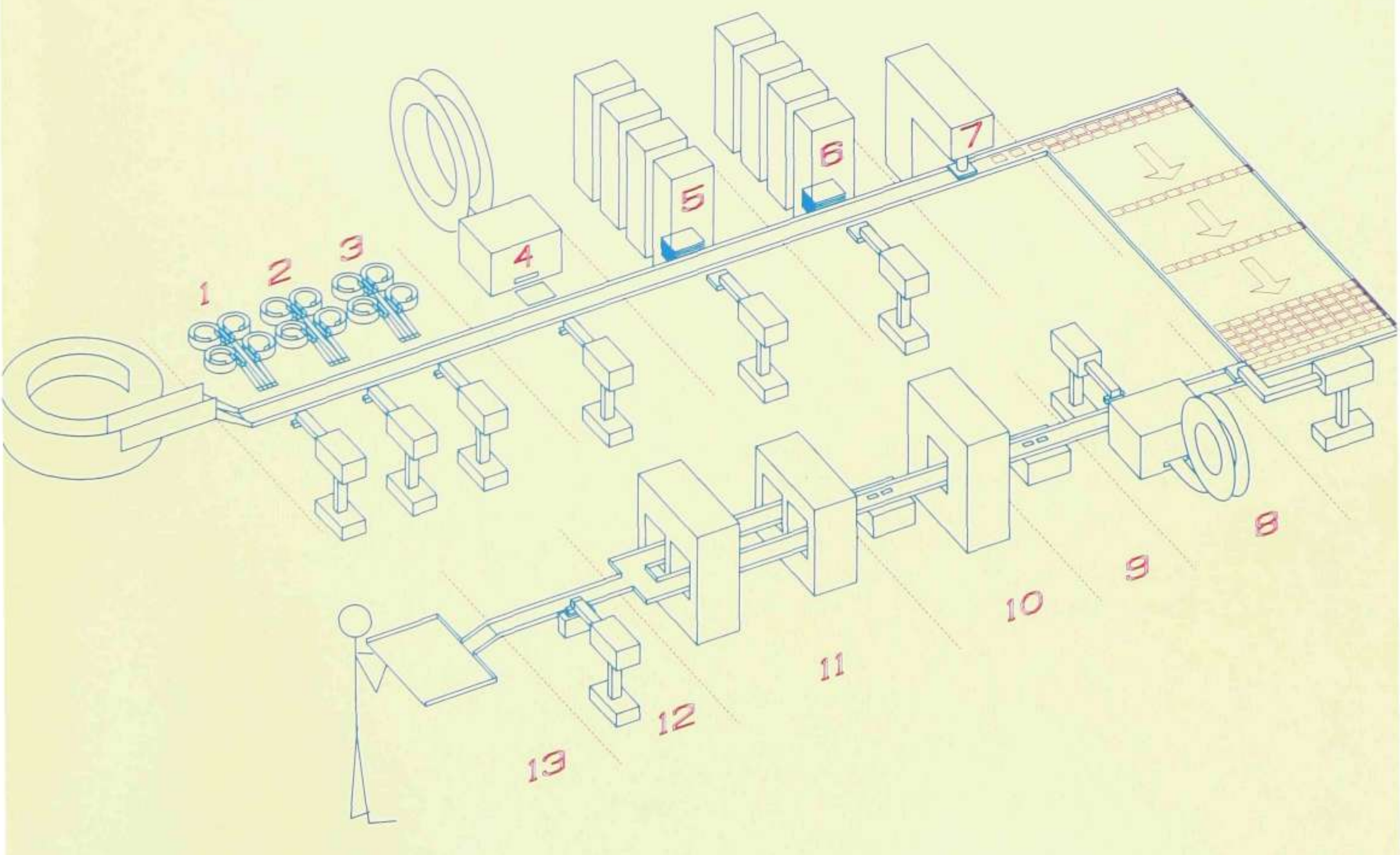
# ERICSSON REVIEW



1 1988



ERICSSON REVIEW

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# Contents

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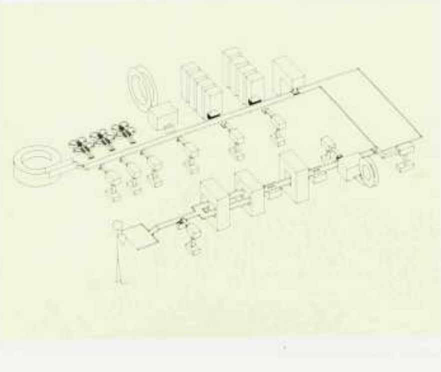

**Cover**
**Diagram of the fully automatic assembly line for push-button sets in Ericsson's telephone factory at Karlskrona, south Sweden**

# Christian Jacobæus
# In Memoriam

Anton Christian Jacobæus, D. Eng., of Stockholm, Sweden, died recently, aged 76. He grew up in Stockholm, went to school there, matriculating in 1929, and went on to the Royal Institute of Technology, where he graduated in 1933. In 1950 he obtained his D. Eng. with the thesis "A Study of Congestion in Link Systems". He was a lecturer in telegraphy and telephony at the Royal Institute of Technology during the period 1950–1959.

Christian Jacobæus was employed by the Ericsson Group on May 1, 1935, appointed department head in 1950, manager in 1954 and member of the board in 1958. In 1963 he was appointed deputy managing director and technical director, a post which he retained until his retirement in 1976. He remained with the Group as a consultant until 1985. His inventions during the period 1952–1965 resulted in some 15 patents.

His work during the 1940s and 1950s as the leader of the development in the telephone exchange field resulted in such products as the transit exchange type ARM, local exchange ARF and rural exchange ARK, all containing crossbar switches and based on the switching of these in link systems. These products gave Ericsson a position in the world market and for a number of years they provided the largest part of the income. The formulae which were based on the results of the doctoral thesis and used within Ericsson for the calculation of these systems' traffic handling capacity have won recognition among traffic researchers around the world and have also been used by Ericsson's competitors.

Christian Jacobæus was one of the initiators of the international teletraffic congresses which have been held every three years since 1955. They are concerned with traffic research and many scientists from Ericsson have participated very actively in these congresses.

Christian Jacobæus has also had a great influence on Ericsson Review. His first articles were published in the magazine in the mid-1940s and he was its responsible publisher during the period 1967–1978. His deep knowledge of technology and its development made the magazine gain increasing importance, not least as a means of spreading knowledge regarding Ericsson technology around the world. His work has greatly contributed to the look and content of Ericsson Review of today.

In 1957 Christian Jacobæus was elected to the Swedish Academy of Engineering Sciences, Department of Electrical Engineering, and in 1974 to the Royal Swedish Academy of Science, the section of technical sciences. In 1976 the Academy of Engineering Sciences awarded him its gold medal, first class, for his research and development work in the field of telecommunications. In 1978 Lund University made him an honorary Doctor of Engineering. In 1979 he was awarded the Alexander Graham Bell medal for his work in the field of telecommunications.

Christian Jacobæus has performed extremely important work in the field of telecommunications and for Ericsson, and our gratitude is very deep.

*Gösta Lindberg*

# Power Supply Equipment for AXE 10 in BYB 202 Racks

Lars Selberg

*Ericsson has developed a new power supply system for AXE 10 in construction practice BYB 202. A number of improvements enable the system to be installed in the switch room. The system contains rectifiers with high-frequency conversion and sealed, batteries. The electromagnetic interference generated by the system is kept at a very low level.*
*The author describes the characteristics, design and function of the system.*

LARS SELBERG
Ericsson Components AB
Power Division

Any power supply equipment intended for installation in the same room as telecommunications equipment has to meet a number of new requirements. For example, it must have a low noise level, the batteries must not leak acid and the cabinets' load on the floor must not exceed that of the telephony cabinets. New components, new power conversion technologies and new types of batteries have made such development feasible.

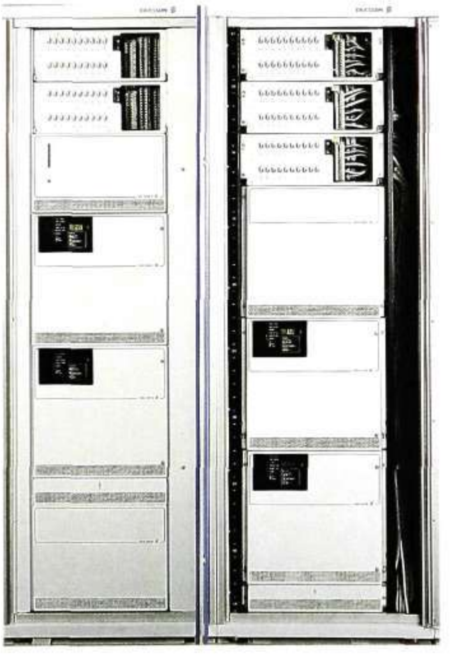

Fig. 1
**A power plant BZA 204 05 comprising two cabinets, with open doors.**
**The left-hand cabinet is eqipped with, from the top, two distribution units, a central supervision unit, two rectifiers, a connection unit for the mains voltage, and a battery fuse unit**

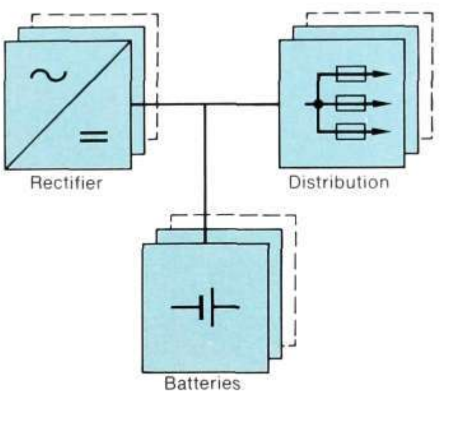


Fig. 2
**Block diagram of the system**

The requirements for the power supply equipment are:
- The rectifiers must have a low noise level and the electromagnetic interference they generate must be very small. This applies to low-frequency interference as well as radio interference, both conducted and radiated
- The equipment must be able to withstand interference from the environment
- The power supply equipment should consist of light units that can easily be installed and maintainted by staff without any special qualifications. Special lifting gear or instruments should not be required
- Mechanically the power and battery cabinets must match the AXE cabinets and their load on the floor must not exceed that of the latter
- The batteries must not leak acid or need topping up with water and they must be protected against over-discharging and overcharging
- The equipment must meet stringent requirements as regards personal safety. It must be possible to switch power units in and out of circuit during operation without any risk of the personnel coming into contact with live parts.

In order to meet these, partly new, requirements Ericsson has developed a new generation of power supply equipment. It is designed for AXE 10 in the BYB 202 construction practice[1,2] but is suitable for all equipment fed with 48 V.

## System function

BZA 204 05 is a modular, extendible power supply system comprising rectifiers, batteries, fuse units for the batteries, distribution units with automatic circuit breakers, connection units for the mains voltage and a central supervision unit with alarm assembly, fig. 1.

BZA 204 05 is a full-float system, fig. 2. By this is meant that during normal operation the electronic load is fed by the rectifiers, which at the same time provide trickle charge for the batteries. The batteries, which are connected in parallel with the rectifiers, take over the current feeding if a mains failure should occur. The battery size determines the reserve time of the system. An undervoltage monitor protects the batteries against over-discharging by activating all battery breakers at a certain voltage level.

## Rectifier

The rectifier, BMJ 401 011, fig. 3, converts the energy at a high frequency. This type of rectifier has been described in a previous issue of the magazine.[3] The incoming mains voltage is rectified without any transformation. The voltage is then regulated to a constant value by the preregulator, a chopper circuit that raises the voltage. The main task of the preregulator is to give the input current to the rectifier a sinusoidal shape, which has several advantages. The d.c. voltage generated by the preregulator is fed to an electrolytic capacitor that serves as a filter and a standby energy source in the case of short mains failures.

The d.c. voltage from the preregulator is inverted in a bridge circuit with pulse duration modulation. The voltage is stepped down, rectified and filtered. The output voltage or current from the rectifier is regulated through control of the pulse duration in the bridge circuit. The two converter stages operate at relatively high frequencies, 25 kHz for the preregulator and 40 kHz for the inverter, and consequently the dimensions of the transformers and filters could be reduced, making the rectifier lighter and smaller than older types with the same output power, fig. 4.

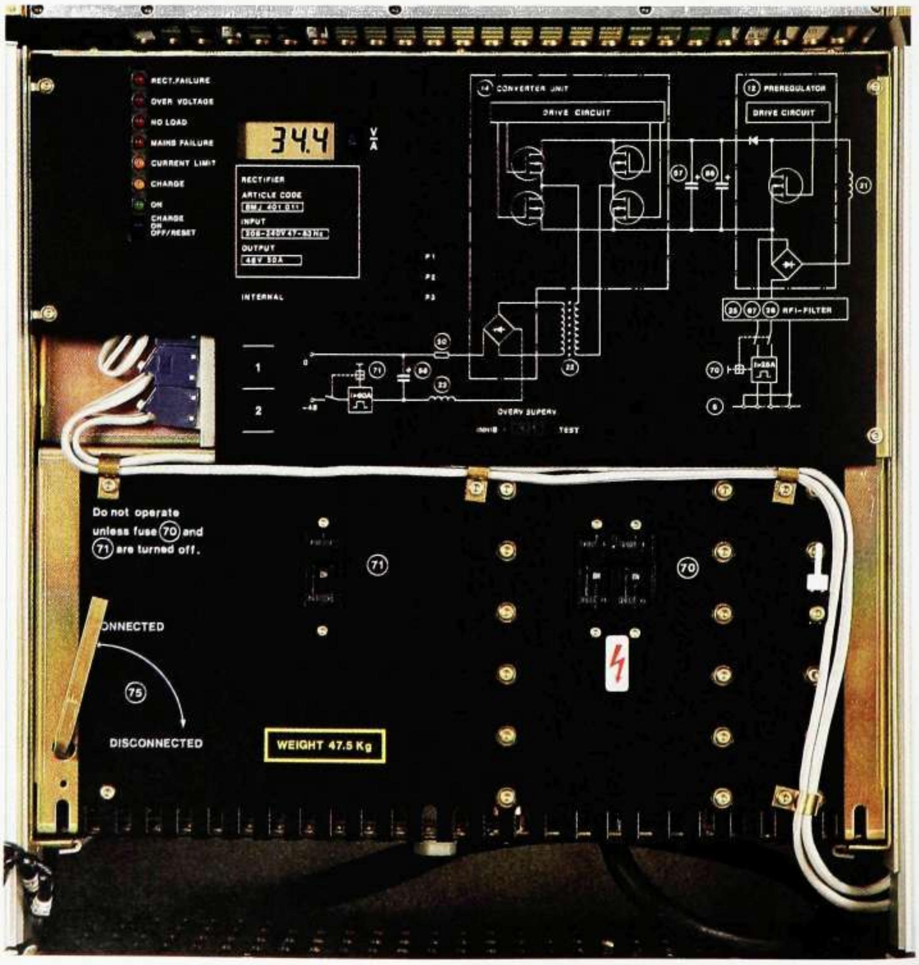


Fig. 3
Rectifier BMJ 401 011 with the outer front panel open. The display in the top left-hand corner shows the output current.
A simplified circuit diagram is printed on the inner front panel, which provides electrical screening

Fig 4
**Units can easily be replaced by one man during operation**

The main characteristics of rectifier BMJ 401 011 are:

- It provides a stable d.c. voltage with low levels of interference
- It meets the requirements applying to conducted and radiated radio interference set by FCC and CISPR
- It takes sinusoidal current from the public a.c. mains at a power factor of 1.0, which means that it behaves like a resistive load. The absence of reactive losses means that there is no need for overdimensioning of the feeding mains fuse and distribution cables. Furthermore the diesel power plant can be dimensioned for the active power drawn by the rectifier. The operating irregularities that often occur when feeding rectifiers from a diesel plant, such as instability and voltage distortion, are also avoided
- The low weight and small dimensions make it easy to install and replace if a fault should occur
- It can be connected in parallel in unlimited numbers with automatic current division between the rectifiers
- It operates noiselessly because of the high-frequency rectification.

Fig 5
**Sealed battery with cell voltage equalizers**

## Technical data for BMJ 401 011

| | | |
|---|---|---|
| *Input data* | | |
| Mains voltage, single phase | | |
| nominally | 230 | V |
| input voltage range | 208 – 240 | V |
| permissible variations | 184 – 264 | V |
| Permissible frequency variation | 47 – 63 | Hz |
| Input impedance with an output current of 5 – 50 A | resistive | |
| Input current waveform with sine-wave input voltage | sinusoidal | |
| Power factor | | |
| with full load | 0.99 | |
| with > 20% load | > 0.95 | |
| Efficiency with nominal input voltage | | |
| with full load | > 0.87 | |
| with 25 – 100% load | > 0.85 | |
| Radio interference meets CISPR and FCC 20 780 class A | | |
| *Output data* | | |
| System voltage | −48 | V |
| Voltage at 2.7 kW rated power | −54 | V |
| Adjustment range | 47 – 55 | V |
| Adjustment range in charging mode | 51 – 57 | V |
| Output current | | |
| rated value | 50 | A |
| adjustable value when in the current limiting mode | 0 – 52 | A |
| Active current division, with rectifiers operating in parallel | | |
| Static regulation | | |
| with load changes of 0 – 100A | 40 | mV |
| temperature dependence −20°C – +35°C | < 40 | mV |
| Dynamic regulation | | |
| voltage deviation with 25% change in the load | 1 | V |
| response time with 25% change in the load | 5 | ms |
| Noise voltage | | |
| psophometric value | < 1 | mV |
| r.m.s. value, 10 Hz – 450 kHz | < 50 | mV |
| *General data* | | |
| Permissible ambient temperature with three rectifiers in the same cabinet | −20 – +50 | °C |
| Sound level, measured at a distance of 1 m | < 45 | dBA |
| Reliability, MTBF | 17 | years |
| Dimensions | | |
| width (19") | 485 | mm |
| depth | 336 | mm |
| height | 435 | mm |
| Weight | 40 | kg |

### Battery

A lead-acid battery installed in the switch room should be of the sealed type, fig. 5. It has very low gas leakage and, hence, does not require topping up with water or measurement of the acid density. Consequently, there is no need for expensive battery rooms with rein-

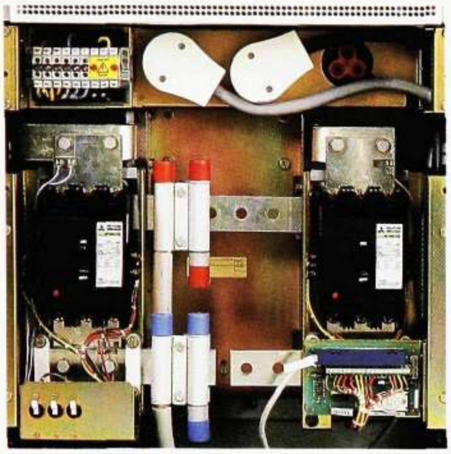

Fig 6
Battery fuse unit with two circuit breakers and alarm equipment. One battery is connected. The connector unit above the breakers contains a terminal block for the incoming mains and three terminals for rectifiers. Two rectifiers are connected

forced floors and special ventilation. The cells are mounted in battery cabinets having the same external dimension and appearance as the power cabinets. They are connected to the power supply system via a battery fuse unit mounted in the power cabinets.

*Battery fuse unit*
The battery fuse unit, fig. 6, contains two circuit breakers for 150 A, 250 A or 400 A. It also includes electronic circuits for supervision and control, with an optional function that enables the central supervision equipment of the exchange to monitor the battery voltage and disconnect the batteries from the load when the voltage is low.

*Battery charging*
It is essential that the battery is kept fully charged so that the maximum reserve time is always available. It is also important that the battery is recharged quickly after a mains failure.

Ericsson has developed a number of methods for charging batteries and maintaining the charge. The raised voltage method is not suitable for sealed batteries since it increases gassing and shortens the battery life. Normally only one voltage level is therefore used. The individual cells have different internal resistances and as they are connected in series they all receive the same charging current and, hence, take up different voltages. This means that some cells do not receive sufficient voltage and thus insufficient charge, while other cells obtain unnecessarily high voltage, become overcharged and may leak gas. If a mains failure occurs, the battery may then not have the expected reserve time because a few cells have been insufficiently charged.

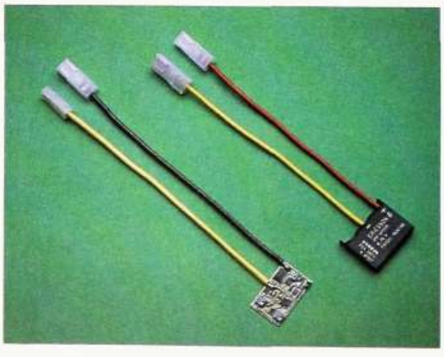

Fig 7
Cell voltage equalizers in hybrid technique. One equalizer is shown before encapsulation. The components are surface-soldered on to a ceramic substrate

One way of solving this problem has been by means of cell selection and by maintaining a slightly higher float charging voltage than would normally be necessary. In this way even the worst cell will receive sufficient charge. The disadvantages of this method are that it results in more gassing and probable shorter battery life. It is also hazardous to change individual faulty cells since the new cells may differ from the original ones.

A new method of solving this problem is to use cell voltage equalizers, fig. 7. The equalizer has been developed by Ericsson for this purpose and is available for 2 V cells and 6 V block containers. It consists of a transistor and a resistor connected in parallel with the battery cell, fig. 8. If the voltage across the cell tends to rise, the equalizer reduces the current to the cell by shunting more current past it. Similarly,, less current is shunted past a cell whose voltage tends to drop; the cell receives more current.[4] The result is that all cells in the battery are kept fully charged, i.e. at the floating voltage, for example 2.25 V.

The cell equalizer has the following advantages:
- the reliability of the whole system is increased
- the battery life is increased because of the lower system voltage
- maintenance costs are reduced because the improved control means that the cell voltages can be checked at longer intervalls.

Power supply system BZA 204 05 can also be used with ordinary lead storage batteries that require ventilation. The system is then equipped with a unit for automatic battery charging, BMP 131, employing the principle of voltage and time measurements. In such cases the battery is installed in a special battery room in the usual manner, and the system voltage is raised during charging.

**Distribution**
Distribution in BZA 204 05 is transient-limiting. It is based on a method developed especially for the power supply of electronic telephone exchanges.[5] Its main feature is that the positive conductors in all distribution branches are connected in parallel to the earth plane in

AXE, which creates a stable signal reference point. The negative conductors, each of which feeds a limited part of the equipment via its own fuse, have high resistance in relation to the internal resistance of the power supply equipment. If a short circuit should occur in the telephone equipment the resistance of the negative conductor limits the current to 1000 A. The voltage division between the battery and distribution impedances is such that the voltage across the distribution bus does not fall below the permissible limit even during a short circuit. This means that only the limited part of the exchange that is normally fed via the short-circuited fuse is affected. The requirement is that a maximum of 128 subscribers should be affected by a short circuit.

Moving the power distribution into the switch room means considerably shorter distribution cables and, consequently, reduced costs.

*Distribution unit*
The distribution unit contains twenty 15 A circuit breakers, a shunt and electronic circuits that measure the total output current of the unit and which can initiate alarms, fig. 9. A 40-mohm resistor is mounted in series with each breaker. The resistor may be short-circuited if the cable resistance exceeds 45 mohms. The unit also contains a terminal block for connecting 20 distribution cables. The largest cable dimension that can be connected is 2 x 10 $mm^2$ per pole.

**Reliability**
The power supply equipment must have very high reliability since a failure may mean the breakdown of a whole telephone exchange. How the reliability of a power supply system is calculated and built into the system has been described in great detail in an earlier issue.[6]

Generally speaking the operational reliability of the power plant can be considered very good if its unavailability is ten times less than that of the whole exchange. For a medium-sized AXE 10 exchange the limit for accumulated down time is two hours of system failure in 40 years. The limit for the power plant is thus 0.2 hours in 40 years.

BZA 204 05 meets these requirements, an achievement which has been reached through considering a number of important factors, such as:
In the system design:
- Redundancy is essential. The rectifier and other important functions are duplicated
- Each unit in the system must be able to operate as an independent unit
- Failure of one unit must not affect the rest of the power supply equipment
- The rectifiers must have automatic current division

In the unit design:
- Component types and suppliers are analyzed carefully before acceptance
- The components undergo extensive testing before assembly
- Large safety margins are built in when dimensioning circuits and units.

**Mechanical packaging structure**
The power supply equipment is mounted in cabinets of the same design as the AXE cabinets, fig. 10. The construction practice is similar to BYB 202 but designed for the power plant and designated BAF 701.

*Cabinet*
The cabinet is 720 x 400 x 2100 mm. The doors are made of double perforated steel plates. They allow air circulation but stop radiated radio interference. The cabinets can be placed in a row of AXE cabinets but must then be isolated from the telephone equipment. They can also be placed against a wall or back to back.

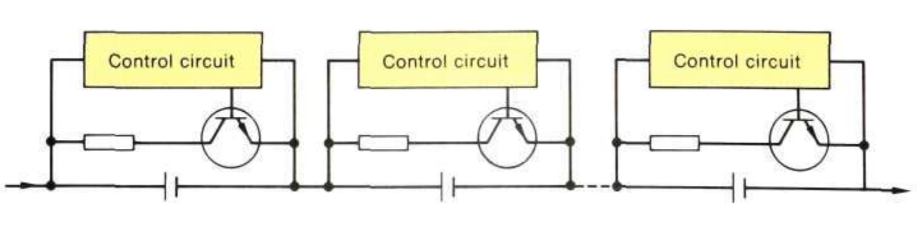


**Fig 8**
**Cell voltage equalizers for individual regulation of the voltage to each battery cell in a series circuit**

A supervision unit, fig. 9, mounted in the first power supply cabonet, collects alarms from all units in the power supply system. Two displays on the door of the cabinet show the system voltage and the total distribution current, i.e. the current consumption of the telephone exchange. The door panel also contains three alarm lamps and a measurement terminal. The lamps show the alarm category. Alarms can also be transmitted via relay contacts to the exchange alarm system. The terminal can be used to measure the system voltage, i.e. the voltage across the busbars.

The busbars are mounted vertically in the left-hand member of the cabinet. When the power plant comprises several cabinets, the individual busbars are interconnected by means of horizontal bars at the top of the cabinets.

*Units*
The units are designed for installation in 19″ cabinets and are connected to the vertical busbars in the cabinet sides. Cooling is by means of self-convection. Every unit is connected to the central alarm unit of the system.

*Installation*
All equipment, except the rectifiers and batteries, has been tested when delivered and installed in the cabinets. The rectifiers and batteries are installed on site. After rectifier tests and a simple system test the power plant can be put into operation. The rectifiers are connected to the mains by means of plugs and to the system busbars via the output switch. Hence there is no need to call in an authorized electrical contractor when a rectifier has to be changed.

The installation time for BZA 240 05 is considerably shorter than for previous power supply systems. The modular structure and the low weight of the system make extension easy.

## Summary

A new power supply system, BZA 204 05, has been developed by Ericsson to meet stringent environmental requirements. It can work in an environment with severe interference but will itself generate very little interference. The system has a modular structure and is therefore suitable for all telecommunications equip-

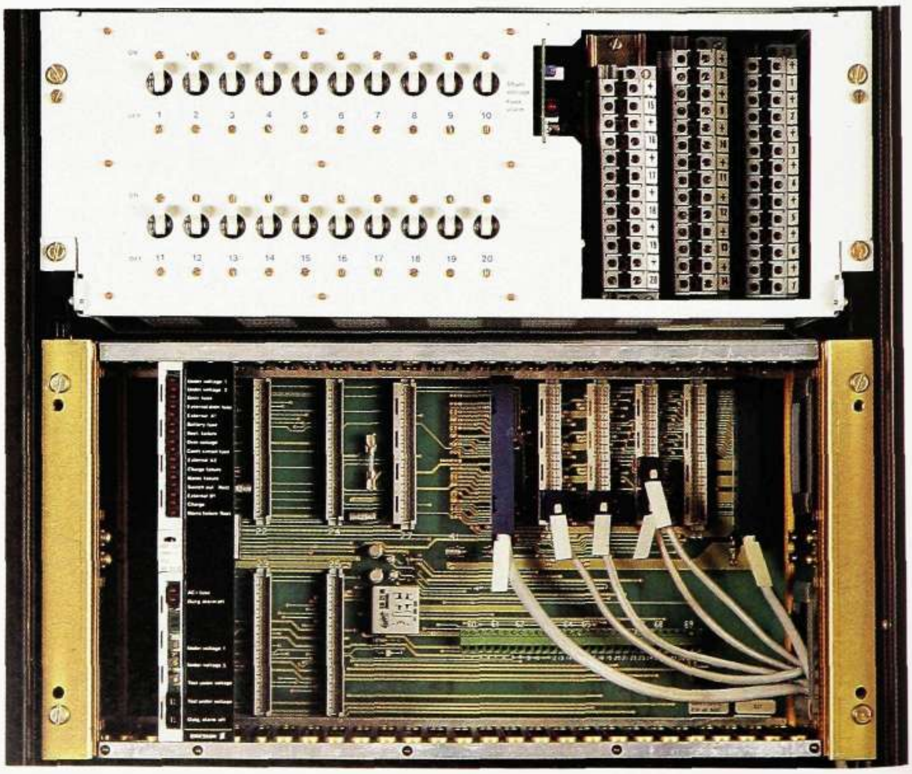

**Fig 9**
**A distribution unit (at the top) with circuit breakers and a terminal block for connecting the load. The lower unit is a supervision unit which collects alarms from the system and forwards them to an external centre. The alarm assembling board is mounted to the left in the unit**

Fig 10
Power supply equipment BZA 204 05.
The front row contains three cabinets with power equipment. The rear row consists of battery cabinets mounted back to back with the power cabinets

ment with power requirements in the range from a few up to several tens of kW.

The power supply equipment with batteries can be installed together with the telephone exchange in ordinary office premises. This means large savings; no need for special power rooms with reinforced floors and special ventilation and less need for distribution cable because of the short distances between power and telephone equipment.

Rectifier BMJ 401 011 is the central unit of the BZA 204 05 system. High-frequency conversion makes for compact construction. The rectifier is light, has small dimensions and operates noiselessly. It has a unique feature in that it constitutes a resistive load on the a.c. mains. This means lower costs for mains distribution and diesel power plants.

The batteries are connected to the system via automatic circuit breakers. A battery can be disconnected automatically if the battery voltage drops too much and thus be protected against over-discharge. Sealed batteries are used in systems installed in switch rooms. They have very low gas leakage and can thus be placed in offices without necessitating special air conditioning.

The distribution is of the transient-limiting type.

All units in the system are built up in the same modular style; compact units designed for mounting in cabinets in a few easy actions. Installation time has thereby been reduced drastically, resulting in considerable cost reduction.

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# Predicted and Observed Failure Rates for Ericsson's Transmission Equipment

Branko Tigerman and Olof Ahlbom

*Follow-up of the behaviour of equipment during operation can provide valuable information about its reliability. The mean failure rate, which is one of the measures of reliability, can be observed for different equipment in operation and compared with predicted values. It is assumed that the prediction model can be used for new designs if there is acceptable conformance between predicted and observed values.*
*The authors describe the basic principles applied by Ericsson Telecom AB in the follow-up and the procedures for collecting and evaluating fault reports for printed board assemblies. The results of comparisons at the printed board and function block levels are presented and conclusions are drawn regarding the trustworthiness and practicability of the prediction method.*

The purpose of failure rate prediction is to forecast how many failures can be expected to occur during a given period of time for a certain type of equipment. The predicted number of failures per unit of time is called the predicted failure rate.

From the point of vew of reliability the failures observed in equipment in operation are divided into relevant and non-relevant failures. The non-relevant category includes manufacturing failures, mechanical damage and failures caused by the human factor or by the fact that the operating environment has not conformed to specifications, for example as regards temperature, voltage or humidity. The observed failure rate is obtained by dividing the number of observed relevant failures by the operating time.

A comparison between the observed and the predicted failure rate gives an estimation of the accuracy of the prediction. When the degree of correlation is acceptable the prediction method is judged satisfactory for practical calculations.

Failures occur at random and probabilistic methods are used for the calculations. The predicted failure rate is the mean value expected for a large number of equipments. Relatively large deviations from the prognosis value may somtimes occur for individual equipments. The variation between individual units, together with insufficient knowledge of the range of application of predictions, has resulted in many people seeing predictions as theoretical calculations of limited worth. However, in reality an expert prediction expresses a realistic expectation and has considerable practical usefulness.

The follow-up must be purposeful and well planned in order to be able to determine the actual failure rate of a type of equipment in operation. One practical problem is caused by the high built-in reliability performance of the equipment. Failures occur only sporadically. Making a prediction with a satisfactory confidence level requires data from a statistically significant number of relevant failures, necessitating long periods of observation of large amounts of equipment in operation.

For the manufacturer the only practical possibility of adequate follow-up is in connection with the repair of faulty units that have been in service.

## Prediction method

The failure rate for a certain type of equipment, for example a printed board assembly, is calculated using the parts count method, i.e. the individual failure rates for all components in the equipment are added. The failure rate for a component is affected by several different stress factors: temperature, voltage, current, vibrations, moisture etc. A complete model for calculating the failure rate for a component therefore includes mathematical expressions for the effect of each relevant stress factor. A completely accurate calculation of the failure rate for a printed board assembly would thus necessitate individual calculation of the actual value of each stress factor for every component. The amount of work involved would be immense and would not be feasible unless the equipment in question was to be manufactured in very large quantities. The calculation model chosen must be sufficiently realistic and at the same time as simple as possible and not cluttered with unessential detail. The required input data should be easily available and relevant to the design in question and the planned applications.

The prediction is based on certain assumptions, conditions and restrictions,

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which result in the following model.[1,2] A failure is assumed to

- be primary, i.e. not caused by other failures
- be complete, i.e. the deviation exceeds the limits for the required function
- occur so suddenly that it could not have been anticipated from previous observations
- have occurred during normal operating conditions
- cause a lasting fault condition; i.e. manual intervention is required for recovery.

Thus the failure concept excludes failures caused by the human factor and by external influences. Such failures are mainly dependent on the user and the application and are beyond the control of the manufacturer.

The prediction was carried out with the aid of the SYPREX21 computer program in software system DEPEND,[3] using the parts count method with component failure rates provided by the TILDA data base. Calculations were made for an operating temperature of +40°C (104°F) using standardized stress models for the components. The operating temperature was considered to be the result of a room temperature of +25°C (77°F) together with 15°C (27°F) excess temperature caused by dissipated heat.

The failure rate was predicted for individual types of printed board assembly and for function blocks, such as 30-channel PCM, 60-channel multiplexers and 2/8 Mbit/s digital multiplexers. The rate is given as the number of failures per $10^9$ hours and is designated FIT. All equipment faults were taken into consideration regardless of their effect on the operation of the system.

## Follow-up of failures during operation

The main purpose of the follow-up is to provide an assessment of the behaviour of the equipment in operation. Analysis of observed failures provides information regarding the manufacturing quality, availability and reliability, performance, component failure rates, typical failure modes and any design weaknesses. The experience gained is utilized in the design of new equipment.

### Follow-up principle

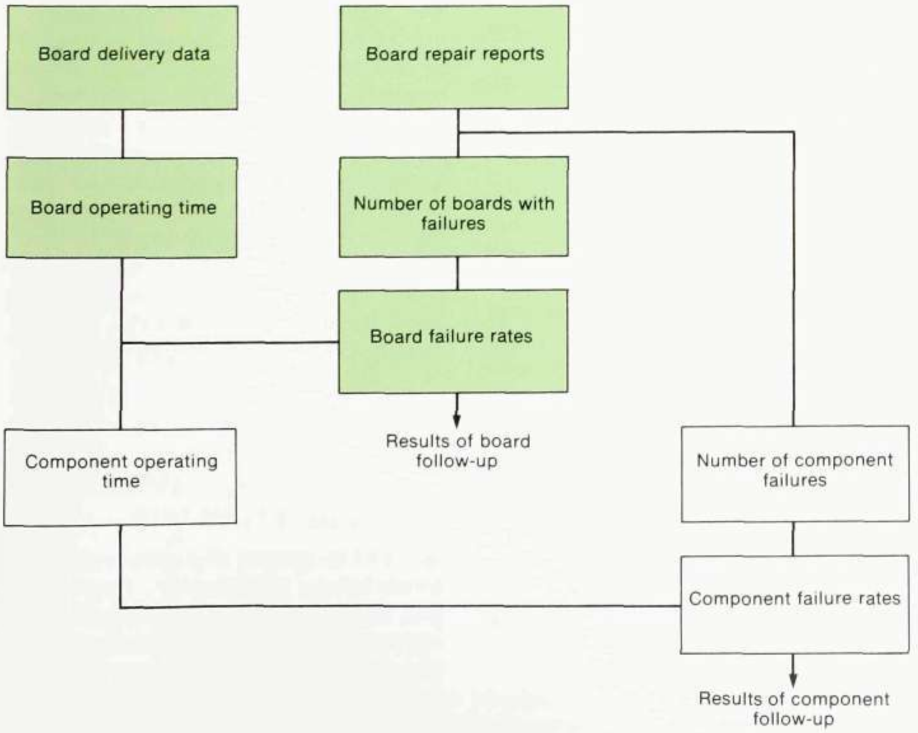
The flow chart in fig. 1 illustrates the basic principle for the follow-up. Information concerning the quantities supplied is obtained from a database and the failure follow-up system REPKON is used to assess the number of failures and their relevance.

For technical and economical reasons the reliability analysis was limited to 99 types of printed board assembly out of the whole product range. They were all selected on the basis of the respective types being widely used, had a large accumulated operating time and had at least four observed relevant failures. These selection criteria were necessary in order to ensure adequate confidence for the observed failure rate. The chosen printed board assemblies were built up into purposeful function blocks (subsystems).

### Estimating the operating time

The operating time for any type of printed board assembly is the accumu-

**Fig 1**
**Flow chart of the follow-up procedure for printed board assembly and component failures during operation. The article only deals with the follow-up of printed board assemblies**



lated time during the number of years when units of this type have been in operation. In most cases the customer has not specified the exact time of the equipment being taken into service; nor that of a failure occurrence. The beginning of the year after delivery was therefore used as the start time and the accumulation was taken up to the end of 1986.

The assumption that each printed board assembly was put into operation only at the start of the year after delivery was the first approximation of the operating time. Spare parts were also included in the delivery and contributed to the calculated accumulated operating time, but not – if they were unused – to the number of failures. However, the number of spare boards was so small, approximately 5%, that the contribution they made to the operating time was negligible compared with the uncertainty regarding the start time.

The operating time was calculated up to the end of 1986, but the number of failures included those reported up to the end of October 1987. Thus the accumulated operating time was rather on the low side, whereas compensation was made for any delays in reporting. The observed failure rate was therefore higher than the real value, to the disadvantage of the manufacturer. The difference could be considerable in cases where large numbers of printed board assemblies were delivered in 1986; the operating time in 1987 would not be included but reported failures would be counted.

### Evaluation of failure reports

The assessment of which failures were relevant was based on reports of the repair of returned printed board assemblies. As far as possible failures during operation were separated from manufacturing faults and transport damage. The latter categories are non-relevant failures in reliability prediction. Incomplete reports from customers made it impossible to eliminate failures detected during installation and during the early failure period. Consequently, the observed failure rate is too high, especially for new designs that have been in operation for only a few years.

Relevant failures are primarily component failures, regardless of whether they have been caused by other failures. Readjustments, undetected faults, change orders, equipment scrapped without investigation etc. were all reported under the heading of *other failures*. According to practice it was assumed that 1/3 of all these unspecified failures were relevant. Thus the number of relevant failures for a printed board assembly is the sum of all component failures and 1/3 of other failures.

The number of repairs carried out internally by the customer is considered negligible. Several large customers make special service agreements with Ericsson Telecom AB after the warranty period. For more than ten years most faulty printed board assemblies have therefore been sent to Ericsson for repair. Hence the number of unreported failures is considered marginal and will not affect failure rate calculations.

### Observed failure rate

The observed failure rate for a type of printed board assembly has been calculated as the quotient of the observed number of relevant failures and the accumulated operating time. Like the predicted rate it is given as the number of failures per $10^9$ hours and is designated FIT.

The observed failure rate for function blocks has been calculated as the sum of the observed failure rates for the printed board assemblies in the block. In comparisons with predicted values all equipment failures are considered, regardless of how they affect the function of the system. The board failure rates can therefore be added also for function blocks that contain redundant equipment, for example function blocks for generating the fundamental frequencies in analog multiplexing systems.

## Comparison of predicted and observed failure rate

In order to assess the accuracy of the predictions, correlation coefficients and regression lines have been calculated and mean values, standard deviations and medians of failure rates for the selected equipment have been compared.

Table 1

Number of relevant failures observed. 99 types of printed board assembly have been studied, but the distribution obtained is likely to apply to all boards in Ericsson's transmission equipment

| Number of observed failures per type | Relative frequency |
|---|---|
| 4–10 | 28% |
| 11–20 | 18% |
| 21–50 | 24% |
| 51–100 | 17% |
| 101–200 | 6% |
| >200 | 7% |

In addition the quotient of the observed and the predicted failure rates has been calculated for each selected item. The quotient constitutes the quantitative measure of the comparison. If it is less than one the equipment is better than predicted and vice versa. A quotient of exactly one means that the failure rate observed during operation coincides with the predicted value. The density and distribution functions of the quotient show whether the prediction method is optimistic or pessimistic.

**Printed board assemblies**

99 types of printed board assembly were selected: 37 in the BYB construction practice and 62 in the older M4 and M5. During the period 1975–1986 a total of over 905,000 boards of these types were delivered. The total accumulated operating time for these boards is more than $2.44 \times 10^6$ years. 8948 failures had been reported by the end of October 1987. 5781 of these, approximately 64 %, were considered relevant to the reliability assessment. About 65% of the relevant failures were identified as component failures. The reason for the relatively small number of identified failures is that fault location and repair may turn out to be more expensive then new manufacture.

The number of observed failures varies greatly from one type of board to another depending on differences in complexity and accumulated operating time. Fig. 1 shows the number of observed relevant failures. In spite of the fact that the follow-up covers a large amount of equipment, the number of observed failures falls below 10 for 28 % of the types and for almost half of the types it is still less than 20. This shows very clearly the difficulties encountered in the follow-up of reliability predictions when working with limited amounts of equipment and short operating times. Since all types of printed board assembly that had less than four failures were excluded, the proportion of boards with less than ten failures is even larger than the figure obtained in the study.

Fig. 2 shows the observed failure rate as a function of the predicted value. Each type of board is represented by a dot in the graph. Red dots indicate boards in the older construction practices M4 and M5, and blue dots indicate BYB boards.

The new types of printed board assembly often have a higher failure rate than the older types because of their greater complexity and larger functional content. In addition their operating time is short. Consequently, the observed results are perceptibly affected by the higher failure rate that always occurs during the beginning of the operating time, the early failure period.

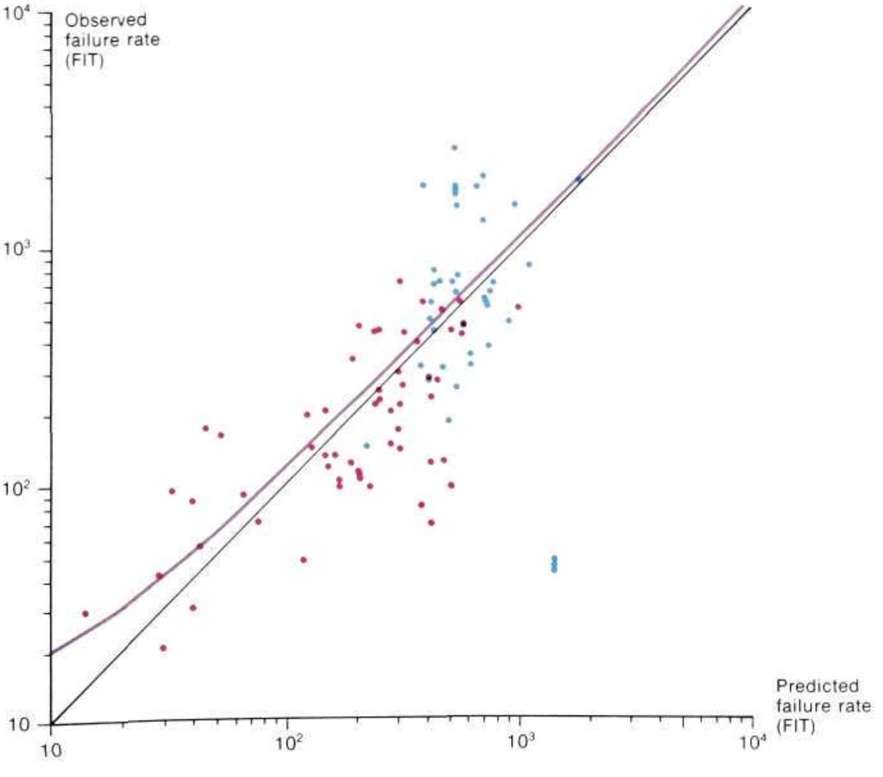
Linear regression in accordance with the least square method gives a correlation coefficient of 0.63. Considering the number of observations, this shows that the probability of there being a correlation between the predicted and the observed failure rate is greater than 99 %. All dots on a line through the origin with a slope of 45° represent the ideal case, i.e. where the observed and the predicted failure rates coincide. Dots below this line represent board types with an observed failure rate lower than the predicted rate. The closer the dots are clustered around the line the better the observed failure rate matches the predicted value.

**Fig 2**
**The observed failure rate as a function of the predicted failure rate for 99 types of printed board assembly.**
**Scatter diagram**

- Items in construction practice M4 and M5
- Items in construction practice BYB

Observed = predicted

Observed = 9.34 + 1.11 (predicted)



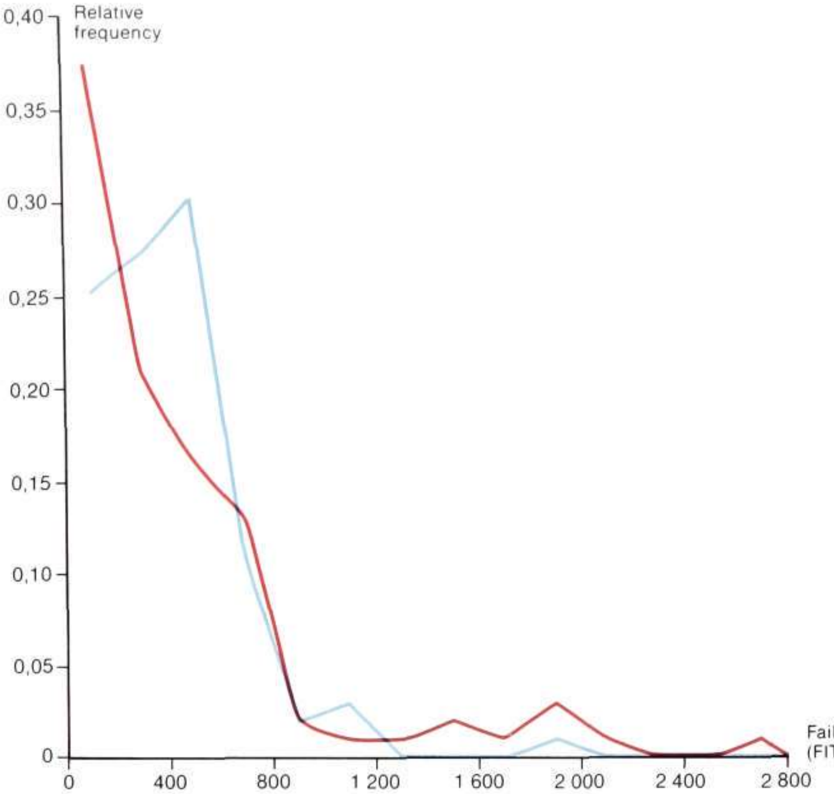
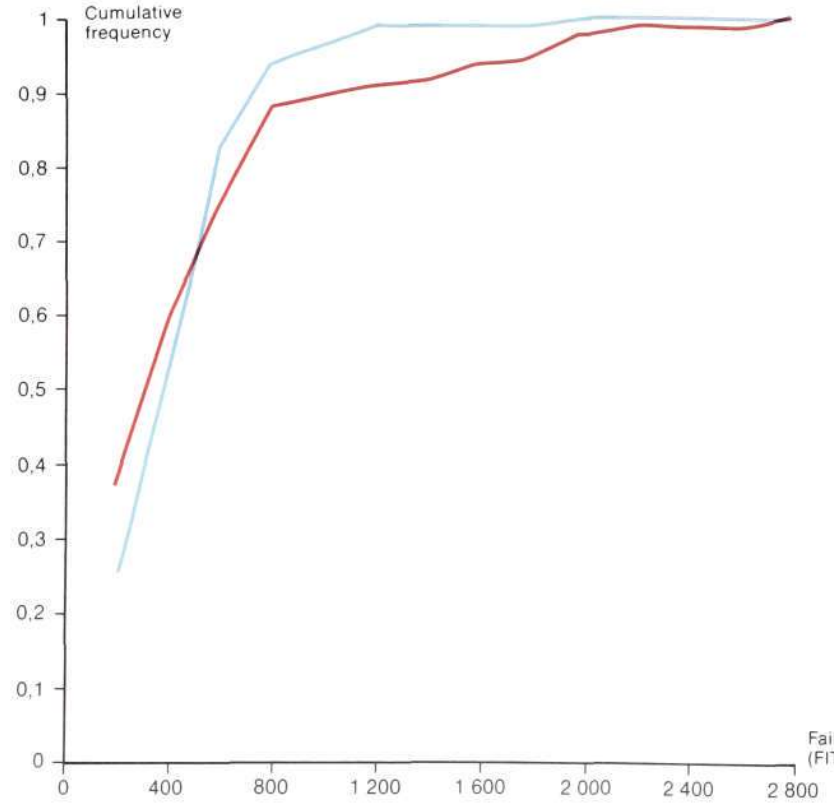



**Fig 3**
**Relative frequency (density function) of the observed and predicted falure rates for 99 types of printed board assembly**

**Predicted**
**Observed**

**Fig 4**
**Distribution function for the observed and predicted failure rates for 99 printed board assemblies**

**Predicted**
**Observed**




The 99 selected types of printed board assembly have been graded according to failure rate. The density and distribution functions for the predicted and the observed failure rates have been calculated. The corresponding polygons are shown in figs. 3 and 4. It should be noted that the functions are only representative of the chosen sample of board types. Other selections result in other functions. This only purpose of these graphs is to compare the observed and the predicted values.

The density function, which shows the relative frequency of a certain failure rate in the selected population, indicates that the observed number of board types with a failure rate of less than 200 FIT was larger than expected from the prediction. The number of high failure rates observed was also larger than predicted.

The distribution function, fig. 4, shows how large a part of the selected board types has a failure rate lower than the corresponding value on the x-axis. The graph shows that the actual failure rate is less than 500 FIT for more board types than expected from the prediction.

The mean value of the observed failure rates is 13% higher than predicted (456 FIT observed as against 404 FIT predicted). However, the dispersion is large, particularly for the observed failure rate: a standard deviation of 503 FIT and 286 FIT respectively. The median, 283 FIT for the observed and 379 FIT for the predicted failure rate, is therefore considered a more appropriate measure. This is always the case with variables showing a high degree of dispersion.

Thus a failure rate of less than 283 FIT has been observed for 50% of the board types although the predicted result for this level was 379 FIT.

The selected types of printed board assembly have also been classified on the basis of the quotient of the observed and the predicted failure rates. The relative frequency of each category is shown as a histogram, fig. 5. If the quotient is $<1$, i.e. the board type is better than predicted, the prediction was pessimistic. The histogram shows that 59% of the

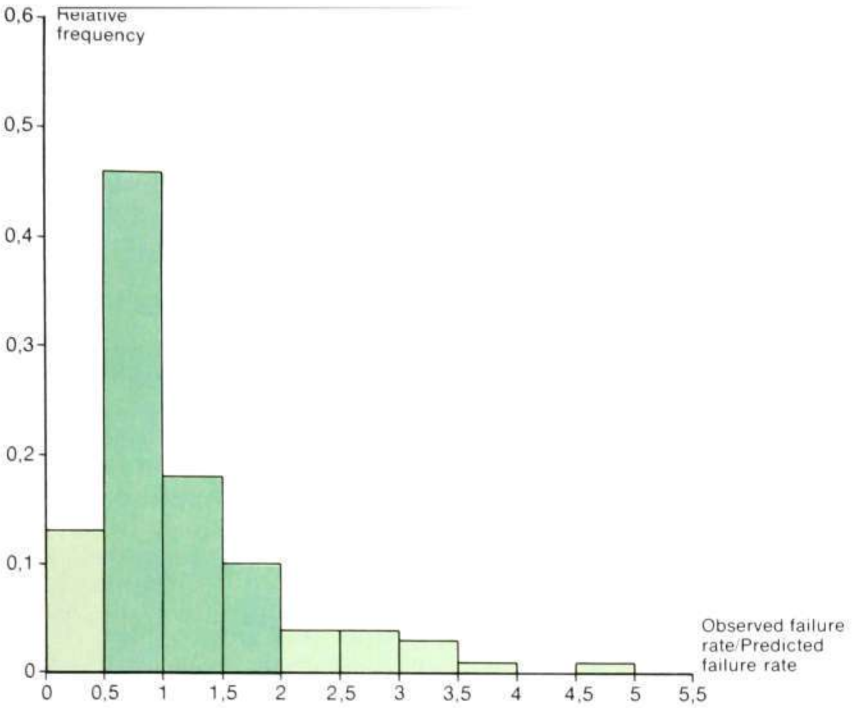
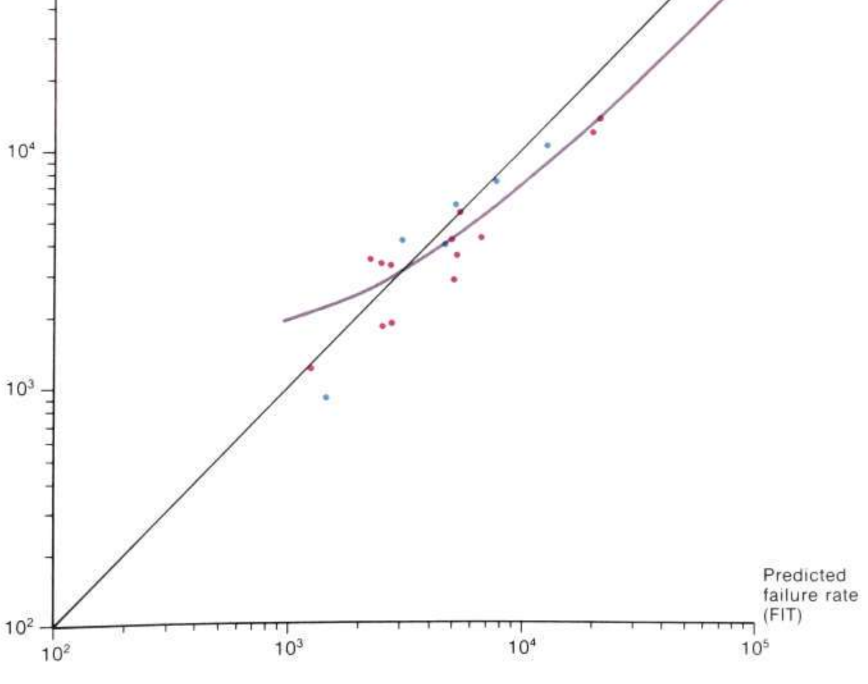



**Fig 5**
**Histogram showing the distribution of the quotient of the observed and the predicted failure rates for 99 types of printed board assembly. The observed failure rate is better than the predicted rate for 59 % of the types. The quotient of the observed and the predicted failure rates lies within the range 0.5–2 for 74 % of the types**

**Fig 6**
**The observed failure rate as a function of the predicted failure rate for 20 types of function block. Scatter diagram**




observed failure rates are lower than predicted, and 74% of the observations lie within the range TWO TIMES BETTER" and "two times worse" than predicted. Only 13% of the observed failure rates are more than twice as high as predicted, and the same percentage of failure rates are more than twice lower.

Large discrepancies between observed and predicted failure rates are caused partly by operating conditions not conforming exactly to the conditions specified for the prediction and partly by deficiencies in the follow-up. In the prediction it is assumed that the population is homogeneous, the failure rate is constant with time and the operating environment meets specified requirements. When assessing the observed results it is assumed that failures can be classified correctly as relevant or non-relevant and that the number of unreported failures is negligible.

However, in practice the population is not homogeneous. Boards are taken into service at different times, so that the early failure period of one delivery coincides with the constant failure rate period (best period) for an earlier batch. It is not always possible to eliminate failures during installation, and the larger number of failures during the beginning of the operating period must not be overlooked for equipment containing a board type that has been in service for only a short period. Failures caused by non-conforming environment, manual actions and any design errors may contribute to an observed failure rate that is significantly higher than the expected value. This results in the quotient of the observed and the predicted failure rates being too high. The board type is assumed to be worse than predicted.

On the other hand, if all failures are not reported – particularly those that concern board types for which the number of observed failures is low – there will be a significant reduction in the observed failure rate. The quotient of observed and predicted failure rates will then be too low. The board type is assumed to be better than predicted.

**Function blocks**
The 99 types of printed board assembly have been used to build 20 blocks for specific functions. Each function block consists of one or more printed board assemblies mounted in a suitable magazine. The failure rate for a function block is obtained by adding the individual failure rates for the boards in the block.

Fig. 6 shows the observed failure rate for function blocks as a function of the predicted value, calculated in a similar way to the graph for boards. In this case also the red dots indicate older types and blue dots newer designs. The correlation between the observed and the predicted failure rates is considerably better for function blocks than for individual board types. Linear regression gives a correlation coefficient of 0.95, which, in view of the number of items compared, indicates good correlation. The better correlation has been obtained because even significant positive and negative failure rate deviations for individual components have been compensated by the large quantities of each component and the great number of different types of components.

The mean value of observed failure rates, 4865 FIT, is approximately 23% lower than the predicted value of 6327 FIT. In this case the dispersion, too, is less for the observed than for the predicted failure rates (3447 FIT for observed as against 5871 FIT for predicted values). The median is 4004 FIT for the observed failure rates and 4985 FIT for the predicted. This means that, on the whole, the function blocks were better than expected.

Fig. 7 shows the histogram of the quotient of the observed and the predicted failure rates. 16 of the 20 function blocks are better than predicted and no observed failure rate deviates by more than 50% from the predicted value.

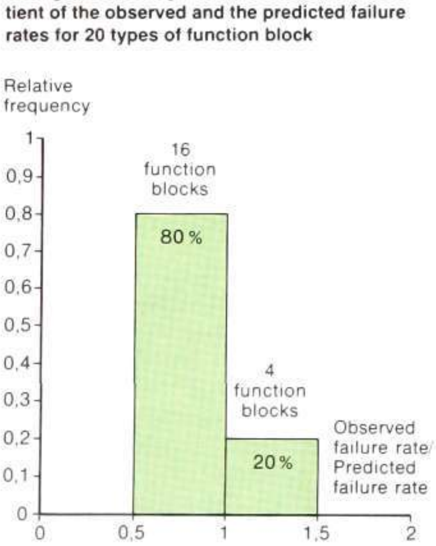
## Summary

The comparison shows a fairly good correlation between the predicted failure rate and the failure rate observed during operation, particularly for function blocks. The method is therefore considered suitable for practical predictions for transmission equipment.

The predicted failure rate for individual types of printed board assembly is most suitably used in predictions for function blocks or systems and in the calculation of spare parts requirements.

The study has also shown that a detailed failure analysis in connection with the repair of printed board assemblies is extremely important if any bad components and design errors are to be detected. It also provides excellent basic data, at the component level, for realistic predictions for new designs.

**Fig 7**
**Histogram showing the distribution of the quotient of the observed and the predicted failure rates for 20 types of function block**

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# Standardization of Telecommunication Management Networks

Walter Widl

*The development of telecommunications networks from wholly analog to the integrated digital networks of today and the wideband ISDN of tomorrow has reopened the question of how to administer and maintain networks during operation. The problem is being studied intensely both nationally and internationally and the results will be that telecommunication management networks, TMN, will be standardized and introduced. The concept of TMN has been developed by CCITT, which will issue recommencations. Representatives of Ericsson Telecom have participated actively in the CCITT standardization work. The author describes the functions and architecture of TMN and illustrates it with some practical cases.*

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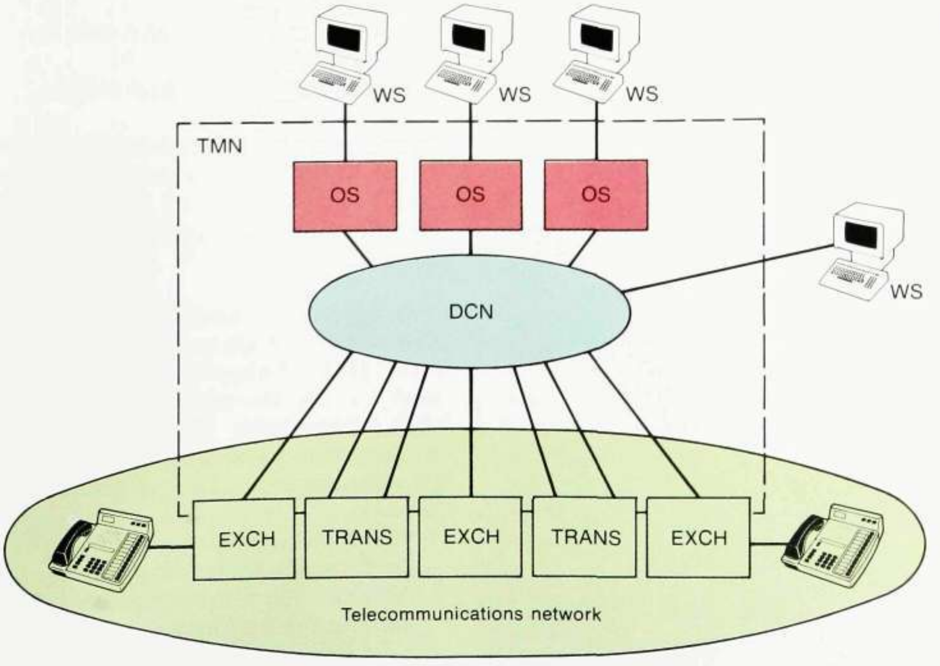
## Basic principles of TMN

The main reasons for the introduction of TMN are considered to be the desire for
- high quality of service at a reasonable cost
- rational working methods
- standardization.

The market for data networks and value-added services is divided between telecommunications administrations and other network providers. It is in the fields of operation, maintenance and administration that a telecommunications administration is able to distinguish itself favourably from other enterprises offering transmission services. An administration can gain considerable economic advantages from an efficient TMN utilized for different services and the faster charging routines it can provide.

Fig. 1
Summary of the relationship between the TMN and the telecommunications network

OS Operations system
DCN Data communications network
EXCH Exchange
TRANS Transmission system
WS Work station




In this context rational working methods means that frequent routine tasks and less frequent technical tasks are handled by different personnel categories. Routine tasks, such as sales, planning and traffic measurements, are performed by computer operators working at administrative workstations. Technical tasks in the field, such as fault clearing and network modifications, require mobile field groups consisting of specialists equipped with technical workstations. One of the purposes of TMN is to facilitate cooperation between personnel working at different types of workstations for operation, maintenance and administration of the network.

Support systems with centralized workstations usually serve networks with equipment of different types, in different versions and made by different manufacturers. In order to reach the goal of high quality of service at a reasonable cost it is necessary that future telecommunications equipment has standardized management interfaces, functions and routines.

The efficiency of TMN in future telecommunications networks is dependent on three basic factors:
- TMN must provide everything included in the concept *telecommunication management*. This involves management of performance, fault, configuration, accounting and security. TMN, which operates as an overlay network for the managed network, will have to cooperate with exchanges, transmission links and network terminals
- TMN will have to serve different types of telecommunications networks, such as IDN, ISDN, data networks and existing digital and analog networks, fig. 1. Management functions in these networks will have to cooperate with functions in TMN
- Management of equipment of different types and manufacture requires a certain degree of standardization. CCITT and other national and international organizations are now

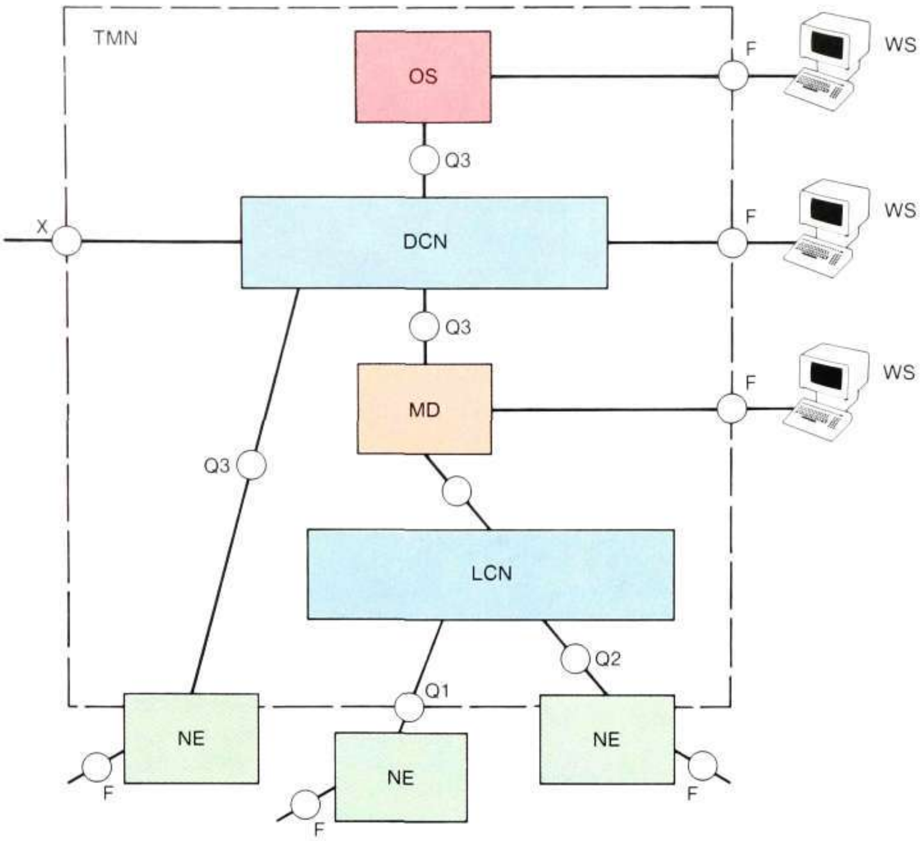



**Fig. 2**
**Physical TMN structure with the different interfaces indicated. The dashed frame in fig. 2 shows the borderline of TMN.**

| | |
|---|---|
| OS | Operations system |
| DCN | Data communications network |
| MD | Mediation device |
| LCN | Local communications network |
| NE | Network element |
| Q1, Q2, Q3, F, X = Interfaces | |

Interfaces

studying recommendations concerning the architecture, interfaces and functions of TMN.

Fig. 2 shows the physical structure of TMN, comprising
- operations system, OS
- data communications network, DCN, mainly intended for long-distance transmission
- local communications network, LCN, mainly intended for short-range transmission
- mediation devices, MD.

The managed telecommunications network consists of objects, which are divided into:
- network elements, NE. Typical examples are exchanges, digital cross-connect systems, cable, transmission equipment, charging equipment
- assemblies of NE, such as circuits, links and connections
- parts of NE, such as maintenance entities, ME, maintenance sub-entities, MSE, and support entities, SE.

The managed objects are connected to the TMN via Q-interfaces, which are also used to interconnect different parts of the TMN. Workstations are connected either direct to the managed objects or to the TMN via F-interfaces. Different TMNs are interconnected via X-interfaces. F- and X-interfaces have not yet been studied by CCITT.

Table 1
Functional blocks in TMN

| TMN general functions | Functional blocks OSF | MF | DCF | WSF |
|---|---|---|---|---|
| transport | | | x | |
| storage | x | x | | |
| security | x | | | x |
| retrieval | | | | x |
| processing | x | x | | x |
| user terminal support | x | x | | x |

| | |
|---|---|
| OSF | Functional block in OS |
| MF | Functional block in MD and NE |
| DCF | Functional block in DCN and LCN |
| WSF | Functional block in WS |

## TMN functions

TMN functions fall into two categories:
- TMN general functions
- TMN application functions.

### TMN general functions

These functions are used in the operation of the TMN and include:

*Transport*
- transports data between parts of the TMN

*Storage*
- stores data for a certain time

*Security*
- checks the authority of users to access or change data

*Retrieval*
- gives access to data

*Processing*
- analyzes and manipulates data

*User terminal support*
- handles input and output of data.

Table 1 gives one example of the way in which the TMN general functions can be assembled in functional blocks. Fig. 3 shows how the functional blocks can be implemented.

### TMN application functions

These functions are used in the management of the telecommunications network, i.e. its operation, administration and maintenance. According to OSI management categories[1] the TMN application functions can be grouped as follows:

*Performance management*
- performance monitoring
  gathers data continuously concerning the performance of network elements

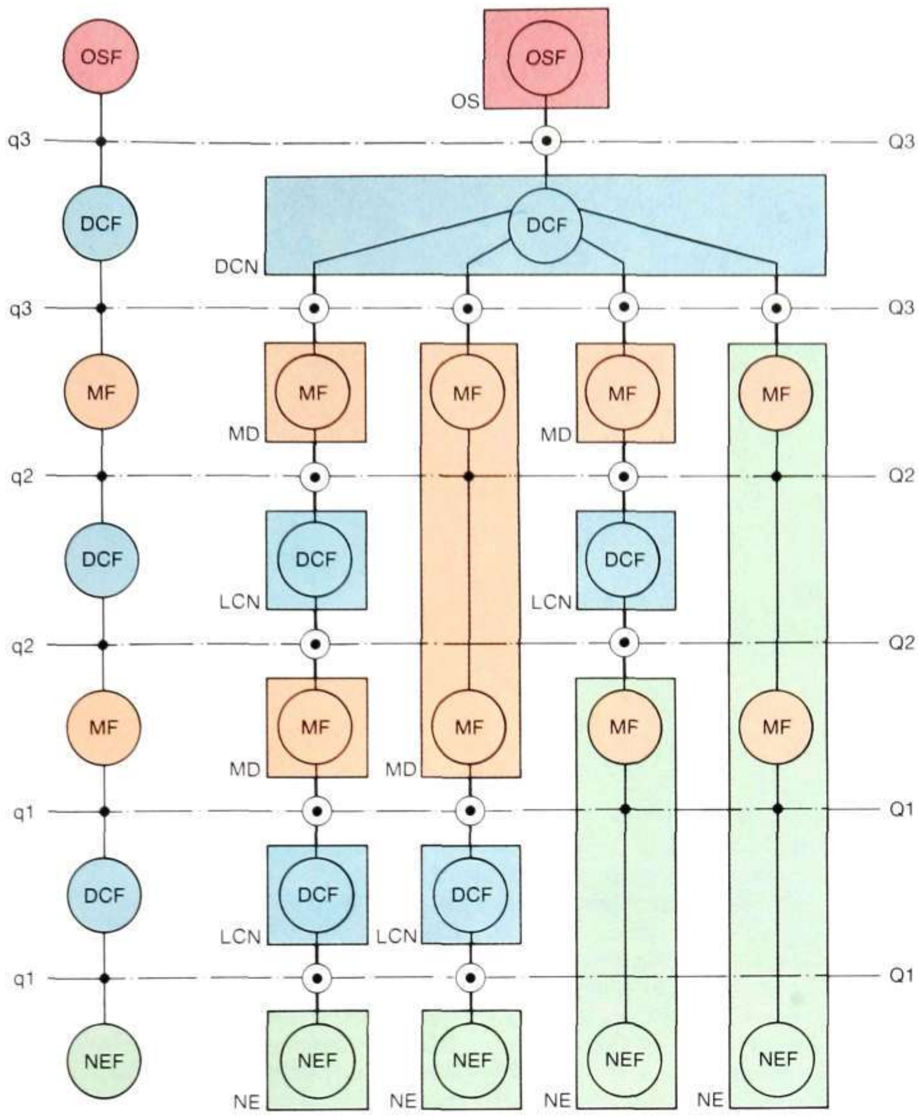



Fig 3
**Functional and physical TMN structure**

| | |
|---|---|
| Q1,2,3 | Interfaces |
| q1,2,3 | Reference points |
| OSF | Functional block in an operations system |
| DCF | Functional block in a data communications network |
| MF | Functional block in a mediation device |
| NEF | Functional block in a network element |
| | Reference point |
| | Interface |
| | Function |
| | Equipment |

- traffic management
  supervises traffic and changes the network configuration to cope with extraordinary traffic conditions
- *quality of service observation*
  monitors and records parameters concerning connections and disconnections, connection quality and charging integrity.

*Fault management*
- alarm surveillance
  monitors NE failures in near to real time and determines the nature and severity of failures
- failure localization
  provides additional failure localization information if the failure cannot be localized by alarm surveillance
- testing
  analyzes the state of circuits and equipment in routine tests or on demand.

*Configuration management*
- provisioning
  comprises the routines necessary for putting equipment into operation except those required for installation
- status and control
  *controls and checks – on request –* functions in NE, such as changing service state, starting internal diagnostic tests in NE and blocking faulty equipment
- installation
  provides support during installation and system extension and reduction.

*Accounting management*
- billing
  collects billing information.

*Security management*
- access control
  checks that only authorized staff is allowed access to data.

The above-mentioned categories can have different scope in different telecommunications administrations. Moreover, a particular TMN function may support more than one management category. The descriptions of the categories should therefore be taken to serve as examples only.

## TMN architecture

A TMN, as defined by CCITT,[2] can be described by means of its functional and physical structures. The functional representation is based on functional blocks such as OSF, MF, DCF and WSF. *The various functional blocks are separated* by reference points. Fig. 3 shows how functional blocks can be implemented in hardware, for example OS, DCN, LCN and MD.

Fig. 3 illustrates the functional and physical structures in detail. Functional blocks, to the left in the diagram, are separated by reference points q1, q2 and q3. The functions can be implemented in many different ways through devices which can be connected via interfaces Q1, Q2 and Q3. Fig. 3 also shows the relationship between the q-reference points and Q-interfaces for point-to-point connections.

Typical implementations are:
- an Operation System, OS, contains OSFs
- a Mediation Device, MD, contains MFs

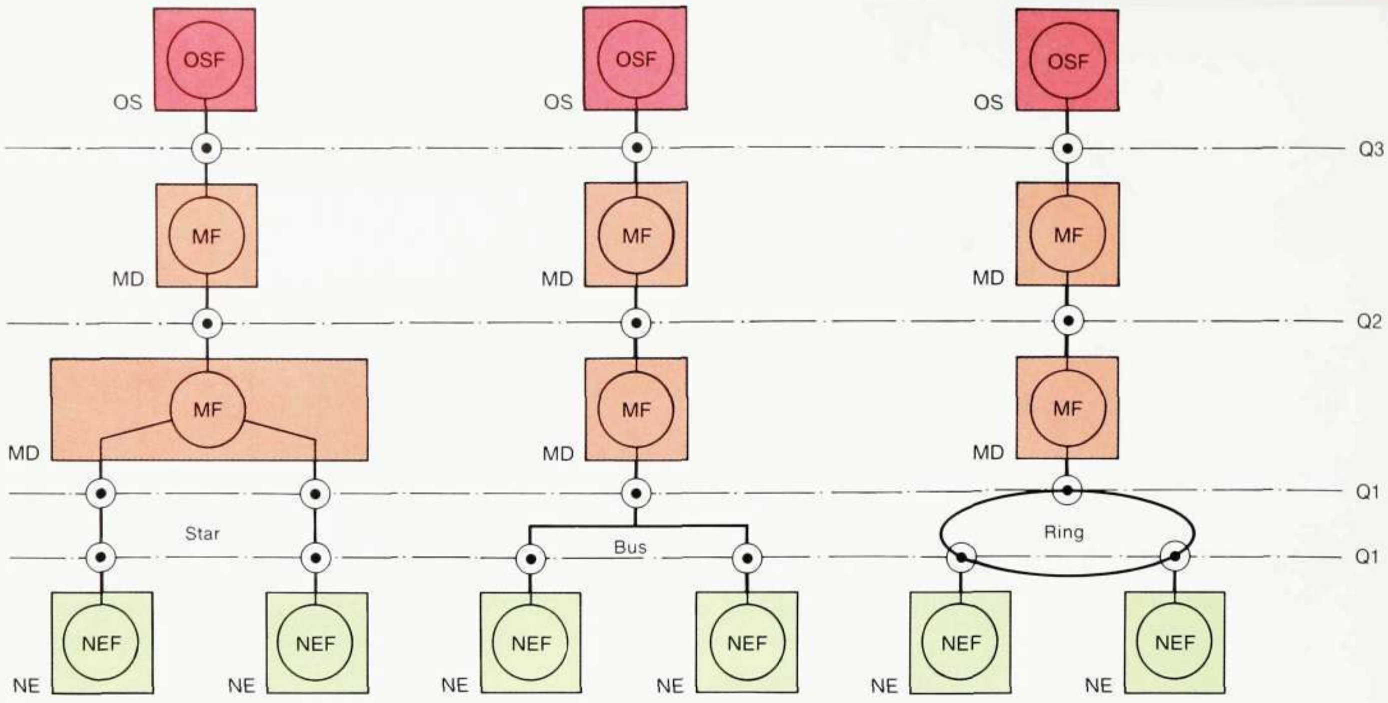



**Fig 4**
**Different configurations of the Q1 interface when several NEs are connected to one MD**

- a Network Element, NE, contains NEFs or NEFs and MFs
- a Data Communications Network, DCN or LCN, contains DCFs.

Fig. 4 shows various configurations with several NEs connected to one and the same MD via the Q1 interface. The interface can be star, bus or ring shaped. Fig. 5 shows configurations with network elements in tandem at the Q1 interface. The interface configurations mentioned above also exist at the Q2 interface. Figs. 4 and 5 are simplified and do not show the data communication functions or their implementation.

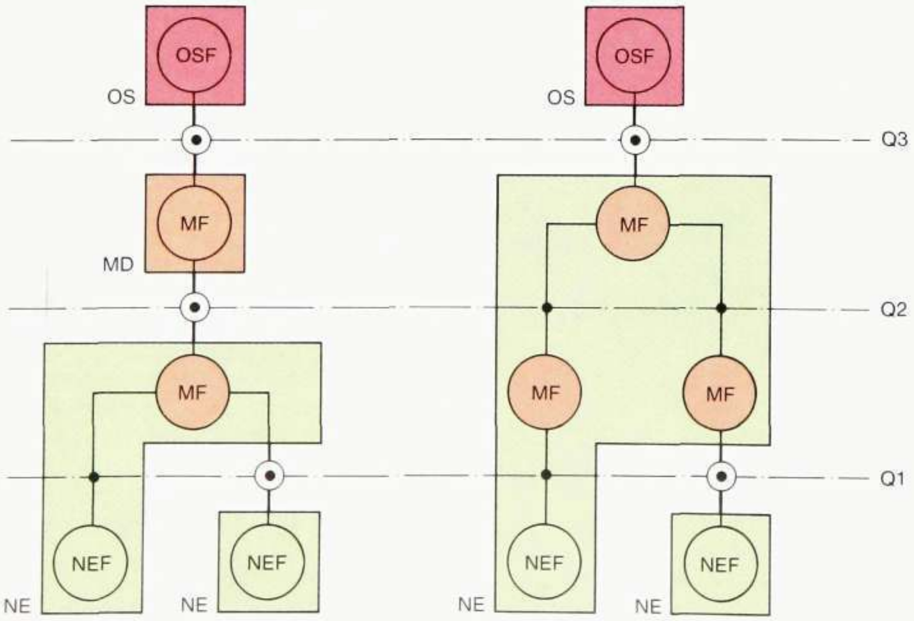
The definitions of q-reference points and Q-interfaces are illustrated in figs. 4 and 5 and summarized in table 2.

**Network element architecture**

The equipment in managed telecommunications networks is divided into network elements, NE, which are connected to the TMN via Q-interfaces. An NE can consist of equipment that is directly involved in the telecommunications process, such as maintenance entities, ME, and also of auxiliary equipment which is not directly involved, for example support entities, SE. If an NE contains mediation functions, these functions belong to the TMN.[3]

Fig. 6 shows some examples of the functional and physical structure of NE. The maintenance entity, ME, implements function MDF, the support entity SE function SEF and the Q-interface adapter function QAF. These functions are separated from each other by reference point m. Fig. 6 shows different types of Q-interface adapter and their connection to ME and SE. QAF is not necessary if MEF and SEF can be connected directly to reference point q1.

**Fig 5**
**Different configurations when NEs are connected in tandem**




## Table 2

*q-reference points*
- q1 reference points connect NEF and MF
- q2 reference points interconnect MFs
- q3 reference points connect MF and OSF and interconnect OSFs

*Q-interfaces*
- Q1 interfaces connect NE (without MF) and MD and also NE (without MF) and NE (with MF)
- Q2 interfaces interconnect MDs, connect NE (with MF) and MD and interconnect NEs (with MF)
- Q3 interfaces connect MD and DCN, NE (with MF) and DCN, OS and DCN.

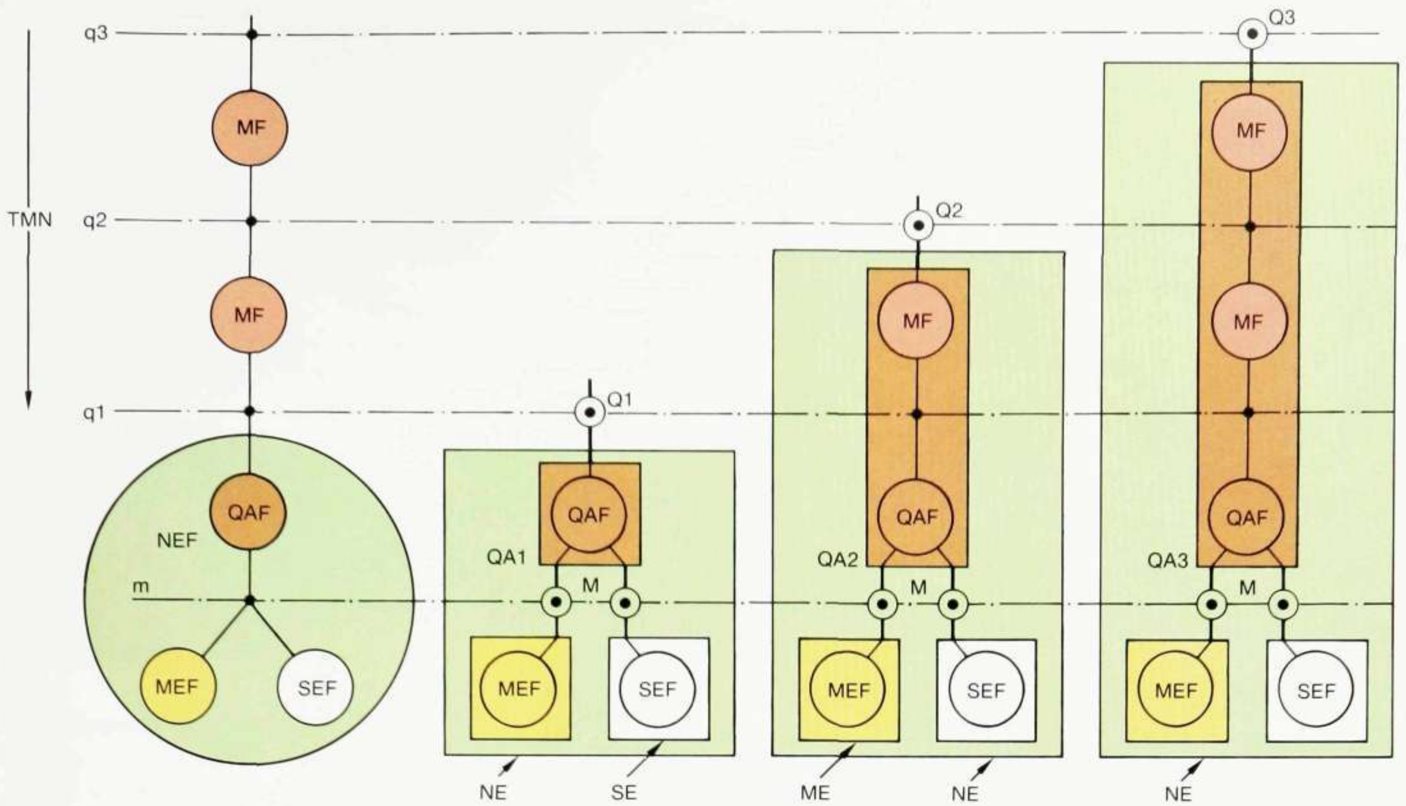
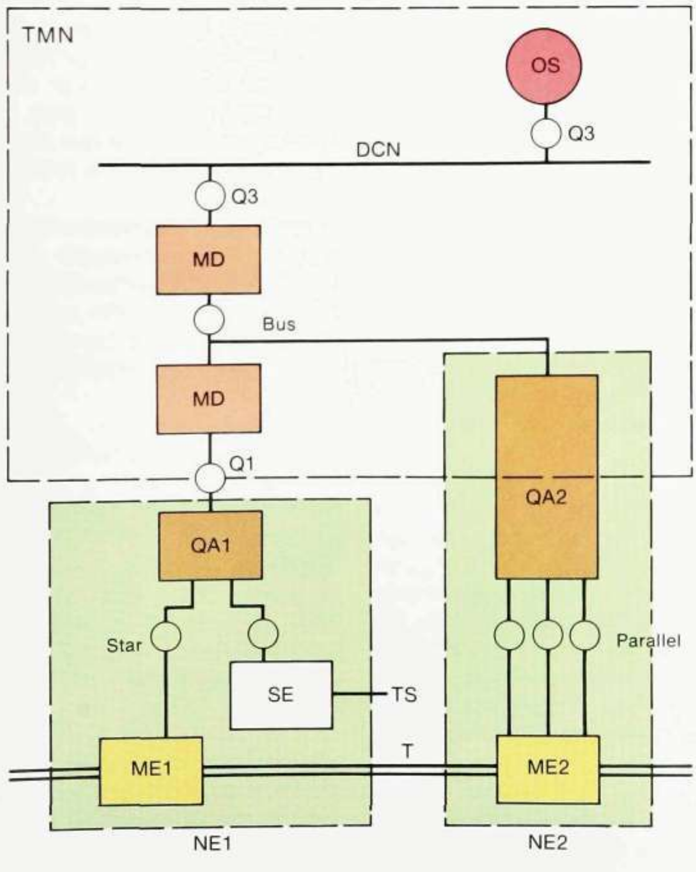



Fig 6
**Functional and physical NE structure**

QA1 Adapter for the Q1 interface
QA2 Adapter for the Q2 interface
QA3 Adapter for the Q3 interface

Fig 7
**An example of the physical implementation of TMN-NE**

M Non-standardized interface
TS The support interface of the telecommunications equipment




Different equipments within an NE are interconnected via M-interfaces. The interface, which is not considered for standardization, exists in different versions, for example
- a serial interface for star, bus and ring connections
- a parallel interface for point-to-point connections.

The various parts of NE are defined as follows:

*Maintenance entity*, ME
An ME is a part of a telecommunications network. It has identifiable interface points and can detect maintenance events and failures.[4] Each ME contains one or more maintenance interfaces for the exchange of support information. Exchanges, multiplexers, line systems etc, constitute MEs.
*Maintenance sub-entity*, MSE
An MSE is part of an ME. It has identifiable interface points and, if that is the case, can be pinpointed as faulty in a fault localization process. Alarms are initiated by the ME that contains the faulty MSE. Line terminals, repeaters and exchange terminals are some examples of MSEs.
*Support entity*, SE
An SE provides support for but is not directly involved in the telecommunications process. SEs include security equipment for premises as well as charging, test and air conditioning equipment.
*Q-interface adapter*, QA
QA performs MDF functions in the TMN, or QAF functions outside the TMN. QAs are not directly involved in the telecommunications process. Q-adapter functions include interface and protocol conversion of management information, fault localization in line systems and the control of standby routes and embedded transmission channels in NE.

There are different versions of QA:
- QA1 is required to connect MEs and

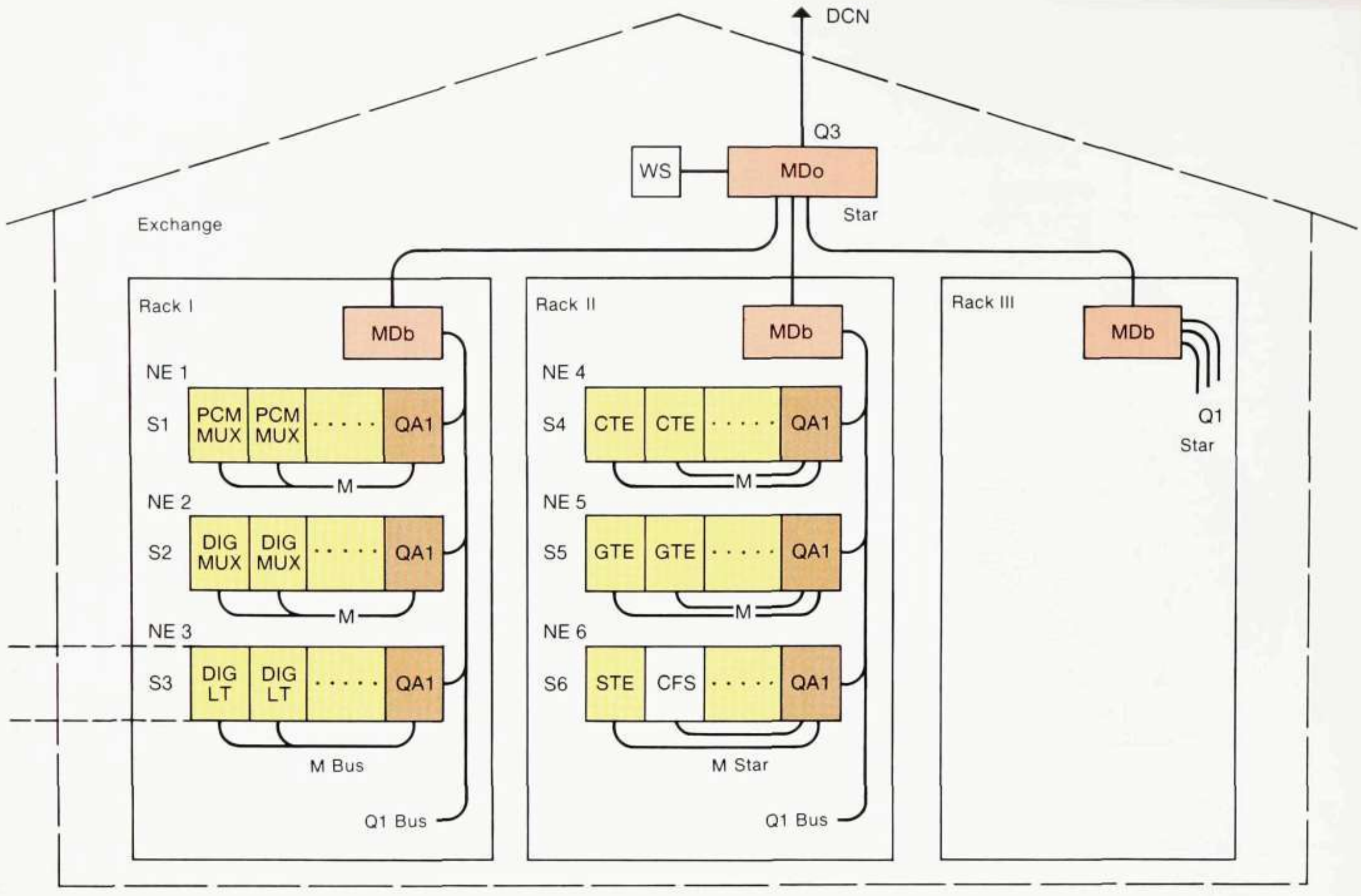



**Fig 8**
**An application of TMN in an exchange**

| | |
|---|---|
| S1 – S6 | Shelves |
| PCM MUX | PCM multiplexer |
| DIG MUX | Digital multiplexer |
| DIG LT | Digital line terminal |
| CTE | Channel translation equipment |
| GTE | Group translation equipment |
| STE | Supergroup translation equipment |
| CFS | Common frequency supply |
| MDb | Rack mediation device |
| MDo | Exchange mediation device |

SEs to the Q1 interface. QA1 does not belong to the TMN.

- QA2 is required to connect MEs and SEs to the Q2 interface. The MDF part of QA2 belongs to the TMN.
- QA3 is required to connect MEs and SEs to the Q3 interface. The MDF part of QA3 belongs to the TMN.

The main purpose of QA is to adapt the non-standardized M-interfaces to standardized Q-interfaces. Typical applications are:

- assembling alarm information from parallel galvanic or electronic contacts in existing analog or digital telecommunications equipment and converting the information into a form suited to the TMN
- connecting MEs, mounted in shelves, magazines or racks, to the TMN via a serial, bus-type auxiliary interface.

**TMN applications**

A number of MEs and/or SEs can be connected to one and the same QA using star or bus M-interface configurations. Fig. 7 shows different ways of connecting NEs to a TMN. NE1 with QA1, SE and ME1 does not belong to the TMN. NE2 with QA2 and ME2 belongs partly to the TMN. Fig. 7 also illustrates star, bus and parallel configurations of the M-interface.

Fig. 8 shows an exchange equipped with three racks – I, II and III – for the installation of telecommunications and management equipment mounted in shelves or magazines.

Rack I contains shelves of digital transmission equipment.
Shelf S1 contains PCM multiplexers. The whole shelf constitutes NE1. One PCM-MUX constitutes an ME.
Shelf S2 contains digital multiplexers (S2 = NE2, DIG MUX = ME).
Shelf S3 contains digital line terminals (S3 = part of NE3, LT = MSE).

In each shelf the maintenance entities, ME, and maintenance sub-entities, MSE, are connected to QA1 via an M-bus interface. In rack I the various NEs are connected via a Q1 bus interface to the mediation device MDb for conversion to a Q2 star interface.

Rack II contains shelves of analog transmission equipment.
Shelf S4 contains channel translation equipment (S4 = NE4, CTE = ME).
Shelf S5 contains group translation equipment (S5 = NE5, GTE = ME).
Shelf S6 contains supergroup translation equipment and the common frequency supply (S6 = NE6, STE = ME, CFS = SE).

In each shelf the MEs are connected to QA1 via an M-interface of star type. In rack III the various NEs are connected via a Q1 star interface to the mediation

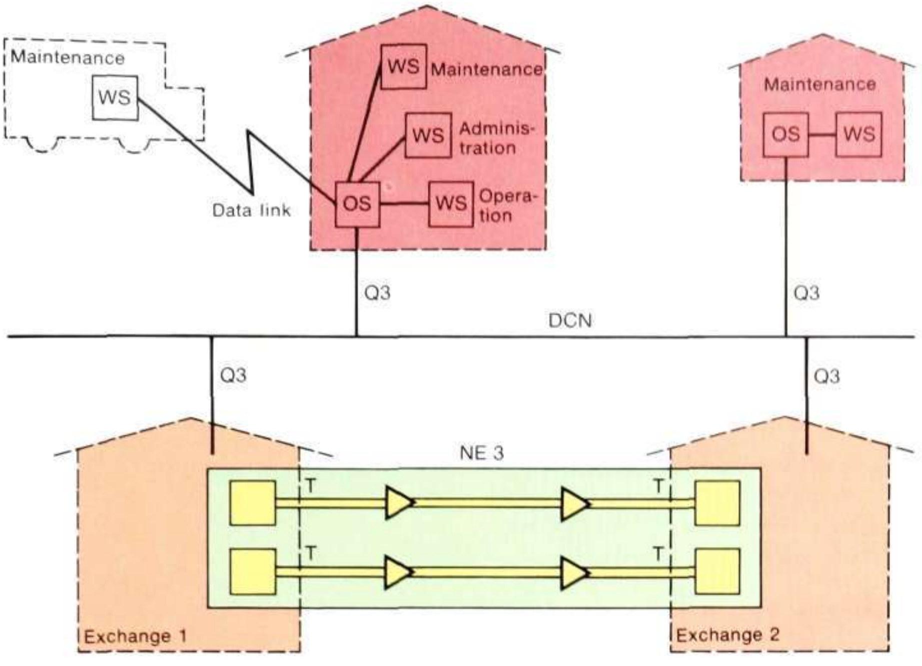



Fig 9
An application of TMN

device, MDb, for conversion to a Q2 star interface. Finally, the Q2 interfaces are linked together at the exchange mediation device MDo to form a Q3 interface.

Fig. 9, which is related to fig. 8, shows the line systems between two exchanges and the workstations for operation, maintenance and management. The line terminals at the ends of a line system both belong to the same NE. NE3, with a number of parallel line systems, encompasses the two exchanges that hold the LTs of the systems. Each line system can be reached from two different points via DCN.

Figs. 8 and 9 illustrate typical applications of the different interfaces:
- M for connections within a shelf
- Q1 for connections within a rack
- Q2 for connections within an exchange
- Q3 for connections between exchanges.

## Conclusions

The need for efficient support of telecommunications networks at a reasonable cost results in the introduction of new management systems designed for the supported telecommunications networks. The principles underlying such systems have been studied internationally, resulting in the concept of telecommunication management network, TMN. The TMN architecture offers a wide choice of implementations, so that support can be provided for telecommunications equipment with standardized and non-standardized support interfaces according to the requirements of the user.

In order to progress from the concept to internationally cooperating systems a number of problems have to be resolved, such as the standardization of protocols and routines for Q, F and X interfaces. These, and other unsolved problems will require intensified studies and activities during the next few years.

The close relationship between Ericsson's support systems and the TMN concept, coupled with Ericsson's continual participation in the standardization process, will simplify adaptation of the Ericsson support systems to future international recommendations. Ericsson will therefore be able to offer its customers complete telecommunications networks with full facilities for efficient management.

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# Bellcore's Technical Analyses of Circuit Switching Systems

Karl Alsmar and Thomas Ivarson

*Seven telephone operating companies in the United States, the regional Bell Operating Companies, represent more than one third of the world market for circuit switching systems. Together they own Bell Communications Research Inc. (Bellcore) which performs research at the request of the operating companies, including technical analyses of circuit switching systems. Such an analysis is an important milestone for a manufacturer who wants to supply the Bell companies. The authors briefly introduce Bellcore and describe the scope and the process of a technical analysis of a circuit switching system.*

*Bell Communications Research Inc. (Bellcore)* performs technical analyses of circuit switching systems at the request of the seven regional Bell Operating Companies in the United States. A Bellcore analysis is widely recognized as being complete and very thorough.

AXE 10 was one of the first non North American circuit switching systems to be analyzed by Bellcore. The analysis started in mid-1985 and is scheduled to be completed by early 1988.

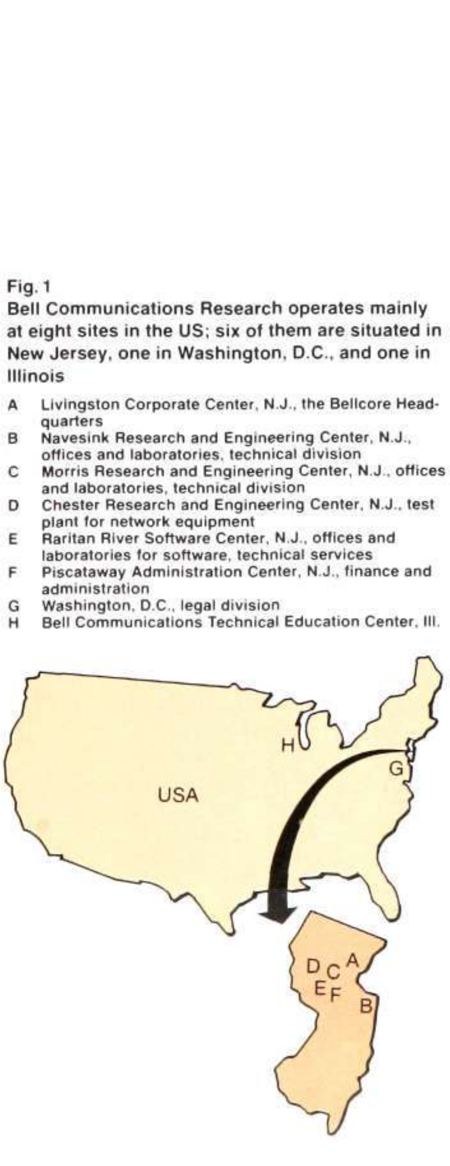


**Fig. 1**
**Bell Communications Research operates mainly at eight sites in the US; six of them are situated in New Jersey, one in Washington, D.C., and one in Illinois**

- A Livingston Corporate Center, N.J., the Bellcore Headquarters
- B Navesink Research and Engineering Center, N.J., offices and laboratories, technical division
- C Morris Research and Engineering Center, N.J., offices and laboratories, technical division
- D Chester Research and Engineering Center, N.J., test plant for network equipment
- E Raritan River Software Center, N.J., offices and laboratories for software, technical services
- F Piscataway Administration Center, N.J., finance and administration
- G Washington, D.C., legal division
- H Bell Communications Technical Education Center, Ill.

## Bellcore

### The end of the Bell system brought about the beginning of Bellcore

In January 1982, the United States Department of Justice and the *American Telephone and Telegraph Company* (AT&T) reached an agreement that reshaped the American telecommunications industry. This agreement, known as the *Modification of Final Judgment* (MFJ), required divestiture of the 22 *Bell Operating Companies*, BOCs, from AT&T. Under the MFJ each of the BOCs is owned by one of seven, unaffiliated, regional holding companies.

The regional companies decided that they needed a centralized engineering support organization and this was provided for as part of the MFJ. Thus, on January 1, 1984, the company that is now *Bell Communications Research Inc.* was created as the nation's largest joint research and engineering consortium.

### Organization

Today Bellcore has approximately 7,200 employees and an annual budget of close to one billion dollars. Bellcore is divided into four divisions: *Technical Services, Finance and Administration, Legal and Corporate Support.* Technical Services, which consists of about 4,400 employees, is in turn divided into five areas:

*Applied research*
- provides the underlying knowledge in emerging and leading-edge technologies of interest to the operating companies.

*Network planning*
- defines and plans new network and operations systems architectures and network service capabilities
- provides centralized support for network standards and network compatibility
- analyzes regulatory proposals that affect telecommunications networks
- maintains the North American numbering plan.

*Technology systems*
- provides definitions of generic requirements for switching, data network, transmission, distribution and operations support systems
- communicates requirements to suppliers and conducts technical analyses of their products.

*Technology applications*
- supports the BOCs in the operation of telecommunications networks and also in the introduction of new services and technologies.

*Software technology and systems*
- builds software systems for the operating companies, furnishing project planning, operations support, engineering and planning, network services and customer services.

## Analysis process

### General

A Bellcore technical analysis is performed at the request of one or more of the Bellcore owners; that is, the seven regional holding companies.

A Bellcore analysis is purely technical and factual. Bellcore does not approve, certify or recommend any product. As a reference point the analysis uses a set of technical specifications published by

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Ericsson Telecom AB

Bellcore. The result of an analysis is documented in a technical analysis report which provides a series of findings but no overall rating or conclusion. It is the responsibility of the regional companies to evaluate the Bellcore findings, integrate their particular economic data and come to individual conclusions.

Bellcore's technical analysis work spans more than one hundred different product categories and the way an analysis is carried out depends on what category a product belongs to. This article describes the generic analysis process of a circuit switching system such as AXE 10.

**Design and Implementation analysis**
A technical analysis of a circuit switching system is divided into two parts, the *design analysis* and the *implementation analysis*.

The design analysis, commonly referred to as phase A, is for the most part a theoretical analysis of the system as described in product specifications and supporting design and operations documents. Bellcore specialists analyze the documentation in detail to determine whether published requirements are met. In addition, the design analysis includes visits to the supplier's factories to review the manufacturing processes. If possible, Bellcore also studies the operation and performance of exchanges in operation.

The implementation analysis, commonly referred to as phase B, is to a large extent a field test of the product in a BOC environment. Hands-on tests are performed by Bellcore with the assistance of the BOC during the period following the turnover to the BOC and prior to cutover into service. In addition several factory visits are made to review
- the manufacture of hardware; primarily quality control, testing and inspection
- the development, testing and handling of software
- installation methods; mainly quality control, testing and inspection.

Visits may also be made to other operating companies which have similar equipment in service. Finally all assumptions, identified deviations and open items from the design analysis are reexamined during the implementation analysis.

**Report**
The result of a design or implementation analysis is a technical report from Bellcore identifying the areas in which the product does not conform to requirements. Typically most features and capabilities of the switching system do conform to the stipulated requirements and the final report may list these. However, it will concentrate on non-compliance areas which may deserve special attention by a BOC. This focusing means that the report unavoidably carries a negative tone that needs to be placed in its proper perspective as the report is considered.

The supplier is provided with a draft copy of the report for review for technical accuracy before it is published in its final form by Bellcore. The report is a proprietary document of Bellcore and is only intended for the internal use of Bellcore, the BOCs and the supplier in dealing with Bellcore and the BOCs.

**Bellcore and supplier commitment**
Typically a design or implementation analysis each takes nine to twelve months. They involve twenty to thirty Bellcore specialists from many different disciplines but also require substantial commitment by the supplier of the switching system. The supplier must have available a large amount of detailed product descriptions and other documents about the switching system. The supplier must also commit staff to train and interact with Bellcore staff throughout the analysis.

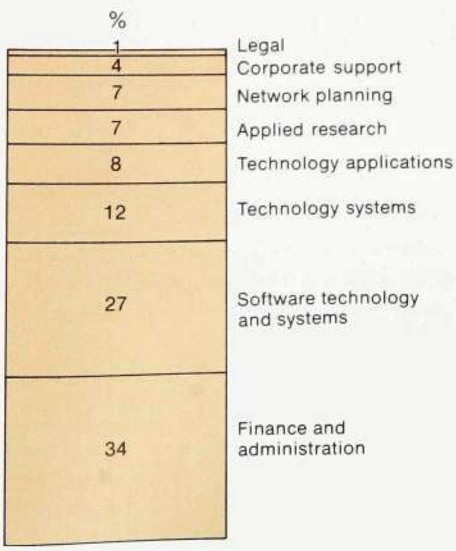
The technical analysis of a circuit switching system is vendor funded. The estimated typical charge for either a design or an implementation analysis is 2–3 million US dollars.

## Scope of analysis

**GENERAL CONFORMANCE TO BELLCORE REQUIREMENTS**

*Features*
The switching system is reviewed and tested as regards its conformance to more than 500 features specified by Bellcore. Not only the existence of a par-

**Fig. 2**
**The percentage of Bellcore personnel employed in the various areas of activity**



ticular feature is analyzed but also the detailed operation. The switching system is also reviewed with regard to its ability to grow, to incorporate new features and to adapt as BOC and subscriber needs change.

*Call processing*
Bellcore analyzes how all types of call are handled by the switching system. Particular emphasis is given to time delays, processor functions involved in each step of a call, and other system resources used. In addition, database and translation capabilities are reviewed.

*Signalling and interfaces*
The analysis seeks to ensure that the switching system is compatible with existing equipment, facilities and customer premises equipment and that it will function properly in an existing BOC environment. Particular attention is paid to determining performance under adverse operating conditions.

*Charging*
In the charging analysis attention is paid to:
- the completeness and accuracy of charging data
- the compatibility of charging data with the operation of BOC charging processing centres
- the maintenance of charging data integrity during equipment faults
- the availability of sufficient charging data capacity
- the existence of a suitable audit process.

*Transmission*
The performance is studied for various types of connections. The study comprises echo control, loss, level points, coding levels, impedance, delay, noise, linearity, and digital impairments.

*Synchronization*
The ability of the switching system to conform to the BOC master-slave synchronization method is reviewed. Tests of accuracy, stability, error detection and pull-in range are performed.

**PROVISIONING**
This part of the analysis covers the internal BOC provisioning activities that are affected by the switching system.

**Traffic handling capability**
*System control*
The flow of control through the various processors and their buses is reviewed, with emphasis on those elements that could degrade service during an overload.

*System capacity*
The call capacity, line capacity and traffic usage capacity of the system are estimated and tested. Particular emphasis is laid on the capacity of the various processors, but other limits are also studied, such as memory limits and the port capacity of the group switch.

*Switching network capacity*
Load-service curves are derived and tested for the subscriber and group switching networks.

*Traffic measurements*
The traffic measurement functions built into the system are studied. Particular attention is paid to the accuracy of the measurements and to the possibilities of scheduling the various traffic measurement programs.

*Equipment engineering*
The equipment engineering process is reviewed. This includes the engineering algorithms used, the documentation provided (worksheets, questionnaires etc.) and the mechanized tools available.

**Equipment**
*Weight and dimensions*
Equipment frame dimensions and floor plans are analyzed, including the equipment and cabling floor load.

*Power and grounding*
Examples of items studied are operating voltage limits, a.c. power requirements, current drain, tolerance to noise, and grounding interface requirements.

*Environment*
Examples of items studied are operating temperature range, heat dissipation, earthquake resistance, fire resistance, electrostatic discharge (ESD) and electromagnetic compatibility (EMC) requirements, lightning protection, and electrical safety criteria.

## The range of a Bellcore analysis

**General conformance**
- features
- call processing
- signalling and interfaces
- charging
- transmission
- synchronization

**Provisioning**
Traffic handling capability
- system control
- system capacity
- switching network capacity
- traffic measurements
- equipment engineering

Equipment
- weight and dimensions
- power and grounding
- environment

**Operation and maintenance**
- system maintenance functions
- circuit and facility maintenance
- database administration
- maintenance measurements
- remote maintenance
- operation support

**Reliability and quality**
- system reliability
- component reliability
- physical design
- manufacturing
- installation quality
- software reliability and quality
- testing
- performance in operation
- field tracking program

**Support**
- documentation
- training
- technical assistance


Fig. 3
The first AXE 10 exchange was field tested by Bellcore in Cañon City, Colorado

Fig. 4
The Mountain Bell exchange building in Cañon City

**OPERATION AND MAINTENANCE**

In this part of the analysis Bellcore investigates the operation and maintenance functions of the system as well as the operational impact of the switching system on a BOC environment.

*System maintenance functions*

Examples of items analyzed are the detection, notification, verification and isolation of faults, service recovery, repair and repair verification procedures, and machine interfaces.

*Circuit and facility maintenance*

The testing capabilities are analyzed with regard to subscriber lines and trunks, carrier facilities, links and signalling system no. 7, and special service circuits.

*Database administration*

Procedures and facilities for modifications and changes in office parameters and switching system programs are analyzed. Backup and recovery methods are also reviewed.

*Maintenance measurements*

Items studied include the availability and accuracy of the service and performance measurements provided for the maintenance staff to evaluate equipment performance, measure the service impact on subscribers and calculate performance indices.

*Remote maintenance*

The facilities provided for remote monitoring and control of a switching system from a distant maintenance centre are studied.

*Operations support*

The functions provided by the switching system with regard to interfaces to external operations systems are examined.

**RELIABILITY AND QUALITY**

The reliability and quality (R&Q) portion of an analysis covers the areas described below. The results obtained are of great significance in the assessment made by the BOCs. Typically about one third of the manpower resources spent by Bellcore during an analysis is allocated to R&Q.

*System reliability*

Generally the reliability characteristics are studied in terms of the annual downtime for subscriber lines, trunks, exchanges etc. In order to analyze these characteristics Bellcore develops Markow models to represent the system under various fault conditions. The analysis also includes an assessment of the system architecture with the main emphasis on hardware redundancy, fault detection and system recovery.

During the implementation analysis, reliability performance tests are conducted to confirm the understandings developed during the design analysis. These tests include:

- system tolerance to single faults in redundant units
- system tolerance to multiple faults
- system tolerance to faults in elements classified as non-critical to the system.

*Component reliability*

A review is conducted of the supplier's practices in vendor qualification, component reliability specification, incoming inspection, testing and screening etc. for components used in the switching system. Also included is an assessment of the supplier's feedback and corrective action efforts.

*Physical design*

A review is conducted of approximately 450 physical design practices. The areas covered include materials and finishes, product identification and marking, component and assembly requirements, packaging, process requirements, product change and repair, fire retardancy, electrostatic discharge, environmental and safety criteria etc.

*Manufacturing*

A review of manufacturing processes is conducted to examine specific processes and associated controls, materials, operations and administration relative to accumulated BOC experience and specific physical, chemical and electrical requirements. The primary focus of this review is an assessment of the suitability of the process for the switching system technology employed.

In addition an in-depth review is made of the supplier's quality system from the standpoint of its adequacy in controlling the performance, reliability and quality of the product within specified endpoint requirements. The analysis considers such factors as sample sizes, quality standards, scope of inspection, non-conformance thresholds, non-conformance action taken etc.

*Installation quality*
This analysis provides an assessment of the supplier's installation quality program, including a review of installation methods and procedures.

*Software reliability and quality*
The purpose of the software reliability and quality analysis is to assess the capability and effectiveness of the process by which all parts of the software product – i.e. the program generic, customer data and firmware – are developed, manufactured and maintained, in addition to assessing certain aspects of the reliability and quality of the software product.

The total software life cycle is analyzed from the perspective of the following general elements: software life cycle plan, management commitment and organization, development support environment, documentation, verification and validation procedures, configuration management, problem reporting and corrective action, data analysis, customer engineering, and software acceptance criteria.

*Testing*
The overall testing procedures a supplier uses to ensure that the product will meet stated performance objectives are reviewed. The analysis focuses on: component and printed circuit board testing, system level factory testing, short-term system temperature testing, software testing, installation testing and periodic requalification testing.

*Performance in operation*
Bellcore assesses the degree of conformance to the requirements and whether the system has any characteristics etc. that may affect the reliability or quality during operation. The analysis typically includes a review of operational data gathered by the supplier in combination with data gathered during several field site visits by Bellcore.

*Field tracking program*
As part of the implementation analysis a field tracking program plan may be developed which is specific to the supplier's product and repaired product handling procedures. The plan includes:
- development of data collection forms and procedures
- definition of repair product flows through BOC maintenance and inventory, and the supplier's repair facility
- development of a database suitable for maintaining field tracking records
- definition of data analysis procedures and summary reports.

**SUPPORT**
The ability of the supplier to provide technical and administrative support for the product is examined. This part of the technical analysis is supplemental to the subjects covered in previous parts and includes items such as:

*Documentation*
The documentation provided for customers is analyzed to determine its applicability for a BOC to engineer, operate and maintain the system efficiently. In addition the procedures for ordering, updating and maintaining documents

**Fig. 5**
**The AXE 10 exchange installed on the same premises as the earlier step-by-step exchange**

are reviewed as well as the media used to deliver the various types of documents.

*Training*
The quality and applicability of the supplier's training courses are assessed. Training facilities are reviewed and the courses available for training at a BOC location are identified.

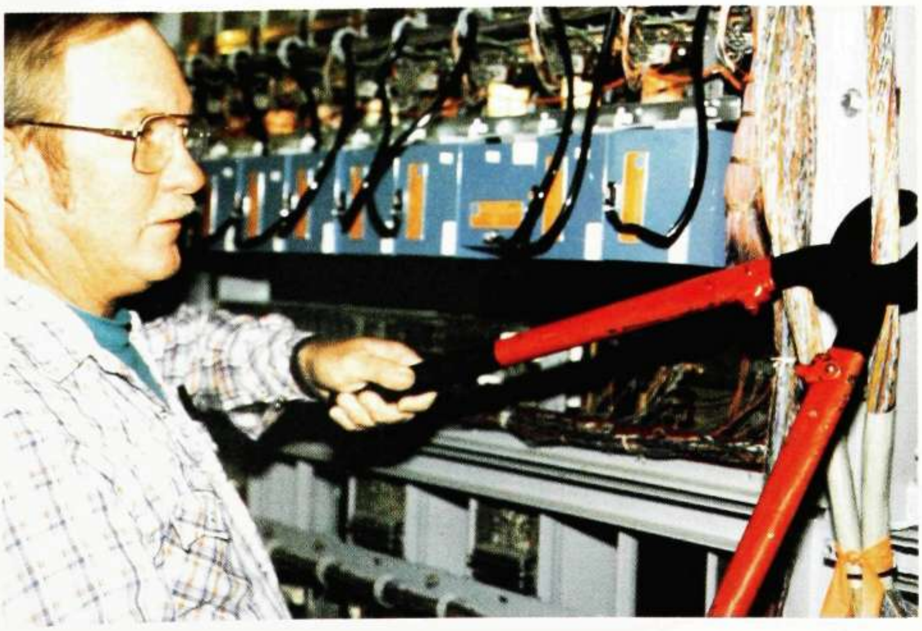
*Technical assistance*
Examples of items analyzed are:
- procedures for receiving, investigating, tracking and responding to fault reports
- procedures to be followed with material returned for repair
- lists of recommended maintenance spare parts
- procedures for obtaining replacement components and parts quickly in emergency situations
- the process for initiating, documenting, applying and tracking both chargeable and non-chargeable changes in the hardware or software
- plans and procedures used to minimize the impact of hardware and software extensions on the operation of the system
- the technical assistance services and procedures provided by the supplier for resolving problems beyond the scope of the telephone company maintenance department.

## Bellcore and AXE 10

The completeness and thoroughness of a Bellcore switching system technical analysis make the findings essential to a company like Ericsson which wants to be established as a major telecommunications supplier in the United States, and also to those BOCs that need to understand what to expect from a particular switching system.

The design analysis of AXE 10 was completed in mid-1986. Two of the Bell regional companies, US West and NYNEX, promptly decided to take an active part in the implementation analysis with one AXE 10 exchange each. The first AXE 10 exchange was made available to Bellcore for testing in August 1987 and the second was scheduled for test during the fourth quarter of 1987. The implementation analysis of AXE 10 is to be completed by early 1988.

**Fig. 6**
**The crucial moment when the subscriber lines to the previous exchange are cut**



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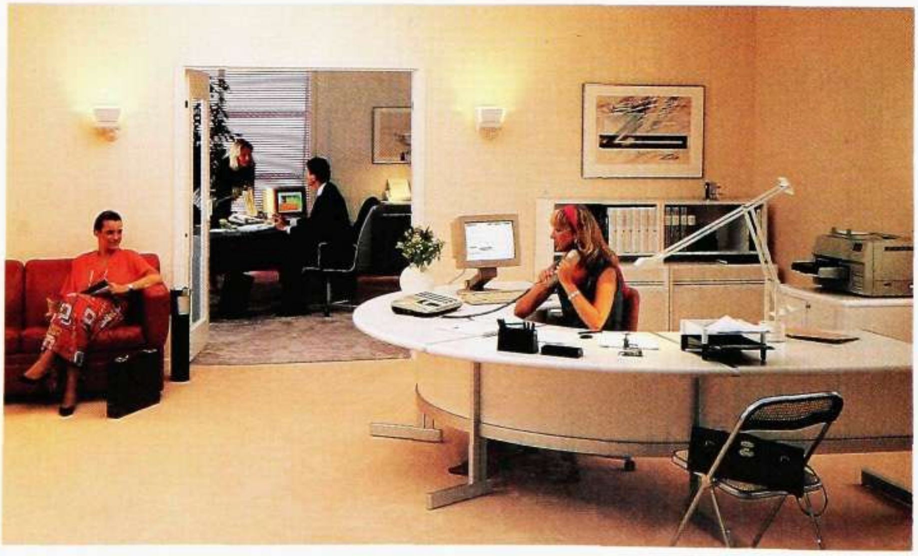
# VDU Ergonomics and Office Environment

Anna-Christina Blomkvist and Bo Schenkman

*Ergonomics is the science of adapting machines to man so as to satisfy human requirements. It uses several research methods, the most important being experiments and field studies.*
*The authors give a general introduction to the methodology of ergonomics and describe how Ericsson Information Systems AB applies the science in the design of new VDUs to ensure good quality.*

In the past, when developing culture and technology, man has had plenty of time to alter and adapt his relatively few tools and machines to suit himself. The ordinary hammer is one example of tools that have been modified over a long period and which by now can hardly be improved. The rapid technical development of today leaves very little time for adapting the technology to suit man. Introducing new jobs, techniques and tools also introduces new risks. A new science, ergonomics, has had to be developed to avoid such risks and be able to quickly adapt new machines to the needs and requirements of man. Ergonomics is the science of the interworking between man and machine. Sometimes the expression human factors is used instead. It has a similar meaning and includes the concept of being able to work comfortably, correctly and quickly.

**Fig. 1**
**A modern office environment**



## The methodology of ergonomics

A science is characterized by having methods for building up knowledge. Ergonomics uses knowledge from many branches of science, especially technology, physics, psychology, sociology, linguistics and medicine. As it deals with problems in very different fields the methods used are also very different and can be categorized in different ways. However, on the basis of the available amount of control over the factors affecting the study object the methods can be divided into two categories: experiments and field studies, although there are other methods that cannot be allocated to either of these groups. In experimental studies the aim is to have the greatest possible control over the factors that influence the characteristic being studied. In field studies, on the other hand, one tends to accept the given conditions.

### Experimental studies

Experimental studies are carried out in order to determine the effects of variations in different selected factors. Other factors that would influence the results are kept constant during the study. This method is used to examine theories, for example the hypothesis that a VDU (Visual Display Unit) with high brightness has good legibility.

In order to get to understand a phenomenon or process it is necessary to be able to control the factors that have the greatest influence on the study object. Often there is one dependent and one or more independent factors. The relationship between these two types of variable must be determined. A large part of empirical science is performed in this manner. Ergonomic experiments often have a subjective dependent variable whereas the independent variables are physical quantities. For example, when studying the subjective variable *legibility* of displays the physical quantity *ambient lighting* is altered while the character width, contrast etc. are kept constant.

Some ergonomic quality factors can be described by means of values of physical quantities, and standards have been set for minimum requirements as re-

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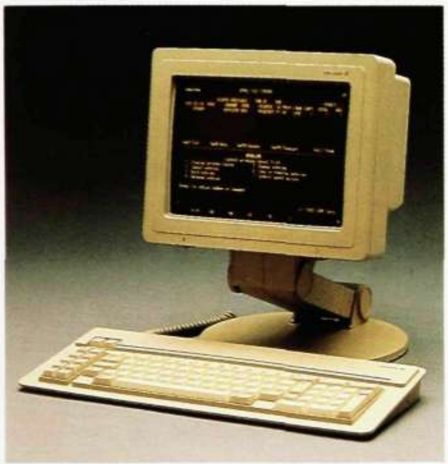


**Fig. 2**
**VDU with yellow text on a brown background**

gards, for example, luminance, colours and contrasts for VDUs in an office environment. However, some characteristics cannot be described by means of physical quantities, for example type face, edge definition and surface structure. Such characteristics can be assessed by comparing alternatives with each other or with an accepted reference. There are also complicated cases where it is inappropriate to measure a number of physical quantities and use the results to make an overall assessment of the suitability of a product. The problem can be illustrated by imagining a beauty contest that is judged entirely on the basis of a number of measurements and weights. In this and similar cases a more reliable result would be obtained with a holistic (weighted) subjective assessment.

The advantage of experimental studies is primarily that they give precise answers to well defined questions. However, the disadvantage is that they are time-consuming and their sphere of applicability is limited. Ergonomics is an applied science. It can often be difficult to predict whether a relationship known from experimental studies has a significant effect on the everyday use of a product. For example, there are many physiological and psychological studies of how the eye works. Nevertheless it is not always obvious what conclusions can be drawn from these studies when designing a new VDU. One solution would be to carry out further studies in which the number and variation range of the independent variables are limited. However, the parameters must not be too much restricted. An experiment in which the effect of the ambient lighting on the ability of the eye to detect contrasts might not be relevant for VDUs if only the recognition is studied and not the legibility – and unless the edge definition has also been specified and varied.

**Field studies**
In field studies, observations are made in the environments where the studied activity will take place. This can show up problems that might otherwise have been overlooked. On the other hand the results of field studies can be influenced by so many uncontrolled, interacting factors that it is difficult to pinpoint the reason why a certain result is obtained. Modern statistical methods can solve some of the problems but they require a fairly large number of observations, which is not always possible. For example, several studies have been made that compare work at VDUs having a light and a dark background respectively. However, the different VDUs have been of different size, had different type faces etc. so that they have differed as regards several parameters that are relevant to visual work, apart from the background colour.

Many times the results obtained are not those expected. For example, a relationship between skin irritation and electrostatic fields has been sought, but no unambiguous results have been obtained.[1] Nevertheless, such a result is also important in the search for a realistic theory. In this and similar cases the search must continue for more obvious causes.

**Other methods**
Many methods fall outside the categories described above, for example introspection and simulation.

Introspection is a method which has previously been used in ergonomics. The data consisted of personal interpretations of experiences. This method can give an idea as to what factors affect a work situation but it does not meet scientific requirements for good methodology.

Mathematical models and computer simulation is another method. It has been used in some areas of ergonomics, but in the main the method is untried. As yet we have no knowledge of many important relationships that must form part of a model. One area where simulation has had good results is in the design of concert halls. The acoustic properties of different designs can be tested before the hall is built.

Ergonomics, like technical fields, has developed standards for interesting quantities. Previously they had only specified *acceptable* values for physical quantities, but now attempts are being made to establish standards also for other types of characteristics. It might even be unsuitable to carry out individu-

Fig. 3
VDU with a positive screen, i.e. dark characters on a light background

al studies of the effects of each factor. The overall effect of all interacting factors could be studied instead. The International Standardization Organization, ISO (TC/159/SC4), is now preparing guidelines on tests with human subjects in order to supplement physical measurements with behavioural tests. In physical measurements the results are often dependent on the technology for which the method was originally designed. When investigating new technology the test results may therefore be less relevant.

In practical development work choices are often made between different alternatives. If six or seven people independently are allowed to choose between two alternatives and all choose the same, a degree of certainty has been reached which is often acceptable for a choice. Sometimes experiments are carried out with a few subjects who are experts in the field being studied. They can then both assess the *correct* items and analyze their own impressions and perhaps suggest improvements. This type of method is used in several fields, for example wine testing.

#### Summary

In spite of the fact that ergonomics is a young science and the many difficulties that exist, as briefly described above, the ergonomist must reach a practicable result. The knowledge and experience successively assembled is then utilized to weight standards, attitudes, vogues, and financial considerations. It is important that the ergonomist retain a sound scepticism to the man-machine relationship and to technical innovations. It is easy to fall prey to overconfidence. In a small internal interview study concerning one of Ericsson's products the external users were reasonably satisfied, whereas those who had worked on the development of the product offered nothing but superlatives.

Fig. 4
Colour VDU

## General aspects of VDU work

Ericsson Information Systems AB manufactures and markets VDUs for computer terminals and personal computers designed for use in office environments. The demands for adaptation to the user's requirements are exacting. The work on the quality of the picture is an important part of the ergonomic work involved. The VDUs used in office automation are mainly based on a 12–15″ cathode ray tube, CRT.

#### Work environment

Modern office work is to a great extent performed with the aid of computers. People sit in front of a VDU, read the text on the screen and enter new information. A person could be watching the screen for several hours, somtimes a whole day. Obviously it is essential that the VDU is so well adapted to the human psychological and biological characteristics that it does not cause problems.

Office environments range from almost industrial to almost home environment. Some premises are light, others dark. The content of the work carried out at the VDU also varies. In some applications good legibility is the main requirement, in others the ability to detect changes quickly. Hence it is necessary both that a manufacturer can offer different solutions and that the user has a certain amount of control over the characteristics of the VDU. In a light room it is usually best to use a positive screen, i.e. with dark characters on a light background. In dark offices it is not so important to have a positive screen, especially when the user does not work with paper manuscripts or is not using other light information media together with the VDU. If one and the same VDU is to be used for different applications it is essential that it has overcapacity as regards the picture quality. A VDU may also need to be adapted to particular user requirements and Ericsson therefore supplies several different types of VDU.

#### Different types of VDU

A popular Ericsson VDU has yellow text on a brown background, fig. 2. This type gives a pleasant and stable picture and is well-tried through both long and intense usage. It does not cause visual discomfort in the form of after-images, which other VDUs, for example those with green text, may do. The choice of the yellow/brown combination is also supported by studies of certain physiological properties of the eye.

One type that is becoming increasingly popular is the positive display, which

DISPLAY TECHNOLOGIES
- Cathode ray tubes (curved)
- Flat panels
  - Luminant
    - Flat cathode ray tubes
    - Electroluminiscent
    - Vacuum-fluorescent
    - Plasma screens
  - Non-luminant (passive)
    - Liquid crystal (LCD)
    - Electrophoretic

has dark text on a light background, fig. 3. This type is recommended by some authorities, for example the Swedish Institute for Work Environment and the Swedish Agency for Administrative Development, which consider that the light surface is preferable, mainly because it reduces the effect of reflections on the screen. This aspect is particularly relevant on premises where it is difficult to avoid glare from daylight and lighting fixtures or where the lighting has to be arranged to suit visiting customers rather than the user. Another important advantage of positive polarity is that it gives better accord with the luminance of other surfaces around the user.

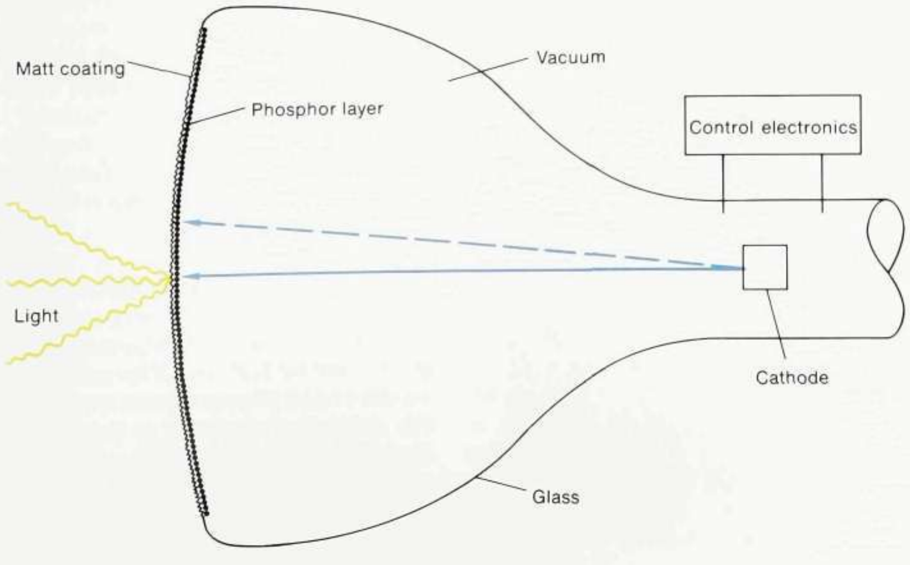
Colour displays are common today, fig. 4. The picture quality, for example the resolution and character style, is often not as high as for monochrome displays, but in certain fields, such as process control, colour displays have definite advantages. The greatest advantages are probably obtained when the colour is used only sparingly. Aesthetic effects contribute to the attractiveness of colour displays. However, it should be noted that aesthetics and ergonomics are not the same thing and there is no clear-cut connection between the two.

### Display technologies

The most common displays today and in the foreseeable future are based on the cathode ray tube. They work in the same way as the ordinary television tube, fig. 5. Electrons are released from a cathode and accelerate towards an anode, forming an electron beam. The beam is focused and strikes the intended points on the screen, which is coated with substances that then radiate light, phosphors.

Other types of display technology have been developed, for example plasma screens. The technology is similar to that of fluorescent tubes. A gas is excited, with the result that it gives off light. Ericsson uses this type of screen for a portable personal computer, fig. 6. Another type already in the market uses liquid crystals and their ability to polarize light. There is now considerable development work in progress on alternative engineering. However, these methods have not been able to provide the same high image quality as the CRT. One of the problems has been low contrast between text and background, which makes the text difficult to read. Another problem, particularly with liquid crystal displays, LCDs, is that the angle of incidence must be small; otherwise it is very difficult to read the text. Furthermore the colour on the LCD changes when the angle of incidence is altered. A summary of the more common VDU types available today is given in the box *Display technologies*.

**Fig. 5**
**Diagram of the cathode ray tube in a VDU. The electron beam sweeps across a layer of phosphor. The intensity of the beam varies during the sweep so that the phosphor particles give off different amounts of light. The outermost part of the glass has a matt coating that reduces reflections**




## VDU ergonomics

### Image quality factors

*Surface or anti-reflection treatment*
- important factors are the surface smoothness, colour, mattness, washability, antistatic properties and filter or layer thickness.

*Image generation*
- important factors are the refresh rate, the spectral characteristics of the phosphors, intensity, persistance and colour, the addressability of the screen, dot size (the size of the smallest display element), definition/resolution, spatial stability (fig. 7), luminance uniformity across the screen, luminance distribution within a display element and between elements of different size, linearity and orthogonality.

*Text generation*
- important factors are the number of

available display elements per picture and per character box, the physical dimensions of the screen, the character height and dot/stroke width and the ratios between these and the character width and line spacing, and also the design of details such as curves and oblique lines which must be dimensioned with regard paid to the differences in luminosity between individual and clustered dots and to the spacing between dots.

*Layout facilities*

- important factors are the type face, methods of highlighting – shaded background, bold type, italics etc. – whether proportional text is used, luminance levels and the existence and legibility of colour combinations.

**Disturbing reflections**

Print on paper has the text and the background in the same plane. The printing ink is often absorbed by the paper so that the text and backgrond have similar mattness. The contrast between text and background is good; the eye only has to adjust to one distance, and the brightness of the background is adapted to the ambient light. Several studies have shown that it is more difficult to absorb text from a VDU than text on paper. For example, reading from the screen is slower.[2]

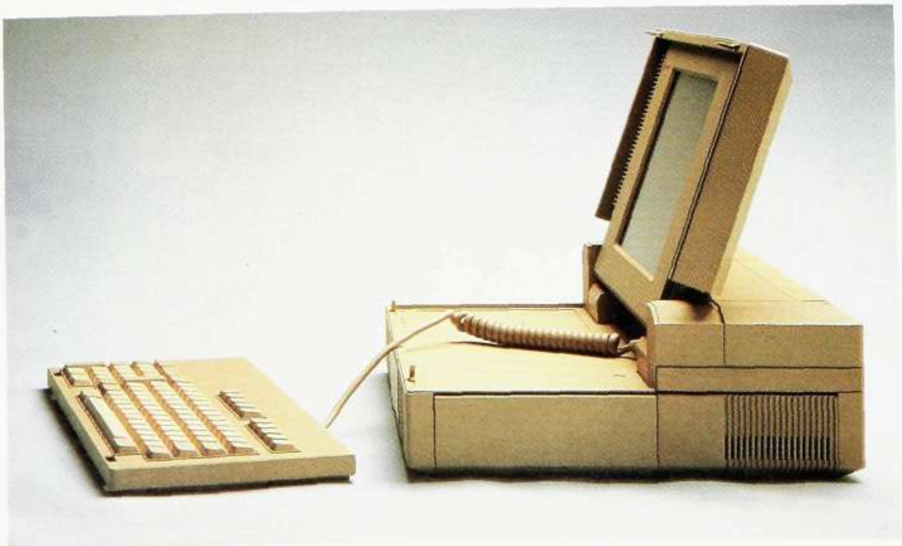
The image on the screen is created in a different way from text on paper, fig. 5, a way which has several disadvantages. The layer containing the information is not always in the same plane as the background and, furthermore, the latter may reflect incident light. In addition, the matting (see below) that is to break up disturbing reflections is placed in front of the information layer. Reflections can be particularly troublesome if the image on the screen reflects small quantities of light or if the active elements have too low intensity.

Reflections can be avoided by means of different methods. The real problem is to get rid of disturbing reflections while maintaining the image quality, particularly the edge definition. Ericsson has found that a matt display surface, obtained by etching the outermost layer of glass, is a good solution. All Ericsson displays have some form of anti-reflection treatment. Tests have shown that the matting process must be chosen with care. For example, its efficiency is dependent on such factors as its coarseness. Coarse matting and a long distance between the information layer and the matt surface reduce the edge definition. When the user moves his head the space between the image and the matt surface gives rise to a relative displacement that causes pronounced diffraction effects; it glitters. The sharper the image and the higher the resolution the more pronounced the effects of the matting.

Some suppliers do not treat colour screens with matting. The definition is bad from the start, and the picture has a microstructure caused by the holes in a shadow mask. The shadow mask is a plate with holes through which the electron beams pass just before they hit the phosphors. The detailed structure is broken up by coarse matting. The poor definition is caused by the fact that a strong electron beam is used in order to obtain more light.

Another way of removing disturbing reflections is to use a dark filter, usually a fine-mesh net, which can be mounted in front of the screen. The filter will absorb incident light, of course, and it increases the subjective contrast of the picture. The mesh also reduces the edge definition and details of the picture. Other filters often increase the contrast and details of the reflection. Moreover, they in-

**Fig. 6**
**Plasma screen mounted on a portable personal computer**



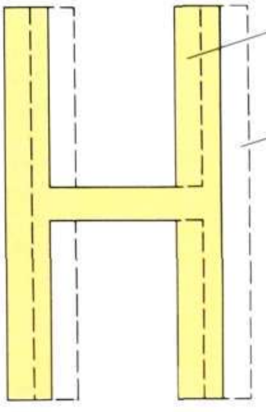



Fig. 7
**Spatial stability, *jitter*. The position of a character on the screen can vary with time because of deficiencies in the electronic circuits**

crease the imbalance in the visual field if a user has to watch a dark screen and also read from a light paper manuscript.

A user may wish to place a filter even on a matt display. However, if the reason is that reflections are irritating it would be better to screen the source of the reflections, by installing window blinds or suitable screens on the lighting fixtures.

Nevertheless, some users still require filters. A field study among operators using and not using filters[3] showed that almost all wanted to keep one of the borrowed filters. The study did not show any noticeable improvement in comfort. Some filters were troublesome, either because they attracted dust or because they were too shiny. At the time of the study the media were discussing the effects of radiation. This debate probably resulted in a slightly more favourable attitude to filters than would otherwise have been obtained.

### Choice of phosphors

It has already been mentioned that the most common display technology is based on CRTs. The light-sensitive substance on the inside of the screen is called phosphor. Different phosphors have different physical properties and react differently on the screen. The choice of phosphors is therefore important when a new display with a CRT is being developed.

Some phosphors glow with high intensity. They can easily be regulated to a suitable level of luminance; they are often activated very quickly and it is easy to achieve high definition with these phosphors. However, their light also deteriorates quickly, which has two disadvantages: It can give rise to flicker and also to flashing. Flicker is the variation of picture stability experienced when the luminance changes at short intervals. The flasing phenomenon occurs when the eye scans the screen at a speed close to that of the vertical sweep of the electron beam. The eye may then see the position of the electron beam instead of the image on the screen.

When Ericsson started work on the VDUs now being marketed, customers were demanding a white screen. Otherwise a more yellow tone could have been chosen which is well-tried and which is recommended for illuminated layout tables in the graphic industry. Other requirements were that the screen should be bright and free from flicker.

In this case the ergonomics department started in the usual manner by choosing phosphors on the basis of tests involving a small group of subjects but, as the flashing phenomenon was unknown in the literature available, the choice was preceded by more extensive experiments than usual.[4] The study showed that flashing and flicker are two different phenomena; they are affected differently by phosphors and by the refresh rate of the VDU and they occur under somewhat different circumstances. The sensation of flicker increases with the nearness to the display since the screen occupies a larger part of the field of vision. Flashing, on the other hand, increases with the distance from the display because the eye can then more easily scan the screen with the same speed as the electron beam. Occasionally the eye catches up with the beam, which is experienced as a flash or a very bright band across the screen. The experimental subjects watched different displays at several different distances. This study enabled the designers to select phosphors with optimum properties.

### Character design

Most VDUs used in offices today present information in the form of written text. The text is based on characters, i.e. letters and figures, and these must be designed for the screen in question so that maximum visual ergonomics is obtained. The group of letters and figures that are to be used together is called a character set. Ordinary writing on paper consists of continuous shapes, but each character on a display consists of a number of separate character elements. In addition each character usually takes up a certain area on the screen, a character box. These factors cause special problems.

The objectives in character design are to achieve good legibility and an aesthetically pleasing result. The characters must meet three requirements:

- they must be visible against the background

- they must be discriminable from each other
- they must be accepted as reasonable representations of the characters concerned.[5]

There are thus many factors to be considered when designing characters. Among the most important are the total number of display elements available per screen and per character box, the physical size of the screen, the height and width of the characters, the width of character stems and the distance between lines. Moreover, curves and oblique lines must be dimensioned with regard paid to differences in brightness.

One detail which must be considered at an early stage in the development of a new VDU is the size of the display element. Once this has been decided the possible stem widths have been settled. In the case of a CRT it is expressed in nanoseconds and is dependent on both the electronics and the phosphors. With displays that are row and column orientated, attention must be paid to the shape of the individual display elements and to what happens in the space between pixels.

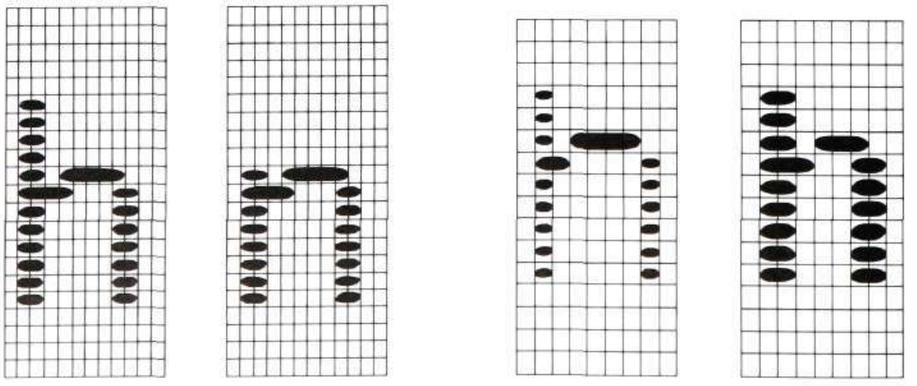
A basic character set is prepared for each new display. Specialists should always be employed to design the letters and numerical characters, but first they have to be told exactly how.

The reason for using specialists is that the designer must be meticulous and consistent. All letters must stand on the base line. Curves must be designed in the same way; the join of a curve to a stem, as in h, must be the same as in n, fig. 8; the bodies of b, d, p and g should seem to have the same size, width differences between characters must be reduced for non-proportional type etc. With all the degrees of freedom suddenly available when moving dots in a matrix it is easy for anybody not used to this work to miss a few details. Inconsistency means that words will not have the right shape. Even if each individual character is identifiable, the overall appearance of several characters together may impair reading comprehension.

The reason why the specialist has to be told exactly what to do is that the display has limitations and should be used at its optimum. Optical character recognition, OCR, forms the basis. Factors to be considered are legibility of both characters and words, aesthetics and the rules and regulations for character design. First the design of capitals such as A and H is decided and what diacritic items are required. Consideration must be paid to the line spacing; adjacent rows of text must not interfere with each other. Next the width of the letters is decided so that the correct ratio of width to height is obtained, taking into consideration the space thereby formed between letters. Then the lower-case letters are designed. The size of the body and the height of ascenders and descenders are settled. The design of curves and oblique lines are arrived at by applying the method of trial and error. Two main requirements for good shapes are that all letters should look as if they belong to the same type face and that they have the same fullness. Special attention must also be paid to characters that are likely to be mistaken for others.

In spite of all modern aids the first stage in the design usually consists of drawing a set of characters on paper. It is difficult to imitate a display screen on another in a satisfactory way. Sheets of paper are therefore cross-ruled in proportion to the shapes and spaces of the picture elements. If the test subjects are then placed at such a distance from the paper sketches that the test is viewed at the correct angle the conditions are right for a first assessment of the character set.

**Fig. 8**
**The letters on the left, *h* and *n*, are in the same character style, used in system Alfaskop 91. The letters on the right, both h, are in a similar style used for personal computers, called square-round. The letter is shown in normal and bold type. The characters on the left have better proportions of body to stem. The lower resolution of the personal computer limits the possibilities of achieving optimum proportions**



It is difficult to make a proper comparison between different character sets because the result is influenced by so many different details in the character design. The test subjects are either given a task such as reading a text or finding an error in a text, or a questionnaire that directs the assessment to certain details.

**Layout**

By layout is meant, in this article, how the information on the display is structured and displayed. Although the end user or a programmer decides its exact design it is the supplier who decides on the framework.

The layout capabilities are dependent on such factors as the type face, the method of highlighting (i.e. how special text is emphasized; by means of background colour, bold type, italics etc.) proportional spacing or not, the brightness levels on the screen, and the available colour combinations and their legibility. Some requirements for the layout are that text in an inverted field must be legible and that cursors on the screen can be distinguished from each other and from the background.

It is the task of the ergonomist to decide whether the layout capabilities meet the set requirements. The ratio of increased and normal luminance should be 2:1. Text in inverted fields must be legible. It must be possible to distinguish different type faces, highlighted text, cursors of different shape and on different backgrounds etc. Ericsson must make sure that the displays provide adequate facilities while at the same time setting good examples for users. Programmers must not include symbols that users cannot identify, or have not had explained, just to give an event a symbol of its own. They might want to warn the user against using the system in the wrong way, but users should be guided, not warned. Warnings should be used to protect the user against danger or trouble. Red flasing text does not belong in an office environment. On the other hand, the user might need a reminder about such actions as changing floppy discs, switching on the printer or selecting a communications line in order to avoid delays. Yellow flashing light or flashing of normal text might then be appropriate.

**Ergonomics for alternative display technologies**

New technologies or alternative display technologies make new demands on measuring equipment and assessment procedures. For example, in order to study passive displays it is necessary to vary both the incident angle of the light and the viewing angle. Ericsson follows a simple plan in order to obtain comparable data from different experiments.

Nothing of importance must be overlooked when assessing VDUs in new technologies. It is necessary to envisage how the product will be used and handled in order to clarify what aspects need to be evaluated. For example, the display will be used in rooms lit by bulbs, fluorescent tubes and daylight, and the intensity of the light may vary from weak to strong.

The low reflectance in relation to paper, and the matting treatment necessary to avoid reflections from the ambient light are two factors that are particularly unfavourable for passive displays. A display should have a background luminance of 120–150 cd/m$^2$ and a contrast of 1:15 with incident light of approximately 300 lux. It must also be possible to read text throughout a wide viewing angle.

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## Note

From April 1, 1988, the field of activity described in this article is the responsibility of Nokia Data AB, in which Ericsson is a shareholder.

# Automatic Assembly of Telephone Keyboards

Nils-Eric Agnéus and Peter Sommansson

*The manufacture of electromechanical components has been influenced by the demand for low price, high reliability and good quality – factors which have directed the development towards component types suited for automatic assembly.*
*The authors describe the automatic assembly of keyboards for telephones at Ericsson's factory in Karlskrona, South Sweden.*

Previously, purchased keyboards were used in telephones manufactured by Ericsson. Now and then quality problems arose that forced us to return deliveries, and long delivery distances made it imperative to keep safety stock which tied up capital. The purchased keyboards were mounted directly on the printed circuit board in the telephone, occupying space that could have been used for other components.

Several intermediaries also affected the price, and certainly did not make it more attractive. Studies indicated that a keyboard designed and manufactured by Ericsson would be a competitive alternative if semi-automatic assembly was used. As a result work was started on developing a new keyboard. The production unit decided on fully automatic manufacture in order to obtain high and uniform quality at a low price.

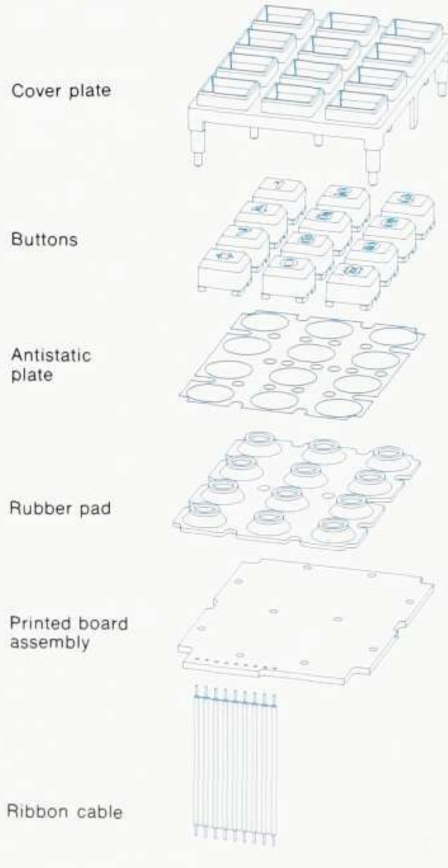


**Fig. 1**
**The parts of the keyboard**

## Design cooperation

Designing a product that is to be manufactured on an automatic assembly line requires close collaboration with the production department right from the start. For many years there has been efficient cooperation between the telephone plant at Karlskrona and the component design department at Ericsson Information Systems AB; now Ericsson Business Communications AB.

A production technician is involved in the design of the component already when it is still a sketch. The choice of construction principles, design of details for easy fit and dimensioning with tolerances are some of the matters settled at this first stage.

Two items concerning the design and assembly principles underlying the keyboard were the subjects of particularly thorough discussions. The first problem was whether the pushbuttons should be manufactured and mounted while still in the extruded block or as separate details. When engineering the assembly line it would probably have been easier – and cheaper – to run the keyboard as a solid block. However, after due consideration we decided to allow individual buttons to be vibration fed to the fetching point. The main reasons for this decision were that

- if one button was faulty the whole set would otherwise have to be rejected
- the plastics factory considered that, with the tool engineering and machines then available, it was not possible to achieve adequate cooling ducts, which implied a reduction of the useful life of the tools
- buttons should admit of being used – singly – as function keys in the telephone set
- the range of variants for different telecommunications administrations as regards the design of the character on the button and the number of buttons

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in the set is very large, which meant that several large tools would be required.

The solution chosen was single buttons and tools with changeable inserts for characters.

The second item was whether the printed circuit board should be screwed to the cover plate or whether the keyboard should be riveted, using plastic rivets moulded into the cover plate. Two external suppliers had been assessed previously in connection with the selection of a suitable supplier for a similar keyboard. The two sets studied had the same design and contact method and they differed in only one aspect. One was riveted and the other held together by screws. The contact quality of the two products differed markedly, and the cause proved to be plastic burrs at the contact point. The burrs were produced when the self-tapping screws formed their internal threds.

On the basis of this experience, previous problems with the feeding of screws and the longer time required for screw tightening, the decision to rivet the keyboard was an easy one.

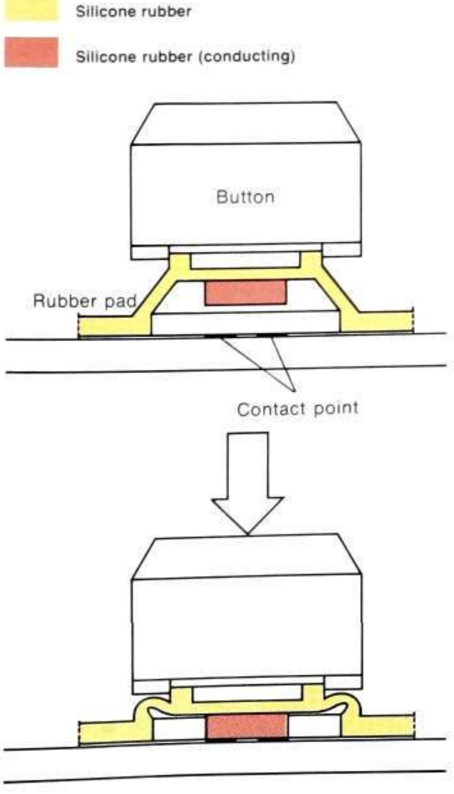
## Design of keyboard

The keyboard consists of six parts, fig. 1:
- cover plate
- buttons
- antistatic plate
- rubber pad
- printed board assembly
- ribbon cable.

The cover plate has guide holes for the buttons and plastic guides for the other parts. Mounting on the plate is in the following order: buttons, antistatic plate, rubber pad, and printed board assembly. The whole package is riveted together by cold-heading of the plastic guides of the cover plate. The ribbon cable is attached to the printed circuit board and machine soldered prior to the final test of the keyboard. This test involves the pressing of each button and, hence, check of both electrical and mechanical characteristics.

The rubber pad, which is made of silicone rubber, has a number of domes – one for each button in the set. A dome serves as a return spring for the button and as a protection of the contact points on the printed circuit board. The centre of the dome contains a contact stud made of conducting, carbon-filled silicone rubber. When a button is pressed, the dome is compressed and the contact stud short-circuits three gold-plated contact points on the printed circuit board, fig 2. The geometry of the dome provides the force travel characteristics – pression, snap-point and return force – required of the keyboard.

**Fig. 2**
**The design and operation of the buttons**




## Principles of automatic assembly

One objective in the development of an automatic assembly line is to base it on known and well-tried principles. The aim is always to *build quality into the process*. This means that each assembly operation is followed by a check or an indication of its having been completed. The line is stopped immediately in the case of non-performed or unsuccessful operation, and the operator then receives a visual and an audible alarm signal. The materials supply is also monitored and an alarm is issued if parts are jammed or run out. In addition to these checks the line is monitored for workpieces at the stations and the operation is stopped if a piece is missing.

In straight lines a number of operations are often performed in series without any intermediate buffer stores. This design has the disadvantage that the efficiency of the line may be very low. Hence, lines are often divided into modules interspaced by buffers. Experience has shown that 90% of all stops along a line have a duration of less than ten minutes. This knowledge is used in the planning of buffer sizes.

It is not always easy to achieve all the characteristics desirable in a buffer but Ericsson aims to satisfy the following requirements:
- a buffer must be cheap
- it must always be possible to stock up a buffer with parts and also remove them. For optimum economy the buffer should be half full
- the buffer must be of the first in, first out type. Any faulty items are then detected as soon as possible

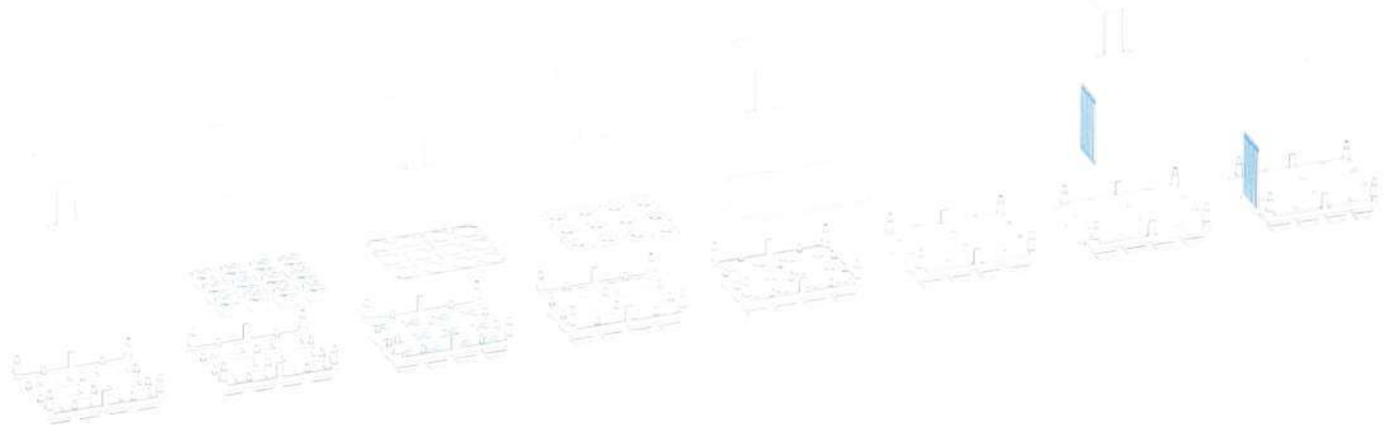


**Fig. 3**
**The different operations in the assembly of the keyboard**

- the buffer must be as small as possible so as not to tie up too much capital.

Before work starts on the detailed design of the line the method of moving the assemblage along the line is decided. The alternatives include transporting the parts on a board or selecting one part that can be transported and mounting all other parts on it. The means of moving the workpiece from station to station is also decided at an early stage. The most appropriate of the known and well-tried feeding systems is chosen, for example conveyor, reciprocating bar with carrier, or feeding slides.

A preliminary factory layout is also prepared if the site of the planned line is known when design work starts. It includes routes for evacuation of the personnel in case of fire, service access and transport of materials. The walking distance between the different stations should be short, and as a result the line might be U-shaped instead of straight. It could also lead to the transport being arranged at ceiling height by means of a conveyor etc.

## Detailed description of the line

### Prerequisites

A complete – and tested – keyboard is to be produced every six seconds with consideration paid to the efficiency of the line. The following description of the line relates to figs. 3 and 4.

### Feeding

The cover plate is fed to the fetching position for the transporter by means of a vibration feeder. The other parts are mounted on the cover plate, which carries the assemblage along the line. When changing between keyboards with 10, 11 or 12 buttons the cover plates in the vibration feeder are also changed.

### *Transport*

The pieces are transported by a slide which moves between two alignment bars with accurately defined positions so that the cover plate will be correctly positioned at each station. The slide makes the following movements

- rises and lifts the cover plate
- moves forward to a defined stop position
- drops to its lowest position, leaving the cover plate positioned between the alignment bars
- returns to the start point while in the lowest position.

The movement is very simple and gentle thanks to damping air cylinders at the end positions. This means of transport is used in most steps of the line.

There is space between the different stations for storing a number of workpieces. This enables the operator to check whether the relevant operation has been performed, and to add any missing parts.

### Station No. 1

The buttons for one row are mounted in the cover plate. The buttons are positioned by vibration feeders. The feeding method necessitates a small stud and a groove on the underside of the button so that the characters will be correctly orientated. The four vibration feeders leave the four buttons in a keyboard row lying with the correct spacing in front of the assembly position.

The four buttons are fetched by a pick-and-place (PP) unit with tongs, which lifts them, swings over the cover plate, drops down and releases the buttons.

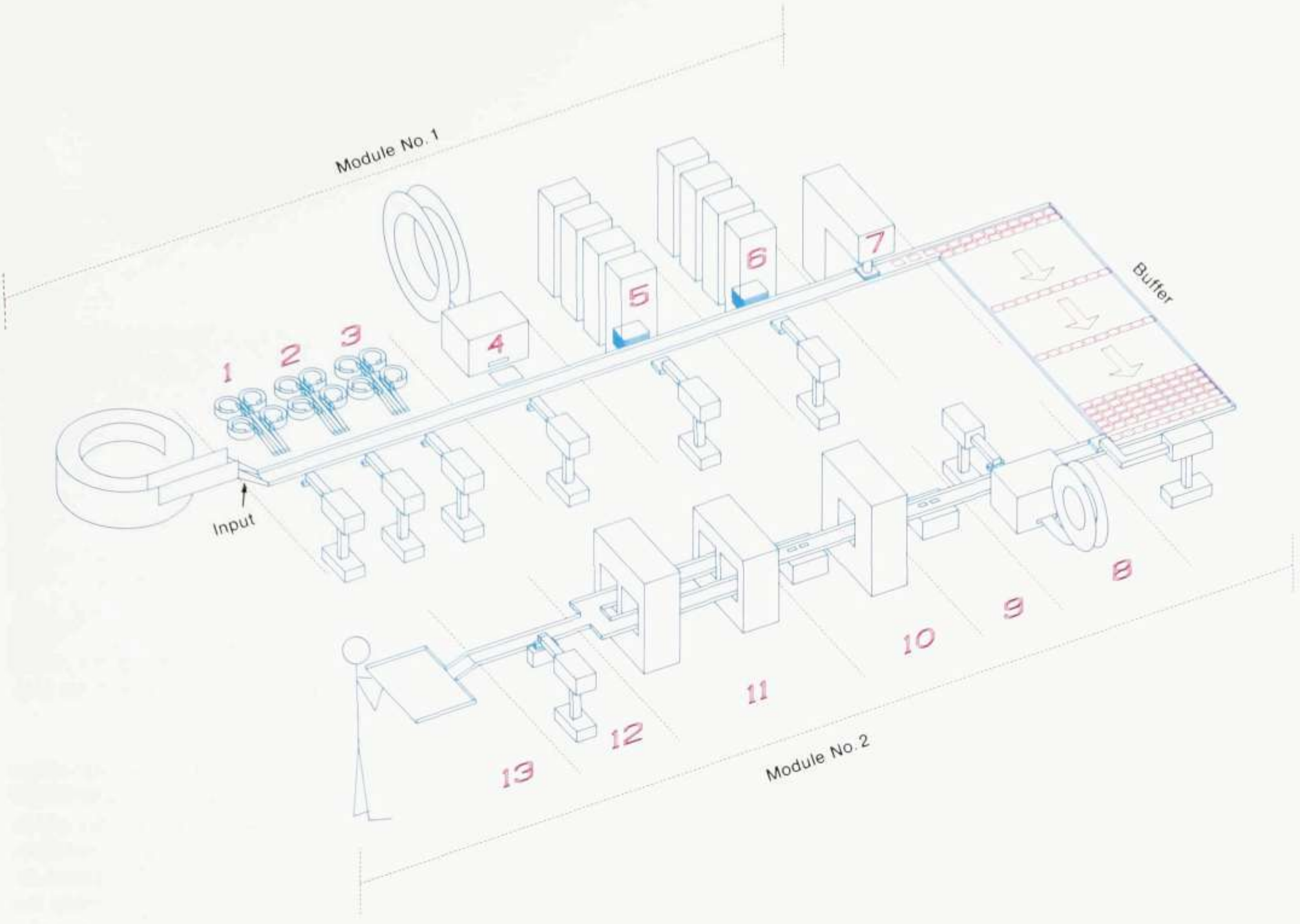



Fig. 4
The keyboard assembly line

Concurrently with the mounting, a test device on the PP unit is lowered to the preceding cover plate at the station. The test device has four contacts which close if the buttons are in place. The line is stopped if any contact does not close. The operator has a small number of the relevant buttons available at each assembly station and replaces any missing button by hand.

When the type of keyboard is changed the operator uses a vacuum cleaner to remove remaining buttons from the vibration feeder and loads the correct type. In order to reduce the down time the feeding chutes have been marked. When making a change the operator pushes the buttons above the mark back into the feeder and starts vacuuming. There are thus buttons left in the feeder chute and the assembly of the first type can continue until they are used up. A skilled operator can change buttons without stopping the line.

When manufacturing keyboards with ten or eleven buttons any superfluous feeders are shut down. Empty holes in the cover plate are blocked and the test devices react as if a button was mounted; i.e. they close, and no program changes are necessary.

**Stations Nos. 2 and 3**
At these stations the remaining two rows of buttons in the keyboard are mounted. The stations are designed in the same way as station No. 1.

**Station No. 4**
Here the antistatic plate is mounted. The plate protects the electronic circuits against electrostatic discharges. The plate has a flange which makes contact with the printed circuit board and subsequently, via the ribbon cable, with an earth point.

The same plate is used for all types of keyboard and it has thus been a factor to consider in the design of different keyboards. The part is made in the press shop as a band with all holes punched. It is washed and delivered to the line as a roll without bends.

In the assembly the flange is bent; the plate is cut off and is placed in the fetching position, where it is picked up by a PP unit with claws. Mounting of this part is checked by means of a light beam, which is reflected from the plate to a photodiode.

**Station No. 5**
Rubber pads, with conducting rubber studs, are mounted at this station. Only one type of pad is used, and it is designed so that the domes fit into the set even when the cover plate has holes filled in.

A buffer has been arranged before this station so that the operator will not have to load material too often. It consists of a number of magazines that rotate in the buffer as they are emptied. The operator can load several magazines simultaneously.

A pad is always positioned at exactly the right height for fetching. In the fetching position the pads are separated by slides which are inserted between the two uppermost pads in the magazine. A PP unit with suction cups picks up the top pad and places it on the cover plate. At the same time the next pad in the magazine is vacuum cleaned by ejector suction equipment mounted on the same PP arm.

The pads are placed in the fetching position with the aid of a long screw which raises the bottom of the magazine to the correct height. The position is indicated by a lamp and a photodiode. When the magazine is empty a split nut on the screw is opened, the magazine is quickly dropped and a new, full magazine is stepped up.

The presence of the rubber pad is checked in the next position by means of photosensing equipment. It is set so that a reflection from the grey rubber does not activate the sensor, but if the pad is missing the considerably stronger reflection from the shiny antistatic plate triggers the sensor.

**Station No. 6**
Here the printed board assembly is placed on the cover plate. The station contains a buffer for boards, similar to that for the rubber pads. It was originally planned that the printed board assemblies should be placed in the magazines as they arrived from the supplier. Unfortunately this was not possible because the boards spread dust from the cut holes during the transport to the factory. The boards are therefore blown clean manually in order to achieve the desired quality. Cleaning is done in another department so as to keep the keyboard assembly room as free from dust as possible.

In the assembly the boards are raised in the same way as the rubber pads, but no slide is needed to separate the boards from each other. A PP unit picks up the top board, advances and places it on the rivets in the cover plate. The latter has a support in the middle of each of two sides to transfer pressure to the larger printed circuit board on which the keyboard is later mounted.

The supports have been designed so that they also aid the alignment of the board in this operation, i.e. they guide the board in both the x and y directions by means of cut-outs on the board. In order to ensure dust-free assembly the PP unit moves the board across a slot where it is once again cleaned with an ejector suction unit.

The check that the board has been mounted is done by a photoindicator, which scans the part of the board that extends beyond the cover plate.

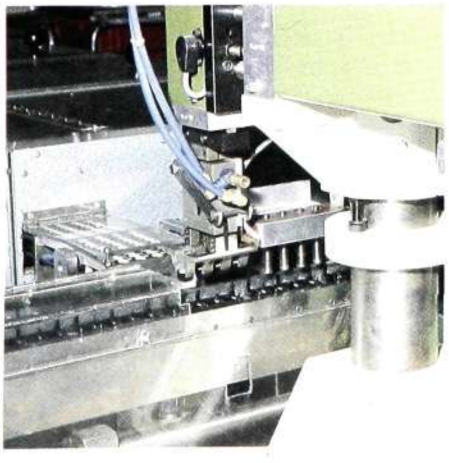
**Station No. 7**
Here the printed board assembly is riveted to the cover plate. All rivet punches descend on the board simultaneously. The punches are very short and have rubber tubes fitted over the lower part. The tubes hit the board first, become compressed and give a good hold; then the punches come down and cold-head the rivets.

The punches are burnished and plane, since the objective is to expand the rivet in the hole for maximum holding force there. A hole cut in a printed circuit board has very sharp edges and can easily shear a plastic rivet head if the board can move in relation to the rivet.

After riveting, the keyboard is transferred to a conveyor belt, not by any tool but by being forced onto the belt by the next keyboard in the assembly line. When ten keyboards have been placed in a row on the belt the whole line is moved out into the buffer, fig. 4.

**Buffer**
The assembly line is divided into two

Fig. 5
Assembly of buttons



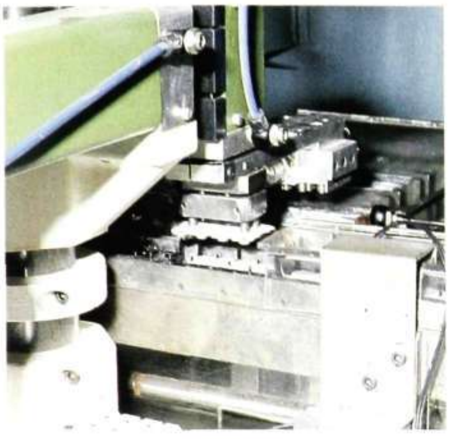


Fig. 6
Mounting of rubber pad

modules. Module No. 1 comprises everything from the input up to and including station No. 7, and module No. 2 comprises the rest. A buffer is installed between the modules. It consists of a wide conveyor belt that holds ten keyboards side by side and approximately 55 boards lengthwise. Normally the belt moves one row for each output of ten keyboards from station No. 7, but if no workpieces are available at module No. 2 the belt moves continuously.

Today the line has a cycle time of just under six seconds, so the buffer lasts approximately 50 minutes. From the buffer a row of ten keyboards is fed out to a new conveyor belt, which transports them to a transfer station. There a PP unit lifts the keyboards one by one onto a transporter similar to the one used in module No. 1.

**Station No. 8**
Here the ribbon cable is fitted. The cable is delivered from the supplier on large drums. They are placed on a driving device which pays out the cable in such a way that there is always some slack at the following Komax 30 machine. The latter cuts and strips the cable fully at one end and partly at the other. By part stripping is meant that the plastic is left on the nine conductors so that they will not be deformed during the subsequent handling and transport.

The machine leaves the cable in a position where it is fetched by a PP unit, which advances, picks up the cable, turns and descends to place the stripped end of the cable on the printed circuit board. At the same time the two outer conductors are bent so that the cable stays in position during the subsequent transport along the line.

The assembly is checked by means of a photoindicator. The line moves on if the cable breaks the beam from the lamp; otherwise it stops. In the latter case the operator fits one of the previously prepared cables available at the station.

**Station No. 9**
Before this station the keyboards are arranged in pairs and transported in parallel. This doubles the time available for each operation. The pair transport mode was chosen in order to provide adequate time, 10–12 seconds, for soldering. The transport is not by means of slides; for this station and the rest of the line an overhead feeder is used which moves forward, is raised, returns in the raised position and finally descends to start the next feeding cycle.

At station No. 9 flux is applied to the joint by means of two ladles which are lifted from a bath of flux. The density of the flux is kept constant with the aid of a device that adds alcohol as required.

**Station No. 10**
Here the cable is soldered to the board. Before this station the keyboard passes a heater that pre-dries the flux and preheats the joint.

The solder is applied by two ladles rising through the surface of the solder bath immediately after the slag has been removed from it by a scraper. The ladles are large in order to retain heat after they have been lifted and in addition they are not removed completely from the solder bath.

After station No. 10, during the transport to the next station, the ribbon cable is bent over the board, at the rear of the keyboard, for easier handling of the set in the subsequent operations.

**Station No. 11**
Here the keyboards are tested. They are turned, two by two, to the correct position and placed at a divider, from which two keyboard paths emanate. Two parallel paths with separate test equipment have been arranged so that, in the case of a failure, the production capacity will only be reduced by a half during the repair time. It was also assumed from the start that testing would be the most time-consuming operation, and the test equipment was expected to require more service than the rest of the line.

During the test the buttons are operated by air cylinders with well-controlled movement. The cylinders are equipped with spring-loaded pads for the actual contact with the buttons. The action of a human finger has been imitated as far as possible. Extensive experiments have been carried out to determine the force/travel characteristics of the *fingers*. A number of people operated keyboards

**Fig. 7**
**The last part of the assembly line. The operator carries out visual inspection of the soldering and packs the keyboards**

and the speed of pushing was measured.

The test equipment measures the contact resistance and checks that there are no short circuits. It also measures the simultaneity of the double make contacts under each button and checks that there are no contact bounces longer than 6 milliseconds, neither when the button is pressed nor when it is released.

The keyboards that do not pass the test are fed out into a container below the line.

**Station No. 12**
After the test the keyboard paths are combined and the sets fed on one by one. Marking is done at this station. Type set up in a holder is coated with marking ink. A rubber plate is pressed against the type, then turned through 180° and pressed onto the keyboard.

The marking serves several purposes and comprises type of keyboard (item number), manufacturing date (period and year) and the Ericsson factory involved. The marking is a seal of testing and approval of the keyboard. The item number gives our customers and ourselves information about the design. The manufacturing date makes it possible to identify keyboards in stores and warehouses if any quality problems should arise.

**Station No. 13**
An operator packs the sets after having checked that the correct buttons are mounted, that the soldering has been done correctly and that there are no tin splashes around the soldered joints.

## Future development

After the assembly line described above was installed, high-quality pumped solder baths have become available in the market. This equipment has been tested by Ericsson in other lines with very good result. Such equipment would eliminate the slow scraping of the solder surface. The cycle time, now six seconds, could then be reduced to four.

Ericsson's quality tests and continual long-term tests have shown a very high and even quality ever since production started. The manual inspection could therefore be removed without any risk of future complaints. The line would then end in an automatic packing station.

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