley could not be used. Straps were attached to the cable and parts of it were pulled back in order to make possible further joints in the future. Surplus cable length was also pulled back. The required tractive force was measured when the cable was pulled out and also when it was pulled back.

The cable laying was carried out by four men from the Stockholm telecommunication area working in gangs of two. Staff from the Telecommunications Administration's Cable Engineering Office provided instruction and carried out the planning.

The work started at the Fredhäll exchange, where the cables were run up from the tunnel through cable shafts into the equipment room. The cable lengths were then laid from a trolley or run out direct on the tunnel floor. Measurements and checking of the tractive force were carried out continuously. Finally the last lengths were pulled up through cable shafts into the Äppelviken exchange and laid on cable runs right up to the equipment rack. The largest measured tractive force was 350 N.

Optical fibre cables are stiffer than plastic sheathed pair cables of a corresponding size. The stiffness makes the cables easier to handle and they show no tendency to wrinkling of the sheath when laid in bends and loops. The cable should be laid from a cable trolley wherever possible. The small dimensions and low weight of optical fibre cable makes the laying work very easy.

In the field trial two men were pulling out the cable, one supervised the drum and one measured the tractive force. When conventional cables are laid it is necessary to use a motor-driven winch. Table 3 gives a comparison between the weight of conventional cables and fibre cables. The advantages of optical fibre cables are obvious.

Jointing

The project group chose arc welding as the best method for splicing optical fibres. Sieverts Kabelverk have developed a splicing equipment for fusing optical fibres, which was used for splicing the fibres in the Sievert cable[3]. The fibres in the Canadian cable were fused using an equipment from Northern Telecom. It was also decided to use a simple plastic box for resealing the sheath since the cables were well protected in the tunnel.

According to the stipulations for the field trial, the Telecommunications Administration's field personnel were to carry out the jointing. The four men who laid the cable were trained in jointing and carried out the work. The training took four days and comprised stripping, cleaning, cutting and fusing the fibres and also restoring the primary and secondary protection layers.

Three of the fibres in one cable were jointed from Fredhäll to Äppelviken. Measurement of the fibre parameters was carried out continuously. In the Äppelviken exchange these three fibres were then jointed to the three remaining fibres in the cable. The jointing was continued back to Fredhäll. The second cable was then jointed in the same way. By this means the variation of the attenuation and dispersion with fibre length could be studied.

Two of the cable joints were made in a tent and the others with the splicing equipment placed in a van, fig. 5, so that the effect of different work environments could be studied. The jointing work caused some problems, mainly in the beginning, since the personnel were not used to handling fibres. The equipments and methods also had certain shortcomings. Jointing in the van gave better results than the jointing in the tent. It was also obvious that practice makes perfect. The results got increasingly better as the work proceeded. The training time was perhaps slightly too short.

It was found that the mains voltage in the tunnel could be far below the normal value during periods of high load. It is therefore essential that the splicing equipment works in spite of mains variations. It was also found that not only the fibres but also the fixtures in the splicing equipment must be kept perfectly clean if good alignment is to be obtained. The cross hair on the microscope was of great help in aligning the fibres.

A method of restoring the primary coating of the fibre by injecting silicone into the jointing sleeve was tried. The method proved to be unreliable. The fibre could be touched accidentally with the injection needle, which resulted in a fibre break. Six fibre breaks were caused in this way.

Of a total of 60 fibre joints, 15 had to be redone because of too high losses. Some conclusions that can be drawn from the jointing work are that

- ordinary field personnel can carry out the jointing after slightly more than four days of training
- the fibre cutting tools used were fairly good, but unsuccessful fibre cuttings occurred
- the splicing equipments used had minor deficiencies

Fig. 6
Fibre cables being equipped with connectors

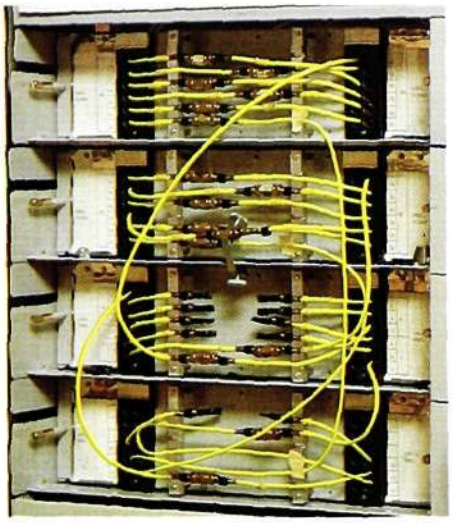


Fig. 7
Patch panel for optical fibres in the Fredhäll exchange

Fig. 8
Measuring station for fibre cables in the Fredhäll exchange

- one of the tested methods for restoring the secondary protection was unreliable
- the splicing of six fibres and the resealing of the sheath should normally take a two-man gang 4–5 hours.

A jointing loss of 0.5 dB was allowed in the original system specification. The measurements on the SKV cable gave a mean loss of 0.3 dB per joint. The difficulties associated with the measuring and evaluation of the attenuation of fibres and fibre joints are dealt with in greater detail in a separate article[4].

PATCH PANEL

In each exchange the fibre cables, measuring loops and connections to the transmission equipment are brought out to a patch panel. A distribution shelf for coaxial cable was adapted for the purpose and can be used for the connection of 12 fibres. Each patch panel consists of a number of such shelves, fig. 7.

LM Ericsson's adjustable fibre connector was used throughout. 68 fibre ends were equipped with this connector to the field trial.

The 500 m loops in Fredhäll were provided with connectors on site, fig. 6. The six fibres in each of the other cables were fused to six short fibre cables, which had previously been equipped with connectors in the factory.

Both methods gave good results, with an average loss of 0.6 dB per connector pair. The connectors in the patch panel proved to be stable, and loss values were reproducible during the measurements carried out within the measuring program.

MEASUREMENTS

The aims of the field trial included
- training the Telecommunications Administration's staff in fibre measurements
- investigating what effect the handling during the installation would have on the attenuation and dispersion of the fibres
- studying the effects of accumulated attenuation and dispersion as functions of fibre length.

Attenuation and dispersion were first measured on each cable length in the laboratory with the cable on a drum. These measurements were repeated after the cable had been laid. The cable was then jointed and the measurements repeated after each joint, in order to be able to evaluate the jointing losses and accumulation effects. Finally the loop Fredhäll – Äppelviken – Fredhäll was measured with and without connectors to determine the connector losses.

Sieverts Kabelverk developed instrument for measuring optical fibre cables in the field[4]. Attenuation measurements were carried out at the discrete wavelength of 877 nm using the insertion method. The fibre to be measured was connected to a well calibrated transmitter, whose output power was determined with a high degree of accuracy with the aid of a very stable radiometer, an optical power meter. The output power from the measured fibre was recorded by another radiometer, which had been calibrated against the first one. The transmitter and the fibre to be measured were connected via a 250 m long launching fibre in order to obtain a stable mode distribution in the fibre to

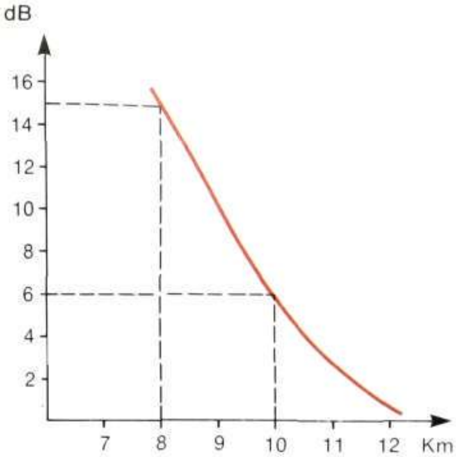
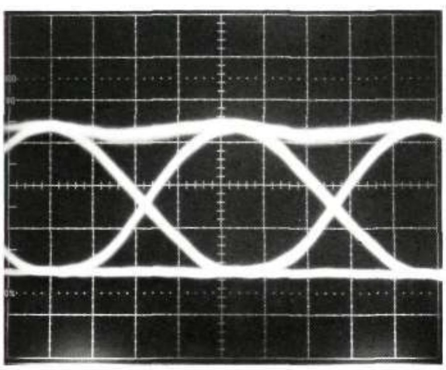


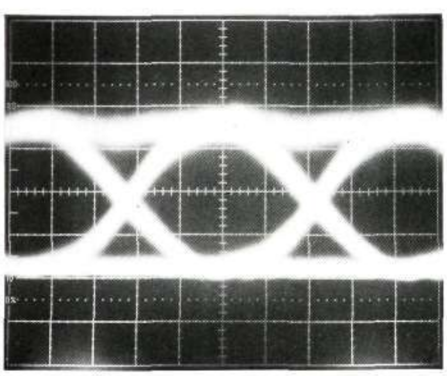
Fig. 9
System margin in dB as a function of fibre length

Fig. 10, right
Laser pulse shape at the transmitter output

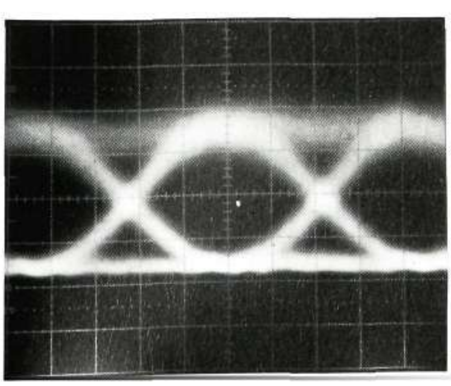
Fig. 11
Eye diagrams for different transmission distances
For 8 km

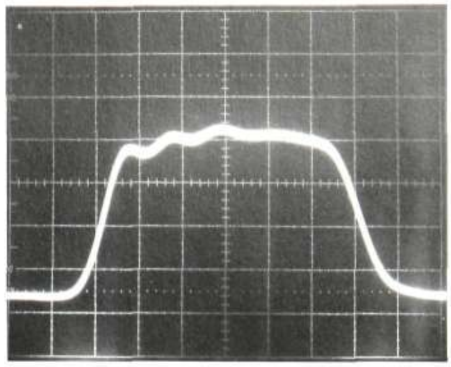


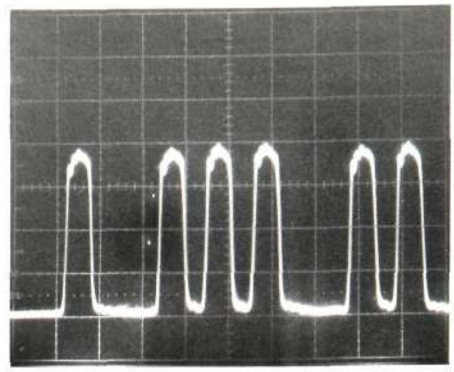
For 10 km



For 12 km







the fibre to be measured were brought together in an alignment fixture. The gap was filled with an index matching fluid in order to reduce the insertion loss, which was estimated to be less than 0.2 dB.

In the case of fibre ends equipped with connectors, no index matching fluid was used. In these cases the insertion loss was about 0.6 dB.

The dispersion measurements were carried out at a wavelength of 850 nm. A short light pulse, ca 400 ps, from a semiconductor laser was launched into the fibre. Also in this case a launching fibre was used to obtain stable mode distribution. At the other end of the measured fibre the pulse was detected by an avalanche photodiode (APD) connected to a sampling oscilloscope. A special equipment recorded values for 10 pulses during each measurement on punched tape. The recorded data were later processed in a computer and values were obtained for the dispersion of the measured fibre at 10 % and 50 % of the pulse height. The bandwidth of the fibre was also calculated by the computer. A longer pulse, approximately 4 ns, was used for long fibre lengths and a preamplifier was then connected in front of the receiver.

The measuring instrument, which consists of a transmitter and a receiver unit was used both in a measurement van in the tunnel and in the station buildings, fig. 8. The measurements provided very useful information.

Tables 4 and 5 (next page) show that the attenuation and dispersion of the cables has only changed very slightly as a result of the handling during the installation. Thus the two cable structures were proved to be suitable for the intended purpose. Very good results have been obtained. The attenuation values given in table 4 should be increased by 0.4 dB/km to correspond to the attenuation at the system wave-length of 826 nm.

Tables 6 and 7 show the transmission data for the distances 8 and 10 km. The system was originally planned for a transmission distance of 8 km. The results of the measurements show that both cables can be used over a distance of 10 km. See also table 1.

The three loops for each cable and the two routes (8 and 10 km) contain the normal number of joints but a larger number connectors than would be required for an ordinary installation. The measured values include jointing and connector losses.

The connector loss mean value was determined to be 0.6 dB, which is slightly higher than the 0.5 dB originally assumed.

The results show that the NT cable has slightly lower attenuation and dispersion values than the SKV cable. This difference may partly be caused by the small numerical aperture of the NT fibre. On the other hand the coupling from a laser to the NT fibre is less efficient. Both cables have proved to be satisfactory as transmission media for line system ZAM 34-1.

Operational experience

The system was put into operation on October 26, 1979. Measurements have been carried out since then in order to supervise the performance of the system and the fibre cables. No changes indicating ageing or any other systematic deterioration have been observed.

The operational limit of the line system is defined as the attenuation at which the bit error rate is $5 \cdot 10^{-10}$. Fig. 9 shows the system margin in dB as a function of fibre length.

The eye diagrams for 8, 10 and 12 km, fig. 11, shows that attenuation is the factor that limits the transmission distance of the system.

Fig. 10 shows the shape of the laser pulse at the transmitter connector.

The results of FOK-79 and other similar field trials show that optical communication over fibre cables is a well developed technology. The choice between optical communication and conventional technology is now mainly a matter of economics.

	Attenuation dB/km			
	Northern Telecom		Sieverts Kabelverk	
	mean	σ	mean	σ
Specified maximum	5.0		5.0	
On drums	2.9	0.5	3.1	0.2
After laying	3.0	0.5	3.3	0.3
Change	0.1	0.3	0.2	0.2

Table 4
Measured attenuation of the fibre lengths converted to 850 nm *wavelength*

	Dispersion in ns/km at 50 % pulse height			
	Northern Telecom		Sieverts Kabelverk	
	mean	σ	mean	σ
Specified maximum 3 ns/km	1.5		1.5	
On drums	1.3	0.2	1.2	0.7
After laying	1.3	0.3	1.4	0.8
Change	0	0.1	0.2	0.3

Table 5
Measured dispersion of the fibre length at 850 nm *wavelength*

Cable length	8 km				10 km			
	Loop 1	Loop 2	Loop 3	Mean	Loop 1	Loop 2	Loop 3	Mean
Attenuation, dB	31.7	27.3	27.8	28.9	40.7	38.3	37.2	38.7
Dispersion at 50 %, ns	4.4	4.9	4.9	4.7	5.4	5.4	*)	
Bandwidth, MHz	101	88	86	92	85	85	*)	

*) No comparable measurement results are available

Table 6
Transmission data at 8 and 10 km.
Wavelength 850 nm. NT cable

Cable length	8 km				10 km			
	Loop 1	Loop 2	Loop 3	Mean	Loop 1	Loop 2	Loop 3	Mean
Attenuation, dB	32.5	33.7	31.3	32.5	43.0	42.2	41.1	42.1
Dispersion at 50 %, ns	4.2	6.6	4.6	5.1	5.4	6.4	5.7	5.9
Bandwidth, MHz	78	60	76	71	70	65	68	68

Table 7
Transmission data at 8 and 10 km.
Wavelength 850 nm. SKV cable

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Contents

COVER
The signal to the left in the cover picture symbolizes modern railway signalling technology

Railway Signalling Systems

Hans S. Andersson

The Ericsson Group have designed, manufactured and marketed railway signalling equipment since 1915. The product range has included such systems as signalling equipment for the track, safety systems for the train routing, remote control systems and systems for supervising the speed. The product range has successively been renewed in step with the technical development. The development in the fields of electronics and computers has contributed greatly to this renewal. This article deals with the background and the present scope of this work. Some of the recently developed systems will be described in greater detail in subsequent issues of the magazine.

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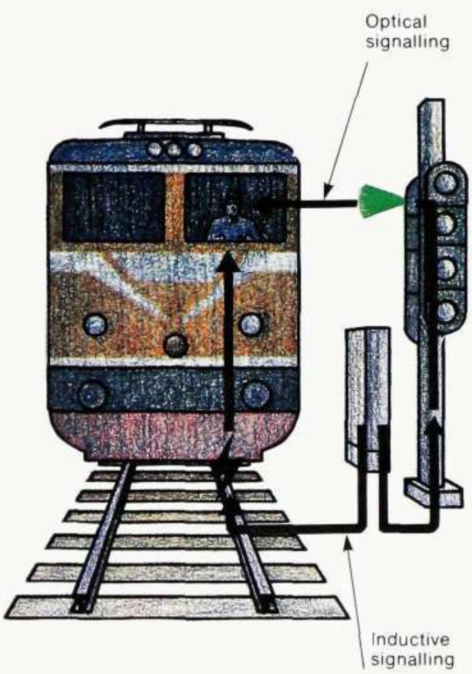

Fig. 1
Signalling to the train driver can be carried out either via signals beside the track or on a panel in the driver's cabin. In the latter case the message is transmitted inductively to the locomotive

The railway administrations are constantly seeking ways and means of utilizing the tracks, rolling stock and personnel more efficiently without any reduction in safety. Rail traffic poses very special safety problems. The high speed and high mass of the trains in combination with the low friction between steel wheels and rails give considerable braking distances. Rigorous rules must be set in order to safeguard against traffic accidents. The aid and devices that help to achieve this safety and efficiency are used to

- set up train routes, control points and signals, ensure that the track is free and safeguard the movements of trains
- transmit information to the train driver
- supervise the speed.

In modern signalling systems the operation of points in order to prepare train routes and to provide protection against conflicting train movements is almost exclusively done with remotely controlled, electrical point machines, fig. 4. However, manual operation of handthrown points occurs on track sections that are seldom used.

A detection device, called a track circuit, is used to check that the track is free from trains and vehicles.

The established train route is protected against conflicting train movements by interlockings. The interlocking conditions state that points in the routes cannot be switched and that conflicting signals cannot be cleared.

The interlocking equipment, which is usually common for a whole station or yard, is normally placed fairly close to the objects, such as points, tracks and signals, that are to be supervised. The control equipment can be placed at a greater distance. Thus the control can be centralized to a few places, fig. 2. Such systems contribute to efficient traffic handling and low personnel requirement.

The information to the train driver is transmitted by means of fixed signs and light signals. Information to the locomotive can also be transmitted inductively from special transponders on the track or via radio, figs. 1 and 5.

Fig. 2
Train movements in stations can be controlled locally or centrally. In the latter case a large number of stations are controlled from the same place, i.e. centralized train control, CTC. The picture shows the local control office in Oslo central station, Norway

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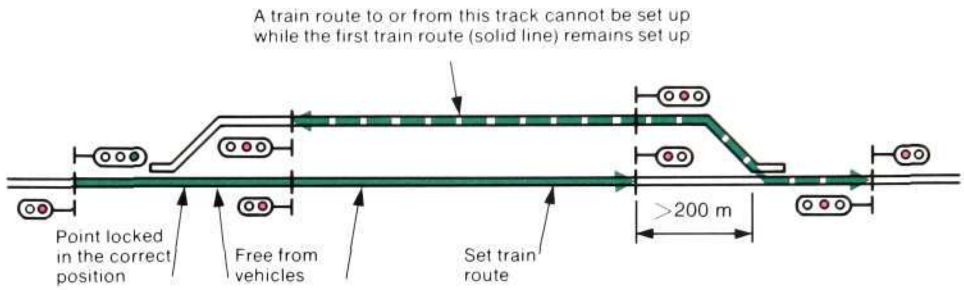


Fig. 3
Certain conditions have to be met to safeguard the movement of a train at a station

Supervisory equipment, which brakes the train if the driver keeps too high a speed, has long been used in underground systems and has also been introduced on certain railway sections, where trains run at a very high speed or where the traffic density is very high. On other sections with very little traffic it has previously not been possible to justify economically even the introduction of automatic braking if the train passes a stop signal. New technology now offers the possibility of speed supervision also on sections with low traffic density and in the long run it will be possible to relieve the train drivers of some of the responsibility they now bear, fig. 6.

Safeguarding of train movements

Train movements must be protected against
- collision with other trains
- collision with vehicles on level crossings
- derailment because of point changes at the wrong time
- derailment because of too high speed.

In order to achieve this protection each moving train is allocated an area of the track network, within which the train can move in accordance with certain rules. Speed limits, signals at stop and stop signs must be strictly observed. The area allocation means that no other trains may move in the area and that points in the area may not be switched as long as the area allocation remains. However, area allocations for shunting do not block point operation.

The track network is divided into geographical areas of different sizes. A moving train can be allocated one or several such areas, depending on such factors as the permitted speed of the train. When the entrance signal to a train route shows "clear", the train route is locked. All points and other devices that belong to the train route are locked in the correct positions, all protective signals show stop and the route is guaranteed free from obstacles, there are no other trains or vehicles in the area, fig. 3.

Interlocking equipment

The conditions that apply for different train routes and train movements can be compiled in an interlocking table for each track area. Conventional signal boxes use safety relays to ensure that all conditions in the interlocking table are

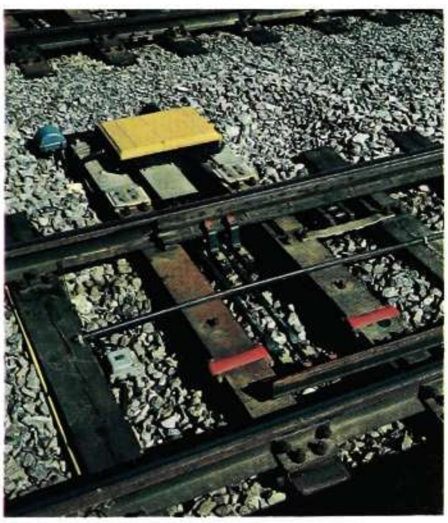


Fig. 4
Point machine for operating points

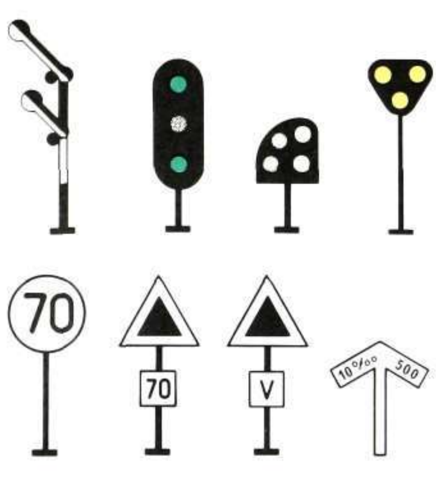


Fig. 5
Some types of signals and signs that are placed along a track

Fig. 6
The train driver must keep a lot of information in his mind in order to be able to drive the train in the best possible way

Fig. 7
Automatic block signals, controlled by track circuits, are used between stations to inform the train driver of the position of the train in front of him

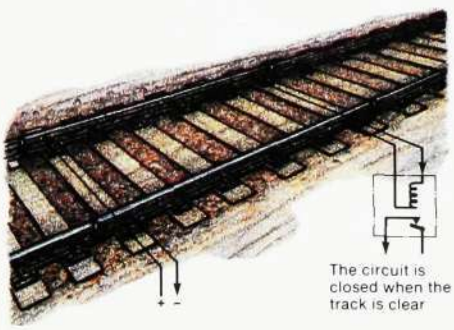


Fig. 8
A track circuit comprises a battery, an insulated part of the track and a relay. The relay is normally operated but releases when a vehicle occupies the track circuit

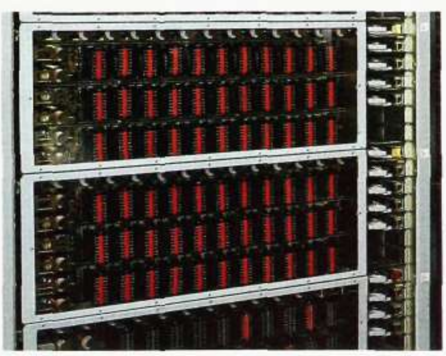
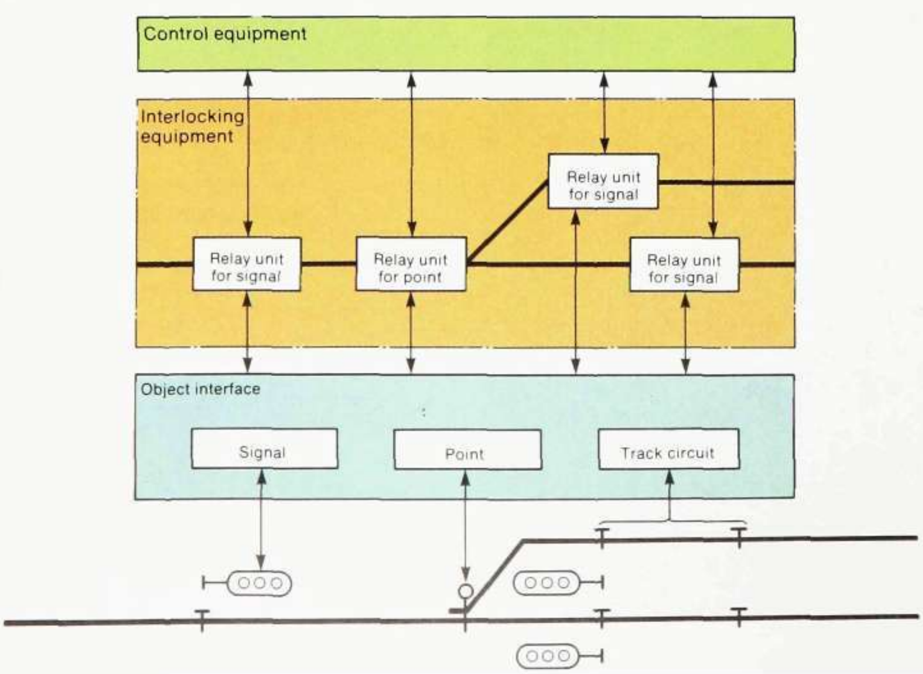


Fig. 9
A "geographical" relay unit for a main signal

Fig. 10
The safety equipment at a station, arranged in accordance with the "geographical" method



met. The relay contacts are connected together to form current paths that correspond to the different conditions.

Another way of stating the conditions is by means of the "geographical" method. The conditions are related to different objects in the track area, points, signals, derailers etc. For each object the conditions are set for each possible state and each possible change of state. The relays that are needed for the interlocking of an object are brought together to a relay unit. One type of relay unit is used for points, another for signals etc., fig. 9. The relay sets, which are also called logic blocks, are connected to adjacent ones by means of multi-wire cables in a pattern that corresponds directly to the track system, fig. 10. The interface between the relay units is standardized.

The same geographical method of stating the interlocking conditions is used in LM Ericsson's computer-controlled interlocking system. In this case the conditions are stated in the computer program instead of in current paths via the relay contacts.

Track circuits

Already at an early stage it was found necessary to be able to ensure, automatically and absolutely reliably, that a track section was free from trains. The oldest and still most frequently used type of equipment is the track circuit. Its design is shown in fig. 8 in its simplest form. A track section is insulated from the adjoining parts of the track. The rails function as insulated conductors. The track circuit is fed with current from a battery at one end. The current through the circuit keeps a relay at the other end operated. The relay releases when a train short-circuits the track.

There are a number of types of track circuits, partly because there are different electrical traction systems for trains. For example, alternating current must be used for the track circuits when the trains are driven with direct current. In some cases the track circuit current is pulsed in order to obtain more reliable function or to combine the track circuit function with inductive transmission of information from the track to the locomotive by means of different pulse frequencies. Two prerequisites for such transmission of information are that the locomotive must be equipped with some form of antenna in front of the first pair of wheels, for receiving the pulses, and also that locomotives enter the track circuit from the relay end.

Track circuits are used to
- check that train routes are free from obstacles
- block any switching of points
- automatically release traversed train routes
- control level crossing protection
- detect the approach of trains
- indicate the position of trains.

Blocking equipment

The section above on interlocking equipment dealt with interlocking in stations. Similar interlocking must of course also be possible between stations. In its simplest form the latter type of interlocking is carried out by means of telephone calls and written routines. Agreements concerning states for train movements between two stations are noted on a form in each station. Sometimes the form routine is supplemented by a technical device that controls the exit signal to the line. With such manual blocking systems there is no need to equip the track sections between the

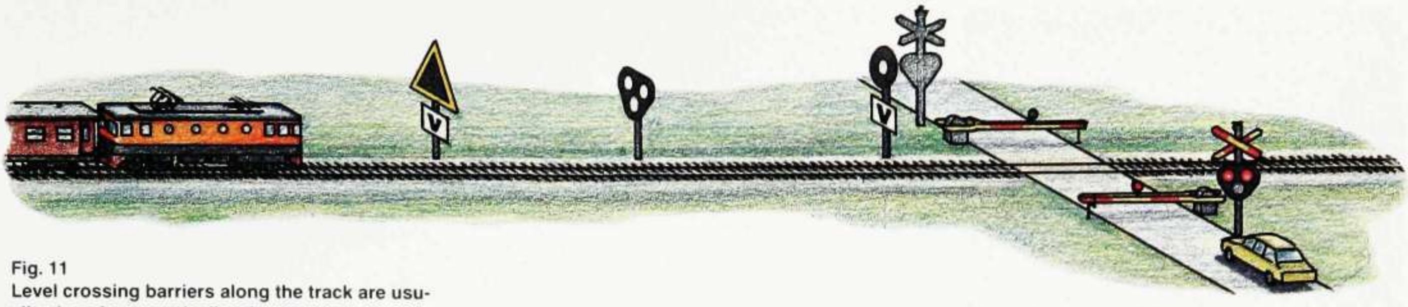


Fig. 11
Level crossing barriers along the track are usually closed automatically when the train approaches the crossing. The distance from the crossing to the point where the barriers start closing is dependent on the speed limit for the track

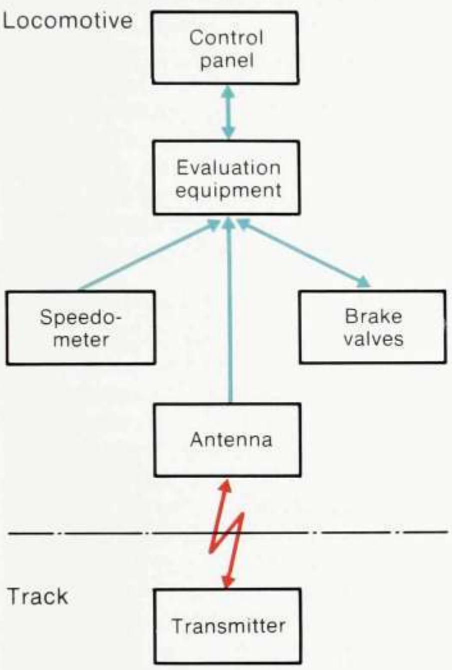


Fig. 12
The parts in an automatic train control system, ATC

Fig. 13
The ATC system supervises that the train does not exceed the speed limits, which are depending on the train itself, the condition of the track and the traffic situation

Automatic blocking systems require track circuits along the whole route between stations. With long distances between stations it is possible to have several track circuit sections and signals, and more than one train can then be moving simultaneously along the track between two stations, fig. 7. When the whole route is free, the block can be turned for traffic in the opposite direction.

Automatic train control

Systems for automatic train control, ATC, supervise the speed of the train and brake the train automatically if the speed limit is exceeded. The transmission of information between the track and the locomotive can be continuous or intermittent, i.e. at intervals along the track. The older systems that are still used in many underground railways have continuous transmission of information, but the number of different messages is limited to three or four speed limits, of which one corresponds to stop. Older intermittent systems usually only transmit stop messages if the train passes a stop signal. In certain cases such systems are supplemented by a function that gives advanced stop warning.

The requirement for safety and at the same time efficient utilization of the track network have led to the track being equipped with a large number of signs and signals, which in good time inform the train driver of the characteristics of the track and the traffic situation. With the aid of this information the train driver is expected to optimize the speed of the train, figs. 5 and 6.

More recently ATC systems with a large transmission capacity have been constructed. Systems for both continuous and intermittent transmission are available. LM Ericsson have developed a system with intermittent transmission, fig. 12. A large amount of track data, such as signal messages, track slopes, curve radii and speed limits are collected, transmitted and processed together with train data, braking ability etc. The processed result is presented to the train driver on a panel, fig. 13. The equipment in the locomotive continuously supervises that the train driver observes the set restrictions, and the train is automatically braked if the speed should exceed the limit at any time.

Level crossing protection

Level crossing protection can consist of
- visual and acoustic signals
- barriers.

The equipment can be operated manually or automatically. Manual operation, particularly of barriers, occurs in densely populated areas. However, protection equipment is usually made fully automatic, fig. 11.

When designing level crossing protection equipment it is assumed that road vehicles should give way to trains. The equipment is usually independent of other signals and interlockings on the track. However, at a station there may be interdependence between the signalling equipment at the station and level crossing protection equipment.

The signal towards the train in independent level crossing protection equipment is usually placed so that the train driver does not have time to stop a train which is running at full speed if he finds that the signal indicates that the protection equipment is not working. It is therefore essential that the signals and barriers for the road traffic are very reliable.

Fig. 14
In stations with local interlocking control the signals may be set with keys in the track diagram

In Sweden an advanced warning signal to the train at level crossings has been introduced in certain places. Complete signalling towards the railway with absolute stop obligation for the trains would mean unacceptable waiting times for the road traffic.

The increasingly large differences in the speed of different types of trains justify the introduction of a control system for level crossing protection that takes the train speed into account. Such systems are already in use in some places. On sections with automatic train control it is possible to include data concerning the level crossing protection in the information that is automatically transmitted to the locomotives.

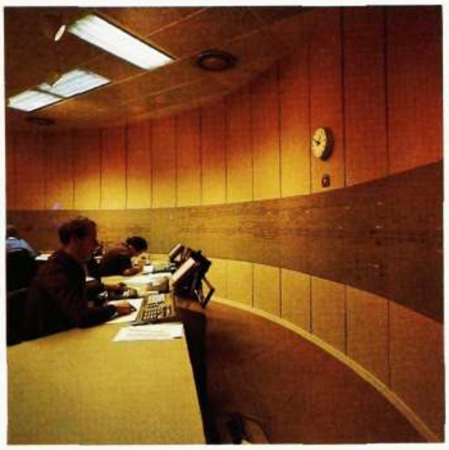


Fig. 15
The CTC centre in Stockholm, Sweden, controls 60 stations and about 400 km of tracks

Control and supervision systems

Basically the handling of railway traffic is carried out in accordance with a predetermined timetable. Traffic controllers can cancel trains, put on extra trains, change train meeting places, change the order of trains and carry out any measures that are made necessary by, for example, engineering work on the tracks within their district.

Station masters at manned stations, fig. 14, and dispatchers at remote control centres, fig. 15, control and supervise the train traffic via control panels. Certain of the tasks of traffic controllers, for example changing train meeting places and the order of trains, can be delegated to remote train dispatchers. The method of establishing a centre for the control and supervision of the traffic in a large geographical area with many stations is called centralized traffic control, CTC.

Centres that handle a large volume of traffic can be equipped with various aids, for example for the recording of train numbers and their display on track diagrams, for automatic route setting and for traffic recording. Traffic recording simplifies statistical follow-up of the train traffic.

LM Ericsson have developed an advanced control and supervision system for areas with high traffic. The system is computer-controlled, uses colour display screens for all indicating and constitutes a means for efficient and rational traffic handling, fig. 16.

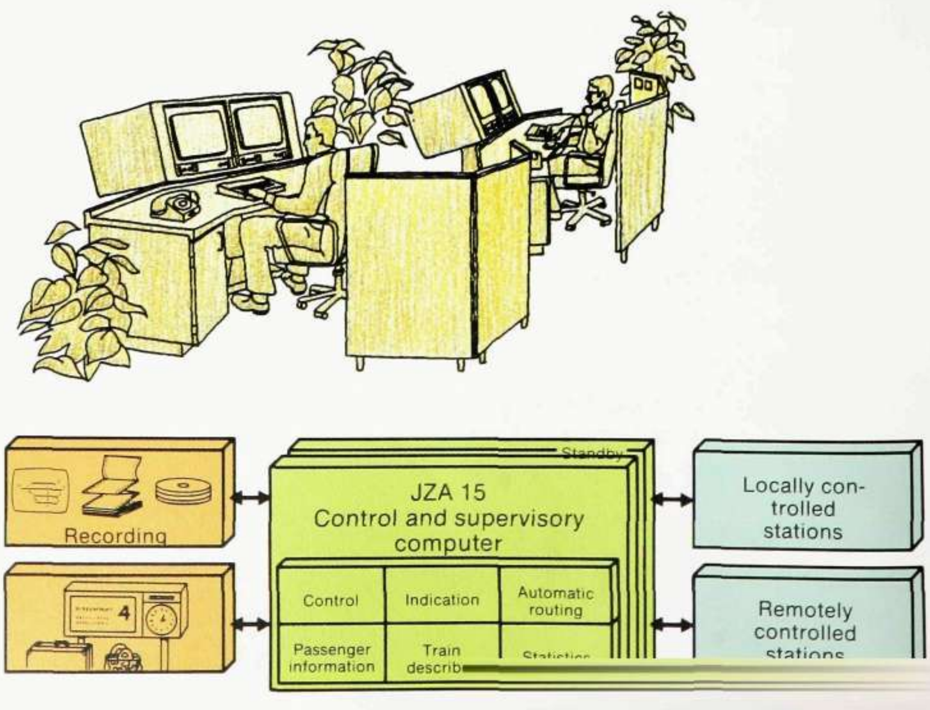


Fig. 16
A computer-controlled control and supervisory system with colour display screens for large stations and for remote control of a large geographical area with many stations

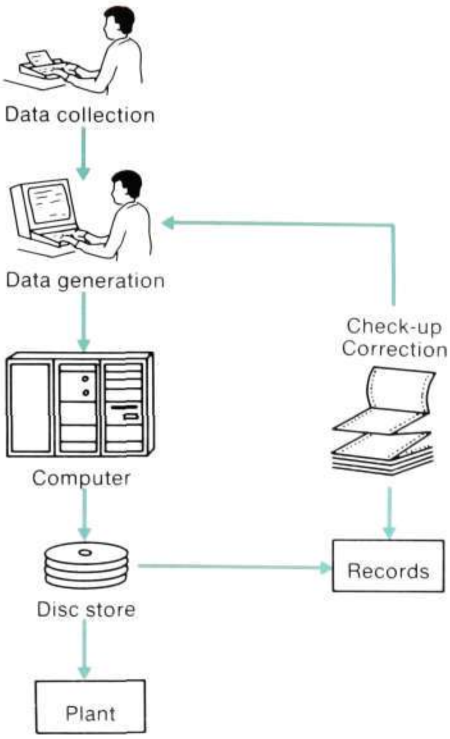
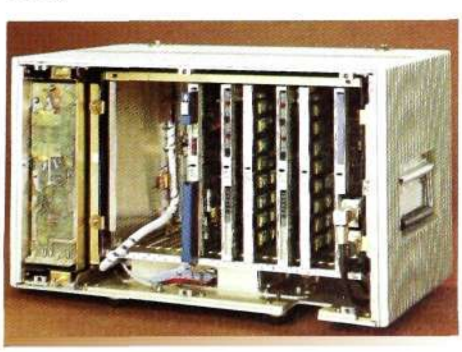


Fig. 17
A computer aid is available that greatly simplifies the work of preparing the data and documentation that is individual to each installation

Fig. 18
Plug-in safety relays are still predominant in interlocking systems not using "geographical" system as in fig. 9

Fig. 19
The evaluation equipment for ATC is based on stored program controlled micro computer technology



Product stipulations

Stringent safety requirements are made on many items in the product range in fault situations. A simple failure must not cause a dangerous situation. Moreover a failure must be detected and cleared fast enough to exclude the possibility that another failure appears which, combined with the first, endangers the safety. This affects the design and manufacture. Great precision is required in the production testing. In addition the equipment will be exposed to great stresses. The heavy railway traffic causes large mechanical vibrations. The traction current is returned partly through earth, and this gives rise to strong electrical disturbances. For example, the disturbances can be very troublesome when the traction current is taken from 16 kV single-phase $16\frac{2}{3}$ Hz a.c. voltage and the locomotive has thyristor control. Furthermore certain equipment must be able to withstand both arctic and tropical climatic conditions.

There are standards for the construction of railway signalling equipment, but the standards are not the same in all countries. However, most conventional equipment with essential safety functions is constructed in accordance with specifications issued by the Association of American Railroads, AAR, British Standards, BS, or the Office de Recherches et d'Essais, ORE, which is a working agency within the Union Internationale des Chemins de Fer, UIC. The construction standards are designed for contemporary technology and usually have to be altered when a changeover is made to new technology. The degree of safety that is obtained with robust relays and large insulation gaps between the circuit elements corresponds to what is obtained with high information and system redundancy in computer-controlled systems.

The traffic regulations also have many national characteristics. The position and meaning of visual signals are different in different countries, as are the conditions for the protection of train movements. Different experience and different assessments have led to different rules and regulations.

These rules and regulations are not greatly affected by a changeover to a new technology. However, in order to be able to apply them in connection with computer-control, it is necessary to give them a more stringent mathematical expression, so the rules and regulations must be rewritten in the form of a process algorithm. This has been done in the develoment work on LM Ericsson's new computer-controlled interlocking system.

Development trends

Intensive development work is being carried out to utilize the facilities provided by new technology for better use of track and rolling stock, partly through higher speed and denser traffic. The railway administrations are also striving towards increased rationalization of the activities and increasing traffic safety. This requires
- efficient control of train traffic
- increased use of ATC systems
- more suitable level crossing protection, for example through the introduction of a control depending on the trains' speed
- equipment that is reliable and easy to service, and which needs only simple planning (fig. 17), short installation time with low manpower requirement and is easy to extend
- interworking of different administrative sections, for example through joint use of the transmission equipment for telecommunication, power and signalling purposes.

The technology based on relays, fig. 18, which is now predominant in equipment with safety requirements, will in the long run be replaced by stored program controlled computer technology where the microcomputer in particular is likely to become very important, fig. 19. One reason for this development is that the cost of relay-based technology increases successively relative the cost of electronics.

Data transmission is increasingly being used for the new systems. Fibre optics could with advantage be used for this purpose in order to overcome the difficult electrical interference problems. Data communication via radio from control centres to the locomotives may also come to be more widely used.

Construction Practice BYB for Transmission Equipments

Per-Alrik Hallberg and Bo Viklund

LM Ericsson's present transmission equipments have been designed using the M5 construction practice, but in future the BYB construction practice, which was developed for telephone exchange systems, will also be used when designing new digital transmission systems. The same printed board format is used in M5 and BYB. In the M5 construction practice the printed board assemblies are installed in shelves that cover the whole width of the rack, whereas in BYB they are plugged into magazines having different widths. A bay that can take both M5 shelves and BYB magazines has been constructed, since both types of equipment will be in use for a long time. In this article the authors give the reasons for the decision to use BYB, show how the construction practices for transmission equipments have successively been adapted to suit new component technology and finally describe the new M5/BYB bay.

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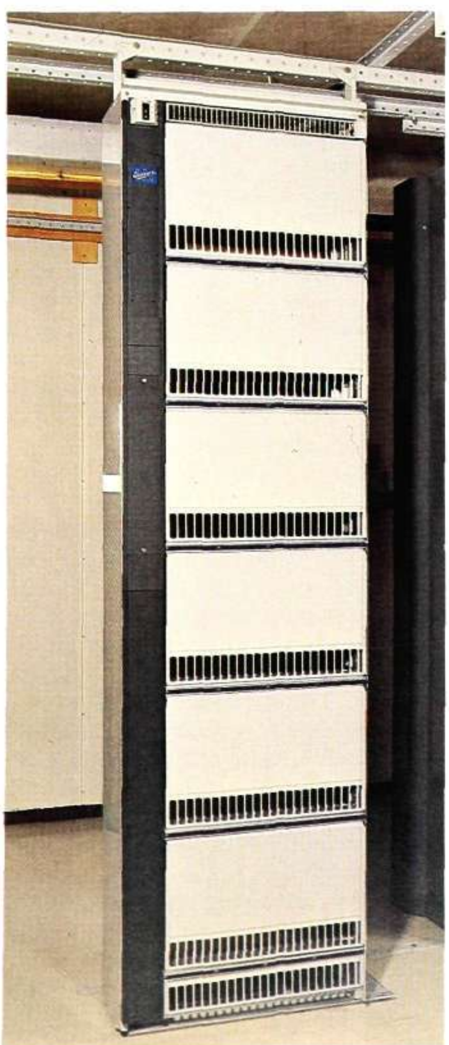
Fig. 1
An M5/BYB bay, equipped with BYB magazines



When LM Ericsson were ready to develop a new generation of digital transmission equipment the question arose as to which type of mechanical construction practice would be most suitable. Should the M5 construction practice be used also in future, or was a change necessary because of the changes in requirements and prerequisites? The argument that motivated the choice of construction practice BYB, which was originally intended for telephone exchange systems, are given below.

Several sizes of magazine

The increased degree of integration and the complexity of the components have meant that the amount of space required for the various system functions has decreased. An M5 shelf is now often too large a mechanical unit for one system function. Several functions have therefore had to be combined in one shelf. It would be better to be able to use a mechanical unit of a size that is appropriate for the functional unit. This is possible with the BYB magazines, since they come in four different widths within the available bay width.

Better ventilation

The higher degree of integration of the components means more functions per unit of volume. However, the power requirement per function has not decreased at the same rate as the increase in function density per unit. The miniaturization has meant a concentration of power. The demand for better ventilation is now therefore greater than the previous demands for a compact construction.

Simpler installation

Transmission equipment was previously used mainly in the trunk network and was concentrated to a few places. Today transmission equipment is used also in the local and subscriber networks. This wider application has led to increasing demands for easy installation. Station cabling that is plugged in on the front of the equipment gives good accessibility and simplifies the installation work. One disadvantage is that the front area available for maintenance functions is reduced. However, this is compensated by the reduced need of maintenance. Generally speaking there is practically no routine maintenance carried out in the bays nowadays, and the corrective maintenance consists mainly of the replacement of printed board assemblies.

Simpler basic equipment

One aim when designing the bays has been to enable the basic transmission equipment required in the first stage to be as simple as possible. For this reason the converters for the power supply have been placed locally in the magazines. Such decentralization, which has been made possible through the use of new components and circuit designs, also gives high reliability throughout.

Installing the units in different bays

The increasing degree of integration of switching and transmission technique, IST (Integrated Switching and Transmission), means that it must be possible to install transmission equipment not only in transmission stations but also in telephone exchanges. This applies, for example, for signal conversion and analog/digital conversion equipment. Thus it is essential that the same printed board assembly or magazine can be placed either in the transmission station bay or in the exchange bay row.

History

In the M3 construction practice of 1959, fig. 2, the bay was a functionally separate system unit, for example a channel translating bay. Printed circuit boards for component mounting and connections were used for the first time. The transistor was coming into use. The

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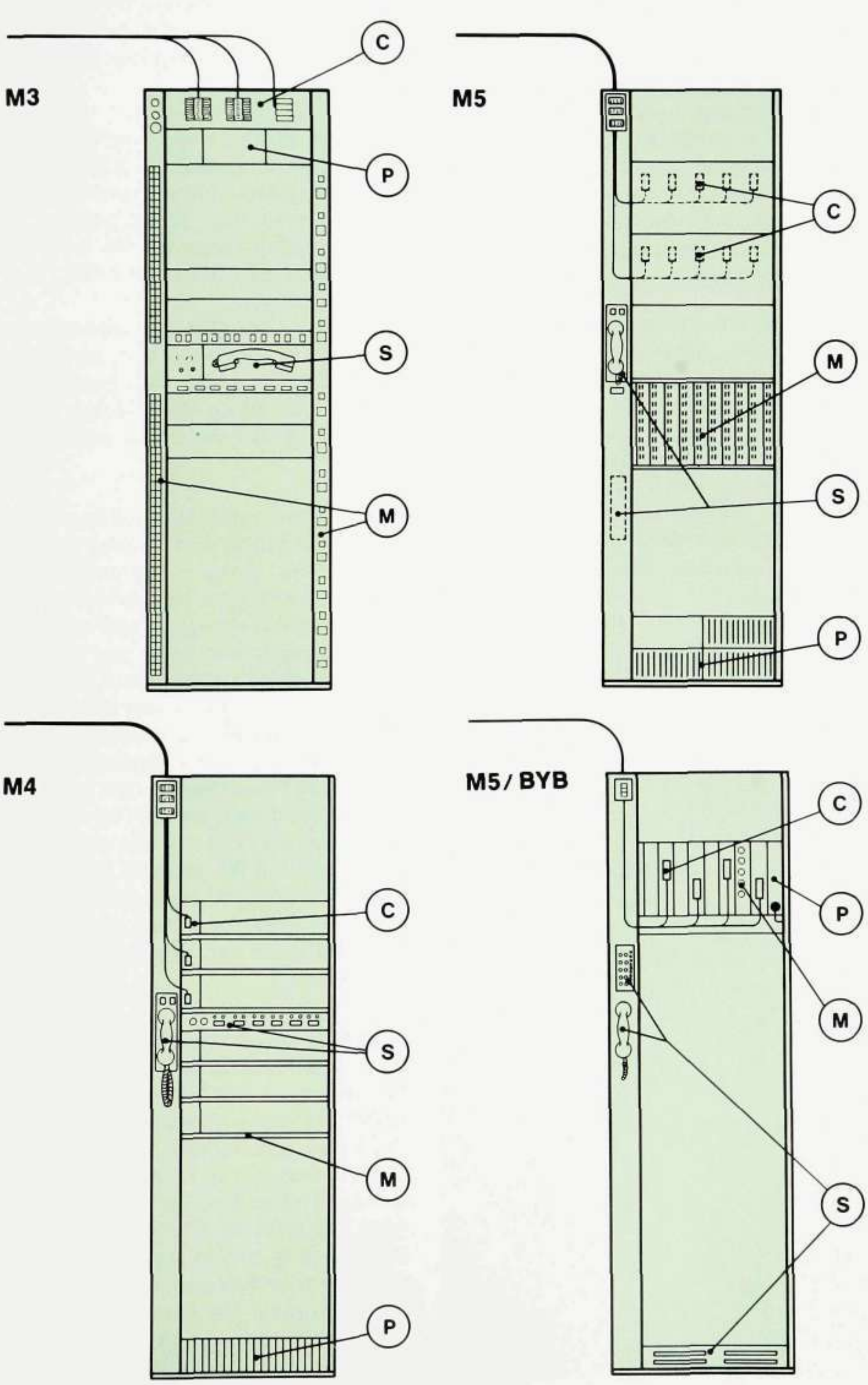
Fig. 2
The development of bays M3–M5/BYB for transmission equipment during the years 1959–1980

C Station cable connection
P Power supply
S Service line equipment
M Maintenance equipment



made at the top of the bays. The power supply equipment was also placed there. The equipment for the maintenance functions was placed along the sides of the racks and the service equipment (telephone unit etc.) was situated in a panel in the middle of the bay.

The volume of the equipment could be reduced as the component technique was developed and the calculation methods were refined, and a bay became too large for a functional system unit.

The shelf construction practice, M4, was introduced in 1967. The station cabling was brought direct to the shelf. The power supply equipment was placed at the bottom of the bay to facilitate successive extension of the bay from the bottom. The equipment for maintenance functions was placed along the lower edges of the shelves and the telephone unit in the left hand upright. In the middle of the bay there was a narrow panel left for alarm lamps and service line jacks.

The continuing development of components led to even more efficient and smaller components. Hybrid circuits and integrated circuits were coming on the market. The format of the printed board was changed. A larger, almost square board was more suitable since it meant fewer connections between the printed board assemblies in the shelf and provided a longer edge for the large number of connectors. The printed boards for digital functions in particular require many connectors.

The M5 construction practice was introduced in 1976. The bay cabling was brought right in to the shelf connectors where the printed board connectors were plugged in. However, coaxial cables were still connected in at the left-hand shelf side. Equipment for maintenance functions was now only placed on the front edges of the printed board assemblies. The routine maintenance had been eliminated or considerably reduced. The telephone unit, alarm unit and service line jacks were placed in a bay upright in order to give maximum bay flexibility. The power supply equipment for up to three voltages was placed at the bottom of the bay.

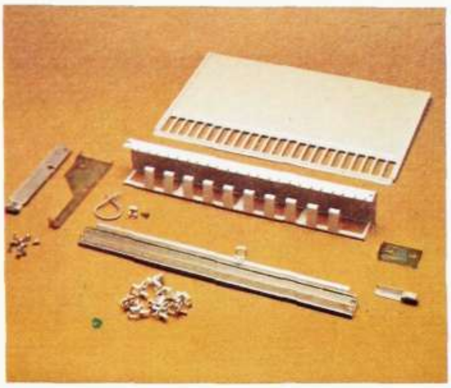


Fig. 4
Assembly kit for a BYB shelf

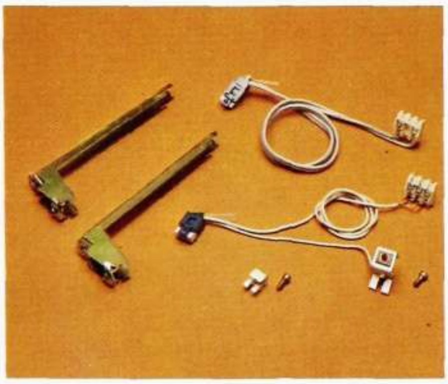


Fig. 5
Assembly kit for a BYB magazine

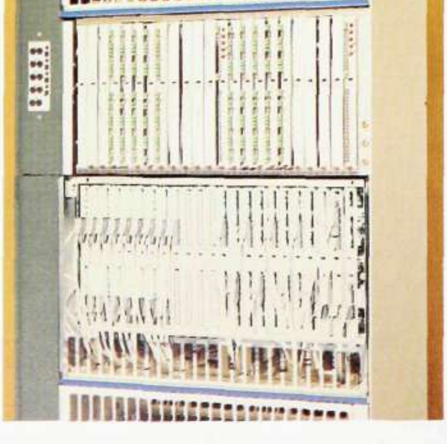


Fig. 3
An M5/BYB bay with BYB magazines and an M5 shelf. The front cover of one magazine has been removed

The M5/BYB bay is introduced on the market in 1981. In this construction the station cabling is taken direct to the front edge of the printed board. This gives good accessibility for installation, inspection and testing. The front edges also contain the equipment for certain maintenance functions. Power converters are provided in each magazine. The magazines have good electrical characteristics and can be used for high frequencies and bit rates without any special measures being required. The telephone unit and service line jacks are placed in the left-hand bay upright, but the associated electronic equipment and the alarm unit are normally placed at the bottom of the bay.

The M5/BYB bay

The M5/BYB bay is very similar to the M5 bay. It is built up of a bay frame with a left-hand and a right-hand upright. The uprights have space for the station cabling and also for power distribution and alarm concentration bars. M5 shelves, or shelves for the BYB magazines, are mounted between the uprights. The shelves are designed to give good ventilation. Extra ventilation units can be installed next to equipment with high power consumption. The connection of the station cabling is designed so that the cables can be prepared and equipped with connectors before the shelves and magazines have been delivered. A bay that is only partially equipped can thus be completely cabled at a moderate extra cost, which simplifies any extension work.

The dimensions of the bay are in accordance with recommendations from CEPT and CCITT. It is 600 mm wide, 260 mm deep and has a height of 2743, 2134 or 1160 mm.

The bays are divided vertically into building modules, BM, of 40.64 mm. The highest bay provides a space of 66 BM for the installation of equipment. The corresponding space for the two other bay heights is 51 BM and 27 BM.

The two bay uprights are connected by means of a base plate and, at the top, two horizontal angle iron bars. Fig. 3 shows a part of an M5/BYB bay equipped with BYB magazines and an M5 shelf.

The left-hand upright is wide enough for the station cables and its brackets. The front of the upright is provided with hinged cover strips. The narrower right-hand upright is designed with three vertical channels, two wide and one narrow, are formed on the inside. U-shaped copper bars for the power feeding and alarm concentration are mounted in the wide channels. In the spaces where no shelves are fitted the bars are protected against accidental contact by means of plastic covers. The narrow channel, to the rear of the the upright, is intended for the incoming power cables. Vertical earth rails made of copper sheeting are mounted at the rear of each upright, on the inside.

Installing and connecting BYB magazines and M5 shelves

Two assembly kits are needed to install a BYB magazine in the bay, one for the shelf and one for the magazine. The shelf kit consists of side members, rear and front rails, a cover plate and magnetic locks, fig. 4. The shelf takes up 8 BM vertically, provides good ventilation of the magazines and makes cable installation easy. The overall width of the shelf corresponds to 12 BM. The magazines are available in widths of 3, 6, 9

Fig. 7
Printed board holder for the alarm unit

and 12 BM, and they can be combined arbitrarily to form a full shelf.

The magazine kit consists of two supports and two connection cables, fig. 5. One cable is connected to the bars in the right-hand upright to provide power, and the other connects the alarm outputs of the magazine to the alarm concentration bars. The latter cable also contains a metal clip with a light emitting diode, which is clipped to the front rail. An alarm in the bay can thus easily be localized to the right magazine even with the cover plate in position. The supports are fixed between the front and rear rails of the shelf. The magazine is mounted on the supports and the station cables are connected to the connectors on the front edges of the printed boards.

The M5 shelf is connected to the earth bars when the shelf is installed and screwed to the bay uprights. The shelf is connected to the power feeding and alarm concentration bars by means of contact tabs, which terminate the shelf cabling, and which are pressed into the relevant copper bar in the right-hand upright and secured by screws, fig. 6. The M5 connectors for the station cabling are inserted in connector mounts at the rear of the shelf before the shelf is fitted into the bay. The printed board assemblies are delivered separately and are the last to be plugged in.

Power supply

Each magazine has its own d.c./d.c. converter. The M5 shelves are fed either from built-in or centrally placed d.c./d.c. converters. The two feeding methods have been described previously in this magazine[2].

In the case of feeding from the mains the rack is equipped with mains rectifiers. The rectifier outputs are connected direct to the bay d.c./d.c. converter for central feeding, and to the feeding bars in the right-hand bay uprights for the power feeding of magazines and any M5 shelves with local converters.

Alarm equipment

The alarm equipment for the rack is mounted in a printed board holder, fig. 7, at the bottom of the bay (figs. 1 and 2). It consists of an alarm concentrator with inputs for the alarms and also its own power feeding input. The unit has a number of separate outputs for different

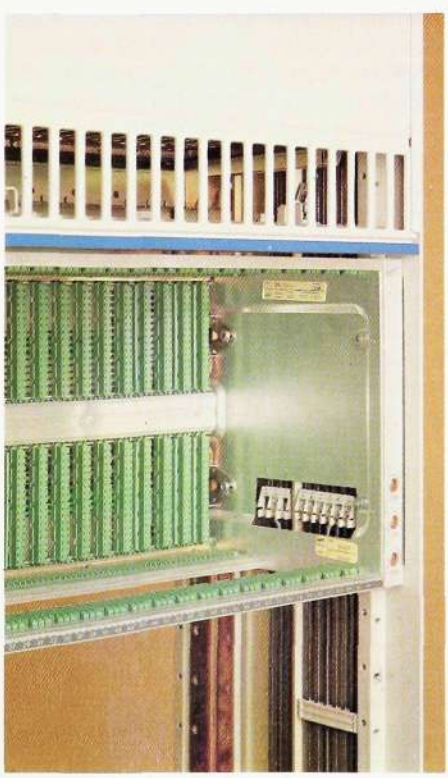


Fig. 6
Connectors for connecting an M5 shelf to the bay

Fig. 8
Alarm interface for printed board assemblies in BYB magazines

alarm categories, intended for different types of exchange alarm systems. The alarm function can be either a break or a closure. There is a choice between earth-free, separated alarm outputs and outputs with common earth. Exchange alarm bells can be connected. Facilities are also provided for alarm acknowledgements and for connecting bay alarm lamps. The printed board holder takes up two building modules vertically. The alarm concentrator is built up on a standard printed board, which is mounted horizontally in the holder. There is space for further printed board assemblies with supplementary functions.

The shelves and magazines are equipped with alarm circuits that provide fault indications. Some conditions that can cause an alarm are, for example, faulty secondary voltage, synchronization error and bit error.

One printed board assembly in each magazine has a connection panel for outgoing alarms and two light diodes for indicating alarm states, fig. 8. The alarm outputs are connected to the bay alarm unit via the alarm concentration bars. The other alarm outputs, which provide more detailed alarm information, can either be connected to a separate alarm system or they can be used direct for fault localization when a fault occurs.

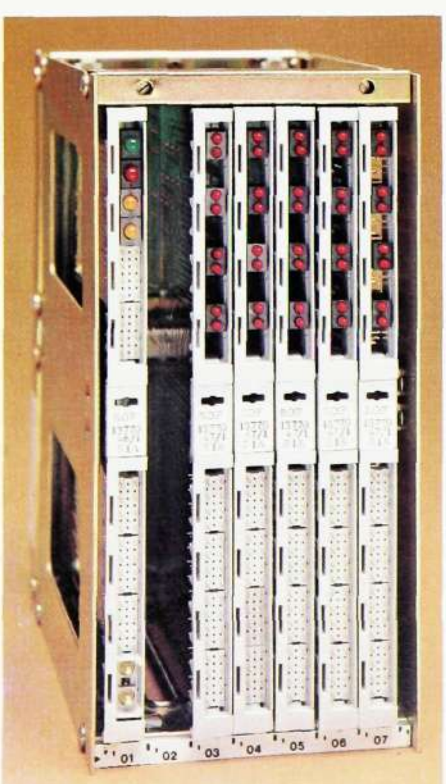
Service telephone

The service telephone line is used in connection with the installation and maintenance of line systems. A printed board assembly for the service telephone is mounted in the printed board holder. The telephone is of the same type as those used along the line, and it is connected to a panel mounted in the left-hand upright cover, fig. 2.

Ventilation

The shelf assembly kit is designed so that air can enter the bay with very little flow resistance, disperse under the magazine, pass up through it and come out at the top. If further ventilation is required, ventilation units having a height of two building modules can be installed in the bay.

Fig. 9
The alarm concentrator and alarm indicators in a BYB magazine having a width of 3 BM



Transmission equipment in BYB 101

The need to be able to install transmission equipment in the same premises as exchange equipment is increasing. It is therefore an advantage to be able to use the same mechanical construction. When the transmission equipment is mounted in magazines, these can be installed and connected in the same way as in the case of exchange equipment in row construction practice BYB 101[3].

The alarm unit then consists of a magazine of three building modules in width, which holds an alarm concentrator and up to five alarm indicators, fig. 9. The alarms from up to eight magazines are collected via an alarm indicator. Thus a total of 40 magazines can be connected. An alarm from a magazine lights a diode lamp on the associated alarm indicator. A diode lamp that indicates the alarm category lights on the alarm concentrator.

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First-Order PCM Multiplex in the BYB Construction Practice

Hans-Henrik Hamacher and Göran Pettersson

LM Ericsson have developed a new generation of first-order PCM multiplex systems, ZAK 1/30-4, as a part of the modernization of their transmission equipments. The BYB construction practice was chosen for the new equipment, partly to make it compatible with existing telephone exchange equipment as well as other transmission equipment. In this article the use of this type of equipment is described, as well as its design and function, together with different equipment and connection alternatives.

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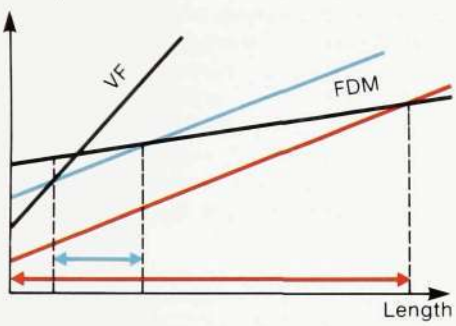


Fig. 3
A cost diagram for different transmission and exchange alternatives

PCM with analog exchanges
PCM with digital exchanges
FDM Frequency division multiplex systems with analog exchanges
VF Physical circuits with analog exchanges

The economical circuit length for digital transmission increases (from blue to red arrow) when digital exchanges are introduced

For many years digital transmission has been used on a large number of circuits between analog telephone exchanges, fig. 1. When the exchanges are also made digital it will be possible to connect the digital lines direct to the exchanges and the number of conversions between digital and analog signal per circuit will be reduced, fig. 2. Thus digital lines combined with digital exchanges provide a more economical network[1], fig. 3.

The changeover to a fully digital network will take many years and will comprise many stages. The number of PCM converters will increase with the extension of the digital areas and the analog/digital conversion will be moved closer to the subscribers. During this expansion it will also be necessary to move PCM equipment, fig. 2.

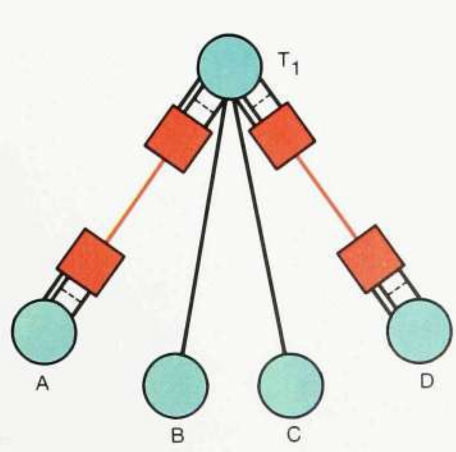
The digital transmission channels obtained by the use of PCM are also suitable for data transmission. It must be assumed that the channels will be used for both telephony and data to an increasing extent as the digital areas grow.

LM Ericsson have developed a new first-order PCM multiplex system, ZAK 1/30-4, for such networks. One of the aims of the development work has been to ensure that the equipment has the following general characteristics:
- easy to handle
- movable
- so flexible that it can be equipped for either telephony or digital data transmission, or both
- easily accessible interfaces for all functions.

ZAK 1/30-4 converts 30 analog telephony channels to one digital channel with a transmission speed of 2.048 Mbit/s. This is done by means of filtering, sampling, analog/digital conversion and digital multiplexing. These processes have been described in previous articles in this magazine[2,3].

Construction practice

The BYB construction practice was chosen for the new multiplex equipment. A general decription of this construction practice has been published in an earlier issue[4]. The characteristics that motivated the choice of BYB for new digital transmission systems are discussed in the preceding article[5]. The following features are of particular advantage in a first-order multiplex system:
- the equipment is delivered with the magazines fully equipped, which simplifies the installation work
- each magazine is an independent unit with its own d.c./d.c. converter. It can be mounted in an M5/BYB bay, in a BYB 101 bay row or a BYB 201 cabinet. This gives great flexibility when planing new systems and when moving PCM equipment



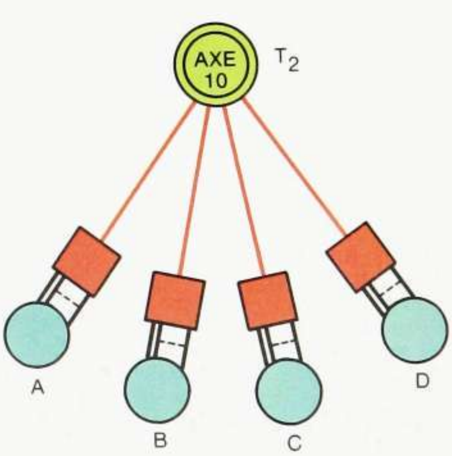


Fig. 1
PCM equipment in an otherwise analog network

Fig. 2
PCM equipment in a mixed analog/digital network

Analog exchange
PCM equipment
Digital lines

Changing the analog exchange in fig. 1 to a digital exchange means fewer analog/digital conversions on the circuit A-D. The PCM converters at T_1 can be moved to exchanges B and C

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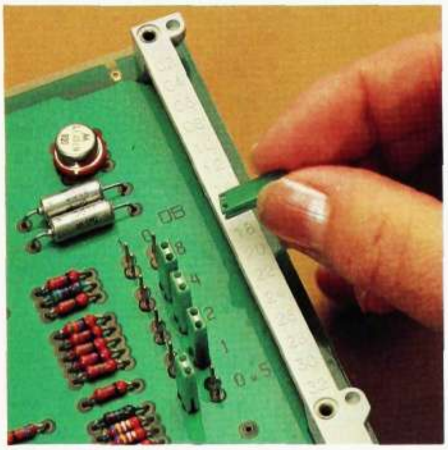


Fig. 4
Adjusting the attenuation of a channel unit. The attenuator is common for eight channels and the steps are clearly marked

– all cabling is accessible from the front, which simplifies both installation and rearrangement.

System characteristics

ZAK 1/30-4 is designed to be easy to install and maintain. It is equipped with efficient fault supervision, which quickly provides information regarding the type and location of any fault.

Installation

The d.c./d.c. converter works with battery voltages between −20 V and −72 V without the operating range having to be adjusted.

The only adjustment that is required during the installation is the matching of the channel levels on the speech channel side. This is done with the aid of attenuators, which are common for eight channels. The attenuation is set by means of plug-in U-links, fig. 4. The attenuation can be changed just as easily, which simplifies any rearrangement of the equipment.

Fault supervision and maintenance

The supervision on the digital side of the PCM multiplex (PCM-mux) is in accordance with recommendations of CCITT. If a fault occurs, diode lamps on the front edge of the printed board light and indicate the type of fault. Individual alarm outputs can be connected to the traditional type of alarm equipment, e.g. urgent and non-urgent alarms for each rack or row. This conforms to the alarm principles of previous generations of PCM-mux. In addition each individual alarm state, such as loss of frame alignment, bit error etc., can be indicated separately. These alarm outputs can be connected to central supervision equipment in the network, for example AOM 101 via LM Ericsson's computer-controlled transmission maintenance system ZAN 01. This gives an overall picture of faulty PCM equipments, fig. 5. The fault clearing time will be short, since the fault is quickly localized and the type of fault determined, and the repairman can be equipped witth the correct spares and sent to the right place.

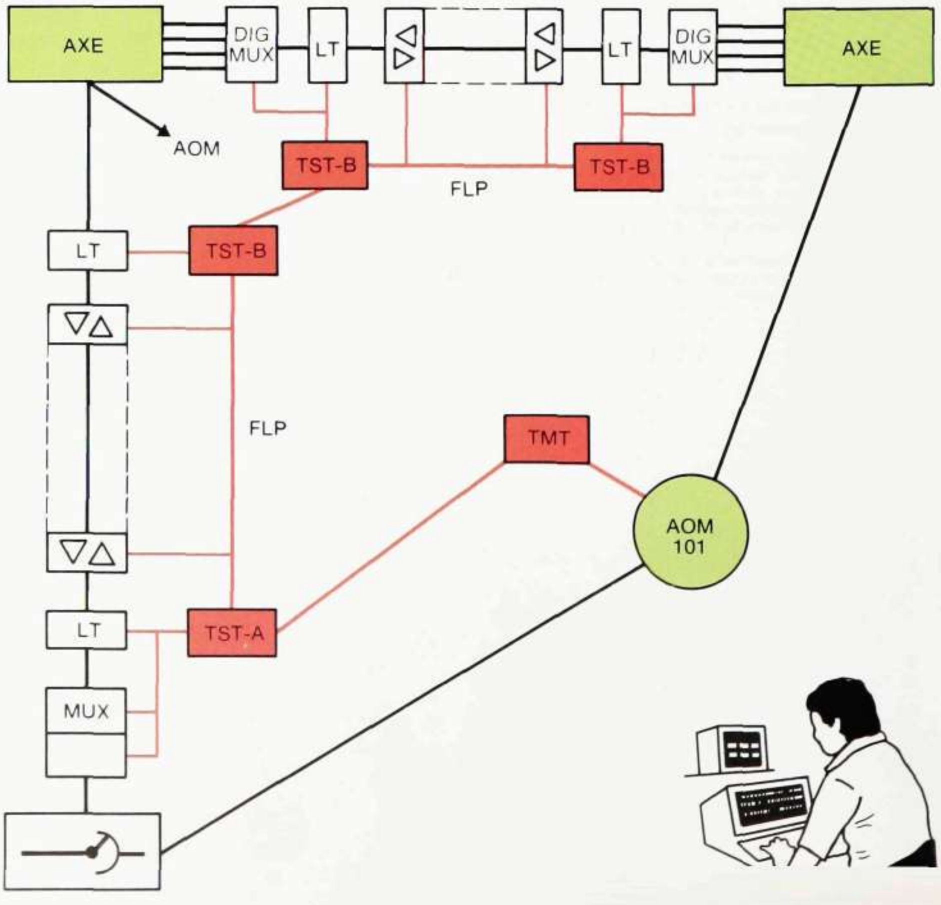
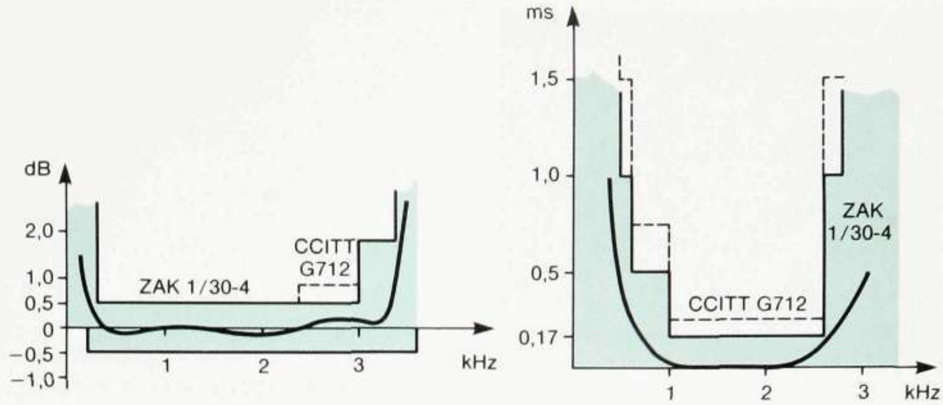


Fig. 5
Operation and maintenance system AOM 101 with ZAN 01 for exchange and transmission equipments. The alarm information from the transmission equipments is collected in blocks TST. TST-A is superior and communicates with TST-B via FLP and with TMT. TMT can be connected to AOM 101

Belongs to ZAN 01
Analog exchange

Fig. 6
The pass band attenuation and group delay distortion in a PCM link. Curves for typical values are drawn



Preventive maintenance is not necessary. The changes in component characteristics that occur because of temperature variations and ageing have been taken into consideration in the electrical design. Well-tried components are used and the power consumption is kept low, which gives the equipment very high reliability.

It has been possible to reduce the number of types of printed board assemblies for standard PCM-mux to five, one of which is the d.c./d.c. converter. High reliability and few types of printed board assemblies mean that the necessary stock of spares is reduced. Central fault supervision, and stores that are common for several exchanges further reduce the number of printed board assemblies that have to be kept in stock[6].

External timing control

The PCM-mux timing can be controlled externally. External timing is used when the system is to work in a synchronous, digital network. The external timing is connected in at the front of the printed boards.

Technical characteristics

In the foreseeable future PCM-mux will be used on circuits with several analog/digital conversions while the network is gradually being digitalized. Particular attention has therefore been paid to the parameters that affect the signal quality when there are several conversions per circuit. The recommendations made by CCITT have been followed, but the limits set for the following characteristics have been made more stringent:

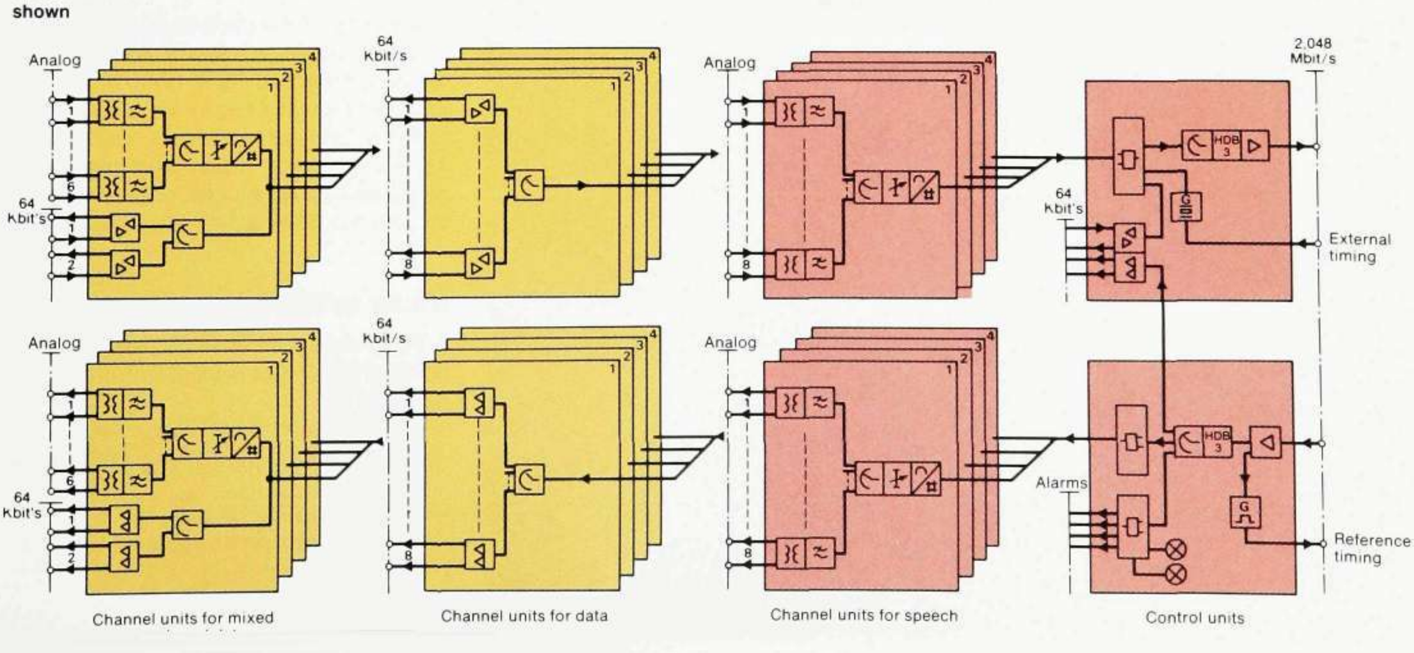
- pass band attenuation
- group delay/frequency distortion
- absolute delay
- noise in a silent channel
- crosstalk
- ripple attenuation
- out-band attenuation.

The pass band attenuation and group delay distortion requirements are shown in fig. 6. The stricter limits give transmission characteristics which make the circuit more suitable for data transmission via speech band modems.

The absolute delay of the system, i.e. the time it takes to transmit a signal from the analog input to the analog output on a PCM link, is of importance for circuits where several PCM links are connected in series. Troublesome echoes can occur and echo suppressors may be necessary if the delay is not kept small.

Low noise and low crosstalk in the PCM equipment is essential if a high trans-

Fig. 7
Block diagram for ZAK 1/30-4.
The basic equipment consists of control units and channel units for speech. Different combinations of data and speech can be obtained by replacing the speech channel units with channel units for data and/or channel units for mixed speech and data. The d.c./d.c. converter is not shown



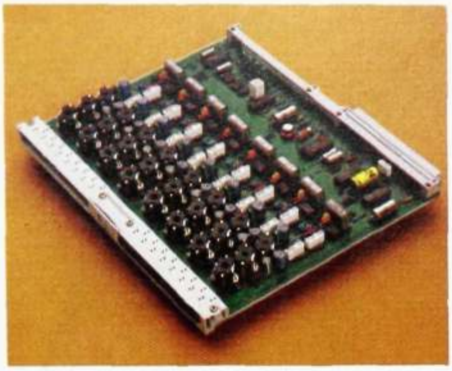


Fig. 9
Send side channel unit

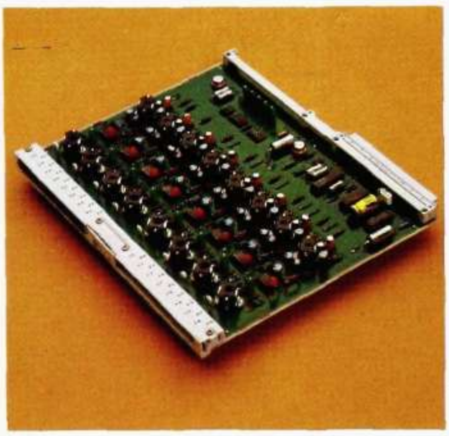
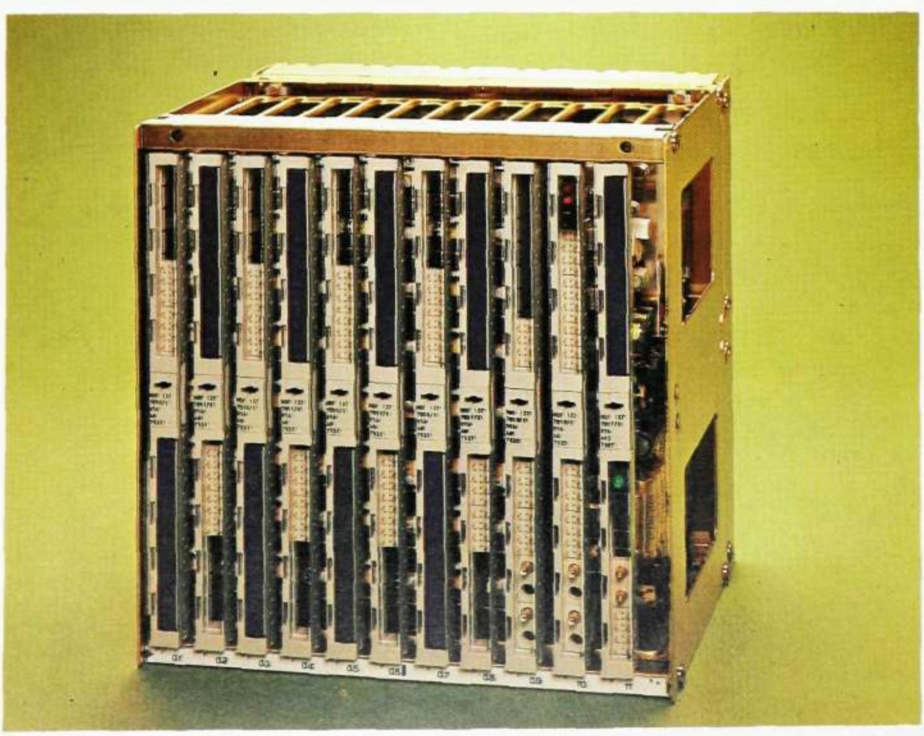


Fig. 10
Receive side channel unit

Fig. 8
ZAK 1/30-4, the PCM multiplexor equipped for 30 speech channels



mission quality is to be obtained. It is particularly important that there should be no crosstalk between subscribers connected to the same PCM terminal, as otherwise neighbours would be able to overhear each other. In this respect the design requirements are more stringent than the CCITT recommendations.

The requirements regarding ripple attenuation are also stricter than the CCITT recommendations. Large ripple voltages can in certain cases be induced into long analog two-wire circuits. It is essential that these ripple voltages are attenuated before the analog/digital conversion stage. Undesirable distortion occurs if the signal voltage is displaced by the ripple voltage.

The out-band attenuation is of importance when PCM-mux is connected to frequency division systems (FDM). With an attenuation level of 28 dB the new PCM-mux is suitable for any type of FDM connection.

Development history

The development of ZAK 1/30-4 started with a study of possible methods for the three main functions: filtering, encoding and decoding, control.

The components that were available when the previous generations of PCM systems were designed had been developed for the computer industry[3]. Since then the manufacturers of microcircuits have extended their product ranges to cover the telephony field, but the available range of components is still rather limited.

LM Ericsson have studied the component market, conferred with manufacturers and assessed the development and future component performances. Extensive component investigations have been carried out and preliminary design studies defined and undertaken for the most interesting alternatives.

As regards filter functions the choice was between active filters, CCD filters (Charge Coupled Devices), digital filters and passive LC filters. The LC filter was chosen, and a further choice had to be made between the traditional iterative network structure and a special single-coil structure.

The codec function can be realized in many different ways. One design that was studied consisted of a central encoder which worked in the time division mode with 30 channels. Intensive studies of different types of single channel codecs have also been carried out. The design that was finally chosen contained an 8-channel encoder.

In the case of the control function there was a choice between standard logic circuits, standard PCM control circuits and more or less customer-tailored circuits for such functions as generation of the frame word, frame alignment and HDB3 encoding, and for the connection circuits for 64 kbit/s data transmission.

Basic systems

A PCM-mux consists of five different types of printed board assemblies, fig. 7, namely:
- send side channel unit for 8 channels
- receive side channel unit for 8 channels
- send side control unit
- receive side control unit
- d.c./d.c. converter.

4 channel units of each type occupies a 240 mm wide magazine, fig. 8.

The filters, encoders and decoders are all placed on the channel unit boards, figs. 9 and 10. This has made it possible to keep the conductors for the sensitive analog signals very short.

The codec function is of the successively approximating type, fig. 11. The equipment consits of monolithic circuits for 8-channel multiplexors, sample and hold circuits, digital/analog converters and Successively Approximating Registers, SAR. This 8-channel codec is less complex and more reliable than the 1-channel and 30-channel codecs, and codec supervision is not justified in order to obtain reliable operation.

The attenuator on the channel unit covers a range of 15.5 dB. The attenuation is adjusted in steps of 0.5 dB by means of U-links, fig. 4.

Low delay distortion has been achieved by selecting the lowest possible grades of LC filters, fig. 6. The low pass filters are of grade 5 and the ripple filter is of grade 2. The band pass ripple value has been reduced to a level lower than that recommended by CCITT. The channel amplifier constitutes an active link in the ripple filter and is also used to provide the necessary limiting.

The low pass filters have the traditional iterative network structure with transformer-coupled coils. The receive side channel amplifier is also used as a second grade low pass filter. The filters are made with the lowest possible phase shift for the given grade in order to reduce the group delay.

The division of the channel unit into a send side and a receive side has certain advantages. For example, the crosstalk problems are reduced since there are no troublesome differences in speech level on the same printed board assembly. The analog/digital and digital/analog converters can work synchronously without complicated control and extra signal delay. Low delay helps the four-wire stability. In this respect the 8-channel encoding is also preferable to single channel encoding. The delay is only 1/8 of the sampling interval of 125 μs.

The send side control unit contains logic circuits for controlling the encoding, for generating the frame word and for feeding the PCM signals into the 2 Mbit/s stream. The crystal oscillator can operate with either free oscillation or external timing. The PCM signal output and the external timing input are placed on the front of the unit. The connection is 75 ohms, coaxial.

The send side control unit also contains send and receive circuits for the signalling timeslot T16. The corresponding inputs and outputs for the 64 kbit/s signalling streams are placed on the front of the unit[3]. Fig. 13 shows the layout of the inputs and outputs on the fronts of the control units.

The receive side control unit contains logic circuits for controlling the decoding and channel distribution, for frame alignment and for recovering the signalling information. The input for the PCM-coded signal and the timing output consists of 75 ohm coaxial connectors on the front of the unit.

Circuits with a high degree of integra-

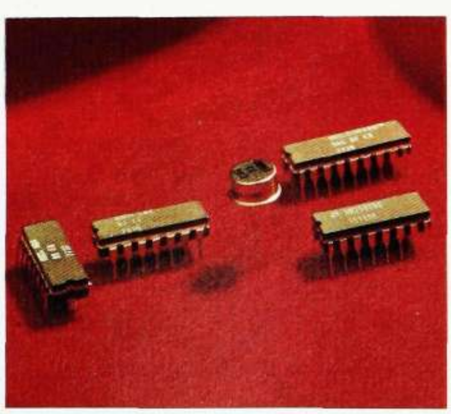


Fig. 11
Monolithic circuits for codec functions.
The same type of codec circuits is used on the send and receive side. On the send side all functions are utilized: multiplexor, sample and hold circuit, D/A converter, comparator and SAR. Only the D/A converter is used on the receive side

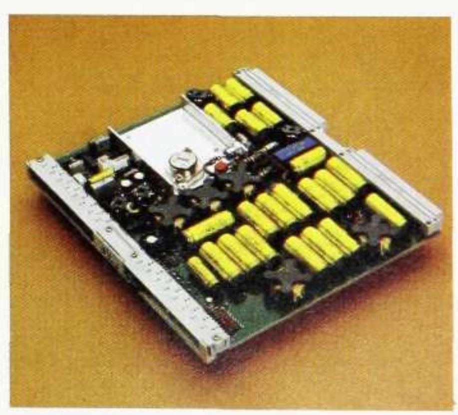


Fig. 12
The d.c./d.c. converter

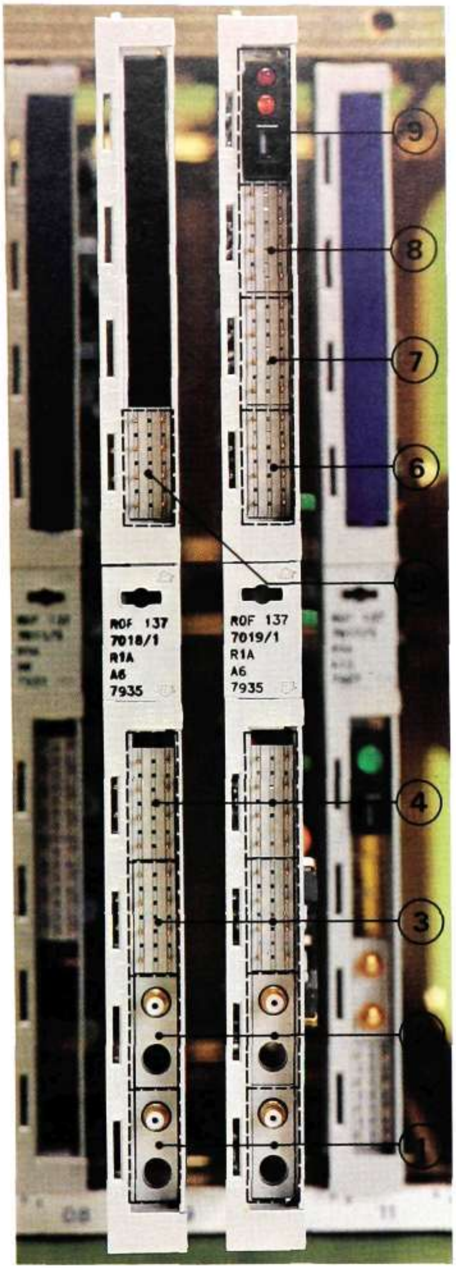


Fig. 13
The layout of the channel unit fronts

1. 2 Mbit/s main flow
2. Input for external timing and output for reference timing
3. Free bits, no. 4–8. Input and output
4. Test points for certain digital signals
5. 64 kbit/s signalling interface
6. Outputs for urgent and non-urgent alarms and for reminder indication
7. Output for system alarms
8. Outputs for power alarm, alarm indication, loss of frame alignment, bit error rate and far-end alarms
9. Push-button for cancelling the bay alarm signal with diode lamps for near-end and far-end alarms

Fig. 14
An example of the utilization of a 64 kbit/s timeslot for data. One 64 kbit/s timeslot corresponds to one speech channel. By means of multiplexing in a special data multiplexor it is then possible to transmit the amount of data shown in the table below instead of speech

Bit/s	Number of channels
600	63
2 400	20
4 800	10
9 600	5
48 000	1

tion have been used for the control units in order to save space on the printed boards. Special monolithic circuits have been used for frame alignment/frame word generation, signalling and HDB3 encoding.

The d.c./d.c. converter, fig. 12, is a three-voltage converter giving the secondary voltages +12, −12 and +5 V. It meets the stability requirements for primary voltages within the range 20–72 V. Chopper technique, careful choice of components and the best possible circuit design have contributed to give the converter 80% efficiency on full load. This unit, like all other units in the system, is only 20 mm wide. The front of the unit contains a breaker and indication Light Emitting Diode (LED) for the primary power supply.

The printed boards are of type ROF 137, with the dimensions 220x178 mm.

Interfaces

The connection between the channels and the PCM-mux is four-wire. Any conversion to two-wire working is done in separate equipment. The channels are connected to the channel units via cables equipped with "half connectors" having 16 tags, which are plugged into one half of a connector on the printed board, fig. 8. The cables with their half connectors can be prefabricated, so that they can be plugged in quite simply during the installation. The half connectors are available with and without bus function. A half connector with bus function makes it possible to carry out parallel measurements on individual speech channels. If the half connector is replaced by a full connector with bus function it is also possible, with certain auxiliary equipment, to cut off individual channels.

The battery voltage is connected direct to the d.c./d.c. converter by means of a battery connector. Test points are provided for the secondary voltages. An alarm output for power unit faults is available on the unit itself and also among the other alarm outputs on the receive side control unit, fig. 13, item 8. Fig. 13 also shows the position of other interfaces and maintenance terminals.

Alarms are given by means of closure to earth via a transistor contact. The alarm outputs are combined into three different groups with common earth within each group. Each group is connected up via a "quarter connector" on the front of the unit, fig. 13.

Bay alarms can be cancelled by means of a push-button on the front of the send side control unit. The system can also be blocked to traffic via the signalling converter by depressing the button. An adjacent light emitting diode then lights as a reminder indication. This diode also indicates all near-end alarms. A second diode indicates far-end alarms.

If desired, detailed measurements can be carried out with the aid of test outputs for

- transmitted and received PCM bit streams
- sender and receiver bit timing
- half bit timing
- the frame timing, half frame timing and bit error counter.

The free bits in timeslot T0, bits no. 4–8, are available on the appropriate control unit for sending and receiving information. These bits can be used for such purposes as transmitting data and alarms.

Each quarter connector contains the necessary earth connections for all interfaces.

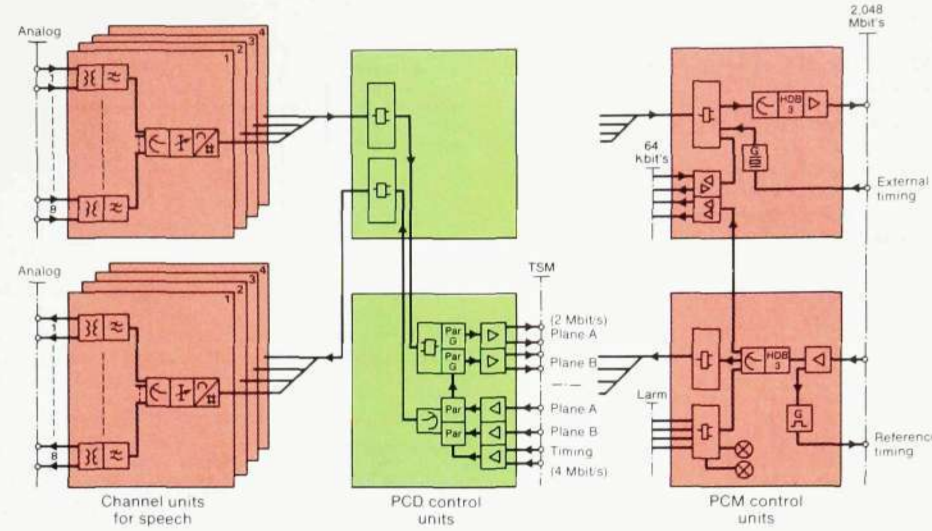
Alternative equipment

64 kbit/s data channels

The PCM channels can be used for data instead of telephony. The data channels are then branched direct into the 2 Mbit/s steam without passing through the encoder. A digital channel is much more efficient for the transmission of digital information than an analog telephony channel. For example, a 64 kbit/s channel can transmit 20 data channels for 2400 bit/s, fig. 14. The multiplexing up to 64 kbit/s is then carried out in a separate equipment.

The equipment has been designed so that it can be adapted to different requirements as regards 64 kbit/s data channels. Each pair of channel units for

Fig. 15
Alternative equipping of PCM-mux/PCD. A PCD can be converted to a PCM-mux by changing the control units



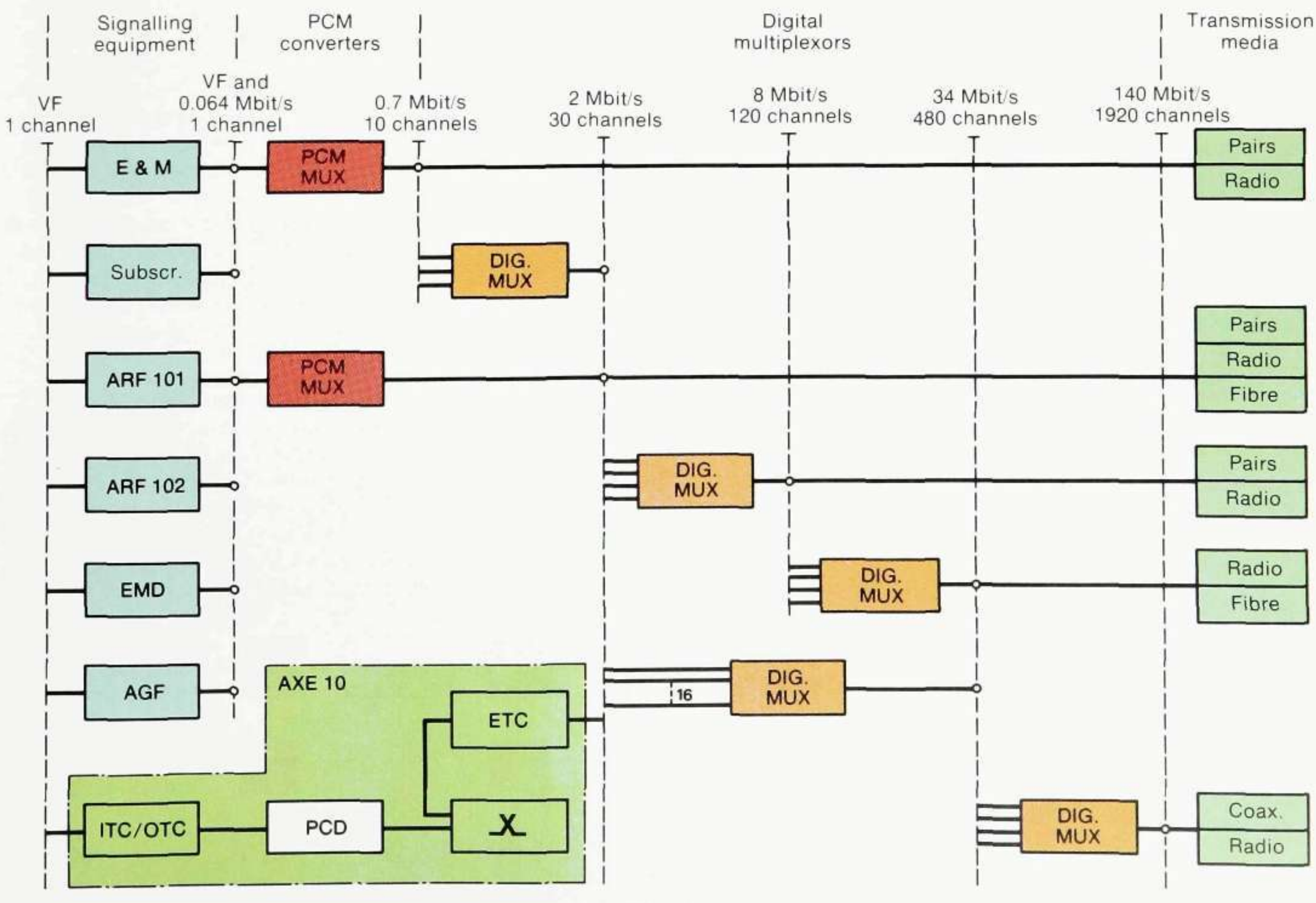
by either printed board assemblies for six speech and two data channels or printed board assemblies for eight data channels. With different combinations of these types of printed board assemblies for the four pairs of channel units, the number of data channels can be increased from two to thirty in steps of two. With the system used entirely for data, a further data channel can be obtained by using the signalling timeslot T16 for this purpose, fig. 7.

The changeover from speech to data or vice versa can be carried out at any time and in most cases without interfering with the other groups of eight channels in the magazine.

Analog/digital converter for AXE 10
The analog/digital converter used in exchange system AXE 10 for connecting analog lines to the digital group selector is designated PCD (Pulse Code Modulation Device). This equipment converts speech signals into digital form in accordance with the same specification as for PCM-mux. The development of the two equipments was coordinated. The same types of magazine, channel units and d.c./d.c. converter are used in both equipments, but different printed board assemblies are used for the control units. The similarities help to simplify handling and the stocking of spares in networks where both PCM-mux and PCD are used, fig. 15.

Fig. 16
PCM-mux and PCD in a digital network.
The figure shows the coupling between the transmission systems and their connection to AXE 10

X Digital group selector



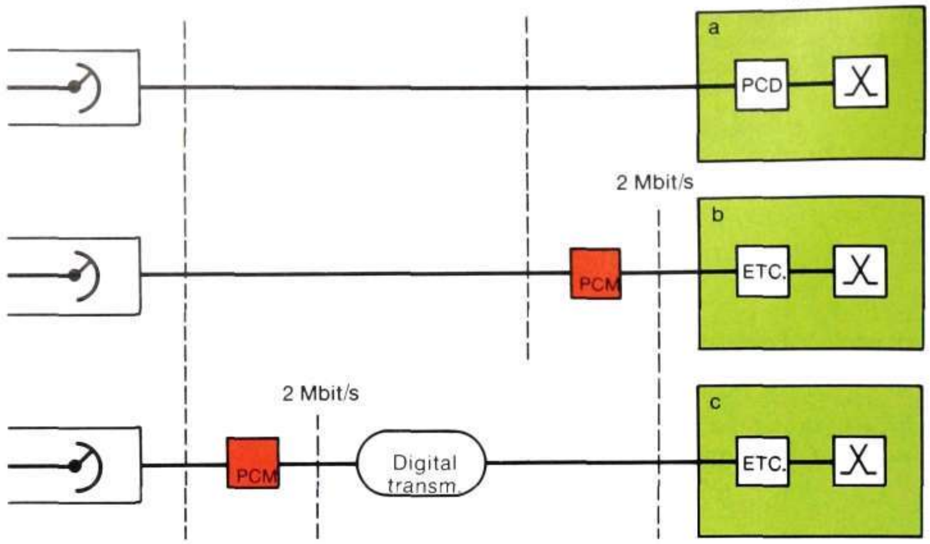


Fig. 17
Connection of analog telephone exchanges to AXE 10. (The signalling equipments are not shown)

a. Analog transmission and PCM conversion in AXE 10
b. Analog transmission and PCM conversion in the same exchange as AXE 10
c. Digital transmission and PCM conversion in the analog exchange

Connection alternatives

Signalling equipment

It must be possible to connect the analog side of PCM-mux and PCD to telephone exchanges or lines of different types and with different signalling systems. All signalling matching is carried out in the signalling equipment, which is connected in between PCM-mux or PCD and the exchange or line concerned. The signalling equipment converts the signals from the analog side, for example digit pulses, charging information and seizure information, into digital form. In the case of two-wire connections the conversion to two-wire working is also carried out in the signalling equipment.

The great variety of signalling systems and connection conditions has necessitated extensive work on developing several types of signalling equipments. These equipments are generally placed in magazines of their own in order to provide greater flexibility for any rearranging, fig. 16.

Connecting analog exchanges to AXE 10

Fig. 17 shows three alternatives for the connection of analog exchanges to AXE 10. Alternative a means that the conversion to the digital group selector in AXE 10 takes place in the signalling equipment and in PCD. This alternative can be chosen if the available cable capacity is sufficient and if the analog lines are to be used for a long time. If, in the future, a digital connection to AXE 10 is wanted, it will be possible to convert PCD to PCM-mux and connect in accordance with alternative b or c.

Alternative b gives digital connection to AXE 10 with signalling equipment and PCM-mux at the exchange AXE 10. Basically this alternative is the same as alternative a, but it requires matching equipment for the digital group selector, ETC (Exchange Terminal Circuit). However, this alternative may be preferable to alternative a if the route is to be replaced by a digital link (e.g. alternative c) in the near future. The ETC equipment is then already installed and the changeover is simplified.

Alternative c is more economical than alternative b if the wire pairs that are saved in the cable between the exchanges are required for other purposes, or if it would otherwise be necessary to lay a new cable. Alternative c can also be justified on the grounds that it gives better transmission characteristics if the attenuation on the analog circuit is high. Otherwise the argument favouring c will be the same as for b, namely that it prepares for future conversion to digital transmission.

Connection to 10-channel PCM systems

The PCM-mux is also prepared for connection to LM Ericsson's 10-channel PCM system[7] via branching equipment, fig. 18. It is also possible to branch off less than 10 channels in each branching point. Up to seven branching points can

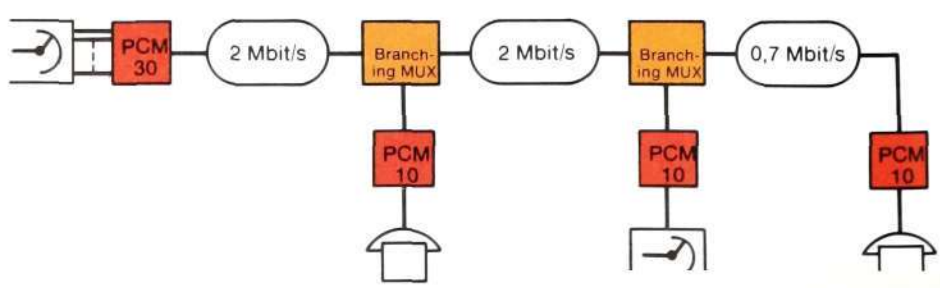


Fig. 18
Branching from a 30-channel PCM-mux to a 10-channel system. The illustration shows three branching points for a mixture of analog exchanges and subscriber equipment.
(The signalling equipment is not shown)

TECHNICAL DATA

Number of channels	30
Coding	PCM, A-law in accordance with CCITT Rec. G.711
Frame structure	In accordance with CCITT Rec. G.732
4-wire analog interface	
CCITT Rec. G.712 with the following additions: (The given values apply for loop-connected system)	
Speech channel bandwidth	200–3400 Hz
Pass band attenuation	
50 Hz	>20 dB
200– 300 Hz	0/+4 dB
300–3000 Hz	−0.5/+0.5 dB
3000–3400 Hz	−0.5/+1.8 dB
Group delay distortion	
500– 600 Hz	<1.0 ms
600–1000 Hz	<0.5 ms
1000–2600 Hz	<0.17 ms
2600–2800 Hz	<1.0 ms
Absolute delay at about 1400 Hz	<0.45 ms
Nominal impedance input/output	600 ohms, balanced
Nominal levels	
input send level	−16 dBr min.
output receive level	+8 dBr max.
level adjustment	15.5 dB (in steps of 0.5 dB)
Crosstalk at 0 dBm0	
mean value	−75 dBm0
maximum	−65 dBm0
Idle channel noice	
mean value	−75 dBm0p
maximum	−65 dBm0p
Spurious out-band signals on the receive side	<−28 dBm0
Attenuation of out-of-band signals on the send side	>28 dB
Level stability during the life of the equipment with a maximum of one adjustment	±0.5 dB
External timing	
The internal oscillator can be controlled by external timing or by receiver timing with a frequency of	2048 kHz
and a level of	max. ±1.4 V
and impedance	75 ohms
Alarms	In accordance with CCITT Rec. G.732
64 kbit/s signalling and data interface	In accordance with CCITT Rec. G.703
2.048 Mbit/s digital interface	In accordance with CCITT Rec. G.703
Power	
Consumption from battery (−20 to −72 V d.c.)	14 W
Mains rectifier 45–65 Hz	110, 127 or 220 V a.c. (+10 %/−10 %)
Dimensions	
Magazine (height x width x depth)	244x244x220 mm
Weight (fully equipped)	8 kg

be used. This means that PCM transmission can now be introduced on routes requiring only a small number of channels.

Connection to higher order systems

30 channels may not be sufficient for high traffic routes. This applies particularly when large digital areas are to be connected together using digital transmission. Multiplexing from 2.048 Mbit/s to higher transmission speeds is carried out in digital multiplexors[8]. Different transmission media are possible, fig. 16. Small digital areas that are situated close to such a large digital route are in a favourable position since they can be connected to the route by means of digital multiplexing equipment. Thus the further digitalization of small areas is intensified. The introduction of digital transmission in the long distance network is an important stage in the conversion of the whole national network to digital working.

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AXE 10—A Review

Bo Å. Nilsson and Kjell Sörme

AXE 10 is a telephone exchange system designed to cover the whole range from large international transit exchanges to small local exchanges and remotely connected subscriber stages. The system also comprises exchanges for mobile subscribers, equipment for traffic handled by operators and equipment for centralized operation and maintenance.
This article gives a review of AXE 10 and describes how the system can easily be adapted to suit different requirements by combining a number of standardized subsystems. These subsystems have well defined interfaces and can be further developed independently. Two such subsystems are the digital group selector and the digital subscriber stage, by means of which the AXE 10 system is adapted to a network with gradually increasing digitalization.

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AXE 10 can be used to build:
- local exchanges
- local tandem exchanges, separate or combined with local exchanges
- transit exchanges for national and international traffic, separate or, in the national application, combined with local tandem exchanges and local exchanges
- exchanges for automatic traffic to and from mobile subscribers, separate or combined with national transit exchanges
- exchanges for rural areas, small towns and suburbs
- remote subscriber stages for AXE 10 local exchanges.

Each of the above applications has a uniform set of functions, achieved by standardized subsystems and function blocks. Thus one and the same system covers all application areas, which means that the same methods, aids and procedures can be used throughout the network, for example for operation and maintenance.

AXE 10 has a clear and lucid structure and is easy to operate. Training course packages have been produced to suit different personnel categories and different qualifications. This means that operating staff with experience of conventional systems can learn to operate AXE 10 after a brief training period. The system is equipped with a complete range of built-in aids which relieve the staff of routine tasks. Each AXE 10 exchange can work as an independent unit as regards operation and maintenance, but it is also possible to coordinate and control these functions remotely, from special centres in the network. System AOM 101 has been developed for this purpose[1].

The group switching subsystem, GSS, the trunk and signalling subsystem, TSS, the traffic routing and control subsystem, TCS, and the operation and maintenance subsystem, OMS, comprise the system nucleus that is necessary for all exchange versions. This nucleus is supplemented by the subscriber switching subsyste, SSS, for local traffic, the common channel signalling subsyste, CCS, for signalling to other stored program controlled exchanges and the operator position subsystem, OPS, for national and international traffic handled by operator, etc. in accordance with the requirements for the individual exchange, figs. 1a–d.

The structure of AXE 10 simplifies the introduction of new facilities and functions. The system can easily be adapted to suit new demands resulting from, for example, the rapid technical development.

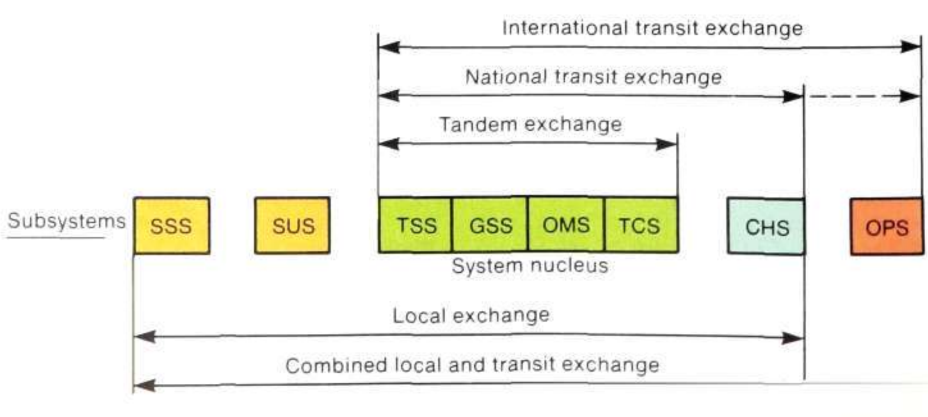

Fig. 1a
Some combinations of subsystems for common AXE 10 applications. GSS varies only as regards size and TCS as regards analysis and routing data. In the other subsystems the functions are selected according to the actual need

TSS Trunk and signalling subsystem
GSS Group switching subsystem
OMS Operation and maintenance subsystem
TCS Traffic routing and control subsystem (software)
SSS Subscriber switching subsystem
SUS Subscriber services subsystem (software)
CHS Charging subsystem (software)
OPS Operator position subsystem

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Systems for digital networks

The requirements for a digital network were taken into consideration when designing AXE 10, namely that it must be possible to:

- connect digital lines and through-connect PCM time slots
- synchronize digital bit streams
- connect together digital and analog networks in accordance with the given regulations for transmission, routing and signalling
- introduce common channel signalling according to CCITT no. 7
- connect remote subscriber stages.

When the main requirements for AXE 10 were set at the beginning of the 1970s it was decided that the design must permit the use of both analog and digital group selectors. The two-wire reed group selector and the four-wire digital group selector were therefore developed in parallel. The first analog group selector was put into operation in Södertälje, Sweden, in 1977 and the first digital group selector in Åbo, Finland, in 1978.

During the 1970s several administrations wanted stored program controlled local exchanges with two-wire analog through-connection. The junction lines were then mainly of the two-wire type.

As was envisaged at the beginning of the 1970s, exchanges with digital through-connection have lately become predominant, since the networks have increasingly been extended by means of PCM systems, and new exchange systems have been introduced.

It is the strictly functional structure of AXE 10 with its separate subsystems

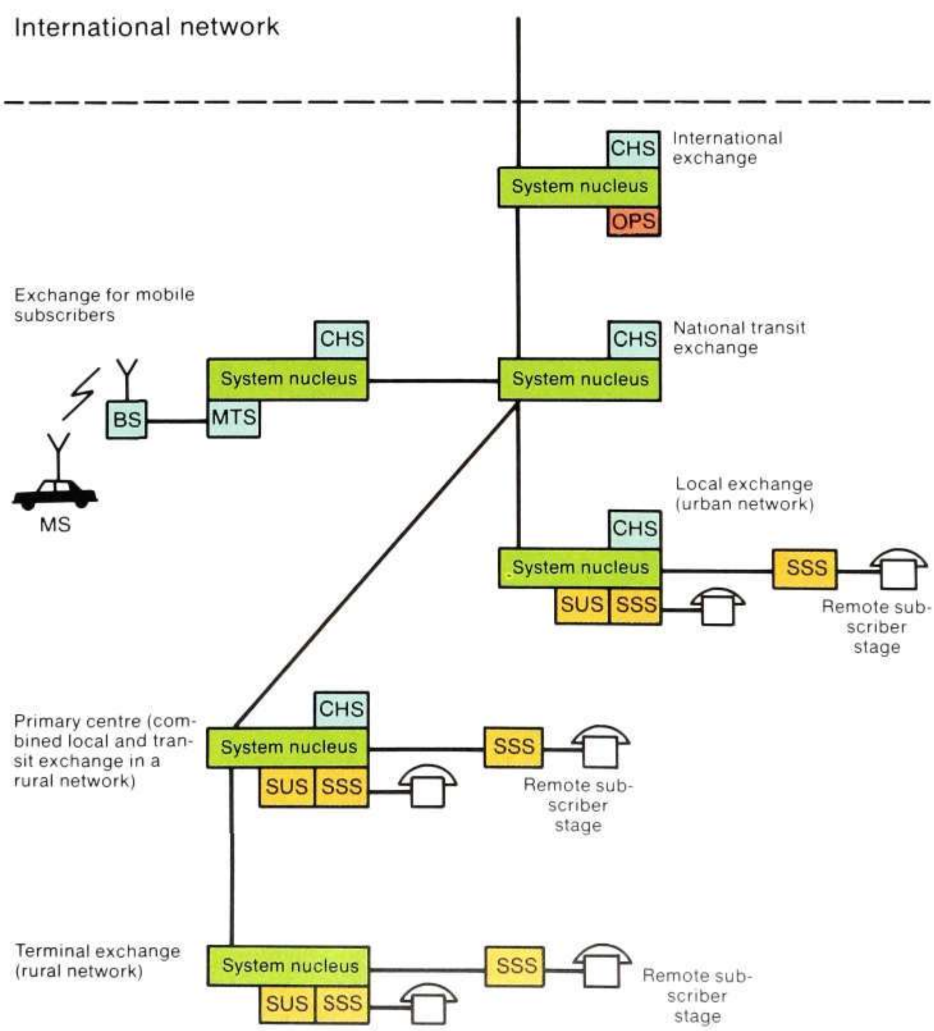
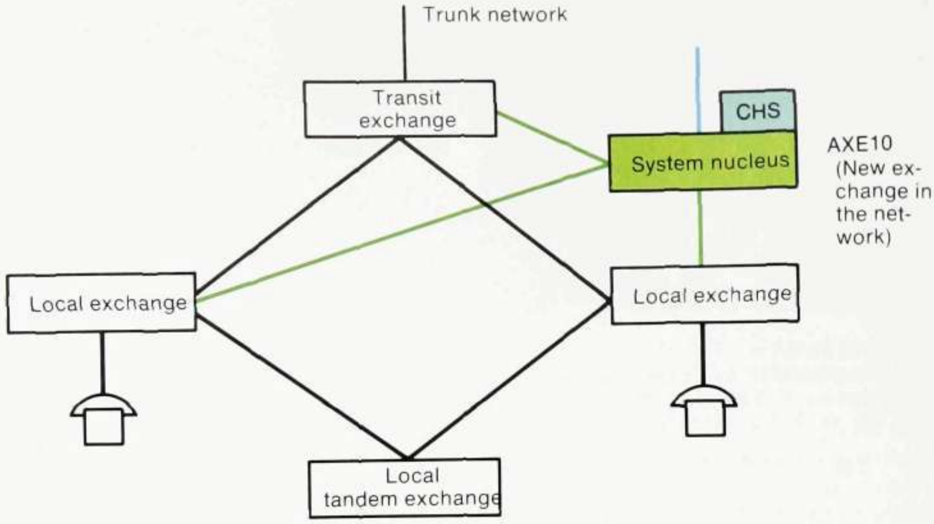


Fig. 1b
A telephone network with AXE 10 exchanges

MS Mobile subscriber
BS Base radio station

Fig. 1c
If an AXE 10 local tandem exchange is provided with a suitably equipped charging subsystem, CHS, and the traffic routing and control subsystem TCS is supplemented with data for outgoing trunk traffic, the tandem exchange can function as a national transit exchange. This reduces the load on existing transit exchanges in the network.

Old lines
New junction lines
New trunk lines



that makes it possible to provide alternative versions with analog or digital group selectors. The differences between the two versions are mainly limited to the group selector subsystem, fig. 2.

New or alternative technical solutions can be introduced in other subsystems in a similar way. For example, the analog subscriber switching subsystem can be replaced by a digital subsystem without any major changes being necessary in the exchange. Fig. 2 shows different versions of an AXE 10 exchange, from a wholly analog to a fully digital exchange.

The digital group selector

The AXE 10 digital group selector[2,3] is a great help in the efforts to make the extension and further development of telephone networks economically viable. The group selector can form part of local exchanges, tandem exchanges, national and international transit exchanges as well as exchanges for mobile subscribers. Remote subscriber stages can also be connected to the group selector.

The digital group selector offers the following advantages:

- PCM time slots can be through-connected without changes, the selector introducing no attenuation
- junction line relay sets and terminal equipments are simple and can be used at any network level. The equipments for switching and transmission can be integrated
- the selector works in the four-wire mode. The transmission properties are improved by the four-wire working being brought further down in the network hierarchy

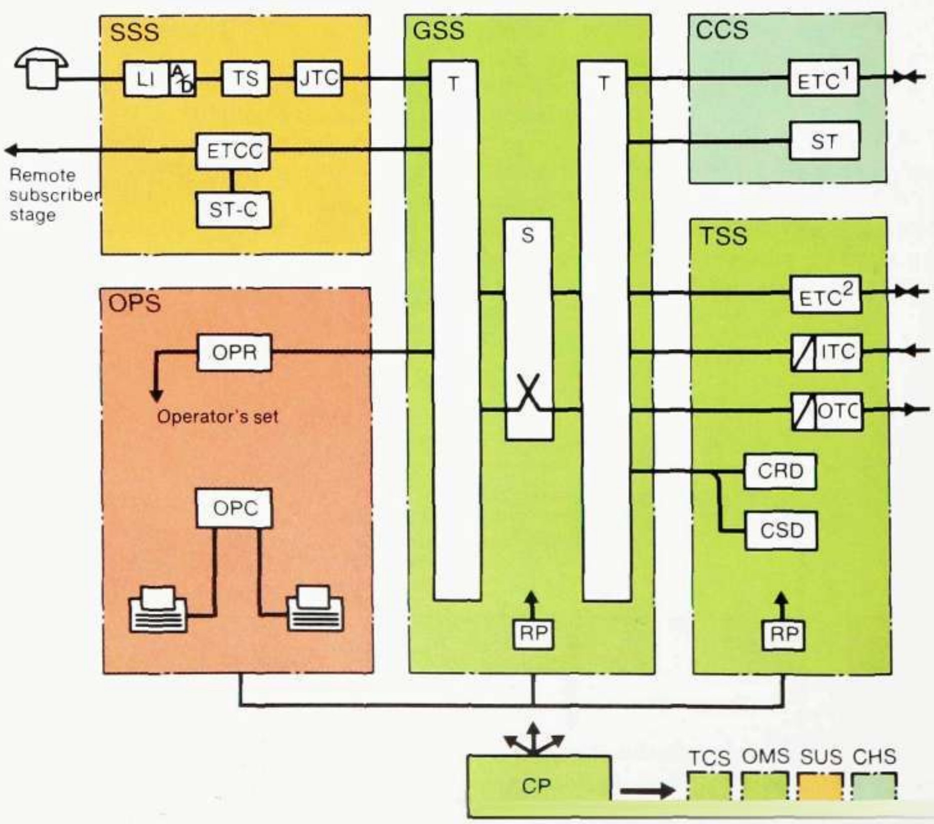
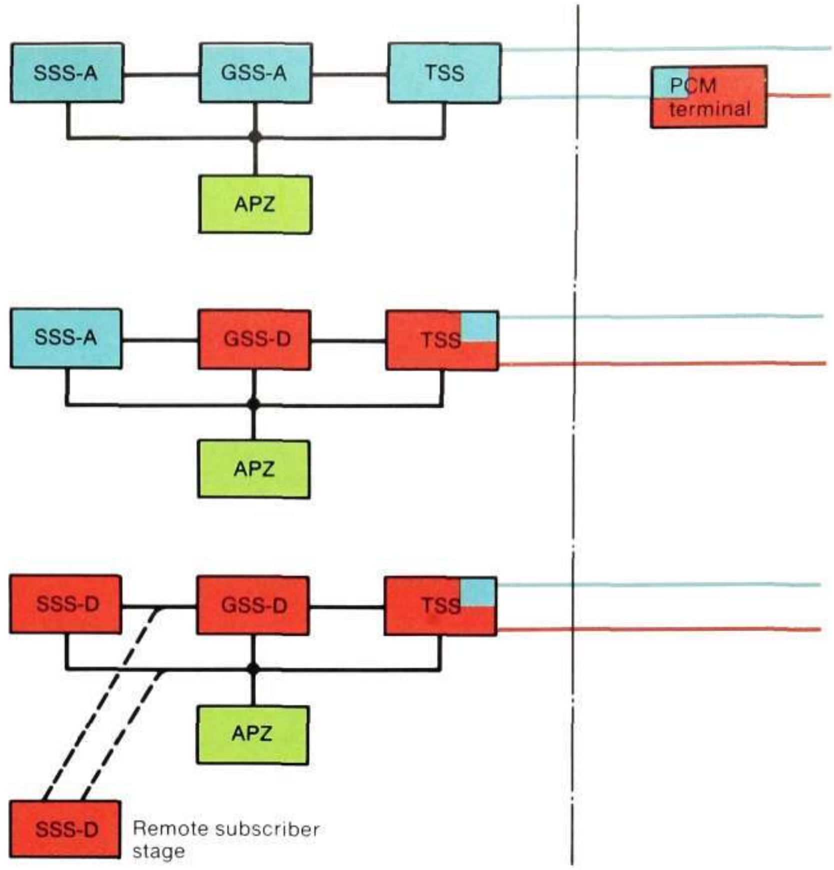


Fig. 1d
A simplified block diagram of an AXE 10 local exchange supplemented with OPS to make a combined exchange with operator service

LI	Line interface
TS	Digital subscriber stage selector for 128 lines
JTC	Interface towards GSS
ETCC	Digital circuits to remote subscriber stage
ST-C	Signalling terminal
ETC[2]	Digital, junctions or trunk circuits with channel associated signalling
OPC	Operator position equipment
OPR	Connection of operator's set
T	Time switch module
S	Space switch module
ETC[1]	Digital, junctions or trunk circuits with common channel signalling
ST	Signalling terminal
ITC	Analog incoming junction or trunk circuit
OTC	Analog outgoing junction or trunk circuit
CRD	Code receiver
CSD	Code sender
CP	Central processor
RP	Regional processor

Fig. 2
Successive changeover from analog to digital AXE 10 without any structural changes

GSS-A Analog group selector
GSS-D Digital group selector
SSS-A Analog subscriber stage
SSS-D Digital subscriber stage
TSS Trunk and signalling subsystem
APZ Control system
Analog line
Digital line



- remote units are conected via PCM, which gives good transmission characteristics, good economy and high flexibility in the local network
- switching of a speech connection can be carried out without clicks or interruptions, for example when a connection is set up by an operator
- the internal congestion of the selector is negligible
- the junction lines can be connected arbitrarily. Lines belonging to the same route can be scattered within the group selector.

The digital subscriber stage

A digital subscriber stage used in conjunction with analog telephone sets necessitates the use of individual circuits for each subscriber line for current feeding, ringing, sensing of hook condition and digital/analog conversion. Intensive work on developing miniaturized circuits for these functions has been in progress for some years.

The AXE 10 digital subscriber stage is offered as an alternative to the analog stage in future deliveries of local exchange systems. It has the following general advantages:
- the amount of space required for the subscriber stage is reduced by almost half when a changeover is made to digital technology
- it makes possible future connection of digital subscriber lines and subscriber line multiples as well as terminals for different types of data services, fig. 3.

The digital subscriber stage in AXE 10 is built up with modules of 128 lines. 16

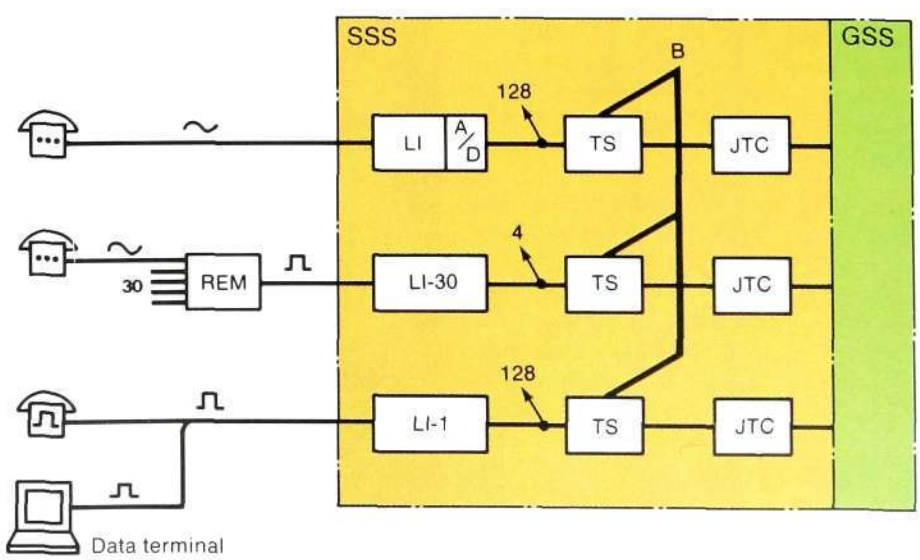


Fig. 3
Some examples of connections to the AXE 10 digital subscriber stage. The figure shows the present and future basic equipment in the subscriber stage

REM Remote Exchange Multiplex—Equipment for connecting 30 analog subscriber lines to a 30-channel PCM system
LI-A/D Line interface—analog subscriber line
LI-30 Line interface—30-channel PCM system
LI-1 Line interface—digital subscriber line
TS Time switch
JTC Interface towards GSS
B Internal bus
~ Analog transmission

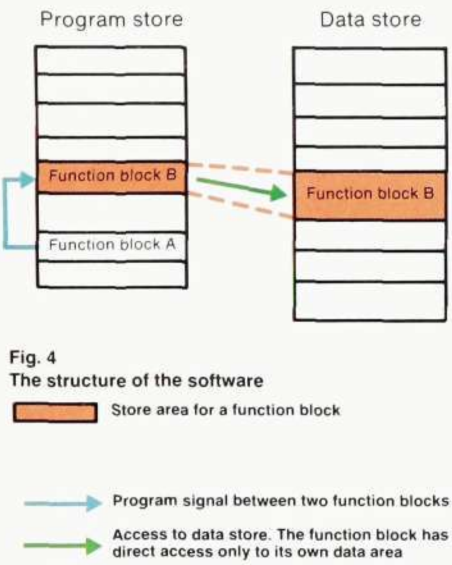


Fig. 4
The structure of the software

such modules form a fully built out stage of 2048 lines. The subscriber stage is connected to the group selector via a number of PCM links, each with 30 time slots per speech direction. The number of links is determined by the traffic, and the maximum number is 16. Each module of 128 lines is equipped with a time switch which connects the subscriber lines to time slots in the links towards the group selector. Full availability is obtained by means of an internal bus between the time switches.

The subscriber stage is connected to the group selector either direct via 30-channel links or remotely via one or more PCM systems. In the case of a remote subscriber stage the control information from the central processor in the parent exchange is transmitted in the signalling time slot of the PCM system. For this purpose common channel signalling with a transmission speed of 64 kbit/s is used. A pair of signalling links, with one working link and a standby, provide sufficient signalling capacity for a fully built out remote subscriber stage with 2048 subscribers.

The subscribers connected to such a remote stage have access to the same functions and facilities as the other subscribers.

Software

The programs for AXE 10 are written in the high-level language PLEX[4]. The software is divided into function blocks with clearly defined interfaces. A function block can contain both software and controlled hardware or only software. Within each function block the instructions are carried out in sequence, with facilities for jumps by means of jump instructions, fig. 4. The processors work with microprograms, which control that the jump possibilities are limited to within the block in question.

When the program handling for a switching sequence is to continue in another function block, the necessary information is transmitted between the blocks by means of program signals. A program signal contains the address and a number of data words. A supervisory function ensures that only correct signals are sent on.

The addressing of jump instructions and program signals is carried out with the aid of a reference store, where relative addresses are translated into absolute addresses. Program blocks and data blocks can be placed in arbitrary order and in arbitrary places in the stores concerned. When a block is written in or moved, the translation table in the reference store is updated. The possibility of arbitrary placing in the stores simplifies any reallocation that may be necessary in connection with extensions and function changes.

The structural, signalling and addressing principles of the system mean that when new or modified functions are to

Fig. 5
Digital group selectors

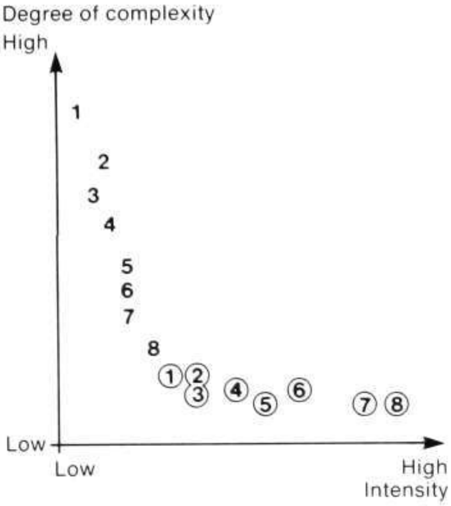


Fig. 6
The distribution of tasks among the central processor, CP, and the regional processors, RP, with regard to the degree of complexity and intensity of the tasks. Some examples:

Functions implemented in central software:
1 Fault analysis
2 Line testing
3 Monitoring of network synchronization
4 Change of subscriber data
5 Tariff analysis
6 Route analysis
7 Number analysis
8 Register signalling analysis

Functions implemented in regional software:
① Control of terminal equipment
② Control of signalling links
③ Control of data links
④ Sending and receiving register signals
⑤ Call supervision
⑥ Control of selectors
⑦ Sensing and control of subscriber line circuits
⑧ Sensing and control of junction line circuits

be introduced the function block concerned can be modified without the other function blocks being affected. In addition they provide good software reliability, since the effects of a software fault are effectively limited and fault localization is easy.

All signals between the various function blocks can be traced. The meaning of the signals and the signalling processes for different switching procedures are documented. If a functional fault occurs, the maintenance staff can pinpoint the faulty unit by studying the signalling sequence, without having to have detailed knowledge of the software.

Control system

The control system in AXE 10 consists of the central processor and a number of regional processors. Fig. 6 shows the distribution of tasks among the various processors. The regional processors are placed together with the equipment that is to be controlled. The control and sensing functions carried out by the regional processors are usually simple, but require large computer capacity. When an exchange is extended, regional processors are added according to need. This way of distributing computer capacity gives good economy over a large range of exchange sizes. The central processor handles the more complicated functions and interworks with the regional processors via a bus system.

The control system is designed bearing in mind PLEX, the AXE 10 high-level language. There is good conformity between the PLEX phrases and the machine instructions. The control system is also adapted to the strict division of the software into modules and the formalized interworking between the modules. All these factors contribute to give system AXE 10 its good handling properties and high software reliability.

The control processor is duplicated and the two processor parts work in synchronism, one actively and the other in the standby mode ready to take over instantly if a fault occurs in the active part. There is continuous comparison of the results from the two processor parts, which makes it possible to detect faults immediately. A hardware fault in the active processor will not interfere with the traffic handling, because the standby part will take over the control without any interruption of the work. The faulty processor part then changes over to automatic fault finding.

AXE 10 in the network

Studies of the network structure and network economy when using PCM systems, digital group selectors and remote subscriber stages have been published previously[3].

Digital transmission systems, PCM systems, make it possible to increase the number of circuits on existing cables and in existing ducts. Expensive digging operations can be avoided or postponed. Consequently for the distances that are common in urban and rural networks, namely 5–50 km, the investment costs of PCM are often lower than the corresponding costs of physical or carrier circuits.

If the interconnection of the transmission links is also made digital, by means of digital group selectors, the expense of modulation equipment in the connection point is avoided. This increases the economical distance range for PCM to 0–100 km.

The use of remote subscriber stages, connected to AXE 10 via PCM systems and placed between the primary and secondary networks, greatly reduces the need of cable in the primary network. The extra costs caused by the remote placing are small compared with the reduction in cable cost. Remote subscriber stages can also be used to extend old exchanges in urban networks and to replace parts of old exchanges which have to be dismantled.

The advantages of digital technology that have been discussed here apply not only for AXE 10 but also for other digital systems with similar facilities. The unique feature of AXE 10 is that the same system is used throughout the network and for all sizes of exchange.

Figs. 1a–d illustrate how AXE 10 is built up of a system nucleus to which different subsystems are added for different applications. There are only small differences between different types of

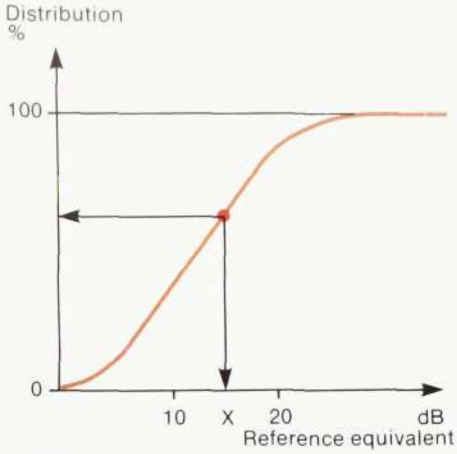


Fig. 7a

Definition of the distribution of the reference equivalent.

●The percentage of calls having a reference equivalent ≥x dB

The reference equivalent is a subjective measure of the quality of a connection set up between two subscribers. It defines the sound level of the speech expressed in decibels (dB) relative an international standard (NOSFER) set by CCITT in Geneva. The reference equivalent is affected by all attenuation and amplification on the connection and by the electrical and acoustic characteristics of the microphone and the receiver. It should be neither too high (= too low sound level in the called subscriber's receiver) nor too low (= too high sound level). The optimum value is about 10 dB.

The distribution of the reference equivalent for the calls set up during the busy hour gives a picture of the transmission quality of the network. The distribution takes into account the type of traffic and the traffic intensity, i.e. common types of connections have greater effect than rare types

exchanges and it has therefore proved useful to combine equipment for different applications in one and the same exchange. In the long run the number of different levels in the network hierarchy can be reduced in this way. The following examples illustrate the principle.

A local tandem exchange will have the same transmission properties as a transit exchange when the four-wire digital group selector is used in both exchanges. If certain function blocks in the charging subsystem, CHS, are added to the tandem exchange and its traffic routing and control subsystem, TCS, is supplemented by routing data for outgoing trunk traffic, the tandem exchange can work as a national transit exchange, fig. 1c. In this way the load on older transit exchanges in the network can be reduced.

A transit exchange can be supplemented with subscriber stages and subscriber services (subsystems SSS and SUS) and then becomes a primary centre with a combined local and transit function, fig. 1b. This is an economically attractive alternative for small towns and rural areas.

In order to further illustrate the possibilities of system AXE 10, some points regarding transmission, synchronization, signalling and charging are summarized below.

Transmission

Telephone networks normally have four-wire long-distance connections and four-wire transit exchanges. The changeover from four-wire to two-wire working takes place on the lines to the local exchanges, either in the transit or the local exchange. When four-wire digital group selectors are introduced in the local exchange, the four-wire work-

Diagram 7b shows the distribution of the reference equivalent for four different types of network shown in fig. 7c:

1. **Analog network, four-wire transit exchanges, four-wire trunk lines, two-wire local exchanges, two-wire lines between the local exchanges and between local and transit exchanges.**
2. **As in 1), but with an occasional PCM line instead of long two-wire lines.**
3. **As in 2), but with digital local exchanges always connected to the other exchanges by means of PCM.**
4. **Digital network, remote subscriber stages, only the subscriber lines remain analog and two-wire.**

Fig. 7b

The distribution of the reference equivalent for four different types of network

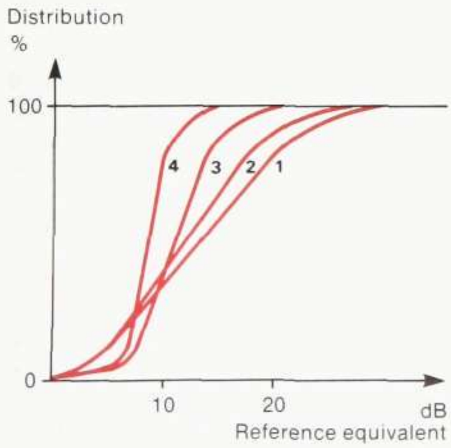


Fig. 7c

Four different types of network

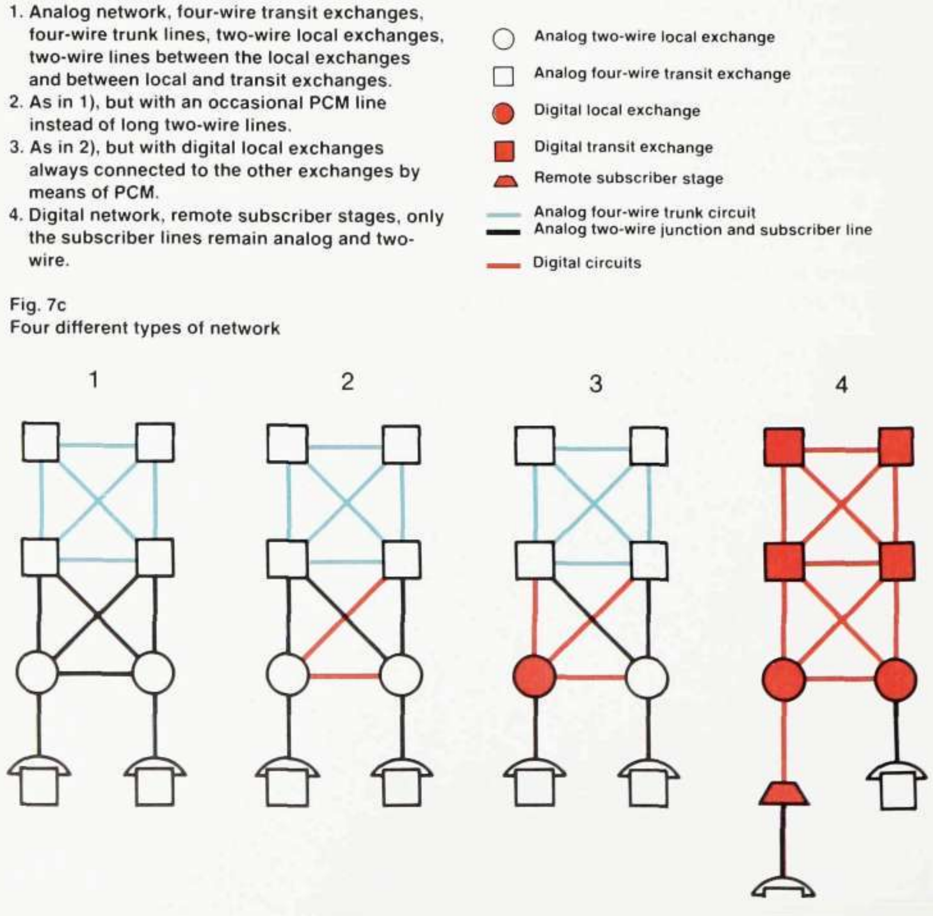


Fig. 8a
The most important network synchronization methods. Plesiochronous operation uses independently oscillating clocks with a high degree of accuracy. Automatic frequency control is used for the synchronous operation

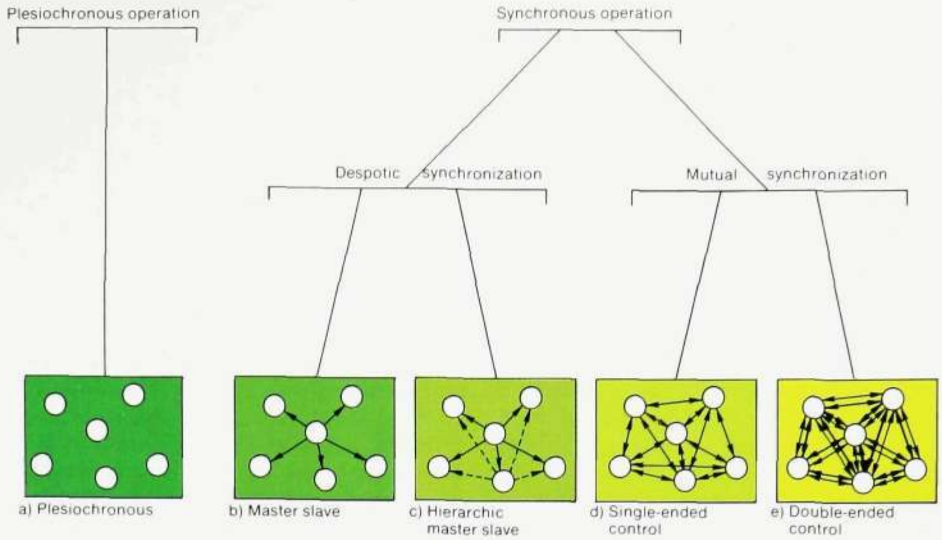
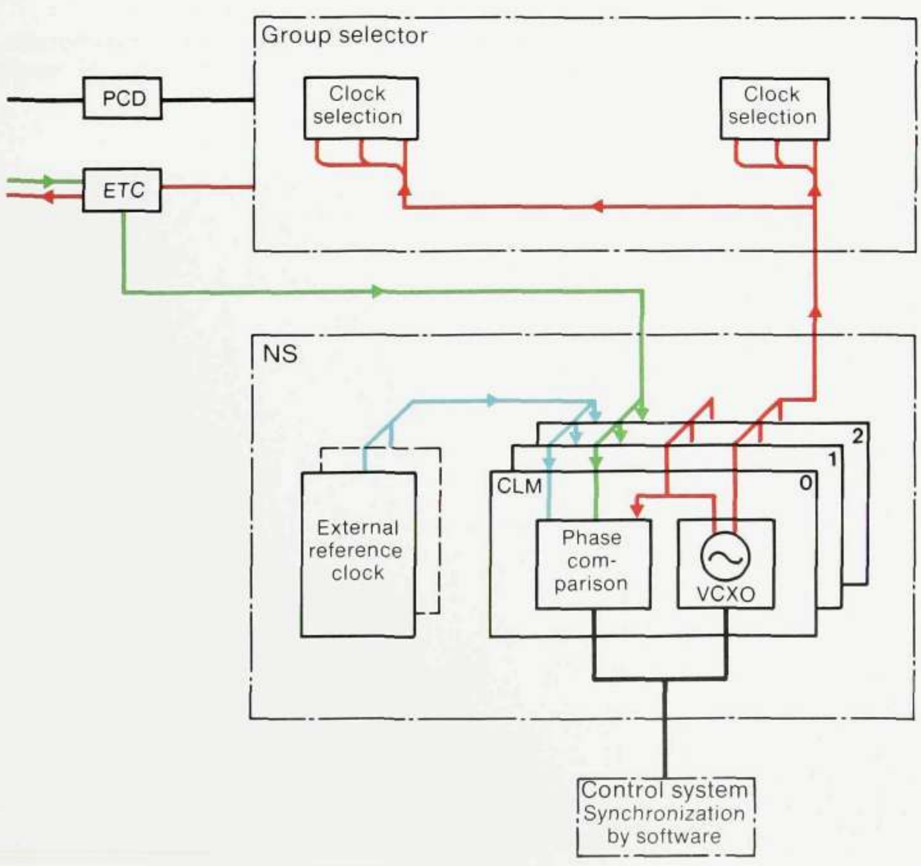


Fig. 8b
Synchronization in AXE 10

NS Function block for network synchronization
PCD PCM terminal device, for analog lines
ETC Exchange terminal circuit, for digital lines
CLM Clock module
VCXO Voltage controlled crystal oscillator
Clock control, internally and over outgoing digital lines
Plesiochronous and master synchronization
Slave and mutual synchronization



ing can be extended so that only the subscriber lines remain two-wire. This result can be achieved early in parts of the network if digital exchanges and PCM systems are introduced at the same time, figs. 7a–c.

One advantage of the extended four-wire working is that different calls in the network will have similar attenuation, measured between the subscriber line inputs. Any differences in attenuation are caused by the fact that analog four-wire lines have a certain, low attenuation. Circuits containing only digital links, which are interconnected with digital equipment, will not give different attenuation for different calls.

The differences in attenuation that remain for different calls are mainly caused by the attenuation in the primary and secondary networks. The differences can be reduced by connecting remote groups of subscribers via remotely placed subscriber stages. The primary networks between the parent exchanges and the remote stages then consist of a number of PCM links without any attenuation.

If two-wire junction lines have to be connected to digital exchanges with four-wire through-connection, it is advisable to check the distribution of attenuation in the network and take the opportunity to balance the two-wire lines well. Stringent demands determine the permissible attenuation and delay/frequency distortion of each four-wire loop. The margin for singing caused by oscillation must be adequate, the contribution of the loop to echoes must be low and the attenuation distortion must also be kept within certain, narrow limits. In addition the permissible number of four-wire loops in the whole circuit is limited.

Synchronization
Synchronism in a digital network means that all links in the network have the same bit rate. If the incoming rate on a circuit through the station is higher than the outgoing rate for the same speech direction there will not be time to send on all 8-bit words. A word will be lost at regular intervals and there is then a slip in the connection. The slip rate is dependent on the difference in speed between the two connected links.

The bit timing in AXE 10 is provided by a clock system, which for reasons of safety contains three clocks that work in parallel. The clock systems can be controlled in different ways by means of regulating circuits, depending on the synchronization plan used for the system[2,3]. The simplest way is the master-slave method, which means that one of the exchanges, for example a transit exchange, provides the timing for the other exchanges through the bit flows to these exchanges. Other methods give different types of mutual synchronization. Control information is then transmitted between the clocks in the network so that they affect each other. Finally there is plesiochronous operation, which means that the exchanges work independently of each other, but with such a high degree of accuracy, for example 10^{-11}, that slip occurs very seldom. Fig. 8a shows different synchronization methods and fig. 8b how they are implemented in AXE 10.

Signalling

A new telephone exchange must be able to interwork smoothly with the existing exchanges in the surrounding network. AXE 10 is designed to suit all types of markets and meet the signalling conditions of the different networks, which can vary greatly from case to case. LM Ericsson systems are operating in networks all round the world, satisfying very different national requirements, and the experience thus gained has been drawn upon in the designing of AXE 10. The influence exerted by different signalling characteristics has been confined to a limited number of function blocks, assembled in a separate subsystem, TSS.

Common channel signalling is an alternative for stored program controlled exchanges. This type of signalling offers many advantages for both local and trunk networks. The signalling between two exchanges takes place over a data link, which is used jointly by many speech channels. There are two different methods, associated signalling and non-associated signalling, fig. 10. Associated signalling is used for routes with many lines, which can carry the cost of their own signalling links. Non-associated signalling is used for small routes, which jointly use signalling links via a signal transfer point, STP, which is placed centrally in the network.

Common channel signalling can be used in both analog and digital networks, but it is particularly attractive in digital networks, since

- the signalling takes place in PCM time slots, at a transmission speed of 64 kbit/s
- no special modem equipment is needed
- the high bit speed enables a large number of speech channels to use the same signalling link
- large amounts of signalling information can be transmitted for each speech channel.

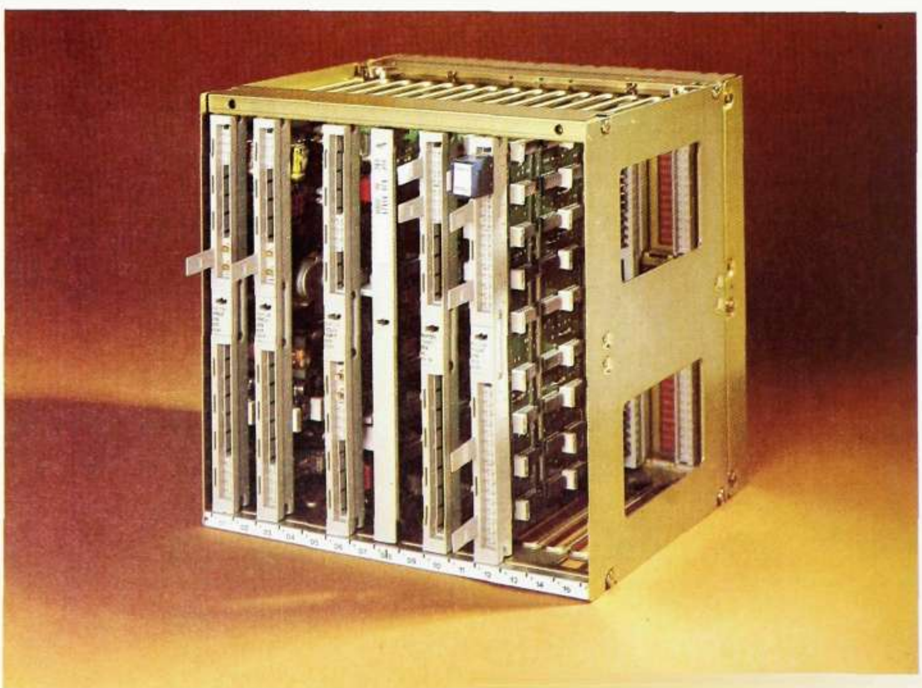


Fig. 9
Magazine for ETC (Exchange Terminal Circuit)

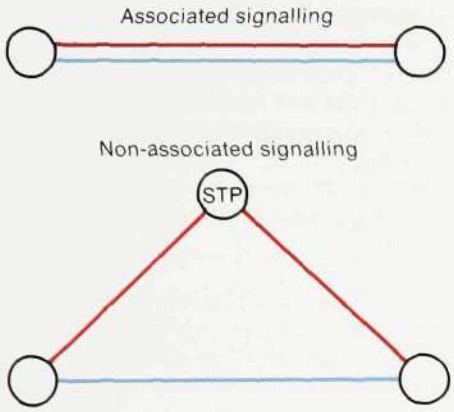


Fig. 10
The methods for common channel signalling

Signalling link
Speech path
STP Signal transfer point

Common channel signalling can of course be used for AXE 10. The system is primarily adapted to CCITT signalling system no. 7, for which a subsystem has been developed, designated CCS. The subsystem has all the functions that are required for sending and receiving over the signalling links, for example procedures for error supervision and requesting a repeat transmission if a fault occurs. If there is a break on a signalling link it will be detected by CCS and the traffic will be switched to a standby link. The signalling links can be reallocated on a routine basis, either locally from the terminal equipment in an exchange or centrally from an operation and maintenance centre.

Charging

The charging subsystem, CHS, in AXE 10 is provided with full traffic analysis facilities. It can be used in all types of exchanges. For example, the choice of tariff for any outgoing call can be made in the local exchange. Alternatively the choice of tariff can take place in a superior transit exchange in the same way as in LM Ericsson's crossbar systems. The charging information is then transmitted to the local exchange by means of metering pulses, or is recorded centrally in the transit exchange, toll ticketing.

With pulse metering the pulses step the subscriber's counter in the data store. For reasons of security the contents of the data store are copied regularly on to a cassette tape. With toll ticketing the A-number, B-number, date, time and duration of the call are recorded. The data are regularly output on to a magnetic tape or a cassette tape. The tape with the charging data is then transported to the administrative centre of the network for processing. Alternatively the charging data can be transmitted from the AXE 10 exchanges to the administrative centre over data links. The transmission is then remotely controlled from an operation and maintenance centre.

Operation and maintenance

The operation and maintenance of telephone networks with AXE 10 exchanges has been described in detail in previous articles[1,5].

The operation and maintenance of AXE 10 is simple. It is only in exceptional cases that staff with comprehensive knowledge of the system have to intervene. The basic concept is that the available, ordinary staff who are trained in the maintenance of crossbar systems, and who undergo a supplementary course in AXE 10, should be able to carry out the normal operation and maintenance of AXE 10 with the operational manual as the main aid.

The quality of service is checked by means of supervision of all connections through the exchange. This provides

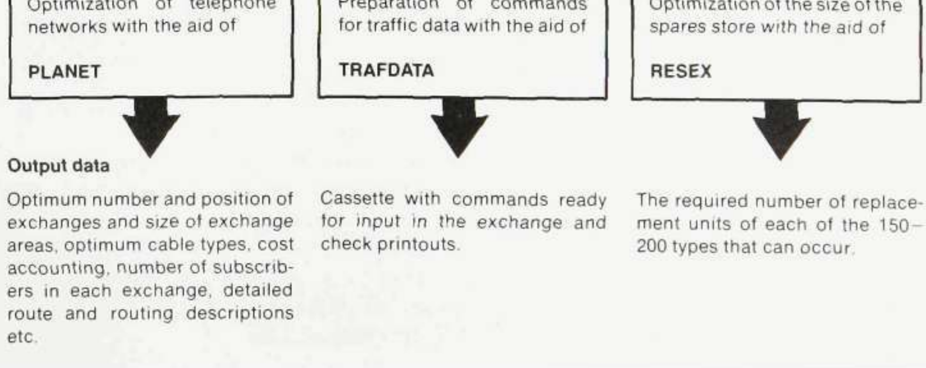


Fig. 11
Some ADP aids for administering networks and exchanges. These aids simplify the work and raise the quality

more complete information than the routine generation of test connections. It also provides information concerning subscriber behaviour. The equipment and software for routine testing have been reduced to a minimum. Thus the personnel are not burdened with routine tests and the subsequent analysis work.

The strict division of the system into function blocks with standardized signalling interfaces means that new functional blocks can be introduced and function blocks can be replaced without the other blocks being affected. Consequently functional changes can be carried out during operation without disturbing the traffic in progress.

The operation and maintenance subsystem OMS in AXE is equipped with a wide range of functions and procedures for supervision, fault locating and clearing, collecting statistics and administration. In these respects the system is designed to work independently in the network and to be operated by the operation and maintenance staff in the exchange. AXE 10 also contains comprehensive functions for remote control of these activities.

LM Ericsson's operation and maintenance system AOM 101 is used for such remote control. It provides many facilities for organizing the activities of a number of centres specializing in different types of work, such as maintenance of subscriber lines, sales, traffic observation etc. These centres can be situated in different places to suit the activity in question.

Auxiliary systems for AXE 10

A number of auxiliary systems have been developed for AXE 10. These make it easier for administrations to administer the networks and exchanges[6]. By means of these auxiliary systems, fig. 11, it is possible to

- optimize different types of telephone networks
- prepare floor plans, cabling information and other documentation for AXE 10 exchanges
- prepare commands in order to equip the exchanges with traffic data for the initial start and major operational changes
- provide operational support in cases of complicated faults, in the planning and introduction of new or modified functions and also in the administration of fault reports received from the network
- simplify the stocking of spares by optimizing the position and size of the stores.

Some other aids that should also be mentioned are training packages for AXE 10 and documentation for exchanges and work centres.

Conclusion

The basic aim when developing system AXE 10 was to create a uniform and flexible system that was easy to operate and which remained up to date. As can be seen from this article this aim has been achieved, thanks partly to the clear and regular structure of the system.

The basic development work on AXE 10 has now been completed and the system has been adapted to suit several different markets. However, research and development work is proceeding in step with technical advances, so that new developments in the fields of components, processor technique, network structure and subscriber services can be utilized.

System AXE 10 has now been introduced or is being introduced in more than 20 countries.

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Operation and Maintenance Functions in ASB 100 and ASB 900

Rolf Mörlinger

ASB 100 and ASB 900 are modern, stored program controlled PABXs for 20–108 and 60–960 extensions respectively. The stored program control, SPC, is utilized to provide the systems with advanced functions, not only for telephony but also for operation and maintenance. The basic principles are the same for the two systems, but certain functions that require large program volume are provided only in ASB 900.
This article gives a detailed description of the operation and maintenance functions in ASB 900, with comments on the features of ASB 100. General descriptions of ASB 100[1] and ASB 900[2] have previously been published in Ericsson Review.

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The PABXs ASB 100 and ASB 900 belong to the same system family. They are both built up using the cabinet construction practice BYB 201, are controlled by identical miniprocessors, an APN 163, and have identical operators' sets. There are also great similarities as regards the component ranges, circuit designs, programming methods and facilities.

Fig. 1 shows the block diagram for ASB 900, which, with a few exceptions, is the same as the diagram for ASB 100. The maximum number of devices is of course considerably higher for ASB 900 than for ASB 100. Moreover ASB 900 can be equipped with MFC receivers for direct in-dialling.

The memory technologies are different in the two systems. ASB 900 has random access memories for both programs and data. A cassette recorder is built into the exchange and provides memory back-up. ASB 100 has programmable read only memories for the programs and battery-protected random access memories for the data.

Both systems are normally equipped with a single control system, but when a very high degree of reliability is required, the control system, can be duplicated in ASB 900, using the active/passive method.

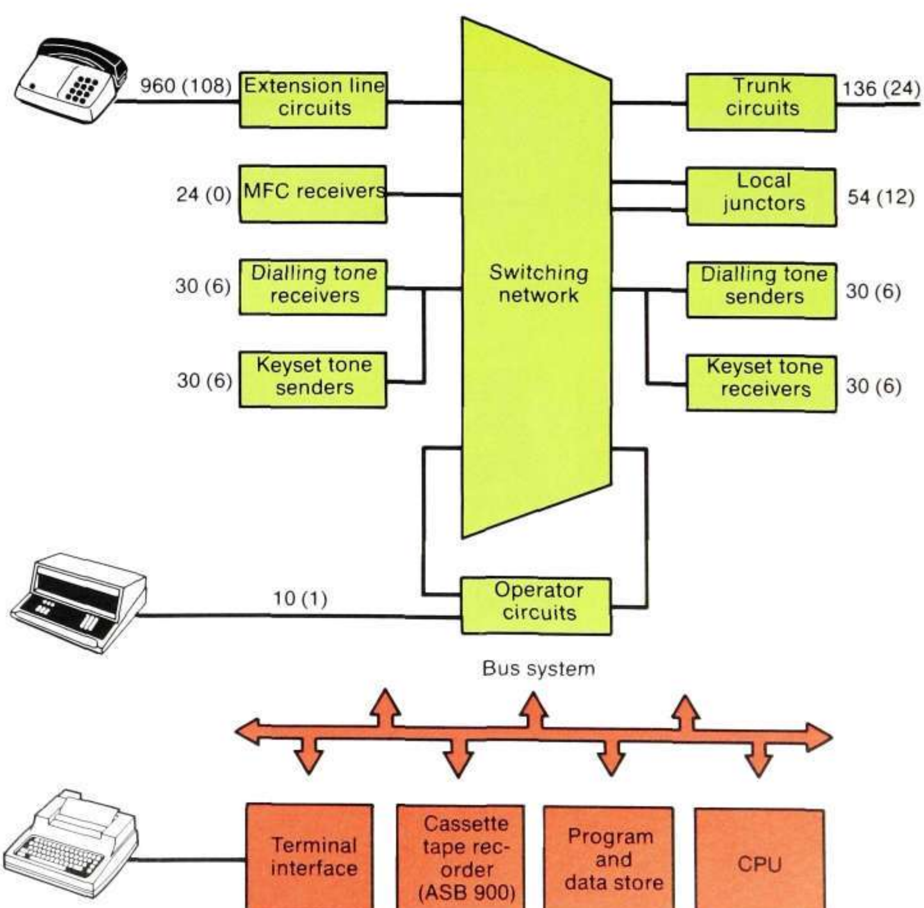

Fig. 1
Block diagram of ASB 900 and ASB 100, giving the maximum number of devices of each type. The figures in brackets apply for ASB 100

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Man-machine communication

Efficient man-machine communication is a prerequisite for rationel execution of most operation and maintenance functions in an SPC exchange.

All communication betweeen the operation and maintenance staff and the ASB systems takes place via standard type I/O terminals. Portable typewriter terminals are normally used. The man-machine laguage is based on English and is a subset of the CCITT MML (Man-Machine Language). The language consists of commands, acknowledgements and edited printouts.

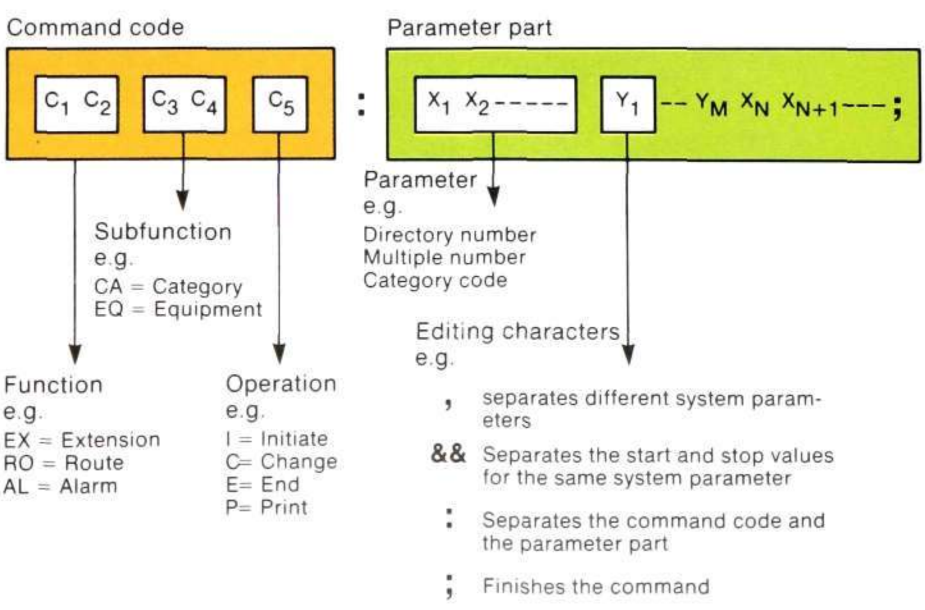
Both systems have commands for
- the handling of exchange data
- fault localization
- the verification of repairs
- traffic recording.

In addition ASB 900 has commands for minor program changes.

A command consists of two parts, a command code and a parameter, see fig. 2. The command codes consists of five-letter mnemonics.

Each command in ASB 900 can be allocated to any one of six possible authorization classes, and each such class can be given an arbitrary pass word of up to 6 characters. Different personnel categories can thus be given access to different parts of the total quantity of commands.

Fig. 2
The structure of commands



The standardized I/O interface of the ASB systems makes it possible to connect up to remote terminals via modem circuits. The most economical method, shown in fig. 3, is then to use switched connections. In this way changes in the exchange data, fault finding and traffic recording can be carried out from a distance, and operation and maintenance centres can be set up, each of which serves a large number of PAXBs.

As a mater of curiosity it may be mentioned that when the first ASB 100 exchange was installed in Belgium (1978), a fault in the exchange could be localized and the exchange data programmed from Stockholm, Sweden.

Loading programs and data

The ASB 900 software is loaded into the exchange store from the built-in cassette tape recorder. The program tape does not contain any information regarding the store addresses of the various program units, only their numbers. The reason for this is that the system has automatic functions for store allocation, which makes it possible to load the various program units in any order, and in one or several batches.

The exchange data are loaded by means of commands from an I/O terminal, either on the spot or prepared in advance in order to reduce the amount of work needed on site. In the latter case either the PABX itself or a separate ASB 900 control system is used to prepare a loading tape, which contains both programs and data. It then takes only three to four minutes on site to load the system from such a tape.

In ASB 100 the programs are stored in permanent memories of the PROM type, and only the exchange data need be loaded on site. In the case of a mains failure the exchange data are preserved for up to 100 hours with the aid of batteries mounted on the memory boards. As an alternative the exchange data can therefore be programmed elsewhere if the transport to the installation site is

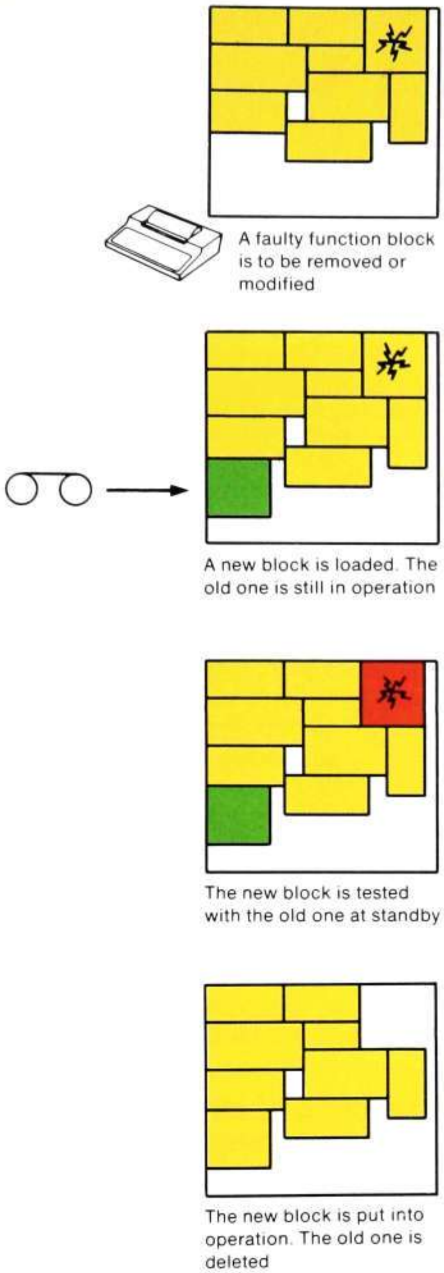


Fig. 4
The software for ASB 900 can be modified or extended without disturbing the operation of the exchange

Modifying and supplementing the software

A modified or new program unit can be loaded in ASB 900 without the other program units having to be reloaded. As can be seen from fig. 4, it is also possible to test the modified or new function on site before it is put into operation. This is done by marking the program unit in such a way that it is only accessible to test traffic. Small program changes can also be carried out from an I/O terminal by means of commands, so-called patching.

Up-to-date information regarding the state of the PABX software is useful after any change in the programs. Printout of the article number and revision code of all program units included in an ASB 900 is initiated with a command.

Handling of exchange data from and I/O terminal

As has already been mentioned, commands are provided that make it very easy to handle data concerning, for example:
- extensions
- number analysis
- routes
- abbreviated dialling
- group hunting.

As far as possible, the commands used are identical for the two systems. A few commands for extension data are described below in order to illustrate the simplicity of handling.

If, for example, a new extension with the directory number 1234 and the category code 32010203 is to be connected to

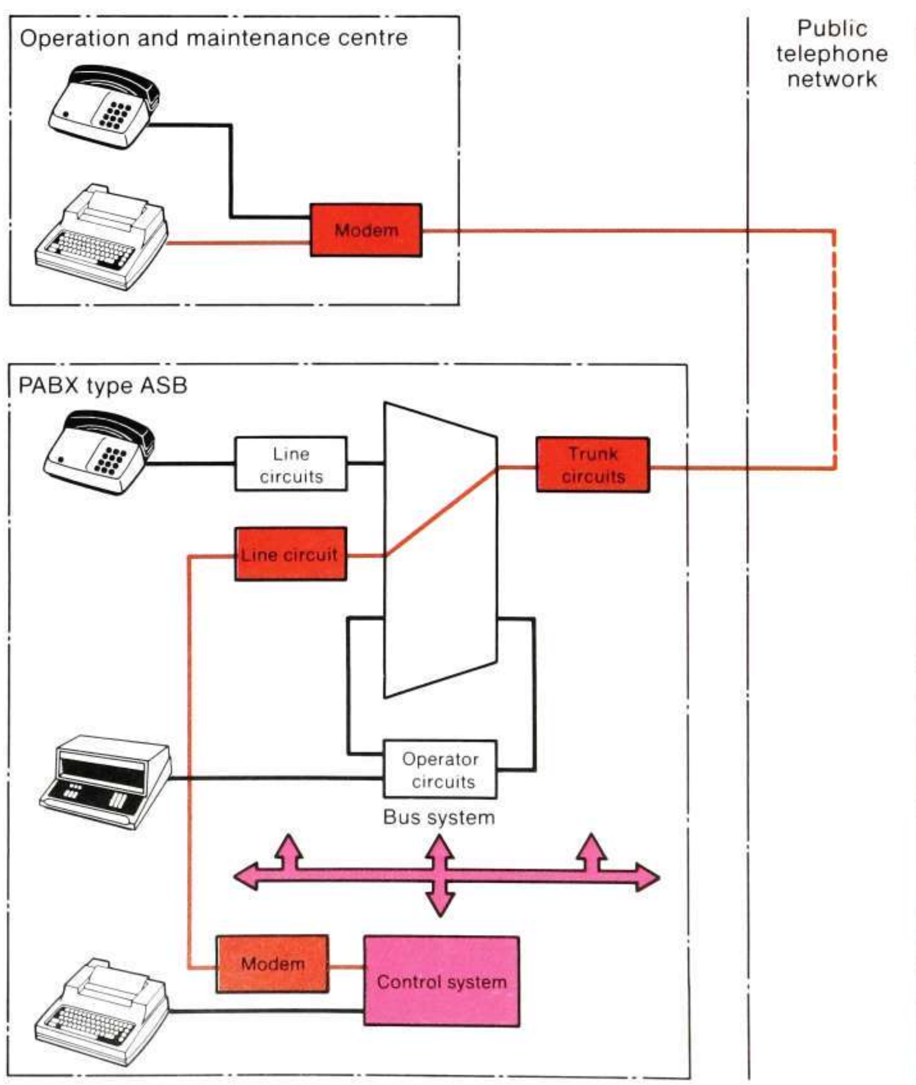


Fig. 3
Centralized operation and maintenance. The handling of exchange data, fault localization and traffic recording for ASB 900 and ASB 100 can be carried out from an operation and maintenance centre

Fig. 5
I/O terminals are used in the ASB systems, for example for programming the exchange data. The terminal in the picture is portable and weighs only 5 kg

multiple position 0001, the following command is given:

EXTEI:1234,0001,32010203;

The command code means EXTEnsion Initiate.

When data are first loaded into a new PABX, series of extensions with consecutive directory numbers and common category codes are often connected to consecutive multiple positions. The command above can then be used in a more powerful way:

EXTEI:1241&&1244,0002,32000103;

This command means that four extensions with the directory numbers 1241 up to and including 1244 and the category code 32000103 are connected to the multiple positions 0002 to 0005. This command can very well be used even if any of the extensions has a different category code, since this can easily be corrected afterwards with the command:

EXCAC:1242,36000103;

The command code means EXtension CAtegory Change, and changes the category code of extension 1242 to 36000103.

If a printout of the data for the extensions connected to multiple positions 0001–0005 is desired, the following command is given:

EXEDP:0001&&0005;

The command means EXtension Equipment Data Print and the system gives the following printout:

EXTENSION DATA

EQ NO	DIR NO	CATEGORY
0001	1234	32010203
0002	1241	32000103
0003	1242	36000103
0004	1243	32000103
0005	1244	32000103
END		

There are also commands for
- moving an extension to a new multiple position
- printout of extension data in directory number order
- printout of free directory numbers and multiple positions
- erasing extension data.

The systems automatically control that the data that are being input are not contradicted by the data already in the store. For example, it is impossible to allocate the same directory number to two different multiple positions, or to give an extension a directory number that falls outside the extension number series that is defined in the number analysis data.

The data that describe the actual hardware equipment need not be programmed into the ASB systems. These data are input by automatic detection of the equipment and can also be output on command. This feature saves time both when taking the PABXs into service and when extending them.

Handling of exchange data from the operator's set

The ASB systems offer a number of sophisticated telephone functions. In order to be able to use them rationally it must be possible to change the corresponding exchange data easily and efficiently. It would not be rational to have operating staff visiting the PABX for this purpose. The systems are therefore designed so that the PABX operators are able to carry out the most common data changes from their sets. One or two-digit function codes are then used instead of command codes, fig. 6. In this way data for the following functions can be programmed:
- number group
- allocation of category to extensions
- common and individual abbreviated dialling
- trunk call discrimination
- group hunting
- call diversion
- night service connection.

However, the operation staff can, by means of a command from an I/O terminal, limit the facilities of the telephone operators to an optional part of the above-mentioned functions.

Function code — Directory number — Category code

***5*1234*36000103#**

Fig. 6
The operators can carry out the most common types of data changes from their sets. The illustration shows the changing of extension category

tion of frequent data changes in ASB 900, facilities have been provided for carrying out the programming of individual abbreviated dialling and the follow-me function from extensions with push-button dialling.

Supervision

ASB 900 is equipped with a large number of automatic supervisory functions.

The control system is supervised in the following ways:

- time supervision of the program execution. This function, which is realized in hardware, detects if the program execution gets into a loop state or stops completely
- error rate supervision (parity faults, improbable program and hardware signals etc.)
- periodic, automatic function testing of:
  - processor
  - program and data store
  - cassette tape recorder
  - bus system
  - circuits for automatic changeover between the control systems.

In PABXs with a duplicated control system the above-mentioned supervisory functions are carried out by both the active and the passive control system in order to ensure, as far as possible, that the passive system is in full working order in case it becomes necessary to change over.

The switching system is supervised in the following ways:

- periodic, automatic function testing of
  - tone and ringing generators
  - senders and receivers for the dialling tone
  - senders and receivers for the key-sending tones
- error rate supervision per
  - trunk circuit
  - local junctor
  - link in the B stage of the switch
  - MFC receiver for direct in-dialling traffic.

The error rate supervision is carried out with the aid of data from the actual traffic. Each device that is being supervised is allocated a counter in the data store. The counter is stepped down towards zero once for each seizure and stepped up an adjustable number of steps for each disturbance. By disturbance is meant, for example, time releases and very short holding times. The behaviour of the extensions will of course sometimes cause the counter to show greater quantities than the ideal value of zero, but the probability is very large that it is only real faults that will cause the counter to reach the alarm limit, which is set to 255.

Fuses and battery equipment are also supervised in ASB 900.

For obvious reasons the mean time between faults will be longer in ASB 100 than in the considerably larger ASB 900, and if a fault occurs it is usually soon discovered by the users. The automatic supervision in ASB 100 has therefore been limited to:

- time supervision of the program execution
- error rate supervision of the control system
- supervision of the battery charging equipment.

Automatic action when a fault is detected

The standard action when a fault is detected is that the system gives an alarm in the way described in the next section.

If the fault concerns the control system an attempt at restart is made automatically. In ASB 900 this includes the reloading of programs and data from the cassette tape recorder. In PABXs with a duplicated control system automatic changeover to the standby system will also take place.

If a fault is detected during the supervision of individual devices in ASB 900, the faulty device is marked as the last choice. This is done in order to limit the effect of the faulty device on the traffic.

Alarm functions

Each of the supervisory functions in ASB 900 has been allocated an alarm code in the system. Thus the error rate supervision of trunk circuits has one code, the same function for local junc-

tors has another code etc. Each such alarm code can then be assigned to any one of three fault alarm classes, which can have the following significance:
Class 1: Immediate action
Class 2: Immediate action during daytime
Class 3: Action at a suitable time

When a fault is detected the alarm class, alarm code and identity of the faulty unit are stored in an alarm table in the exchange data store. The alarm is indicated by means of a lamp on the operators' sets, but it can also be indicated on a separate alarm panel, which contains one lamp per alarm class.

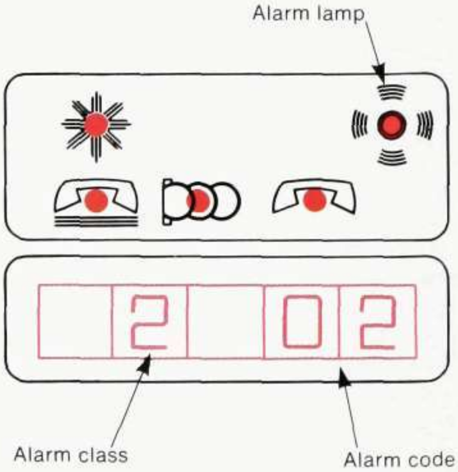
The operator can order the system to indicate alarm class and alarm code when the alarm lamp is lit. These data are presented on the digit display on the operator's set. The operator passes on this information to the maintenance section, which is then able to send out a man to the PABX with the necessary spare parts, at a time appropriate for the seriousness of the fault. The maintenance man is also able to obtain a printout of all the information in the alarm table via an I/O terminal, fig. 7.

ASB 100 has only a few alarm functions and the sources of the faults are indicated by means of the alarm lamp in the operator's set in the following way:
- Steady light — Program execution alarm
- Slow flickering — Error rate alarm
- Rapid flickering — Battery charging alarm

Fault localization and clearing

The alarm data provided by ASB 900 normally provide all the information that is required to pinpoint the faulty unit. In addition, both ASB 900 and ASB 100 are equipped with facilities for ordering

If the system detects a fault, an alarm lamp is lit in the operator's set. The operator can then order the system to indicate the alarm class and alarm code. The alarm code gives the type of device and type of fault



The maintenance man can, via an I/O terminal, request a printout giving the alarm class, alarm code and name and number of the faulty device

ALDAP;
ALARM DATA

CLASS	CODE	DEV TYPE	DEV NO
2	02	TSC	001

END

Fig. 7
Alarm functions in ASB 900

– program controlled function testing of
  - processor
  - program and data store
  - local junctors
  - tone senders
  - tone receivers
– controlled test connections
– printout of device states.

When a fault has been localized with the aid of alarm data or any of the above functions, the following repair routine is normally followed:
– blocking the device or devices on the faulty printed board assembly
– changing the faulty printed board assembly
– testing the new printed board assembly with the aid of program-controlled function tests or controlled test connections
– deblocking the device or devices on the new printed board assembly.

ASB 900 is also equipped with sophisticated functions for localizing program faults. For example, it is possible to set up break points at different levels in the program system by means of commands. When such a break point is passed in the program execution, a printout is obtained of the contents of the central processor registers and a number of previously specified data areas.

Traffic recording

Both in ASB 900 and ASB 100 it is possible to order, by means of commands, the collection and printout of traffic recording data for all device groups that carry traffic, namely
– routes
– local junctors
– operators' sets
– tone senders and tone receivers.

The following data are collected in ASB 900 during 15 minutes long recording periods, the number of which is specified in the start command:
– the traffic, in erlangs
– the number of seizure attempts
– the number of cases of congestion towards outgoing routes and local junctors
– the number of calls queueing for access to operators, tone senders and tone receivers
– mean length of the queues to the operators.

The first printout takes place after an hour and contains the compiled data from the four first recording periods. After this a printout is made every 15 minutes with data for the last hour. Thus printout no. 2 contains data from recording periods nos. 2–5.

The traffic recording data can be stored on a cassette tape recorder for a later printout instead of an immediate one. It is also possible to order the system to start the traffic recording automatically at a certain time, for a number of consecutive days.

The need of traffic recording is considerably less in ASB 100. In this system the function is limited to the collection and printout of the amount of traffic per device group. In this case also, the data are collected in periods of 15 minutes, but the printout after each such period contains only the data for the latest period.

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Antenna System for the EXOSAT Satellite

E. Roland Karlsson

EXOSAT is a satellite for scientific observations. It is equipped with instruments for measuring x-ray-radiation in space. The instruments will be aligned by orientating the whole satellite towards the x-ray source concerned. An omnidirectional antenna system is therefore essential for communication with earth.

The antenna system for EXOSAT has been developed and manufactured by LM Ericsson. The system consists of two antennas, each of which radiates over more than half a sphere. The antenna elements are cone-shaped spirals. Each antenna consists of four spirals with associated feeding device. In this article the design of the antenna elements and the optimizing of their position on the satellite are described, as well as the extensive measurements of performance that have been carried out using LM Ericsson's new automatic antenna measurement equipment.

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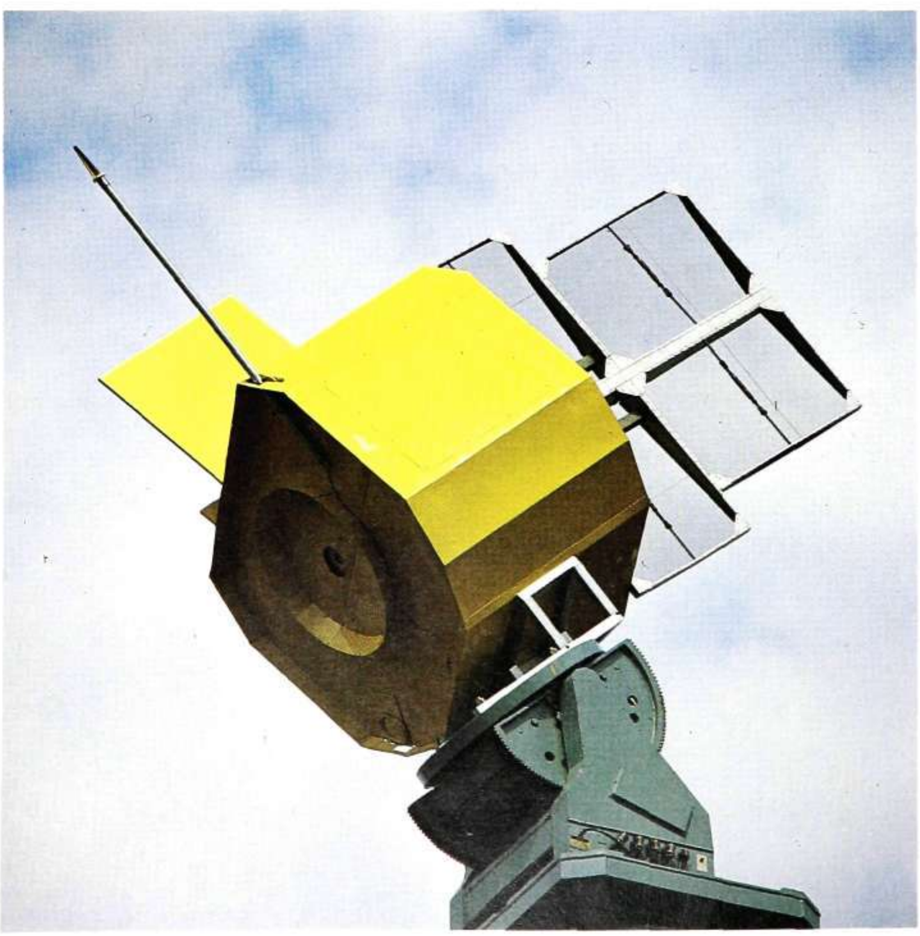
Fig. 1
A model of the satellite with an antenna mounted on a 2 m long boom, top left



EXOSAT is a triaxially stabilized satellite, which will orbit the earth in a strongly elliptical path. Its greatest distance from earth will be 200 000 km. The satellite is equipped with various instruments for measuring x-ray-radiation in space. The instruments will be aligned by orientating the whole satellite towards the actual x-ray source.

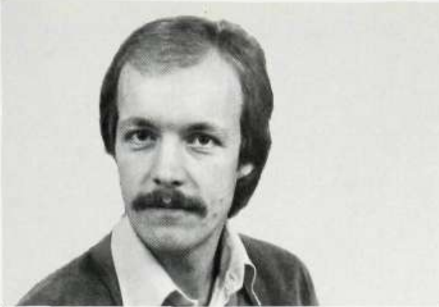
The satellite is being developed for the European Space Agency, with the West German company Messserschmitt-Bölkow-Blohm as main contractor. During the spring of 1977 LM Ericsson was given the task of designing the antenna system. The measurements of the performance of the completed units for the satellite were completed in January 1980. The launching is planned for the spring of 1981.

The antenna system will be used for two-way traffic. Control data for the satellite will be sent from earth, and measuring data and information regarding the different satellite subsystems are to be transmitted to earth.

Requirements for the antenna system

The position of the satellite relative earth is determined by the direction to the x-ray source concerned and the orbit of the satellite. This means that the satellite can be aligned arbitrarily in space. The antenna system must therefore be omnidirectiontal. However, the satellite movements are slow, which means that the requirement for an omnidirectional antenna can be moderated slightly, and it is therefore possible to use two antennas, each of which radiates over more than half a sphere, if the switching between such antennas can be done quickly enough.

The antenna system must operate in the S-band, at a frequency of 2.1 GHz for the link up to the satellite and 2.3 GHz in the other direction. The polarization must be circular. The lowest power gain of the antenna in the critical downward direction is −3 dBi and in the upward direction −8 dBi. (The antenna gain is measured relative an ideal omnidirectional antenna; i = isotropic). These limits are to be met for all possible positions of the large panel of solar cells, which will always be turned towards the sun, fig. 1. This panel causes strong reflections which worsen the performance of the antenna system. Since the satellite will sometimes have to carry out measurements towards the same source for a long time, extreme temperatures will prevail. The lowest temperature for an antenna shadowed from the sun is cal-



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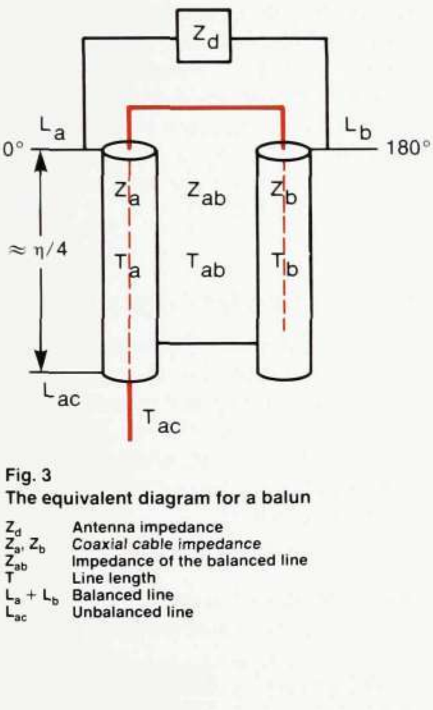


Fig. 3
The equivalent diagram for a balun

Z_d	Antenna impedance
Z_a, Z_b	Coaxial cable impedance
Z_{ab}	Impedance of the balanced line
T	Line length
$L_a + L_b$	Balanced line
L_{ac}	Unbalanced line

that the antenna will be electrically heated. The highest temperature for an antenna in the sunlight will be about +100°C.

Antenna design

Choice of antenna type

When a spacecraft is to be equipped with an omnidirectional antenna system which operates at wavelengths that are several times shorter than the dimensions of the spacecraft, several antenna units must be used, placed several wavelengths apart. This causes interference in the areas where the antenna diagrams overlap. In the case of EXOSAT such interference is avoided by using only one antenna unit at a time. The two antenna units point in opposite directions, and the active unit is being selected by a switch.

All radiation that reaches the satellite is reflected against it and causes undesirable disturbances in directions where radiation is wanted. In order to reduce such disturbances, each of the two EXOSAT antennas is placed at the end of a separate 2 m long boom. One of the antennas can be seen in the top left-hand corner of fig. 1. Positioning the antennas in this way also helps to reduce the radiation back towards the satellite. In this position the radiation is at a maximum in an area that is 5° larger than a half sphere and at a minimum in a 130° cone backwards.

The most suitable type of antenna was considered to be a type of spiral antenna usually called a resonant quadrifilar helix. This consists of four short spirals, which are fed at the same amplitude but at different phases, namely 0°, 90°, 180° and 270°.

Antenna optimization

A computer program intended for analyzing antennas built up of wires was used to calculate the performance of several different antenna alternatives. The parameters that were altered were the number of turns per spiral and the pitch, radius and cone angle of the spiral. The final spiral shape is shown in fig. 2. The structure is only partly resonant, approximately 10% of the current being reflected where the spirals are short-circuited at the base.

Feeding

The antenna spirals can be fed either from the front or the rear. Front-end feeding gave the best result. The feeding cables must therefore be placed in the centre of the antenna. Fig. 2 shows how this is done. The feeding network that provides the four spirals with the correct signals consists of a 90° hybrid and two baluns (balancing units). The 90° hybrid has one input and two outputs. There is 90° phase difference between the two outputs. The hybrid is manufactured using stripline technology and consists of a laminate with seven layers. On each side there is, from the outside in, an earth plane, an insula-

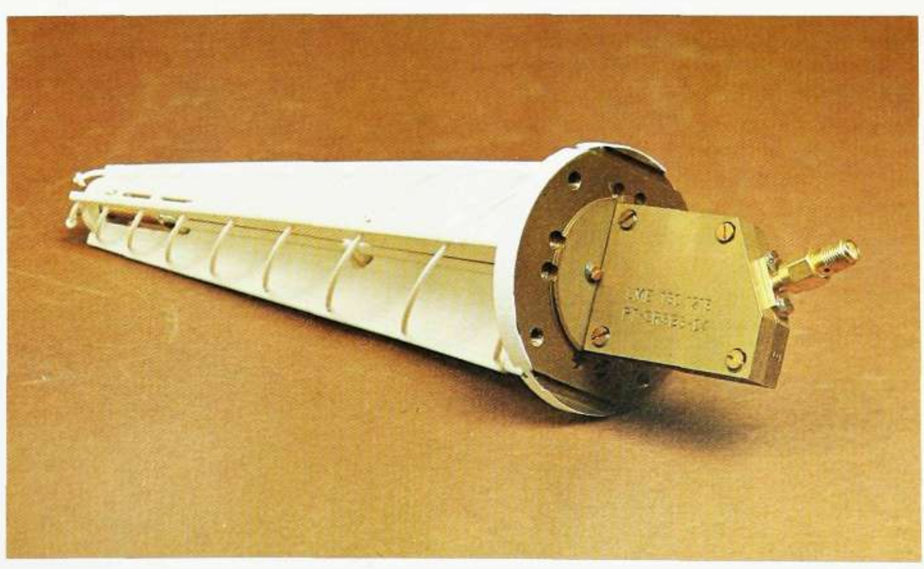


Fig. 2
The antenna.
The 90° stripline hybrid is placed in the housing which is fixed to the base. One of the coaxial cables that feed the antenna can be seen along the centre of the framework that supports the antenna spirals.

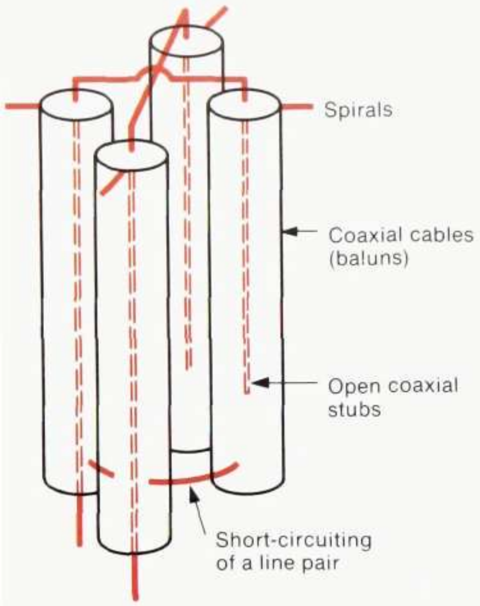


Fig. 4
The coupling of the balun system, at the front end of the antenna, to the four spirals

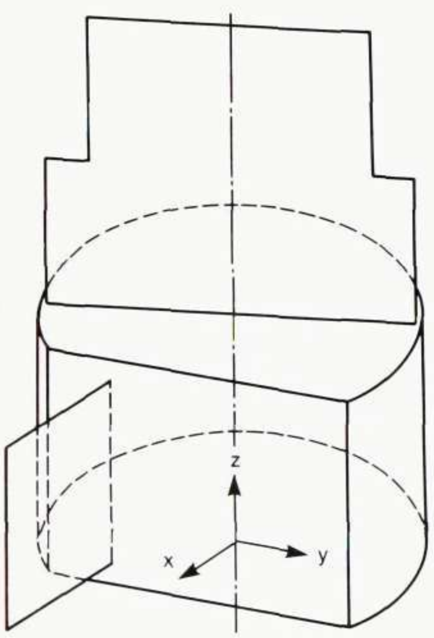


Fig. 5
Schematic drawing of the mathematical satellite model that was used for the theoretical calculation of the optimum antenna location

tor and a conducting plane, and in the centre a thin insulator. The balun, fig. 3, consists of a coupling between a symmetrical and an unsymmetrical conductor, which gives the desired 180° phase shift for opposite spirals in the antenna. Fig. 4 shows how the two coaxial cables from the hybrid are connected to the antenna wires and to the coaxial cables in opposition. The centre conductors in the cables in opposition are only a few centimetres long. The screens of the coaxial cables are used as short-circuited pairs in order to obtain impedance matching between the feeding network and the antenna spirals.

Manufacture

The antenna spirals are formed of beryllium copper in a special tool, in which they are also heat treated in order to avoid deformation during assembly and handling. The spirals are mounted on a framework of glass fibre reinforced plastic, which in turn is placed on an aluminium base. This base also forms the housing for the stripline circuit in the feeding system. The part of the antenna which is exposed to space is to be coated with a special white paint in order to obtain optimum temperature conditions.

Antenna location

The antennas must be placed within certain limited areas so as not to interfere with other systems in the satellite. Computer calculations were carried out to determine the optimum location. The calculations were based on geometrical diffraction theory. Several different positions were tried, the main aim being to find the ones that gave the lowest interference in areas with a low signal level. The satellite body was represented by the mathematical model shown in fig. 5 for calculation of the contributions due to direct, reflected, diffracted, doubly reflected and reflected and then diffracted radiation etc. A total of 61 radiation contributions were added. Furthermore the calculations had to be repeated for different positions of the solar panel. Fig. 6 shows an example of the results obtained, with only the reflected radiation shown for the sake of lucidity. The final antenna positions were determined by measurements with the antenna mounted on a model that was accurate from an electrial point of view, fig. 1. The measurement results conformed well with the calculation results.

Performance testing

Functional and environmental tests were carried out on the different parts of the antenna system in order to check the performance of the system. The tests were carried out in accordance with a previously prepared specification and in the following order:

- initial electrical functional testing of each unit
- checking of the mass, position of the centre of gravity and moment of inertia
- vibration testing with sinusoidal vibration and noise vibration (random)
- vacuum and temperature testing
- final electrical functional testing of each unit
- measuring of the radiation diagram with the antenna mounted on a model of the satellite.

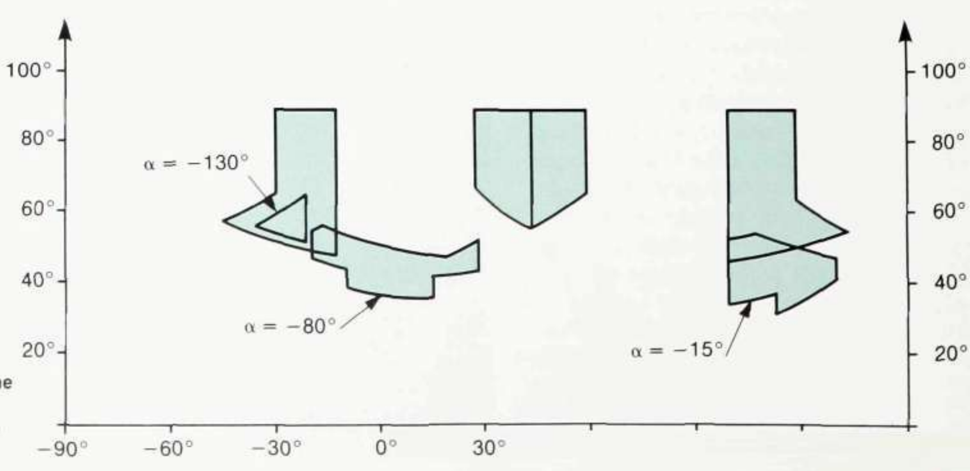
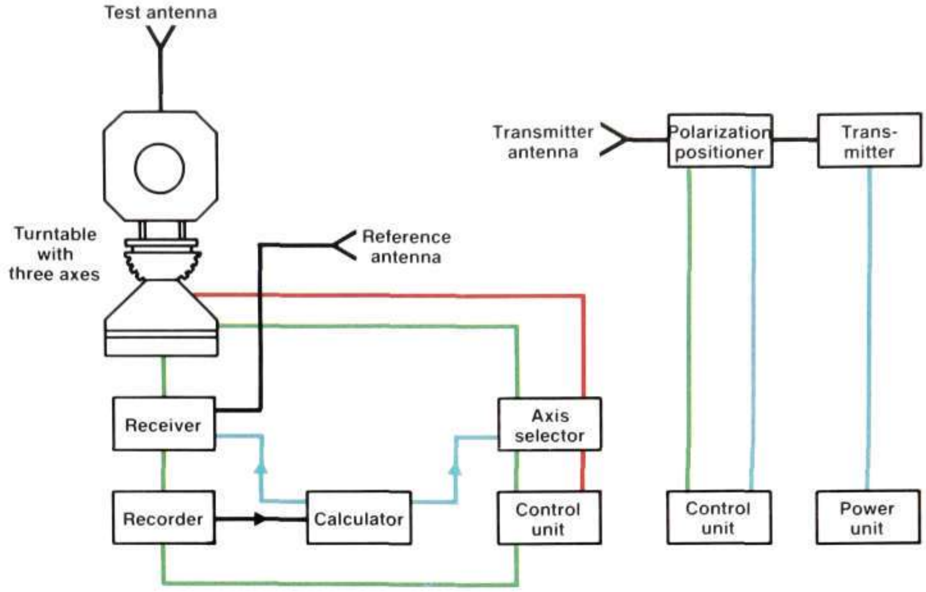


Fig. 6
Example of areas where reflected rays occur. The areas indicate different parts of the satellite which have caused reflections. The α values are different angles of the solar panels

Fig. 7
The connection for the radiation diagram measurements



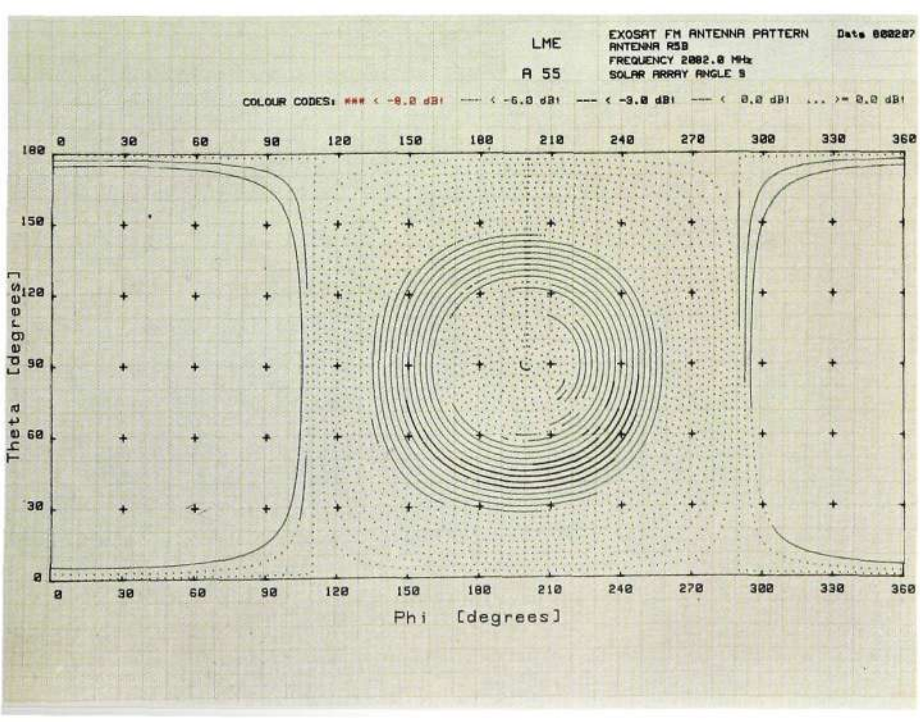
The radiation diagram was measured with the antenna mounted on the same model as was used for the optimizing of the antenna position. The model was mounted on a turn table. Fig. 7 shows a block diagram of the measurement set-up.

The power gain of the circularly polarized antenna was measured at one point using a linearly polarized rotating transmitter antenna. The measurements were then continued using a circularly polarized transmitter antenna, the first measurement value being used as a reference for the subsequent values.

The measurements were controlled by a computer, for which a measuring program and an evaluation program had been compiled. The program stepped one angle in a spherical coordinate system in steps of 2.5° at a time. The satellite was rotated one turn for each step.

The measurements were continuous, and a recording was made for every second degree. The power levels and frequencies were checked before each measurement stage and were adjusted by the program when necessary. Each stage was also printed out in the traditional way by an antenna diagram printer, so that the measurements could be checked at any time. When a whole series of measurements had been completed for different solar panel angles and frequencies, all measurement data were presented, both in table form and as Θ-Φ maps. The maps are in the form of level diagrams in order to give a comprehensive picture of the antenna performance. Fig. 8 shows a map that covers a whole sphere and shows the performance of one antenna.

Fig. 8
A Θ-Φ map which shows the radiation diagram for all space angels, with level contours



Summary

The combination of technical and experimental work required for the development of the EXOSAT antenna system is typical of antennas with large coverage intended for spacecraft. For all such systems the performance measurements are extensive. LM Ericsson have carried out several similar projects. The staff are experienced, the methods are rational and the comprehensive measurements can therefore be performed quickly despite the quantity of measurements.

LM Ericsson is the first subcontractor to complete all the activities connected with their commitment. The antennas meet all requirements laid down in the specificaton. The time schedule has been met, and the cost limits have not been exceeded.

A Telephone System for Foreign Exchange Trading

Karl-Gustav Carlsson and Arne Svensson

LM Ericsson Telemateriel AB have developed a telephone system, AVE 100, for internal answering service or direct communication within a company. A touch on a button is all that is needed to answer a call or set up a speech connection. The system can also be used as a multiline telephone. The system was introduced at the beginning of the 1970s and has since been supplemented to be suitable also as a communication system for the foreign exchange departments in banks. In this article the new functions for this purpose are described, as well as the flexibility and rational operation of the system.

UDC 621.395.22

Foreign echange trading carried out by the foreign exchange departments in banks requires a reliable communication system that is fully adapted for this activity. The number of foreign exchange dealers can vary from a couple to several dozen depending on the size of the bank and the extent of its foreign exchange trading. Each dealer must be able to get in touch with trading centres all round the world, with colleagues in other banks and with other employees in hos own bank, either via direct lines or via switched connections. He must be able to have two calls connected up simultaneously to his control panel, since he often has to arrange a transaction between a seller and a buyer very quickly. The foreign exchange dealer must also be able to make conference calls and have access to special functions required for his work.

AVE 100 for communication in foreign exchange trading

System AVE 100 provides a very suitabel communication system for foreign exchange trading. In such applications it functions as a large multiline telephone system, where each dealer has access to many common external and internal lines from his control panel. Each panel, fig. 1, also contains two telephone units, each with a handset and a push-button set for dialling, and two loudspeakers with volume control. The loudspeakers are intended for two special supplementary functions, namely monitoring and camp-on listening.

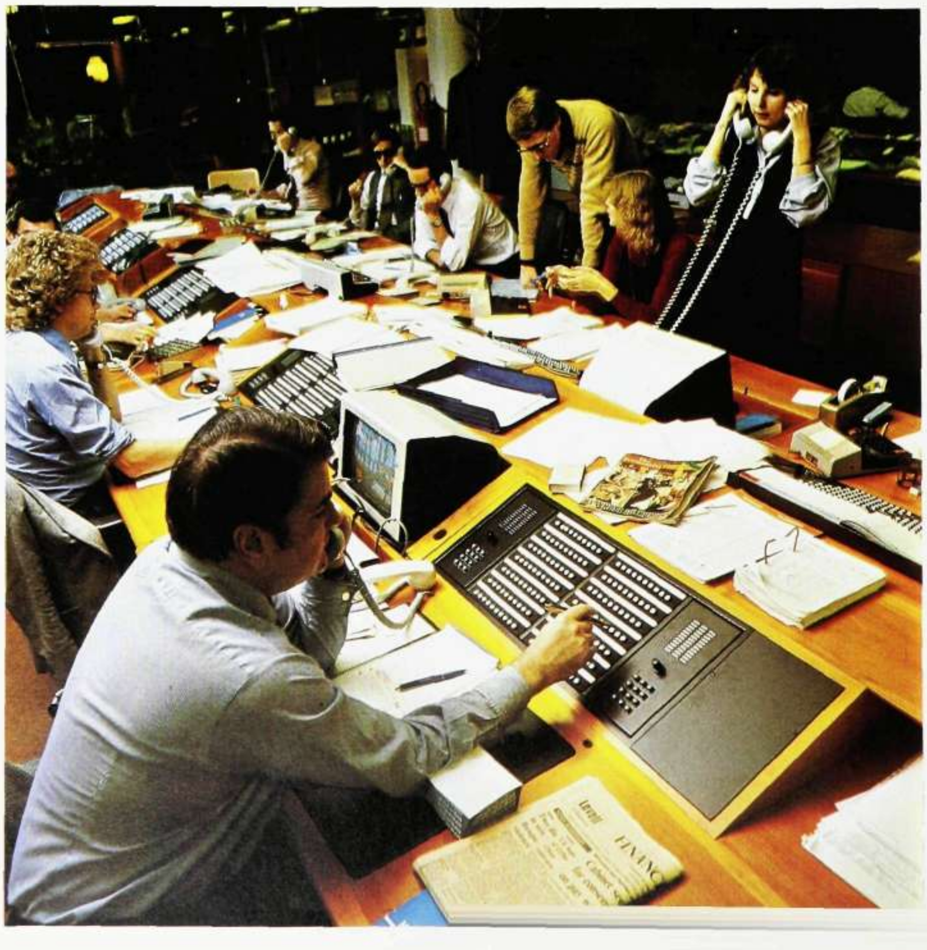


Fig. 1
A telephone system for foreign exchange trading in full operation

KARL-GUSTAV CARLSSON
ARNE SVENSSON
LM Ericsson Telemateriel AB

Monitoring means that a speech circuit, often between the foreign exchange departments of two banks, is connected up to a loudspeaker. Any number of people can take part in a monitored call. During such a call both parties will normally have a loudspeaker connected in. A foreign exchange dealer who wishes to transmit a message uses his handset. The message is broadcast through the loudspeakers to the other participants. Only one dealer at a time in each group can transmit a message.

Camp-on listening means that the foreign exchange dealer is able to connect in a special loudspeaker when he is waiting for a message to come in on an established circuit, and wants to have his hands free in the meantime. He then takes the call on his handset when the message comes.

A complete system comprises control panels and a central unit that is dimensioned for the relevant number of lines and participants. The central unit is controlled from the control panels for connecting a certain line to a certain telephone unit.

Control panel lines

The line operating wires between the control panel and the central unit are connected to push-button strips in one of the two fields in the control panel, fig. 2. The lines in the left-hand field are connected to the left-hand telephone unit when the relevant push-button is pressed, and the lines in the right-hand panel field are connected to the right-hand telephone unit. It is essential that the control panel lay-out is rational and the operation simple if this demanding work is to proceed smoothly even during very busy periods. The push-button strips can therefore be arranged in the order that is most suitable for each individual case. They are equipped with label strips which show clearly which line is obtained with each button. There is also a light emitting diode for each button, which shows the state of the line: free, busy, call attempt etc.

Fig. 3 shows an example of a line layout in the control panels of a system with 100 lines. The lines are grouped as follows:

Left-hand panel field
10 monitoring lines
20 lines to the public exchange
10 lines to the PABX

Right-hand panel field
10 direct lines ("hot lines") for long-distance connections
30 direct lines ("hot lines") for short-distance connections
10 lines that are individual to each participant
10 spare lines

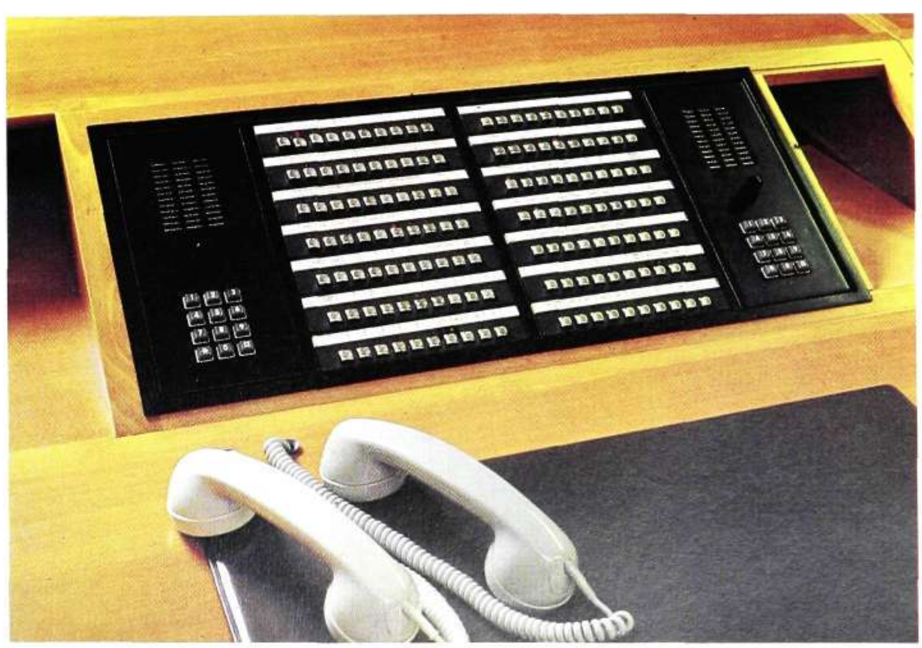


Fig. 2
The control panel in a telephone system for foreign exchange trading

The monitoring lines can be point-to-point or switched circuits to foreign exchange brokers or banks within the country or abroad. The point-to-point circuits are established on permanently connected, leased lines or speech channels. The switched circuits are set up using ordinary exchange lines, possibly via the PABX, and are connected up with the aid of the push-button set in the telephone unit. The 10 monitoring lines can consist of any desired combination of point-to-point and switched circuits.

The connection to the public network is made via 20 exchange lines and 10 PABX lines. The combination of exchange lines and PABX lines is optional. The exchange lines are mainly used for outgoing traffic and reduce the load on the PABX. This is important, since the volume of traffic from foreign exchange departments into the public network is usually quite high. PABX lines are provided primarily to enable the PABX operators to set up calls to the foreign exchange dealers. All lines can of course be used for both incoming and outgoing traffic. A group number is usually used for the foreign exchange dealers both in the public exchange and the PABX in order to facilitate inward calling.

By direct lines are meant lines direct to a predetermined person or group of people. They can be divided into lines for long distance and lines for short distance depending on the technical equipment.

By long-distance lines are meant connections outside the local area in question, via leased two-way speech channels to other places or other countries.

The short-distance lines are intended for local traffic, to local bank offices as well as within the dealers' own bank premises.

The individual lines are adapted to the requirements in each individual case. It is usually an advantage for the dealers to have their own extension numbers in the PABX and intercom system. Direct lines are also provided to close colleagues outside the foreign exchange trading group as an aid in the practical work.

Traffic facilities

The functions and properties of the various lines are described here using the numbering of the push-button strips shown in fig. 3.

Monitoring

One of the foreign exchange dealers decides which lines are to be available to the other participants in the system at a certain time. The lines are connected up by means of push-button strip no. 3. This strip is therefore usually only fitted in the control panel of one dealer (the others have dummy strips).

The push-buttons in strip no. 1 are used by the dealer to connect in an optional monitoring line to the loudspeaker above the left telephone unit. A volume control knob is mounted under the loudspeaker.

When the dealer wants to deliver a message he depresses the corresponding

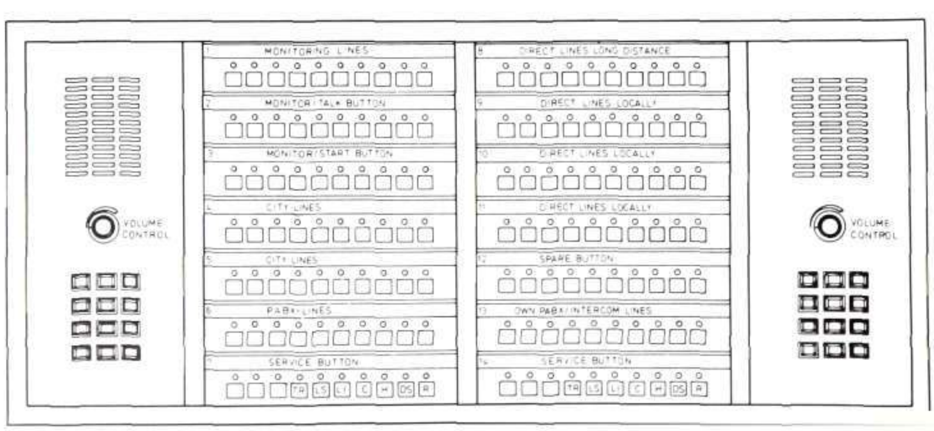


Fig. 3
An example of the layout of the push-buttons in the control panel

speech button in strip no. 2 and speaks via the handset. The loudspeaker in his own panel is then disconnected in order to avoid acoustic feedback, but the other loudspeakers broadcast the message. During the message the speech buttons for the monitoring line in question in the other participants' panels are blocked, and a light diode above each button indicates that the speech facility is being used by another dealer. When the message is finished a return to the listening state is made by pressing button R in strip no. 7.

Traffic via the public network
The push-buttons in strips no. 4–6 represent the lines to the public network, either direct or via the PABX. Outgoing calls are dialled using the push-button set in the left-hand telephone unit.

A call in progress can be put on hold and another call initiated or answered. There is no limit as regards the number of calls that can be kept on hold. A call is automatically put on hold when another line is connected in to the control panel.

A call on hold can be taken over by anybody in the foreign exchange trading group by pressing the line button for the call in question. The call is disconnected with button R in strip no. 7.

Traffic via the direct lines
Push-button strips no. 8–11 are used for direct lines to prearranged persons and groups. A call is set up by pressing the relevant line button and is disconnected with button R in strip no. 14.

Individual traffic
Calls via the dealer's own extension line in the PABX or intercom are connected up using strip no. 13. Outgoing calls are dialled using the push-button set in the right-hand telephone unit.

Strip no. 13 can also be equipped with 8 direct lines to provide the dealer with rapid connection to close colleagues outside the foreign exchange department. Internal conferences with several participants can be set up using these lines.

Camp-on listening
Camp-on listening can take place on all lines except the monitoring lines, and means that an established call can be switched from the handset to the loudspeaker in the right-hand telephone unit. This is convenient for a dealer who is waiting for a message to be delivered over an established connection. He has his hands free during the waiting period and the message comes via the loudspeaker.

Fig. 4
The foreign exchange department of the Christiania Bank og Kreditkasse in Oslo, Norway

Fig. 5
The central unit in AVE 100 for foreign exchange trading

The line is connected up to the loudspeaker or the handset by button LS in push-button strip no. 7 or 14. Two-way speech communication via the handset can be resumed at any time by pressing button LS again. The handset in question is thus not free for other calls during the waiting period.

Joint call
By a joint call is meant a call where two dealers are simultaneously connected in to the same end of a line. The speech units of the two dealers are connected in parallel to the line, giving a slightly lower transmission level. During such a call the light diode for the line in question will give a special signal in all control panels, indicating that the joint call facility is being used and no third person can be connect up to the line. To set up a joint call one participant must press the joint call button (LI in strip no. 7 or 14) while the other connects up the line. This avoids the possibility of accidental joint calls.

Conference
The conference facility enables a dealer to call two different people via two optional lines, for example in strip no. 6. After this individual notification of a conference the dealer can connect up a three-party conference by pressing button C in push-button strip no. 7.

Manual holding
Although the system is equipped with automatic holding of established calls when another line is selected, manual holding can be necessary in certain cases. Push-button H in strip no. 7 or 14 is pressed for temporary holding of a call, or if another dealer is to take over the call.

Recording of calls
Each telephone unit is equipped for the connection of a tape recorder for the recording of calls. The recording is controlled with button TR in push-button strip no. 7 or 14. Most tape recorders with remote control can be used.

Automatic number transmitter
An automatic number transmitter can be connected to the system as a separate unit. It can then be used on any line on which the push-button set is used for dialling.

A number transmitter is not included as a standard part of the equipment because the requirements regarding capacity and construction vary greatly. However, the majority of the foreign exchange telephone systems are equipped with some type of automatic calling device in order to ease the work.

Indications on the control panel

A diode lamp is provided for each line and is placed above the line button in the control panel. It can indicate the following line states:

Line free	Extinguished
Call in progress	Lit
Incoming call	Rapid flashing, 1 Hz
Call on hold	Slow flashing, 0.5 Hz
Joint call	Flickering, 3 Hz

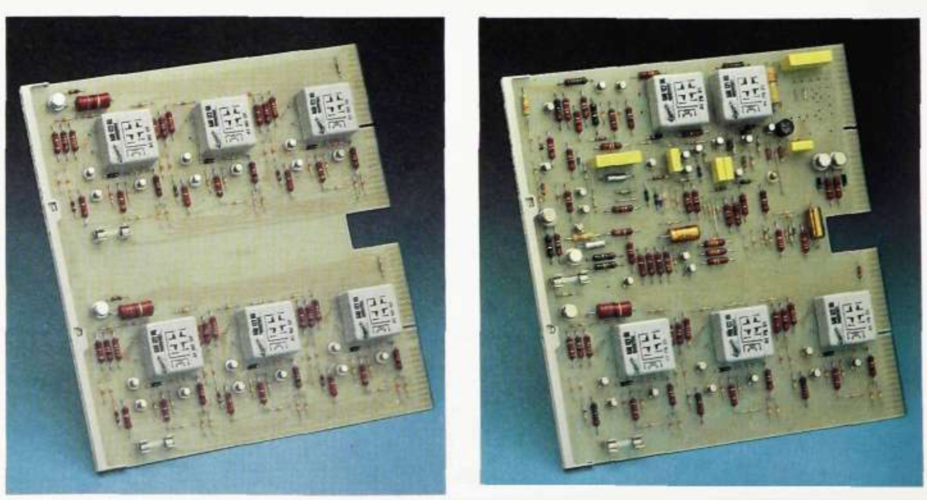


Fig. 6
Printed board assemblies for the connection of three control panels, right, and for another six control panels, left

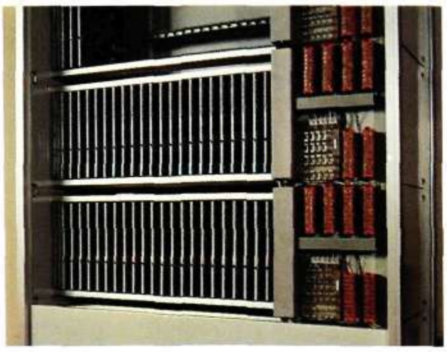


Fig. 7
Shelves for the printed board assemblies

Central equipment

The central equipment, fig. 5, consists of printed board shelves, which are placed in a rack or cabinet. Each shelf holds 20 printed board assemblies. The printed board assemblies for normal lines, fig. 6, consist of two main types. One type holds interface circuits for one line and three control panels. The other type holds the interface circuits for two times three control panels. The two types of printed board assembly can be combined in different ways so that the number of foreign exchange dealers who can reach the same line is increased from 3 to 6, 9, 12 etc. The shelves, fig. 7, can be equipped in different ways, for example with 20 lines to three dealers, or with 10 lines to nine dealers. The number of dealers per line can be increased in steps of 3 or 6 by means of additional shelves.

Thus the size of the system is determined by the number of shelves and printed board assemblies and can easily be adapted to meet individual requirements. The shelves are complete units, wired in the factory, which are interconnected by means of plug-in cables. The control cables to the dealer's panels are also equipped with plugs, for simple and easy installation and servicing.

Ordinary telephone cable can be used for the connection of the control panels to the central equipment.

The system is powered by two separate 24 V batteries, each with automatic charging rectifiers. A signal generator is provided for the direct lines.

Operational experience

The system described here is built up of the basic units that form part of ordinary AVE 100 systems, with the addition of the following special functions: monitoring, camp-on listening and external conference. AVE 100 systems have been marketed since the beginning of the 1970s. The operational experience has been very good and the fault rate has been low. The special functions that are included in the system for foreign exchange trading have also functioned very well in the more than 50 systems that have so far been taken into service.

Custom Design Circuits for Telecommunications

Gunnar Björklund and Jan Johansson

This article is one of a series devoted to the activities of RIFA and deals with integrated circuits for telecommunications. The use of electronic circuits that are custom designed for a certain function can provide the space saving or technical advantage that makes a new design profitable. Furthermore the performance is often improved at a low cost through small additions to the circuit. This is illustrated here by some examples of circuits that have been designed and manufactured by RIFA.

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It has often been necessary to resort to special techniques in order to meet the stringent requirements imposed on electronic components for telecommunications. As early as the 1920s the Ericsson Group manufactured filter capacitors adapted for carrier systems on aerial lines[1]. At the beginning of the 1970s custom design components, such as hybrid circuits, resistance networks and precision capacitors, were developed for LM Ericsson's new M5 construction practice[2]. The availability of special components has also proved to be a prerequisite for many recent projects in the field of telecommunications.

The monolithic and thic'film techniques are predominant in the manufacture of modern integrated circuits for telecommunications.

Monolithic technique

The monolithic technique has been the driving force in the development that has led to the custom design circuits of today. The circuits are almost exclusively built up on silicon substrates. The degree of integration is high, digital monolithic circuits with 3000 gate functions are not unusual. It is more difficult to give a figure for the possible degree of integration of analog functions, but it may be mentioned that today it is possible to integrate on a single silicon chip all the analog functions for the line interface circuit in a fully electronic subscriber stage. Of particular interest in telecommunications is the possibility of integrating both analog and digital functions on the same silicon chip.

Monolithic circuits for telecommunications must usually be hermetically encapsulated. Fig. 1 shows standard hermetic packages for mounting on printed boards. There are special packages for surface soldering, for example to ceramic substrates, see fig. 2.

Thick film technique

During recent years the use of thick film technique has become widespread in the field of telecommunications, for simple resistance networks as well as for more complex hybrid circuits. The hybrid technique makes it possible to build a complete electrical functional unit on a single piece of ceramic substrate with conductor layers and precision-trimmed thick film resistors. To the substrate it is then possible to connect special monolithic circuits, high and low power transistors or chip capacitors. The electrical characteristics of the

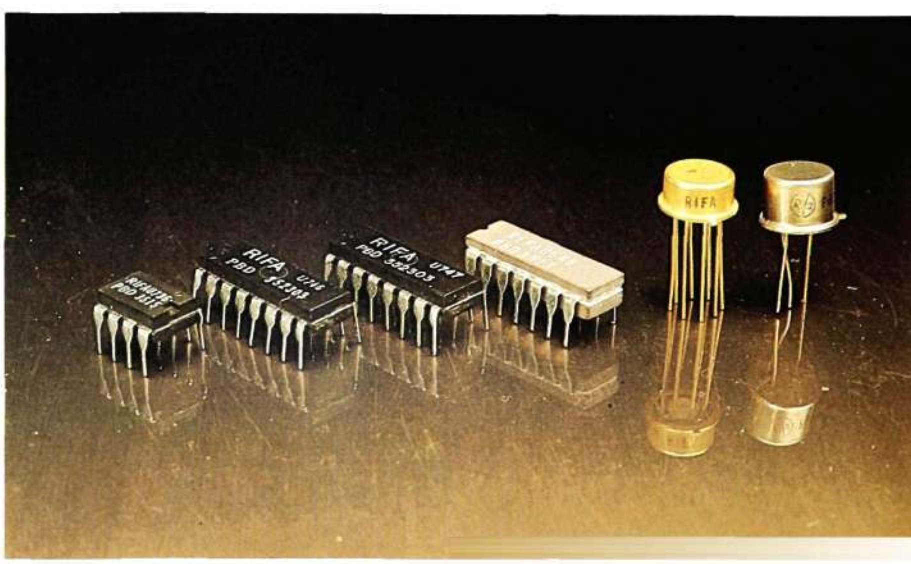


Fig. 1
Standard hermetically sealed packages for mounting on printed boards

GUNNAR BJÖRKLUND
JAN JOHANSSON
AB RIFA

hybrid circuit can be adjusted to meet stringent requirements by means of functional trimming, i.e. laser trimming of resistors with simultaneous measuring of the circuit.

The high heat conductivity of the ceramic and the small dimensions of the add-on components facilitate very compact construction. The M5 construction practice for transmission equipment[2] is one example, and more recent component designs, which are decribed below, are other examples of the high packing density made possible by the use of hybrid technique.

Standard circuits versus custom design circuits

Components for modern telecommunication equipment must be of high quality and be able to perform complicated technical functions. The development towards more complex functions also means that an increasingly larger part of the system is built into a few components. Varying system requirements make it difficult for manufacturers of standard components to design a component that meets the needs of several customers. Since the component designer usually has only a limited knowledge of telecommunication systems, he must base his work on specifications from an established manufacturer of telecommunication equipment.

The user of standard circuits must choose between passing on his knowledge of system requirements etc. to the manufacturer or waiting until a new standard circuit, based on the specifications of a competitor, is available on the market for general use.

Another alternative is the custom design circuit. It can be optimized for the user's own system requirements, and can be kept exclusive as long as desired.

Custom design circuits

An efficient circuit design presupposes that modern techniques, i.e. monolithic and thick film techniques, are exploited to the full. This often means an overall optimization that reaches far beyond the function which was originally intended to be integrated in the circuit. A design that provides the best overall economy usually means that the largest possible number of functions are included in the circuit. The number of additional components is reduced to a minimum, the circuit reduces the required printed board surface, the heat dissipation is facilitated by the mechanical design of the circuit etc.

One prerequisite for a good circuit design is that the requirement specification utilizes the advantages offered by a special technique. This requires close collaboration between the customer

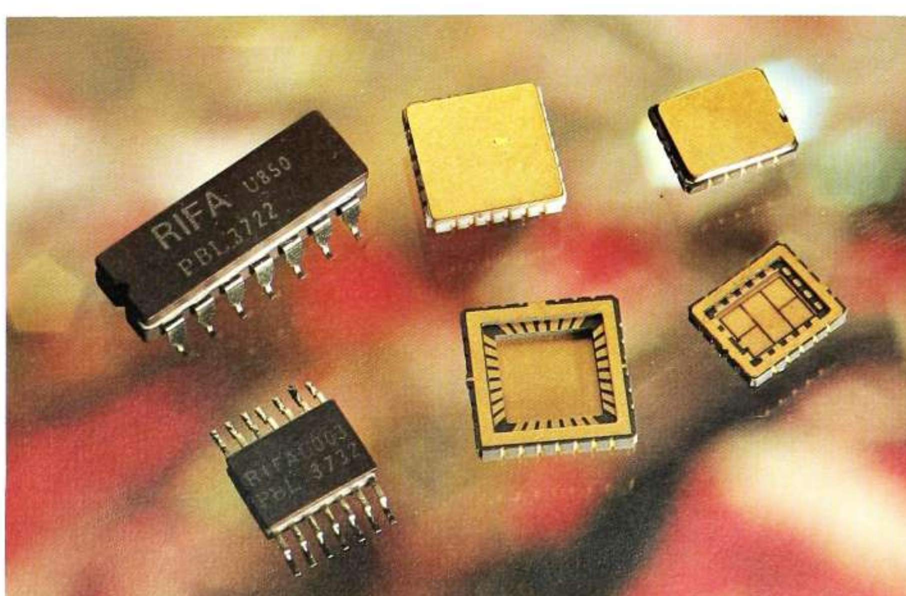


Fig. 2
Monolithic packages for surface soldering

and the manufacturer. The customer must have a fundamental knowledge of how components are designed. The manufacturer in his turn must be able to state the technical and economic consequences of different specification requirements.

Today the development and manufacture of monolithic and thick film circuits is a mature and well established technique. Advanced computer aids and considerable, well tried production resources are available. The factor that now restricts the spreading of the use of custom design circuits to other fields of use is insufficient design resources among customers and manufacturers rather than lack of applications for the circuits.

Full-custom or semi-custom design?

The high fixed costs that are normally inherent in the development of a new circuit restrict the use of monolithic technique. Not only must the cost of designing the electronic circuit be covered, but also the cost of generating photo masks and developing prototypes and test programs. This has led to efforts on the part of several manufacturers of custom design circuits to simplify the design work.

One method of manufacturing small series of monolithic circuits at a reasonable cost is to use a standard pattern of components and to vary only one or two of the last mask layers, containing the connections between the transistors and the outputs. Several customer orders can be combined to give economical production runs with an identical production flow up to the last stages of the process. This semi-custom method for digital MSI and LSI circuits makes series of a few thousand circuits per year economically feasible.

Full custom design is usually profitable in cases where the annual circuit requirement exceeds 10 000. Original patterns are then usually generated for all the mask layers (7–9) on the silicon wafer. In spite of this the design times and the cost of producing masks can be kept reasonable, particularly for digital monolithic circuits, by using computer-aided design, with cell structures and layout rules stored in the design computer memory. The main advantage of designing circuits individually right from the start is of course that the chip surface is utilized better, which has a considerable effect on the manufacturing cost of large series. Moreover, if analog functions are required in addition to digital, the monolithic circuits must be equipped with very special function blocks so that the semi-custom method is not feasible.

For thick film circuits the full custom method is predominant, since the time and money spent on developing a new hybrid circuit, from the completed circuit diagram to the prototype, is considerably less than for a monolithic circuit.

Circuit exemplifications

This section describes some custom design circuits developed in different techniques for customers within LM Ericsson by the RIFA design departments for monolithic and thick film circuits.

Two-tone generator

In modern telephone exchange systems the transmission of digits between the telephone set and the exchange is carried out by means of tone frequency key sending. Seven frequencies are used, four that correspond to the rows of the

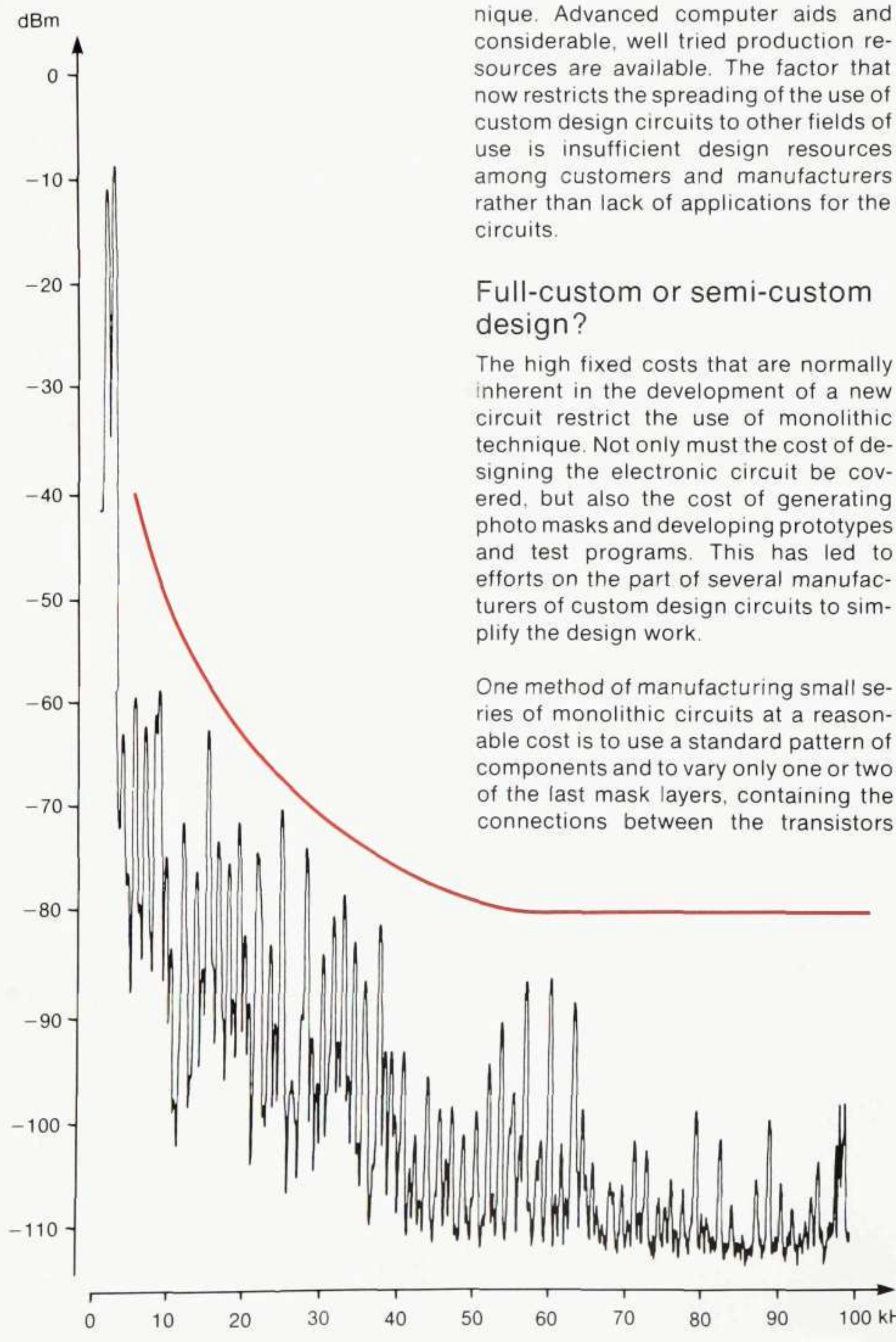


Fig. 3
The harmonics spectrum from a two-tone circuit

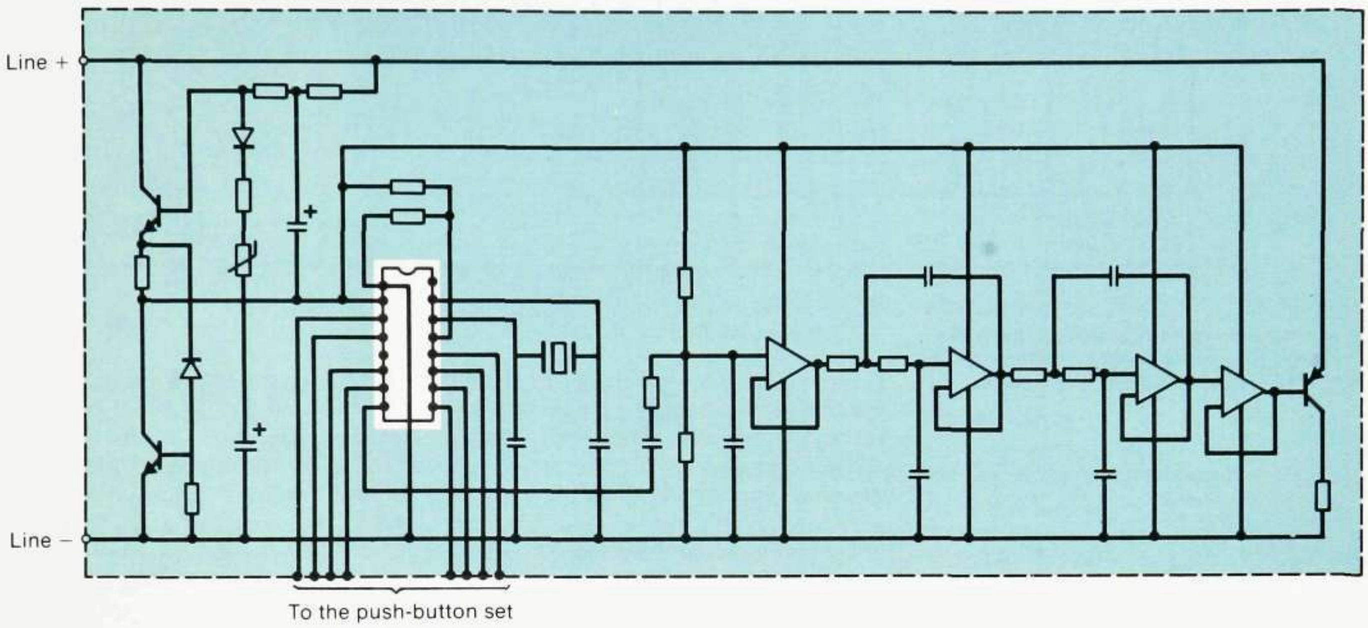


Fig. 4
A standard type of digital two-tone circuit with external components for filtering and line matching

push-button set and three that correspond to its columns. Previously two-tone generators in telephone sets were manufactured using LC or RC technique.

A crystal-controlled oscillator can be used instead. The desired frequencies are then generated from the crystal frequency by means of digital synthesis. Circuits for this function can be made very small and give very well defined frequencies. However, with the digital method harmonics of the desired frequencies occur. These harmonics must be suppressed to an acceptabel level.

Fig. 3 shows a typical harmonics spectrum for the signal from such a tone generator. The CEPT requirement has been included for comparison. Harmonics in the upper frequency range must be attenuated to about 70 dB below the level of the basic frequencies by means of a lowpass filter, which may require a large number of components.

The technical development has been very rapid since the introduction of digital two-tone generators. The first two-tone generators comprised a digital circuit with external amplification and passive components for filtering and single matching to the telephone line, fig. 4. Today the complete function can be integrated on a single silicon chip, fig. 5.

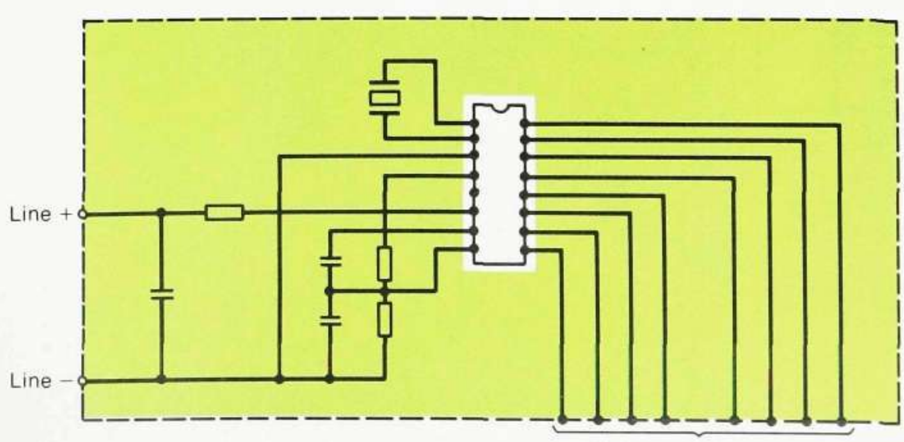


Fig. 5
The RIFA digital two-tone circuit with a minimum number of external components

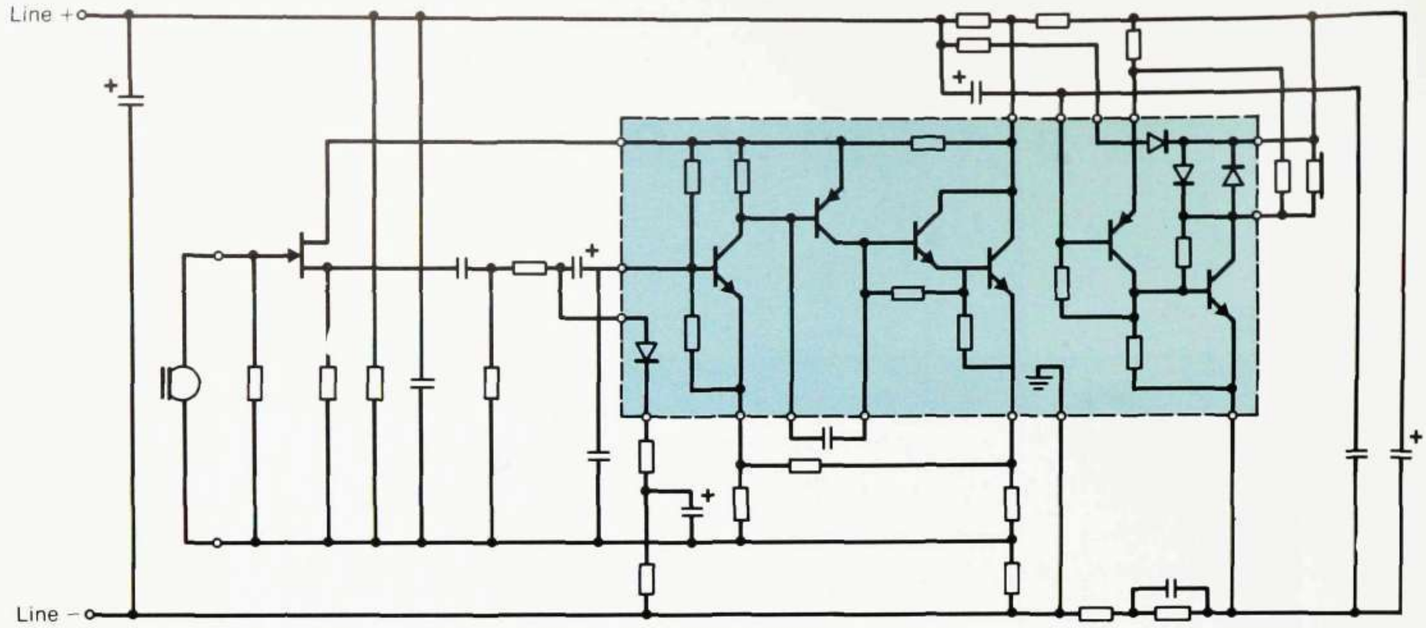


Fig. 6
A speech circuit for an electret microphone. The first generation, with a simple monolithic circuit and a large number of external components

This reduction in size was achieved when it became possible to combine linear functions with fast and densely packed, low-current logic circuits on one and the same silicon chip.

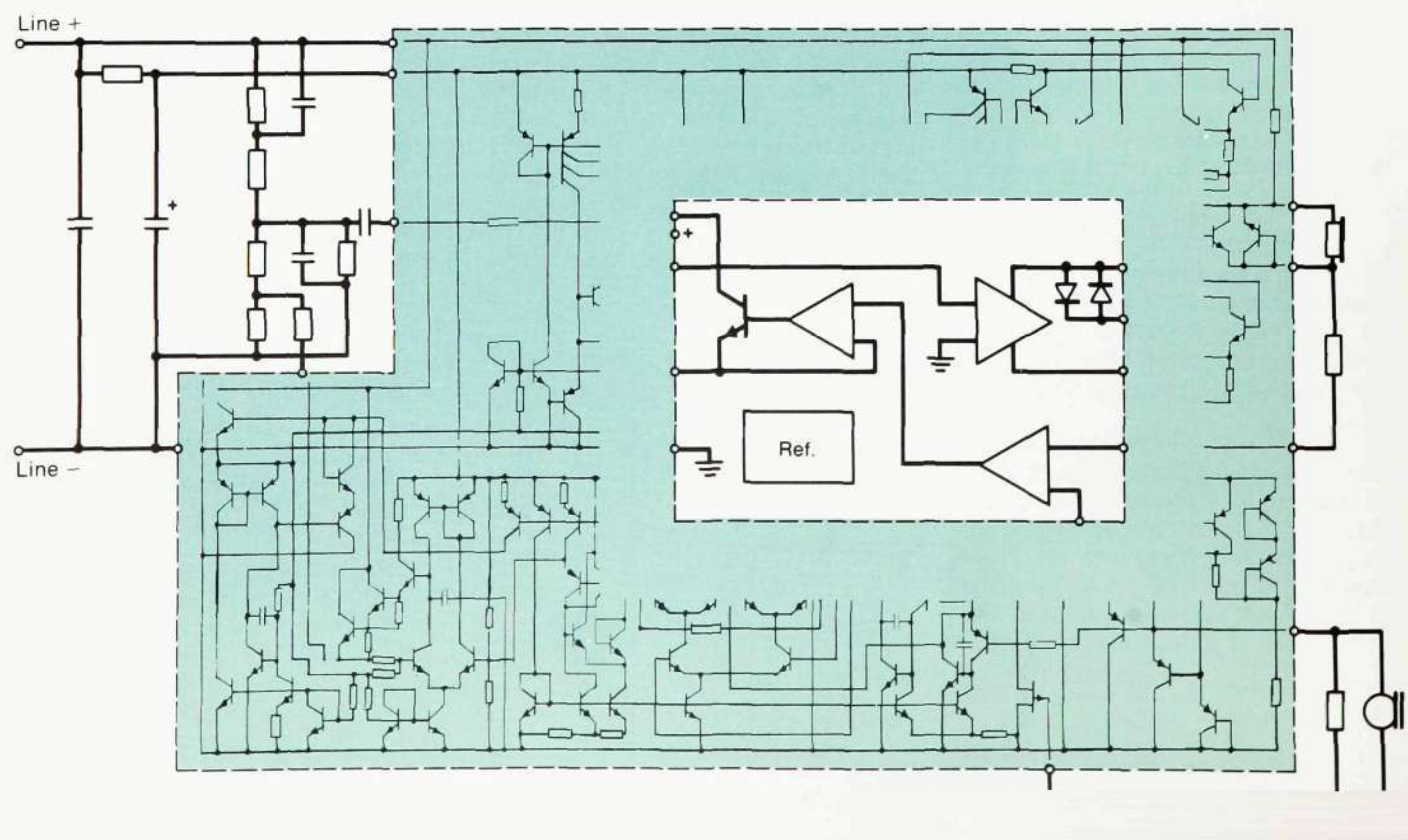
As can be seen from fig. 5 the circuit has also been designed so that the number of external passive components is reduced to a minimum apart from those needed for adaptation to the various markets.

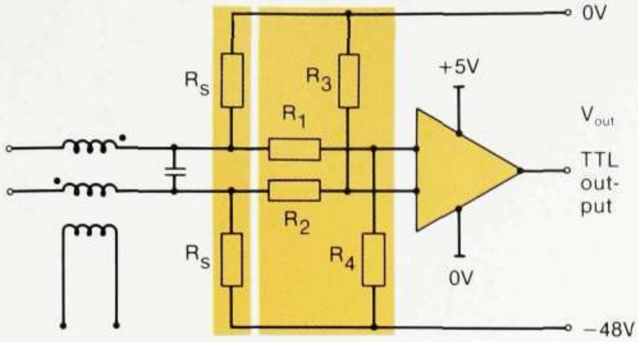
Speech circuit

Figs. 6 and 7 show two electronic speech circuits. Externally they are identical, and they are intended for use in a telephone set together with an electret microphone and an electromagnetic receiver, for example in ERICOFON 700 and DIAVOX 100. The circuit in fig. 6 is a forerunner to that in fig. 7. Both circuits have been constructed as mechanically identical hybrid circuits, fig. 8.

The first circuit consists of a simple monolithic circuit and a number of active and passive components on a thick film substrate. Function trimming of the complete hybrid circuit was accepted in order to make it possible to use a sim-

Fig. 7
A speech circuit for an electret microphone. The second generation, with a complex monolithic circuit and a minimum of external components





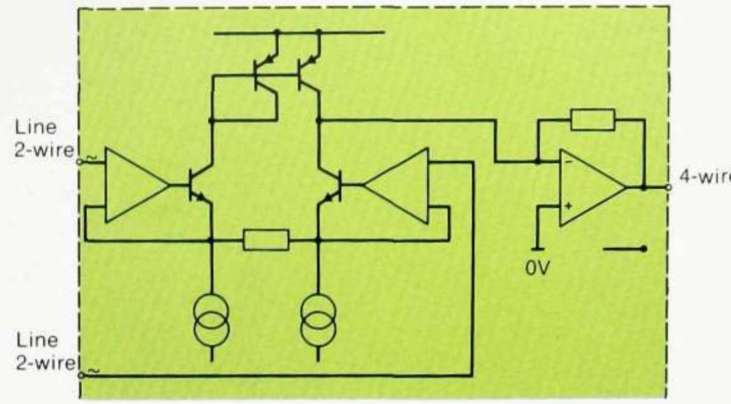


Fig. 9
A loop sensing circuit consisting of a monolithic circuit in high-voltage monolithic technique and a precision resistance network

Fig. 10
Differential voltage amplifier in monolithic technique for an SLIC

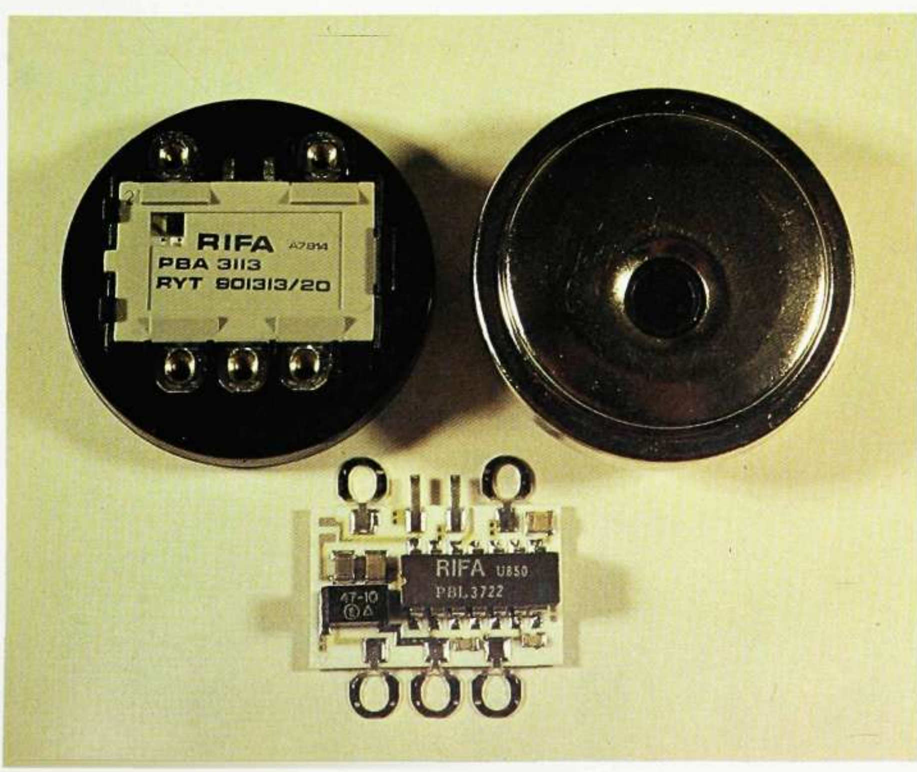
plified circuit design. In the second circuit the monolithic technique has been exploited in full and the number of external components on the thick film substrate has been reduced to a minimum. The monolithic technique offers very good relative tolerances. This fact has been utilized in the design, and hence no function trimming is necessary.

The integrated circuit for the input amplifier in fig. 7 contains a field effect transistor, J-FET, in order to obtain good matching to the electret microphone. The amplification is controlled by the direct current on the line. This current in its turn is dependent on the length of the line. In this way it is possible to compensate for the attenuation, which is proportional to the line length.

The output amplifier transmits the amplified microphone signal to the telephone line and regulates the voltage between the line branches to a suitable level.

A part of the circuit, which replaces the transformer and line balance, separates the signals in the two directions of transmission. The received signal is amplified in the circuit. In this case also, the amplification is dependent on the line length and the output is adapted for driving the receiver inset.

Fig. 8
A complete speech circuit hybrid, mechanically, electrically and acoustically integrated with the electret microphone



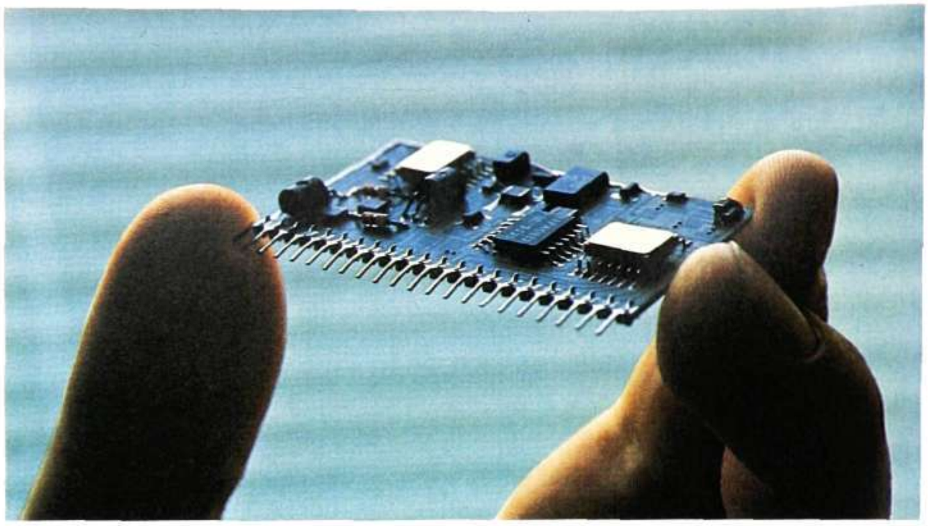
Loop sensing on the line circuit board
In modern exchanges the sensing of the line state, i.e. on-hook, off-hook, is done electronically. Fig. 9 shows a circuit for loop sensing.

The line state is registered as a change of the voltage V_{out} from low to high level, or vice versa, with the aid of a resistance bridge R_1-R_4 and a comparator circuit in monolithic technique. The loop sensing circuit is equipped with high-ohmic thick film resistors which have been laser trimmed to low relative tolerances, ±0.1%. It has low-level input current and low bias. This gives the circuit the following properties:

- correct loop sensing even with high values of line resistance R_L
- effective protection of the comparator inputs against ringing signals and voltage transients
- loop sensing easily adapted to the demands of different administrations (e.g. different values of R_S) by laser trimming of the resistors to the desired resistances
- high packing density on the printed board
- high stability of the changeover levels of the loop sensing, thanks to the encapsulation and the choice of basic technique for the bipolar monolithic circuit as well as the thick film resistors.

Line interface circuit
The subscriber line interface circuit, SLIC, requires a large number of components if standard components are used. Fig. 10 shows an example of a differential voltage amplifier in monolithic technique. The use of this type of integration gives an SLIC with very good performance, for example as regards the attenuation of longitudinal noise. The packing density is high. This part of the circuit occupies approximately 0.5 mm^2 on the chip, or about 2% of the

Fig. 11
An SLIC hybrid



total silicon chip surface for the whole SLIC.

Fig. 11 shows a hybrid circuit for the complete line interface. The circuit contains three special monolithic circuits in miniature packages. The hybrid circuit contains all SLIC functions, interrupter-controlled current feeding, ringing, loop sensing, ring tripping, pulse receiving, earth button sensing, hybrid, balance and digital interface to a micro computer.

Summary

The design examples described here show in different ways how custom design circuits have provided the most economical solutions to problems in the telecommunications field.

The two-tone generator shows how requirement specifications can be met with sophisticated monolithic technique and how far the number of external components can be reduced.

The speech circuit shows how a combination of a monolithic circuit and a hybrid circuit can give complete mechanical and electrical integration.

The loop sensing shows how a satisfactory circuit has been obtained by using a monolithic circuit and a thick film resistance network, mounted as separate components on a printed circuit board.

Finally the line interface circuit shows how a combination of sophisticated monolithic and hybrid techniques gives an economical and efficient design for one of the most demanding functions in the field of telecommunications.

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UDC 656.25

Andersson, H. S.: *Railway Signalling Systems.* Ericsson Rev. *57* (1980): 4, pp. 118–123.

The Ericsson Group have designed, manufactured and marketed railway signalling equipment since 1915. The product range has included such systems as signalling equipment for the track, safety systems for the train routing, remote control systems and systems for supervising the speed. The product range has successively been renewed in step with the technical development. The development in the fields of electronics and computers has contributed greatly to this renewal. This article deals with the background and the present scope of this work. Some of the recently developed systems will be described in greater detail in subsequent issues of the magazine.

UDC 621.391.3.002

Hallberg, P.-A. and Viklund, B.: *Construction Practice BYB for Transmission Equipments.* Ericsson Rev. *57* (1980):4, pp. 124–128..

LM Ericsson's present transmission equipments have been designed using the M5 construction practice, but in future the BYB construction practice, which was developed for telephone exchange systems, will also be used when designing new digital transmission systems. The same printed board format is used in M5 and BYB. In the M5 construction practice the printed board assemblies are installed in shelves that cover the whole width of the rack, whereas in BYB they are plugged into magazines having different widths. A bay that can take both M5 shelves and BYB magazines has been constructed, since both types of equipment will be in use for a long time. In this article the authors give the reasons for the decision to use BYB, show how the construction practices for transmission equipments have successively been adapted to suit new component technology and finally describe the new M5/BYB bay.

UDC 621.395.4:
621.376.56

Hamacher, H.-H. and Pettersson, G.: *First-Order PCM Multiplex in the BYB Construction Practice.* Ericsson Rev. *57* (1980):4, pp. 129–137.

LM Ericsson have developed a new generation of first-order PCM multiplex systems, ZAK 1/30-4, as a part of the modernization of their transmission equipments. The BYB construction practice was chosen for the new equipment, partly to make it compatible with existing telephone exchange equipment as well as other transmission equipment. In this article the use of this type of equipment is described, as well as its design and function, together with different equipment and connection alternatives.

UDC 621.395.34

Nilsson, B. Å. and Sörme, K.: *AXE10– A Review.* Ericsson Rev. *57* (1980):4, pp. 138–148.

AXE 10 is a telephone exchange system designed to cover the whole range from large international transit exchanges to small local exchanges and remotely connected subscriber stages. The system also comprises exchanges for mobile subscribers, equipment for traffic handled by operators and equipment for centralized operation and maintenance.
This article gives a review of AXE 10 and describes how the system can easily be adapted to suit different requirements by combining a number of standardized subsystems. These subsystems have well defined interfaces and can be further developed independently. Two such subsystems are the digital group selector and the digital subscriber stage, by means of which the AXE 10 system is adapted to a network with gradually increasing digitalization.

UDC 621.395.2

Mörlinger, R.: *Operation and Maintenance Functions in ASB 100 and ASB 900.* Ericsson Rev. *57* (1980):4, pp. 149–155.

ASB 100 and ASB 900 are modern, stored program controlled PABXs for 20–108 and 60–960 extensions respectively. The stored program control, SPC, is utilized to provide the systems with advanced functions, not only for telephony but also for operation and maintenance. The basic principles are the same for the two systems, but certain functions that require large program volume are provided only in ASB 900.
This article gives a detailed description of the operation and maintenance functions in ASB 900, with comments on the features of ASB 100. General descriptions of ASB 100 and ASB 900 have previously been published in Ericsson Review.

UDC 621.396.67
621.371.36

Karlsson, E. R.: *Antenna System for the EXOSAT Satellite.* Ericsson Rev. *57* (1980):4, pp. 156–159.

EXOSAT is a satellite for scientific observations. It is equipped with instruments for measuring x-ray-radiation in space. The instruments will be aligned by orientating the whole satellite towards the x-ray source concerned. An omnidirectional antenna system is therefore essential for communication with earth.
The antenna system for EXOSAT has been developed and manufactured by LM Ericsson. The system consists of two antennas, each of which radiates over more than half a sphere. The antenna elements are cone-shaped spirals. Each antenna consists of four spirals with associated feeding device. In this article the design of the antenna elements and the optimizing of their position on the satellite are described, as well as the extensive measurements of performance that have been carried out using LM Ericsson's new automatic antenna measurement equipment.

UDC 621.395.22

Carlsson, K.-G. and Svensson, A.: *A Telephone System for Foreign Exchange Trading.* Ericsson Rev. *57* (1980):4, pp. 160–165.

LM Ericsson Telemateriel AB have developed a telephone system, AVE 100, for internal answering service or direct communication within a company. A touch on a button is all that is needed to answer a call or set up a speech connection. The system can also be used as a multiline telephone. The system was introduced at the beginning of the 1970s and has since been supplemented to be suitable also as a communication system for the foreign exchange departments in banks. In this article the new functions for this purpose are described, as well as the flexibility and rational operation of the system.

UDC 621.3.049:
621.39

Björklund, G. and Johansson, J.: *Custom Design Circuits for Telecommunications.* Ericsson Rev. *57* (1980):4, pp. 166–172.

This article is one of a series devoted to the activities of RIFA and deals with integrated circuits for telecommunications. The use of electronic circuits that are custom designed for a certain function can provide the space saving or technical advantage that makes a new design profitable. Furthermore the performance is often improved at a low cost through small additions to the circuit. This is illustrated here by some examples of circuits that have been designed and manufactured by RIFA.

UDC 656.25

Andersson, H. S.: *Railway Signalling Systems.* Ericsson Rev. 57 (1980): 4, pp. 118–123.

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