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CONTENTS

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Electroluminescence Display Techniques and Applications

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Electroluminescence is now commercially established as a display technique and for use as a solid-state element in complex logic systems. The article, after briefly discussing the mechanism of electroluminescence, surveys some of the many applications of the phenomenon, including diagrammatic display which has high potential use in educational, training, and industrial instrumentation.

EACH year sees an increasing degree of automation in industry and a corresponding need for the display of information. This may be merely a need to present an up-to-date report on the state or position of equipment or, alternatively, the display may play an active part in the control system. In either event the electroluminescent diagram offers a unique solution. Complex machinery, plant and systems also give rise to a requirement for specialized training for the engineers and technicians who will be responsible for their operation. Here again, electroluminescence can offer a particularly flexible type of display, with a wide range of colours and the ability to display fine detail beyond the capability of economically comparable systems.

Other applications of electroluminescence include two or three colour matrix display, instrument lighting, alpha-numeric display, multiple lamp units, information display in text form, uses in radar plotting rooms and control centres, civil and military aircraft instrumentation and cockpit lighting, and a whole range of devices using combinations of electroluminescence and photo-conductors.

The outstanding characteristics of electroluminescence devices are listed below:

(*a*) The method of construction admits the production of the most complicated shapes and designs, any parts of which can be arranged to be switched independently.

(*b*) A number of switching methods are available enabling the diagram to be integrated into any logic system, or operated from any type of pick-off or transducer.

(*c*) They are cold light sources, thus eliminating the problem of heat dissipation.

(*d*) The illumination is completely uniform over the whole lit area.

(*e*) Typical thickness of panels is less than $\frac{3}{8}$ in. (9·5 mm) and may be thinner than this in special applications.

(*f*) Power consumption is very small.

(*g*) A wide range of colours is available.

(*h*) The number of switching operations does not affect life.

(*i*) If broken accidentally there is no hazard from explosion or implosion nor are any noxious vapours or substances released.

Development

Electroluminescence may be defined as the emission of light by certain substances when these are placed in an electric field. Historically, this phenomenon was recognized and described as long ago as 1923 by Lossew and Claus as occurring in silicon carbide. More detailed development work was done by Destriau in 1936 using phosphors in powder form suspended in an insulating medium—a form of electroluminescence excited only by alternating fields. However, the development of this laboratory work into a commercial proposition was delayed until a transparent conducting medium could be found, and it is only in the last few years that electroluminescence has been developed to a commercially acceptable level.

Theory

The theory of electroluminescence is complex and there is a voluminous literature dealing with it in great detail. The following treatment is greatly simplified and a short bibliography is appended for those wishing to deal with the subject in greater detail. The essential feature is the production of a pure phosphor base (zinc sulphide) which then has an activator and a co-activator added in carefully controlled proportions. The activator and co-activator give rise to

This article is an expansion of subject matter that appeared in *Electronics and Power* February, 1965; Author, D. Reaney.

' luminosity centres ' from which light can be emitted. The emission of light results from the displacement of electrons in certain atoms in the luminosity centres upon the application of an electric field and the return of these electrons to the original energy levels when the field is removed. As differing energy levels are involved with different activators and co-activators it follows that a range of emitted frequencies is possible and therefore a range of colours. A substantially white emission may be obtained by suitable admixture of two coloured phosphors.

Preparation of Phosphors

A number of different substances may be made to exhibit electroluminescence, for example, silicon carbide and gallium phosphide, but only the zinc sulphide phosphors have any commercial significance at the moment in the production of a.c. electroluminescence. Gallium phosphide is interesting in that it exhibits d.c. electroluminescence, which is discussed in a later section.

The phosphors are prepared by heating pure zinc sulphide with the appropriate activator and co-activator. The activator is usually a copper compound and the colour of the electroluminescence can be changed within the green/blue range by altering the percentage of copper activator. Yellow may be produced by the addition of a suitable manganese compound. It is also possible to produce a direct red phosphor, using zinc selenide or a mixture of selenide and sulphide. These last two phosphors are not as efficient as those used for other colours. Moreover, the response of the human eye to red is rather poor and consequently the red phosphors always appear to be rather dull. It is better to obtain reds by using a green phosphor in conjunction with a cascade filter or by filtration from orange phosphors.

Construction of Electroluminescent Panel

The method of construction is to form a sandwich consisting basically of transparent conductor, phosphor and back electrode. This construction is shown in Figure 1 and includes all the elements necessary to make a practical electroluminescent panel. The substrate is generally glass, although panels may be prepared on metal substrates and even on flexible plastic strips.

The first operation is to prepare a transparent conducting layer on the substrate. This layer consists of tin oxide which has a typical resistance of a few hundred ohms per square and an optical transmission of about 80%. It is produced by either spraying stannous chloride in acetone on to the glass which is heated to just below softening point, or the heated glass surface may be exposed to the vapour of tin chloride and the coating cooled in a reducing atmosphere.

The phosphor is next sprayed on to the conducting surface, and the medium in which the phosphor is dispersed is very important. It will have high fields across it of the order of 10^5 V/cm and must therefore have a high dielectric strength. It should be as translucent as possible, have a low power factor and be chemically inert, even when heated by the operation of the panel. Ideally, all the field should appear across the phosphor grains and it follows that the dispersal medium or binder should also have a very high dielectric constant. No material will meet all these requirements but generally satisfactory results can be obtained using certain types of epoxy resin.

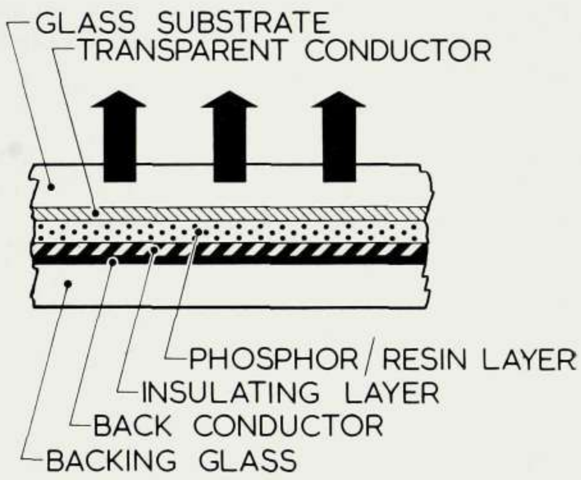


Figure 1—Basic construction of an *electroluminescent* panel

After the phosphor/binder has been cured, a layer of barium titanate is added. This serves two purposes; firstly, it increase the dielectric strength of the panel and, secondly, it acts as a reflecting layer and increases the amount of light emitted in a forward direction.

The final operation is the evaporation of the back electrode. This is either a continuous layer for plain area panels or a series of independent shapes for the more complicated types. The evaporation may be through a mask for multiple operations, but for single panels individual masking with tape may be used.

At this stage the panel is complete and will operate correctly, but it is still necessary to protect it against ingress of moisture or any other substances which will cause deterioration of the panel. For this purpose a backing glass is sealed over the back electrode. Finally, permanent connections are made to the conducting transparent layer and the back electrode using indium solder is sealed with epoxy resin.

Panel Characteristics

The most important characteristics of a simple panel made as described above are discussed briefly to give a broad appreciation of the device.

(a) Equivalent Circuit

The equivalent circuit is that of a capacitor in parallel with a large resistor. The values of the capacitance and resistance depend upon the thickness of the phosphor binder and barium titanate layers. Typical values are 1000 pF per square inch and 5M ohms per square inch. From this it will be seen that the load presented to the power supply will be almost purely capacitive—a point to be remembered when designing power supplies.

(b) Operating Voltages

The operating voltage has two ultimate limits; a low value where the light output is too small to be of value, and a high limit where the panel breaks down. Typical values for operation range from 115 to 400 volts. Lower operating voltages are related to thinner layers of phosphor and have correspondingly lower breakdown limits.

(c) Operating Frequency

The integrated light output is a function of frequency and increases with frequency up to the point where rising dielectric losses prevent further increase in light output. If the operating frequency is increased beyond this point the light output falls rapidly and the panel will start to overheat. Practical values range from 50 c/s to 5000 c/s, but the most commonly used value is 400 c/s, as this is a standard frequency readily available in aircraft and other installations.

(d) Waveshape

In principle there should be small differences between sine-wave and square-wave operation, but in practice these differences are not readily observed. At 50 c/s the panels are operated directly from the mains supply, whilst at 400 c/s, the voltage is conveniently derived from a static inverter which has a substantially square-wave output.

(e) Light Output

This is one of the most important characteristics of an electroluminescent panel and is a function of such factors as the amplitude and frequency of the applied voltage, temperature, the dielectric material, and the phosphor layer thickness. Many empirical formulae have been proposed, among these being Destriau's formula:—

$$L = AV^n \mathrm{Exp}\,(-b/v)$$

where A and b are independent of V and n has a value between 2 and 3. This formula is for a fixed frequency dielectric material and phosphor thickness and gives a good approximation to the measured results.

The light output is proportional to a power of the voltage and, in general, the level of light output increases more rapidly in the vicinity of the breakdown limit (see Figure 2). In addition the output varies more or less linearly with frequency although the losses prevent the full theoretical gain being achieved. For

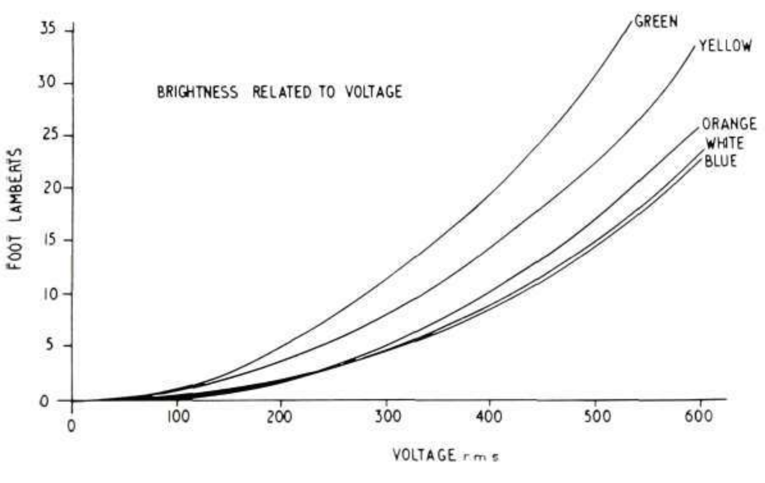
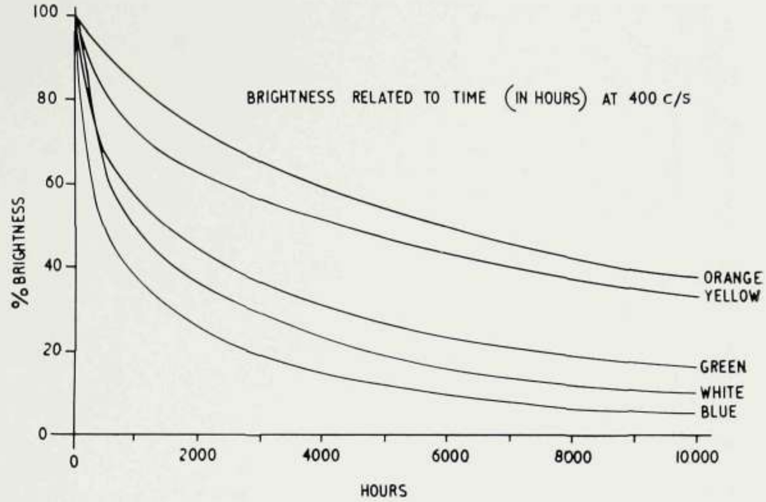


Figure 2—Light output increases rapidly with voltage and also depends on colour

Figure 3—Output drops with time, but the human eye can barely recognize a 50% reduction



example, the increase of light output between 50 c/s and 400 c/s is only about 6·0 instead of the theoretical 8·0. The characteristic breaks away completely at high frequencies due to the rapidly increasing dielectric losses.

(*f*) *Life Performance*

The very nature of the construction leads to a robust unit and, provided the sealing is satisfactory, its life is long and reliability high. During normal operation of an electroluminescent panel some reduction in the level of light output occurs. Typical curves are shown in Figure 3 relating to operation at a certain frequency. The rate of change is dependent upon the frequency of the operating voltage being greater for higher frequencies. Note that the general shape of the characteristic is the same for all phosphors although the rates are different. It is worth mentioning at this point that the graphs do not give a very good indication of the actual appearance of the panels because the human eye is not able to distinguish between levels of brightness differing by 40% and can only just recognize 50%.

Note also that the characteristics tend to be asymptotic to values round about 40% of the initial levels. The panels are aged after manufacture to about 80% of the initial levels so that in normal operation the changes in level are not readily detected by eye.

Mimic Diagrams

The term ' mimic diagram ' is used here as a general expression to describe an electroluminescent display showing in diagrammatic form a plant, installation or equipment. Individual parts of the system or installation will be displayed in different colours, and in a large mimic diagram there may be up to two or three hundred separately lit areas, all of which may be switched independently. Some typical mimic diagrams are illustrated in Figures 4 to 7.

Mimic diagrams are conveniently divided into two main groups; firstly, there are diagrams for teaching, training or demonstration and, secondly, the industrial group, where the diagram is connected directly with and is operated by the associated installation.

The following list gives some idea of the enormous range of applications of these diagrams.

Training Diagrams

- Aircraft operational systems
- Aircraft flight simulators
- Animated diagrams of complex equipments, for example, jet engines and telephone exchange traffic flow. Also very detailed diagrams (sections being switched or animated by the instructor as required) for use in medical schools, universities and technical colleges

Industrial Diagrams

- Process control diagrams of all types (see Figures 4 to 6)
- Chemical works and refinery systems and processes
- Pipe-line simulators
- Traffic control systems
- Railway signalling systems
- Airport runway and approach systems
- Underground railway systems (station identification and routing)
- Conveyor systems in mines and factories
- Diagrams associated with waterworks and filter systems

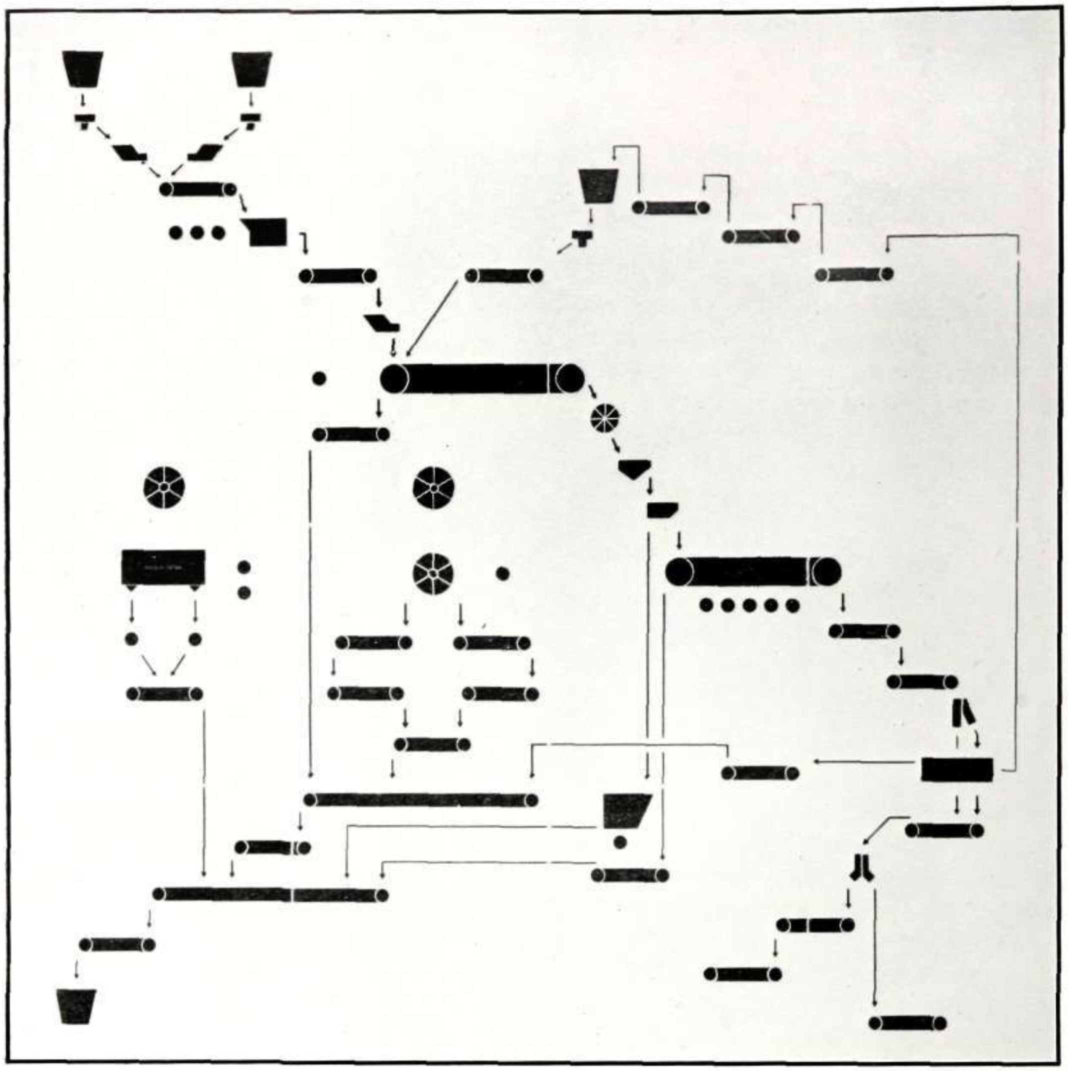


Figure 4—Materials handling diagram of a sinter plant, shown illuminated on the opposite page

Dockyards and marshalling yards

Shipborne applications, e.g. position of watertight doors, engine-room repeaters and fire-control equipment

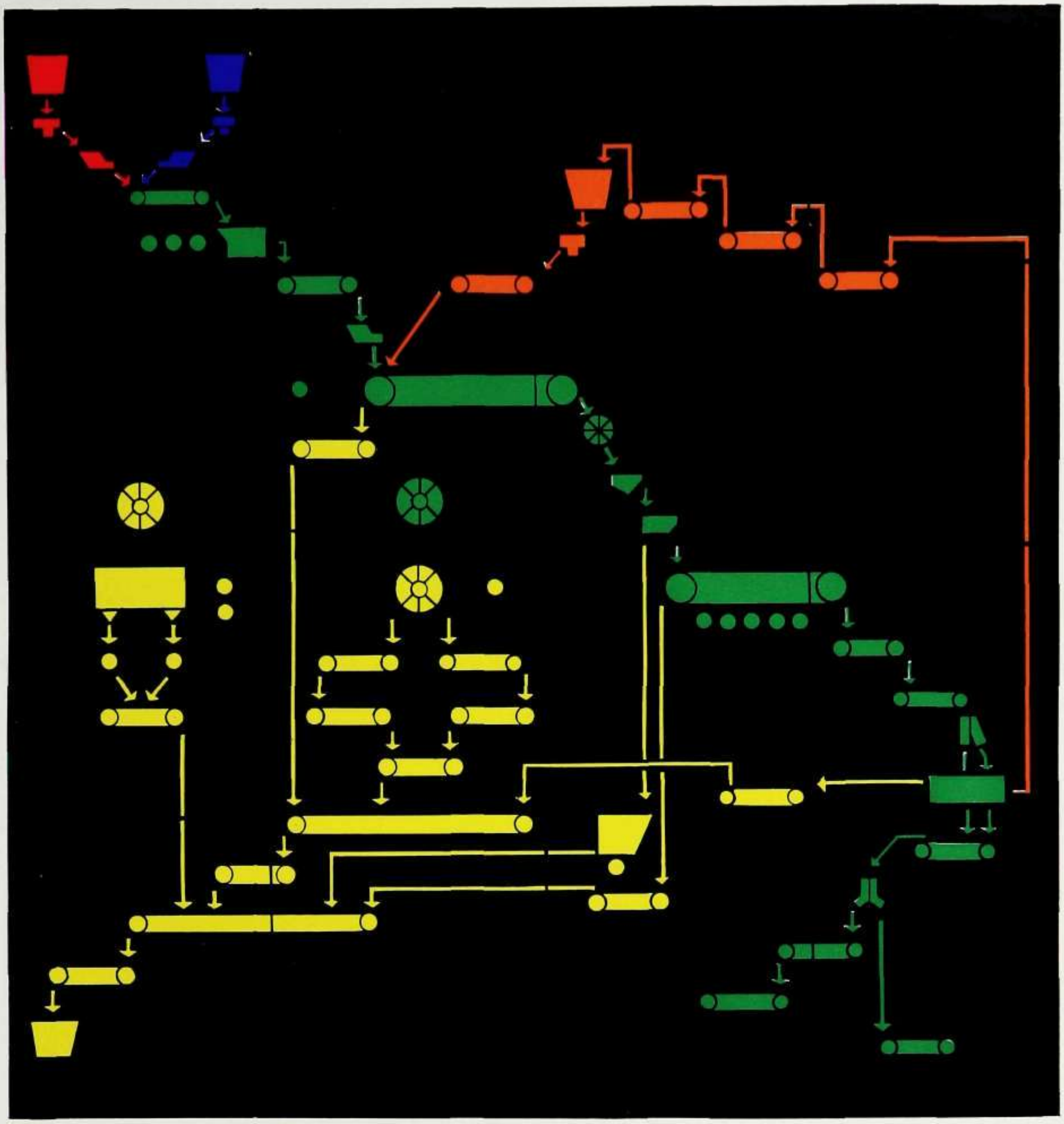
A diagram is built up from a number of tiles each of which is approximately 9 in. (23 cm approximately) square. Other sizes and shapes are also used, but only where the standard tile is unsuitable. The advantages of using a standard tile of these dimensions are:—

(*a*) In the event of accidental breakage by the user, it is easier and cheaper to replace.

(*b*) If the user wishes to alter the diagram at a later date, for example, owing to expansion of the plant, it is possible to do this without having to replace the whole diagram.

Tiles are mounted on to a backboard by nylon bolts which are secured to the tiles by means of mild steel cups cemented to the backing glass.

The front of the diagram consists of the artwork overlay. This is one of the important parts of a diagram and may be made of perspex or glass. The representation of the various items should be in reduced, simplified or even diagrammatic form but must always bear some resemblance to the actual



object. Interconnections, either electrical or mechanical are usually shown as straight lines. Differing systems can be in different colours. Where it is desired to show movement and/or flow, the line is broken into a series of small independent sections connected to an animation unit. The connections to the various parts of the tiles are by means of flexible leads and these are terminated near to the panel using terminal strips or other suitable connectors.

The various switching units, such as relays and photactors, are usually mounted on the back of the diagram and individual inputs provided on connectors suitably sited for convenient access. Power supplies are frequently located in the base of the diagram, but this is largely a matter of convenience and other locations are equally suitable.

A diagram showing typical construction is seen in Figure 8.

The complete diagram is mounted in a cabinet or, in some instances, fitted into the walls of a specially designed control room. It should always be kept in mind that electroluminescence is an area illuminant; thus, for the best results the ambient lighting levels should be controlled.

The whole concept of the electroluminescent diagram is new and if the maximum use is to be made

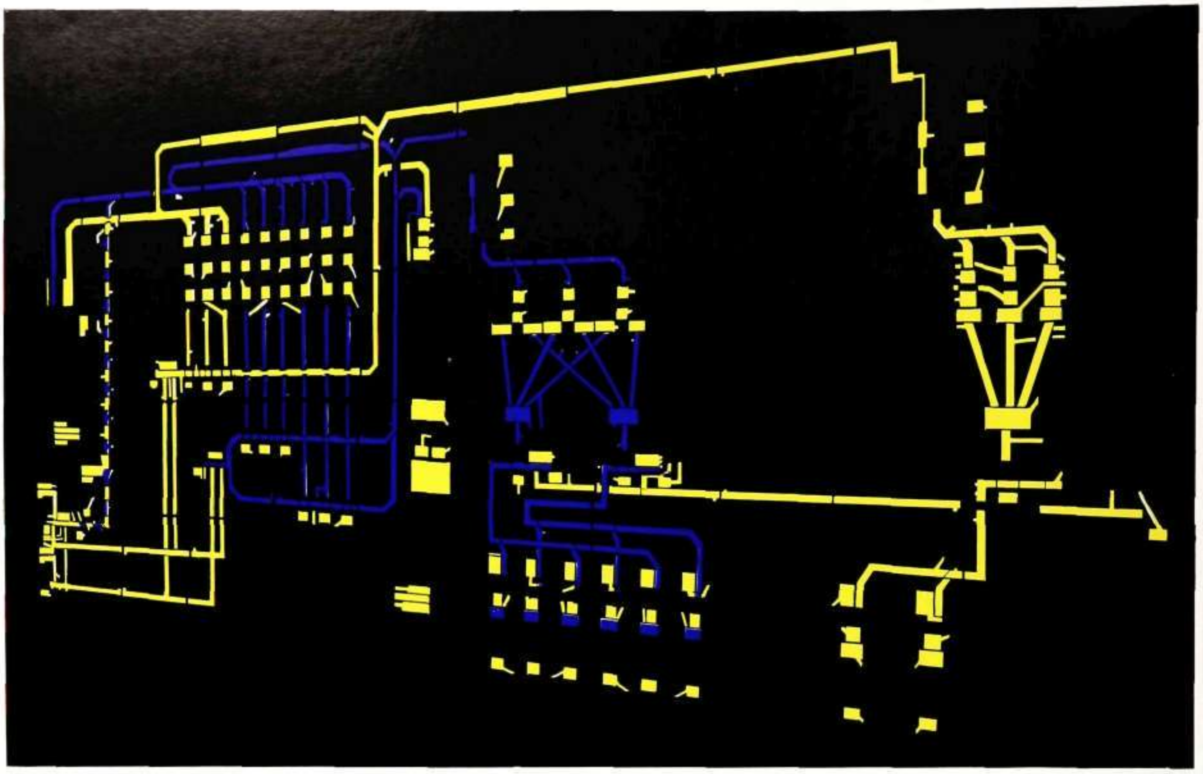


Figure 5—Illumination of the diagram in the control console (seen on the opposite page) showing bin levels and movement of ingredients in a large automated bakery

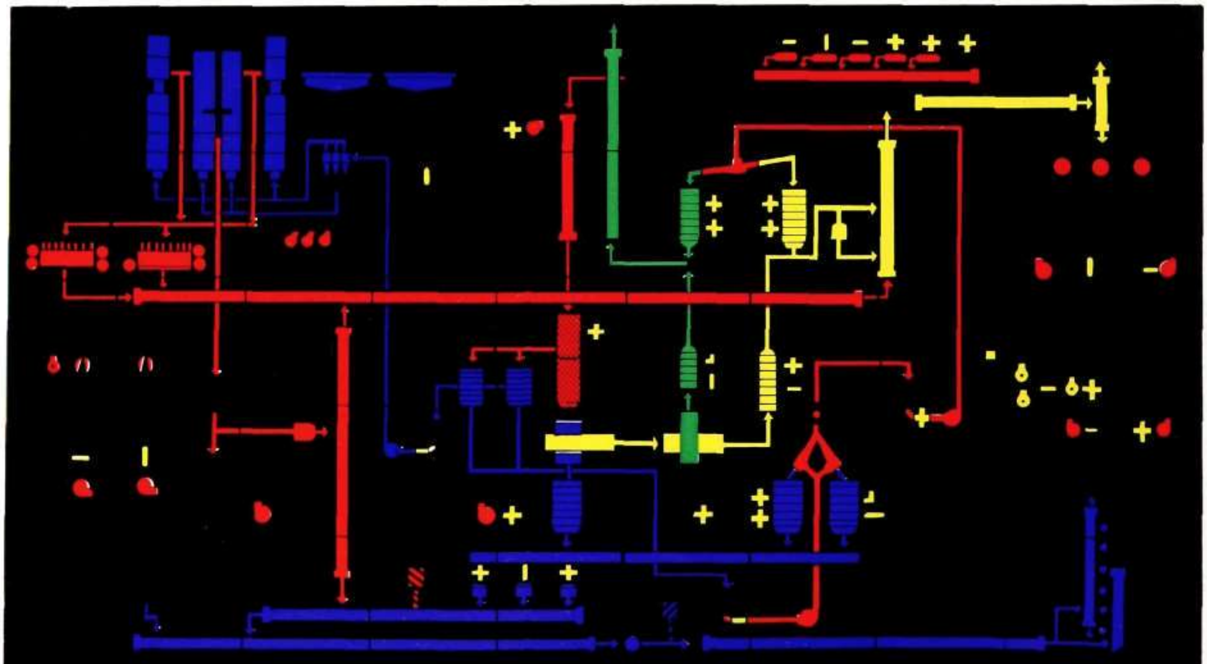
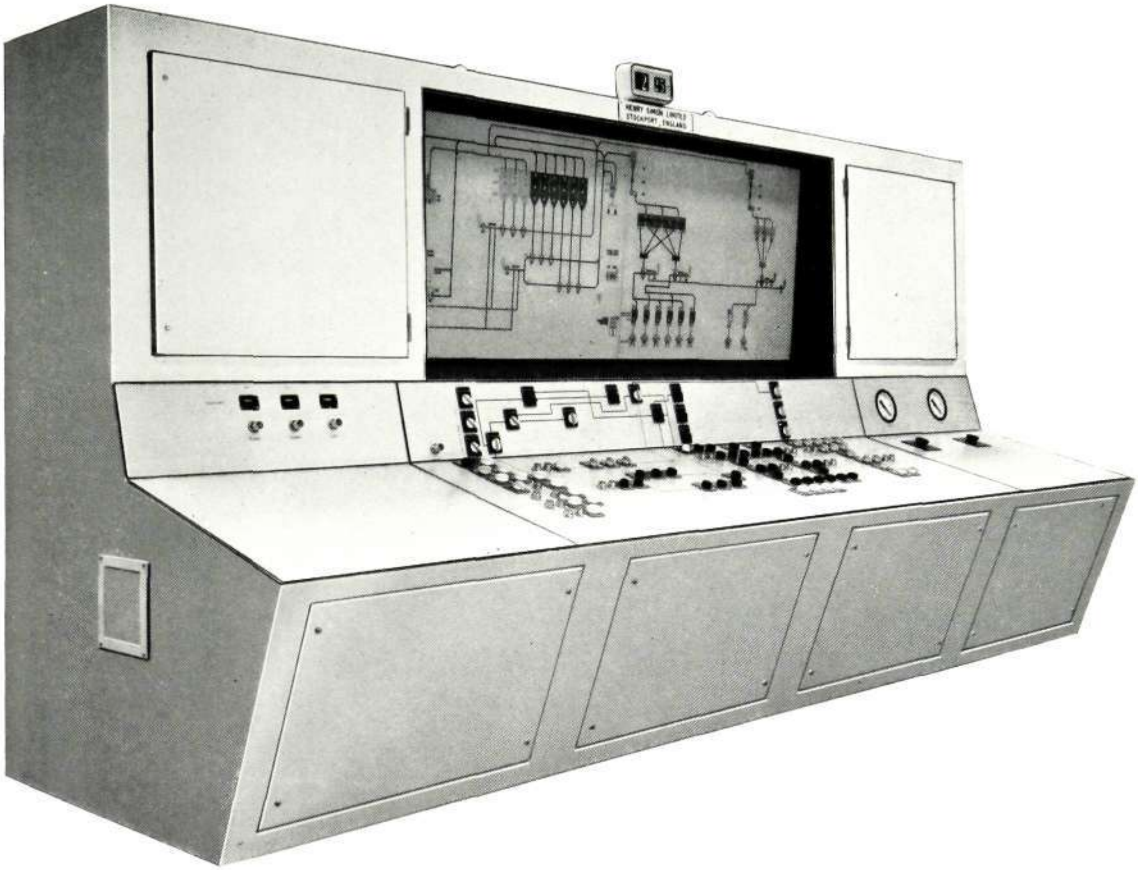


Figure 6—Illumination of the diagram (shown on the opposite page) for a typical mineral handling plant


HENRY SIMON LIMITED
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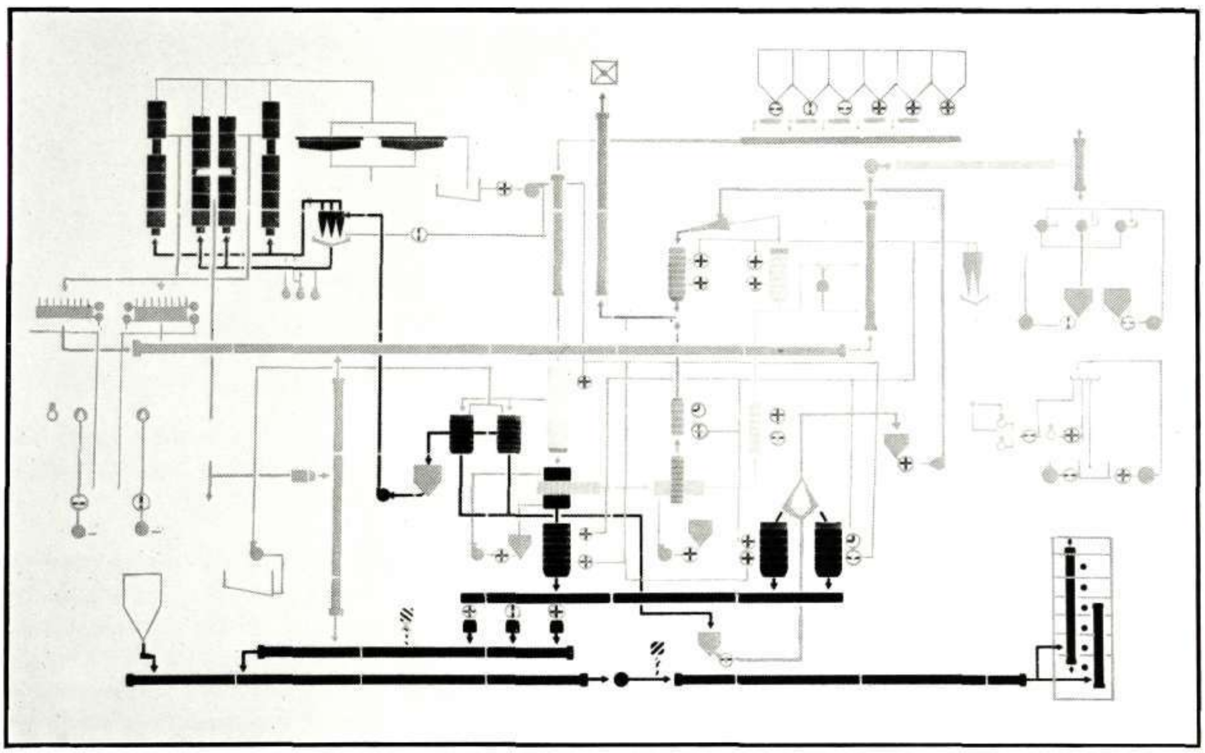


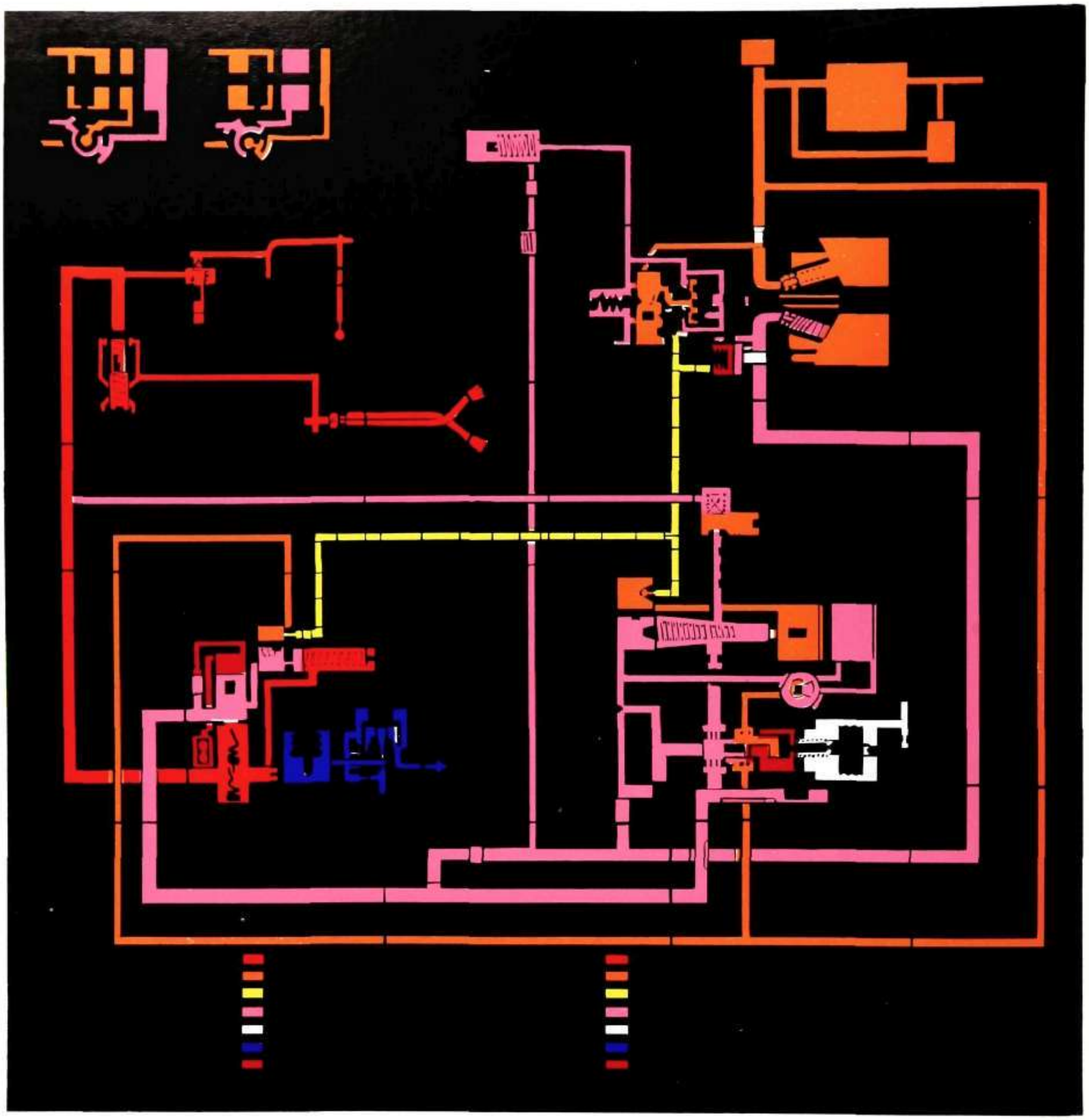


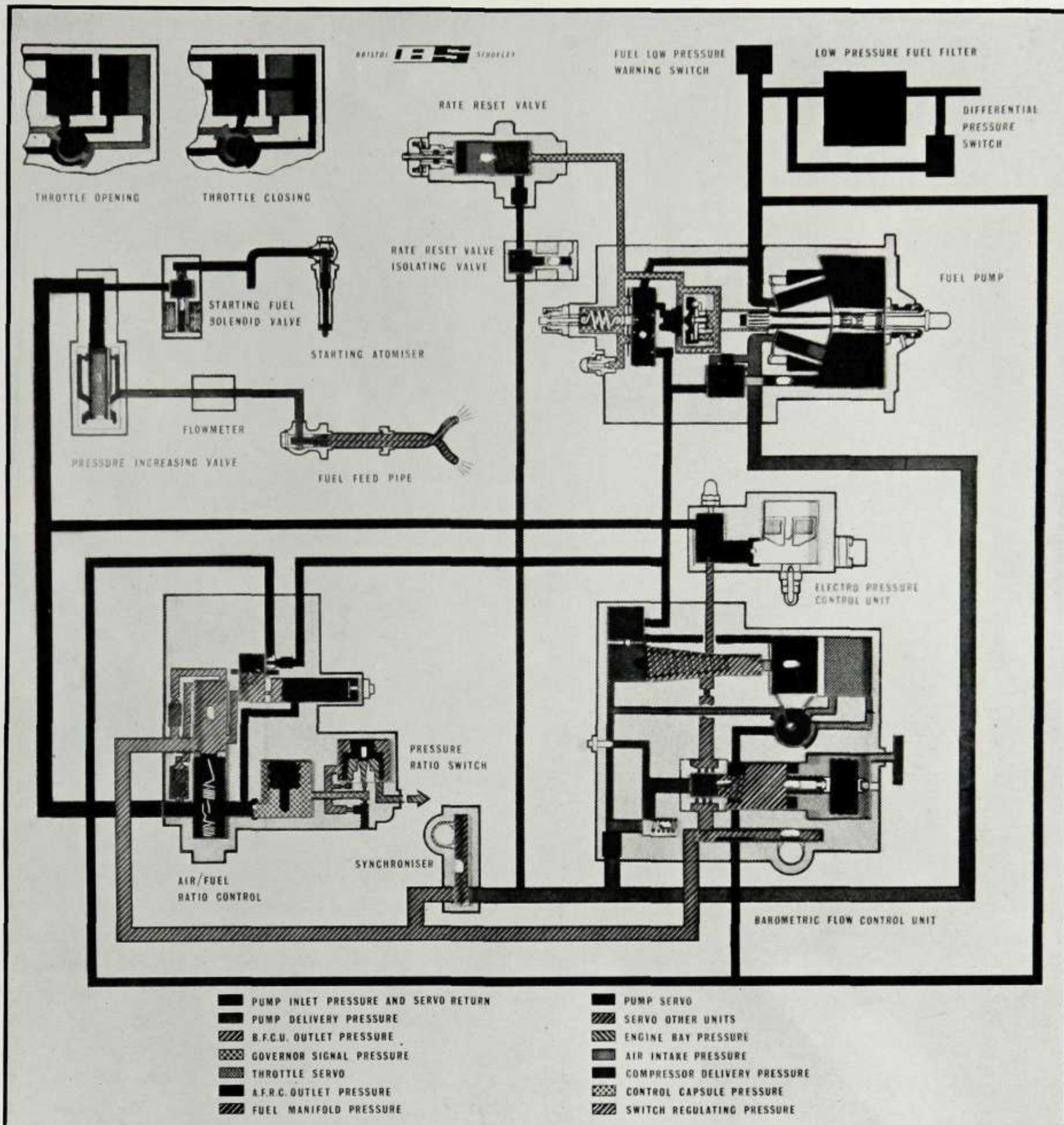
Figure 7—Illumination of a typical training diagram shown on the opposite page

of such a device it is necessary to plan the location along with the rest of the plant. In a similar manner the design of the diagram and the facilities that it can be made to offer require detailed study and planning.

Ancillary Equipment

As already stated, the switching of the various sections of a diagram may be accomplished in several ways. These include the use of relays, photactors and saturable reactors. All these methods have advantages and the final choice is often determined by the switching signals available.

Power supplies are required to operate panels at about 400 volts 400 c/s, and transistor static inverters offer a good solution. The design of these inverters must be such that they will work into a substantially capacitive load. At very high power levels the use of a rotary converter may be economically justified.



BRISTOL SIDDELEY VIPER 521
FUEL SYSTEM

Where movement and flow are required the provision of an animator is necessary. The animator unit consists of a four-stage ring counter, using cold cathode tubes for high reliability, operating four relays for the direct switching. The device is completely self-contained to operate directly from 250-volt mains and has provision for the speed to be varied over a wide range.

Aircraft Applications

Very much wider usage of electroluminescence is now to be found in the aircraft industry. There are two main types of application; firstly, in the trans-illumination of control panels (the colours used being white or aviation red) and, secondly, the provision of illuminated signs for use in the aircraft cabin.

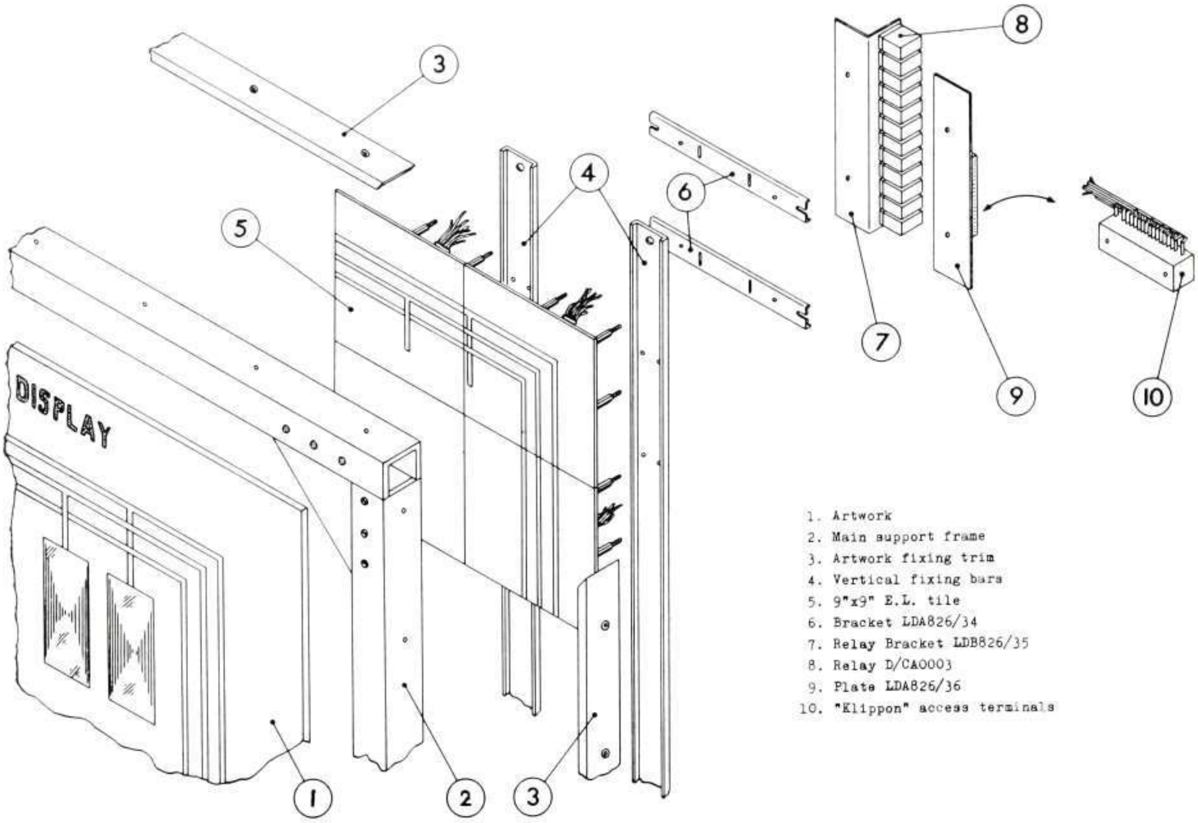


Figure 8—Exploded view of mimic construction

The former application has brought about the development of very small panels operating at either 115 or 208 volts, derived directly from the aircraft's main 400 c/s supply. Aviation red light is obtained by the use of a green phosphor plus a red cascade filter.

The illuminated signs are simple applications and offer advantages in their essentially flat nature. But the use of illuminated texts extends far beyond the use in aircraft. It has been found possible to produce signs in which the text can only be seen when the sign is actually switched on, otherwise the text is essentially ' secret '. Additionally, as any word or part of the sign can be switched separately it is possible to change the meaning or direction of the sign at the touch of a switch.

Alpha-Numeric Displays

Of a similar nature to illuminated display in aircraft are the alpha-numeric displays, where letters, numbers or symbols can be formed from segments. When arranged in groups these devices are capable of displaying complicated messages or information.

A small numerical display of the type shown in Figure 9 has the additional interest that it accepts binary-coded decimal information. The decoding from binary to decimal is accomplished using a combination of electroluminescent lamps and photo-conductors deposited on a single wafer. The coding from decimal to ' segment ' is done in a similar manner. It is, of course, quite practicable to devise wafers to perform many other types of code conversion and then to display the information in the required form. One can even envisage a transistorized, battery-operated pocket calculator using these techniques.

Logic Elements

A combination of electroluminescent lamps and photo-conductors can also be arranged to provide most of the logic functions normally encountered. It should again be borne in mind that the speed of these elements is comparatively slow, and they are best considered for use in equipment where a human operator is involved.

Latching Relay

The simplest device is probably the latching relay which can be made by using two electroluminescent lamps and a minimum of one photo-conductor for latching purposes. Additional photo-conductors are included to provide the switched outputs.

The basic construction of a latching relay device is illustrated in Figure 10(*a*). To unlatch the relay it is necessary either to interrupt the supply momentarily or, alternatively, to place a further photo-resistor across the lamp (as shown), the illumination of this photo-resistor unlatching the relay. In this arrangement it is of course possible to provide the equivalent of light and heavy contacts simply by using photo-conductors of greater or lesser areas.

AND/OR Gates

The conventional AND gate shown in Figure 10(*b*) requires only two electroluminescent lamps for input, together with two photo-conductors plus output lamp. The equally conventional OR gate is shown in Figure 10(*c*).

Sequential Counter

There are several possible ways of producing a sequential counter all of which require a combination of a latching facility associated with some means of sequential triggering. The basic unit employed in a typical system, see Figure 10(*d*), consists of a series combination of an electroluminescent lamp and a photo-conductor. There are two groups of these, one group being the latched stable-state elements and the other group the triggering elements. In this arrangement it is assumed that the section $P' — L'$ is operating and latched by means of the light from the lamp being optically fed back into P'. When the trigger line is energized, the lamp L'' will light since its associated photo-resistor P'_T is illuminated by L'_T. No other trigger lamp will light as no other trigger photo-resistor is illuminated. The trigger lamp then illuminates photo-resistor P'' which turns on L'' and thus latches on. Photo-resistor P'_E is also illuminated and shunts L' so that it ceases to emit light. The associated photo-resistor P' then returns to its dark (high resistance) state. The trigger line is de-energized and the counter will remain locked until the arrival of the next trigger pulse.

Random Access Store

The main advantages of this type of store are its small size and the fact that all the internal connections are made by evaporating the conductors. It is comparatively easy to produce a store of this type for any number of digits expressed in almost any code. A typical N-digit store accepting 4-bit binary coded information

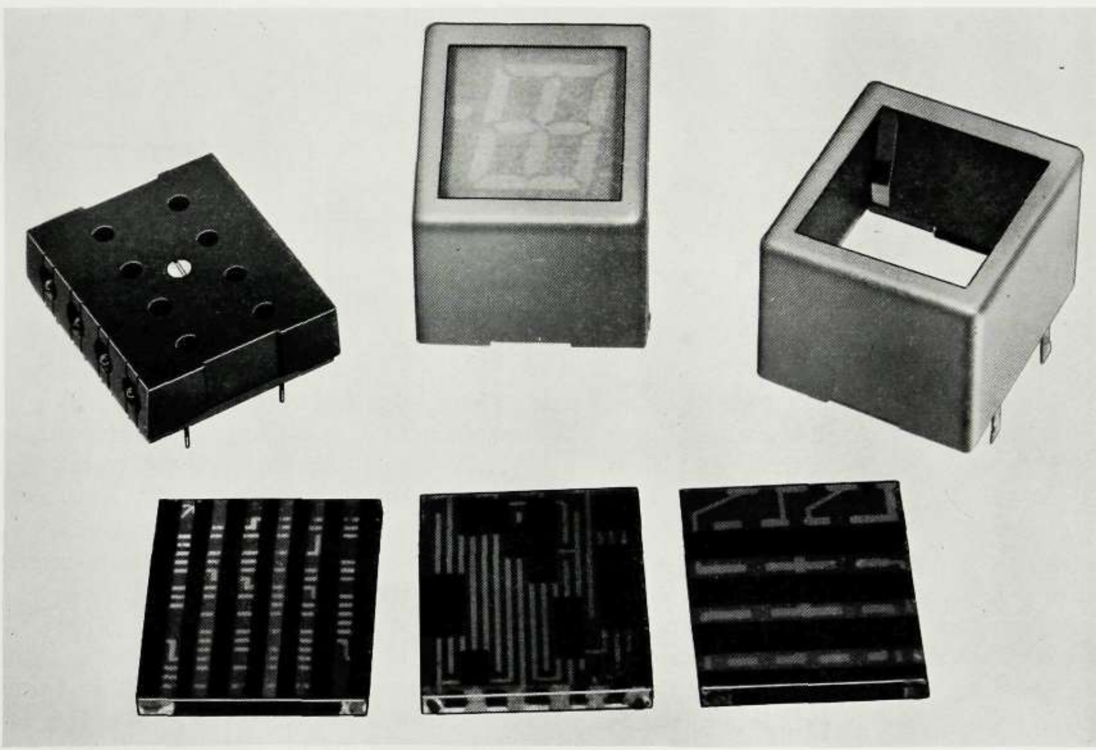
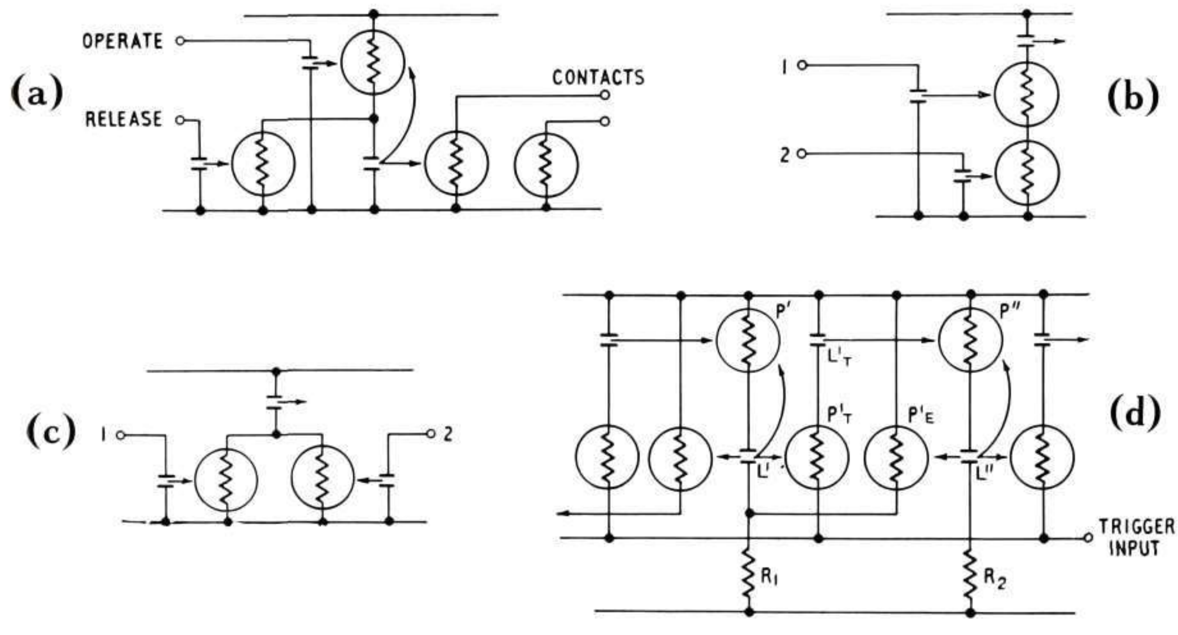


Figure 9—Electroluminescent numerical indicator dismantled to show system of code conversion

is illustrated in Figure 11. The functioning of this store is best understood by first considering the basic elements shown in Figure 11(*a*). It will be seen that this consists of a photo-resistor P′ and its associated electroluminescent lamp L′ with a further photo-resistor P″. There is additionally another electroluminescent lamp (read/write lamp) which is arranged to illuminate a whole column of P″ photo-resistors. Consider the state of the components when the store is energized but contains no information. Under these conditions all the electroluminescent lamps L′—L^n are unlighted. In order to put information into the store the read/write lamp is illuminated and this turns on all the photo-resistors P″ — P^{nn}. If the point A is now connected to the supply voltage, lamp L′ will light low and determined primarily by leakage currents. If the element contains a 1, then the photo-resistor P′ will be in the on-state and the voltage at point 'A' will be approximately equal to the supply voltage. The ratio between these two voltages is very high and there is no difficulty in discriminating between the 0 and 1 states.

Matrix Displays

The final application to be described is the X-Y co-ordinate display, where the electrodes consist of two orthogonal sets of strips, one being the X co-ordinate and the other the Y co-ordinate. Such a device can be produced with the Y co-ordinate in two different colours with a complete set of connections for each colour.



(a) **Basic construction of latching relay**
(b) **Conventional AND gate**
(c) **Conventional OR gate**
(d) **Section of typical sequential counter**

Figure 10—Basic logic units

and in combination with photo-resistor P′ will latch-on. Similarly, information can be fed into other elements of the store and all the digits in the store may thus be entered. On completion of the process of writing information into the store the read/write lamps are disconnected and the information stored will be retained until required. The store may be cleared completely by momentarily disconnecting the input supply voltage. To readout from the store the read/write lamps are again illuminated and the points 'A' are scanned. If the element being scanned contains the digit 0 then the photo-resistor P′ is in the off-state and the voltage at the point 'A' will be quite

These panels offer the possibility of scanning of the co-ordinates and so building up a composite picture. It is necessary to pulse the supply voltage, as otherwise the integrated brightness levels are too low to be of use. A good deal of development is still required before such a scanning device is available but successful prototypes have been demonstrated in the U.S.A.

Development Targets

The present development is aimed at two main targets; the first is to increase the levels of light output and, the second, to achieve new methods of fabrication. This work involves the evaluation of new phosphors,

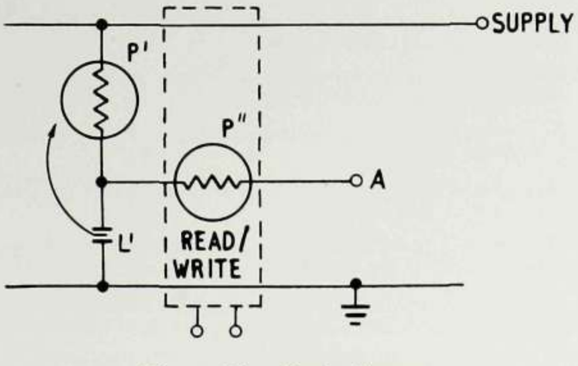


Figure 11a—Basic element

and the investigation of new materials with high dielectric constants that offer possibilities of increased light output. Additionally, the methods of fabrication are being constantly reviewed and improved and it is thought that panels should ultimately be made in plastic form as well as on glass or metal substrates.

The final future development to be mentioned is d.c. electroluminescence. This has always been known in single crystals, of course, but the main requirement is the large area panel. These panels may be made by evaporation techniques and will generally operate on either a.c. or d.c. The light output under a.c. operation is higher than with d.c. Operating voltages are quite low (20 to 40 volts) and the devices will be compatible with transistor techniques.

Conclusions

The development of the electroluminescent panel has resulted in a new form of display diagram which can be an integral active part of a large system or installation. The most complicated designs can be produced with comparative ease on panels less than $\frac{3}{8}$ in. thick (9·5 mm approximately) and almost any form of data, symbol or diagram can be produced in a wide range of colours. Switching is simple and the reliability of the device is high. Owing to the high density of information which can be displayed for easy assimilation by the viewer, designers can now produce very large diagrams in proportions suitable even for desk presentation. It is possible that a new form of instrumentation may ultimately develop from the electroluminescent display since data can be presented in a completely different way, which is more meaningful to the observer.

It will be extremely interesting to watch the progress of electroluminescence in industry as it has such a large application potential and should play an important part in the realization of industrial automation.

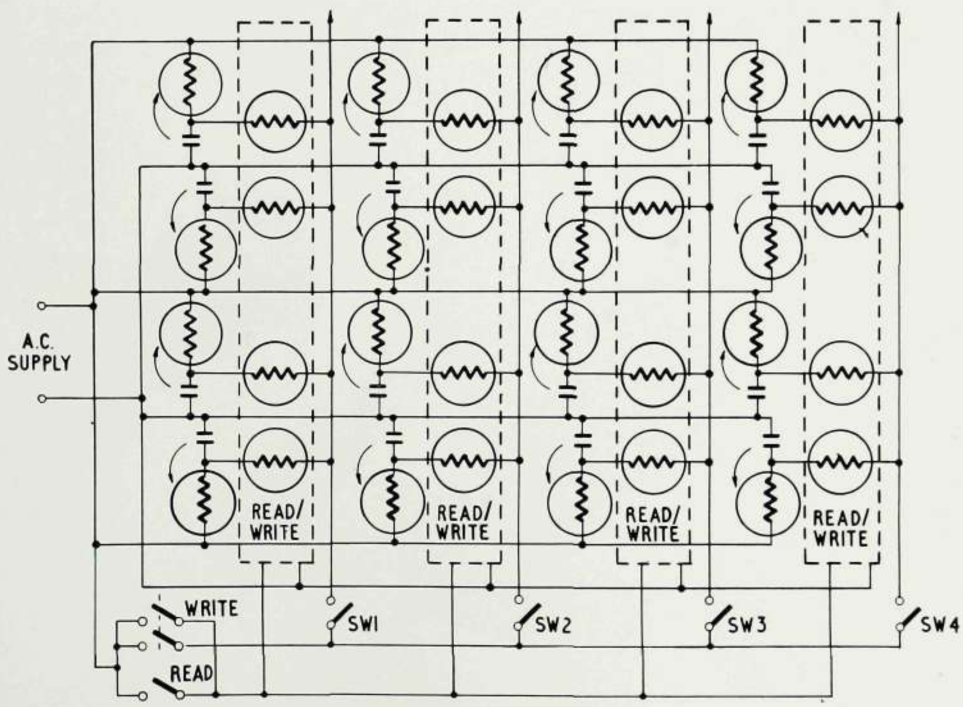


Figure 11—Simplified schematic of random-access store

ACKNOWLEDGMENTS

Referring to illustrations Figures 4 to 7, acknowledgments are due to the following:—

Figure 4—Stanton & Staveley Group, Huntingdon Heberlein Co. Ltd., Field & Grant Co. Ltd.

Figure 5—Henry Simon Ltd., Industrial Models Ltd., W. H. Smith (Electrical Engineers) Ltd.

Figure 6—Head Wrightson Minerals Engineering Ltd., The Belmos Co. Ltd.

Figure 7—Bristol Aircraft School

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U.D.C.621.318.44

Glass-Nylon Coil Formers

J. M. BRAMLEY, A.R.I.C.—Production Laboratories

and

A. GREATOREX—Apparatus Engineering Department

As a result of extended development, relay coil formers moulded in glass-filled nylon are now a highly satisfactory alternative to the conventional 'fabricated' type. Apart from economic advantages, these formers have permitted technical improvements in coil winding. Because of their strength, relay designs embodying demountable coils are now practicable.

THE extensive use of electromagnetic devices in telecommunication systems creates a large demand for wirewound coils. The scale of this demand is evidenced by the annual production within Ericsson Telephones Limited of over three million relay coils, as well as a very large total of coils for uniselectors, subscribers meters, ringers, etc. Coil winding is thus a field of production where effort to improve winding techniques and investigate new materials is particularly well repaid; this effort is and has been continuous and the rewards are to be found both in increasing reliability and more favourable production costs.

The most valuable of recent advances in materials has related to the construction of the coil former or bobbin. A typical relay former is a composite construction, having three main components of insulating material: the two cheeks, known as armature end and heel-end, and the sleeve or tube between them. These three components are supported by the core-iron of the relay, the heel-end cheek normally being 'staked' to the core-iron prior to winding, thus locking the assembly on the core-iron. This cheek also serves to carry tags for the termination of the windings.

In the traditional 'fabricated' bobbin assembly the two cheeks are mounted on the core-iron first, the relay then being prepared for winding by adding the tube. This consists of flexible insulating sheet material wound on the core-iron to a sufficient total thickness, the edges being slit so as to splay over the end-cheeks. Figure 1 shows stages in the preparation of 3000-type relay bobbins. The discs, cut radially so as to permit threading on to the tube, are added last and serve to give added insulation at the ends of the winding layers.

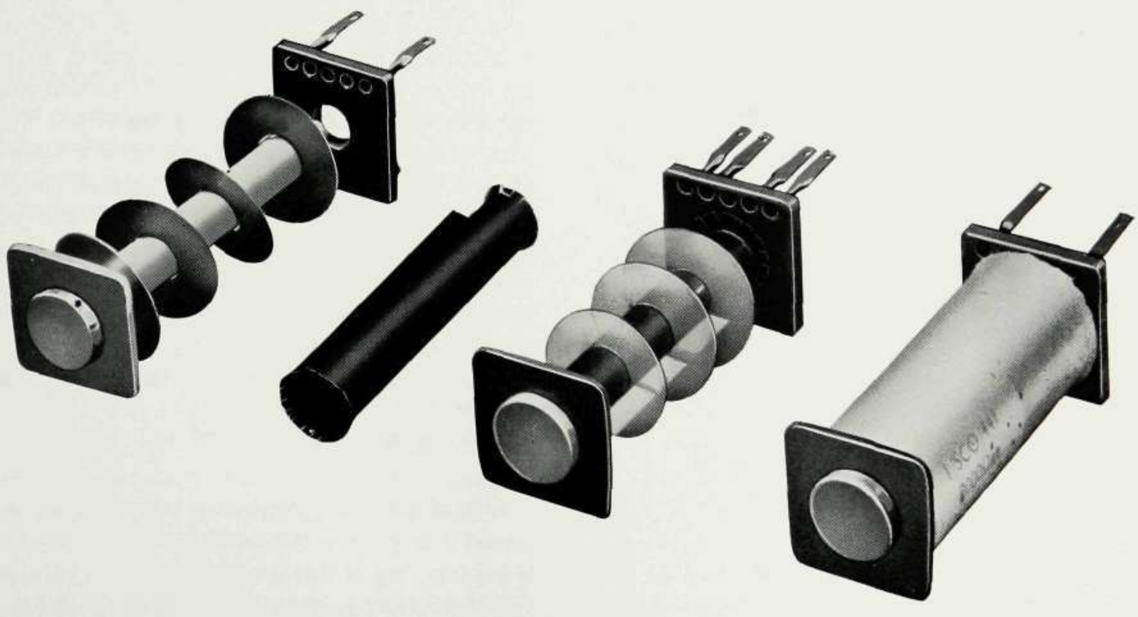


Figure 1—Fabricated construction of 3000-type relay coil former

The term 'fabricated' is applied to the above method of bobbin construction in the sense that one part of the former, i.e. the tube, is in effect built up on the core-iron.

Obviously the bobbin must fulfil a number of other requirements apart from providing winding space for the designed number of turns. Principally these are as follows:—

(*a*) The mechanical strength of the heel-end cheek to be sufficient to withstand the swaging-in of the tags and the staking operation.

(*b*) Satisfactory mechanical resistance to tensile stress (force tending to pull the heel-end cheek off the core-iron) and torque (force tending to rotate the heel-end cheek on the core-iron).

(*c*) The whole bobbin assembly to be dimensionally stable.

(*d*) The insulating material to possess high surface track resistance together with high surface and volume resistance under adverse climatic conditions.

(Surface track resistance and surface resistance are separate properties; for example, a given insulator may show a satisfactorily high value of surface resistance at low voltage but exhibit 'tracking' when the voltage is raised.)

(*e*) A sufficiently high softening temperature in the heel-end cheek material to obviate loosening of the tags during soldering operations.

(*f*) This softening temperature not to fall excessively *under pressure*. This quality does not necessarily accompany (*e*). It is a vital quality, because even light strain on a tag during soldering may set up very high local pressures. It must also be shown to a lesser extent by the rest of the bobbin material, since the winding may exert considerable pressure upon it. With unsatisfactory material in high ambient temperatures this could lead to deformation.

(*g*) A true cylindrical tube shape, without surface irregularities or areas of 'give'.

(*h*) No rotary movement of tags possible when making off the winding ends or external wiring.

The fabricated former shows less than ideal performance in respect of condition (*d*). The weak points are the flexible material of the tube and the imperfect barrier to moisture given by the tube-to-cheek abutment.

There are also shortcomings in respect of the last two conditions. Considering (*g*), a wound-on tube build-up cannot produce a completely uniform component. At best there is some eccentricity and a 'step' over the starting-point of the wind, and in bulk production factors such as skew in the material and inevitable variations in winding tension increase the departure from uniformity. The effect is to produce either over-stressed or loose turns in the overlying winding, the one leading to possible breakage in the finer gauges and the other to displacement of turns out of their proper layers, with consequent danger of shorting. It will be realized that any irregularity in the first layer of a winding 'prints through' the whole bulk.

Considering condition (*h*) there is always a possibility of rotation of tags swaged into circular holes, and to guard against this it has been customary to make off the winding wire on to a thicker flexible lead prior to the tags. The joint causes local stress and disturbance in the windings, and may break or pierce the insulation surrounding it.

A long-term survey, based on examination of faulty coils found in production or recovered from service, shows the above causes as by far the most prominent in producing failure.

Moulded Formers

It is apparent that the disadvantages described are inseparable from the fabricated form of bobbin construction. This was the initial reason for considering replacement of the main components by mouldings.

The immediately apparent advantages were that the sleeve could be made uniform and concentric, permitting a much closer approach to a true layer winding with even wire tension throughout, and that tag rotation could be eliminated since rectangular or specially shaped holes are as easily moulded as round. This would open the possibility of direct termination of winding ends on the tags, avoiding make-off leads and joints. Further, the electrical performance could be improved, particularly with reference to the tube, both by reason of the superior insulation properties of plastics and the more satisfactory tube-to-cheek abutment possible with a moulded construction. Moisture penetration between tube and cheek at the armature end could be eliminated entirely, by moulding this cheek and the tube in one piece.

Ease of moulding was an obvious criterion in the plastic to be used; any difficulty in this respect would be encountered primarily with the tube, which in the 3000-type relay is only 0·18 to 0·20 in. thick, the overall length being 2·5 in.

Figure 2—Moulded construction of 3000-type relay coil former

Melamine Mouldings

Initial trials were made with mouldings in a short-fibre glass-filled melamine. Figure 2 shows the components and assembly of a typical former (3000 type) made from this material. Notable features are the close-fitting recess for the tube in the heel-end cheek, and the groove in this cheek for the inner end of the winding. The advantages of winding on to a smooth concentric tube were at once apparent, a much closer approach to a true layer winding being possible. The tags were swaged into specially shaped holes which prevented any possibility of rotation, and numerous tests including impact and shock proved that direct termination of wires down to ·0032 in. diameter was completely safe and practicable. The majority of coils could thus be directly terminated.

Both of the two principal causes of coil failure had thus been eliminated. After further trials, large-scale production of formers in melamine was commenced, and continued successfully for several years.

Other Materials

During this period of production, further advances in the field of plastics naturally took place. Among promising new materials to appear were those having thermoplastic properties (melamine is thermosetting). Such materials melt on the application of heat and thus lend themselves to a relatively short moulding cycle; the material can be melted in bulk and dispensed to the moulds whereas with thermosetting materials each mould has to be charged ' cold ' and the contents heated up.

A number of the new thermoplastic materials were assessed in the light of the qualities reviewed in the introduction of this article. Among these qualities, adequately high softening temperature seemed likely to be the most difficult to satisfy since the majority of injection moulding materials have softening points well below 140°C, considered the minimum for safe soldering of tags.

The nylon (polyamide) range appeared most promising in this respect, but the softening temperature of commercially available forms was found to fall too rapidly under pressure for these materials to be regarded as the final solution. The torque resistance also was less than adequate.

A number of nylons, including those known by technical descriptions as types 6, 6-10 and 6-6, were assessed during prolonged laboratory and small-scale production tests. All of these nylons were unfilled.

Glass-Filled Nylon

In 1961 this material became commercially available under the technical description ' Maranyl A190 '; its basis was the 6–6 nylon already referred to. The favourable properties of glass-filled nylon had been recognized for some time prior to this, but because of economic considerations its investigation had not been considered worth while.

Table 1 shows the very marked improvement in softening temperature under pressure of Maranyl A190 as compared with unfilled nylons. Table 2, in which glass-filled melamine is included for comparison, shows a similarly marked improvement in torque strength and also a useful gain in tensile strength.

All the measurements in this table were made with the materials assembled into 3000-type bobbins. Some properties of glass-filled and unfilled nylon 6–6 are compared in Table 3.

Initial moulding trials showed that a reasonably rapid cycle could be attained, and that even with the presence of the glass-filler it was practicable to mould a thin-wall tube of the 3000-type without undue difficulty in production. Prototype quantities of tubes and end-cheeks were moulded in the material, assembled, and exhaustively tested as regards mechanical properties, these being entirely satisfactory. Soldering tests on the tags were also carried out, the results again being favourable.

Insulation Tests

Bobbins were tested for insulation between winding and winding, and between winding and core iron under accelerated test conditions. Tropical testing involves exposure to 24-hour cycles consisting of 12 hours at 35 ± 2°C, relative humidity not less than 95%, and a minimum of 5 hours at 20 ± 5°C. The remaining 7 hours (maximum) in each cycle is taken up by the transition from one condition to the other. Thirty such cycles are imposed and on completion the components are placed in a controlled atmosphere of 20 ± 2°C at a relative humidity of 75 ± 2% for the recovery period. Insulation measurements are made at regular intervals throughout the period of test. Figure 3 shows a Maranyl A190 former

Figure 3—Maranyl A 190 former prepared for winding tests

Nylon Type	*Heat Distortion Point °C* 66 p.s.i.	264 p.s.i.
6	146	78
6 — 10	160	55
6 — 6	200	75
Glass Filled 6 — 6 ..	250	245

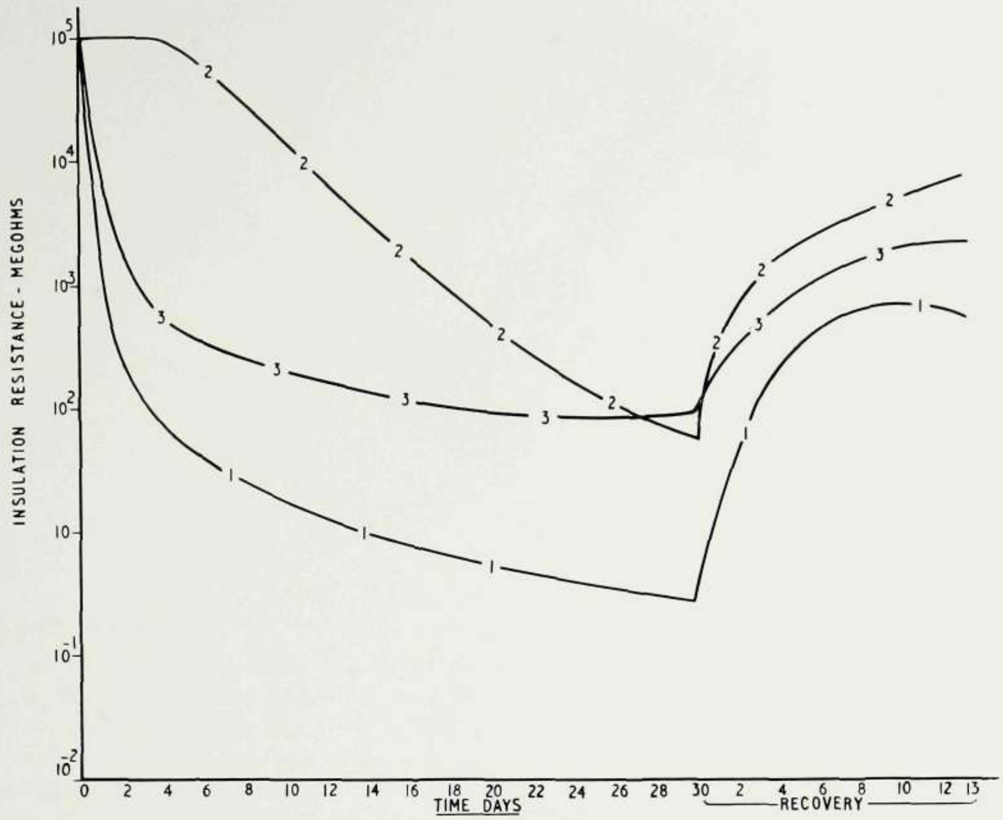
Table 1—Softening temperature of nylons under pressure (Heat distortion point)

Material	*Tensile strength lbs.*	*Torque lb. ins.*
Glass filled Melamine ..	94	10
Nylon 6	151	6·5
Nylon 6 — 10 ..	160	6·5
Nylon 6 — 6	165	7·0
Glass filled nylon 6 — 6	197	23·5

Table 2—The tensile and torque behaviour of various materials when assembled into 3000-type relay bobbins

Property	*Units*	*Glass-filled 6 — 6 Nylon*	*6 — 6 Nylon*
Tensile strength	in/sq. in	23,000	11,500
	kg/cm²	1,600	800
% Elongation at break	—	1 — 2	80 — 100
Impact strength	ft/lb/in	1·3 — 1·8	1·3 — 1·8
	kg.cm/cm	0·71 — 0·95	0·71 — 0·98
% Water Absorption: saturation ..	—	5·6	8·9
% Water Absorption: 24 hr. $\frac{1}{8}$ in. (3·2 mm) disc.	—	0·7	1·5
Coefficient of linear thermal expansion	in/in °F	$1 \cdot 3 \times 10^{-5}$	$5 \cdot 6 \times 10^{-5}$
	cm/cm °C	$2 \cdot 3 \times 10^{-5}$	10×10^{-5}
Volume Resistivity	ohm.cm.	10^{14}	10^{13}

Table 3—Comparison of properties 6-6 nylon and glass-filled 6-6 nylon



(1) Fabricated bobbin **(2) Glass-filled melamine bobbin** **(3) Glass-filled nylon bobbin**

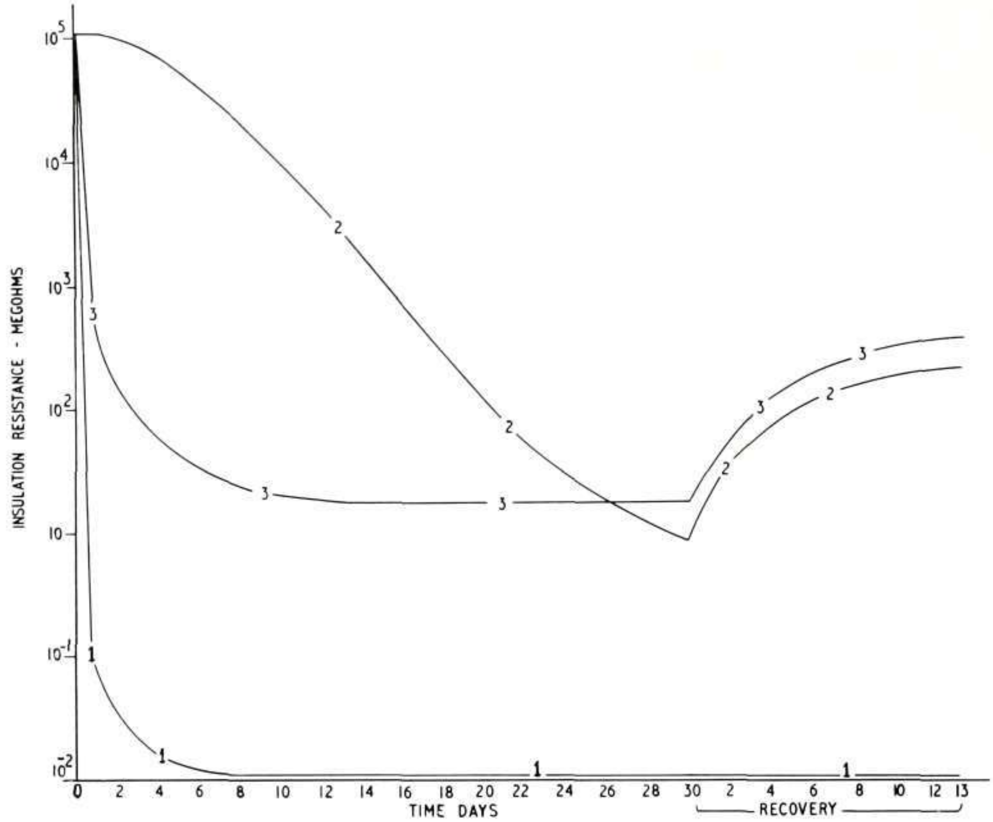
Figure 4—Typical measurements of winding-to-winding insulation resistance under conditions of tropical test

prepared for winding-to-winding tests; each winding consists of two layers of 0·03 in. wire with a $\frac{1}{8}$ in. gap between the windings. Figures 4 and 5 show typical results in tropical testing for winding-to-winding and winding-to-core-iron resistance respectively. Each compares the performance of glass-filled nylon (3), glass-filled melamine (2), and fabricated formers (1). The graphs show that the insulation resistance of glass-filled nylon drops more quickly than that of glass-filled melamine, but after the 30-day exposure both drop to a similar value and follow a similar recovery pattern. The superiority of moulded formers in either of these materials over the fabricated type is particularly emphasized in Figure 5, which shows a drastic and irrevocable loss of performance in the latter type after an exposure of less than 8 days.

Production Advantages of Glass-Filled Nylon

One improvement in the manufacturing process was found possible as a result of a study of the water absorption properties. The heel-end cheeks were subjected to a conditioning process, involving immersion in boiling water for a short period. After immersion the amount of water retained in the moulding is the same as would be absorbed if it were allowed to reach equilibrium with air at a relative humidity of 50%.

This treatment gives a marked gain in flexibility. One immediately valuable result was that a heavier stake could be applied, i.e. an increase of air pressure in the pneumatic device used for the staking operation. A second advantage was that the tube could be made somewhat oversize in length, typically $\frac{1}{16}$ in., so that compression of the tube resulted when the cheek was staked on. The conditioned cheek easily withstood this without risk of fracture and a tighter tube-to-cheek abutment was obtained. The most dramatic benefit however was the reduction, virtually to zero, of the number of bobbins damaged by handling in production. In the 3000-type bobbin construction the heel-end cheek is the only vulnerable component, the other cheek being protected by the flange on the core-iron. Conditioning thus provided a complete answer to the problem of breakages.



(1) **Fabricated bobbin** (2) **Glass-filled melamine bobbin** (3) **Glass-filled nylon bobbin**

Figure 5—Typical measurements of winding-to-core-iron insulation resistance under conditions of tropical test

FIELD TRIALS

With the satisfactory completion of all development testing it was now practicable to consider introducing glass-filled nylon formers into general production. In view of the large output, however, it was deemed necessary to carry out a production trial before finally abandoning mouldings in melamine in favour of nylon. By arrangement with the Engineering Department of the B.P.O.. relays were produced for field trials at two automatic telephone exchanges, namely, Bakewell and Sedgley. Sufficiently large numbers were involved to confirm the economic aspects of nylon formers, and also to establish that they were robust enough to withstand all normal handling. Formers produced from nylon mouldings are now in general production for all relays similar to the P.O. 3000 type.

Figure 6—Coil former of Strip Relay (Type 12)

**Figure 7—
Coil former
of Reed Relay**

Demountable Coils

The successful introduction of glass-filled nylon as a material for coil formers, and improved moulding techniques for thermo-plastics, has made possible a new approach to design of electro-mechanical devices. With conventional relays the core-iron is an integral part of the coil and any coil fault in service has necessitated the removal and replacement of the winding, former and core-iron. A coil former produced in two halves (Figure 6) is strong enough to accept the required windings without the support provided by an integral core-iron. This feature has been incorporated in the design of the Strip Relay, Type 12 (described in Bulletin No. 47), where the core-irons are part of the relay frame. Faulty coils in service are readily replaced and only the winding and coil former have to be discarded.

An alternative design developed for coil formers which is basically two tapered tubes with an interference fit is illustrated in Figure 7. This former is used in reed relays, with the reeds (two leaf contacts enveloped in a glass tube and activated by a magnetic field) contained in the tubular portion.

Conclusion

There is no doubt that the rapid development of thermo-plastics and moulding techniques will offer further possibilities for improvement in design techniques and manufacturing practice. With the advances already on record, the attainable quality in formers and windings is not only much superior to that of ten years ago, but can be realized more conveniently and economically in production.

British Patents Nos. 923,804-5; 49131/63 and corresponding foreign patents

U.D.C.621.395.45.453

Balanced Quad Transmission Systems in Canada

J. ATTEWELL, A.M.I.E.E.—Carrier and H.F. Development Department

A low cost trunk cable system designed to meet the particular requirements of the Sudan has been found to be applicable to similarly sparsely populated areas in Canada. Experience in Canada has led to an extension of the system facilities and suggests further new applications.

ETC 601 systems are replacing open-wire lines as the basis of the main trunk network in the Republic of the Sudan, each providing up to 120 carrier circuits and operating over two ploughed-in polythene single-quad cables. With the successful commissioning of the first scheme, Khartoum-Wad Medani-Sennar,[1] it was realized that, although the system was designed specifically for the Sudan, there were other parts of the world where the problems of the provision of low-cost trunks were similar. One such area, despite obvious differences in climate and terrain, is Northern Canada.

The bulk of Canada's population is concentrated in the extreme south of the country where the population density is such that trunk circuits can be provided

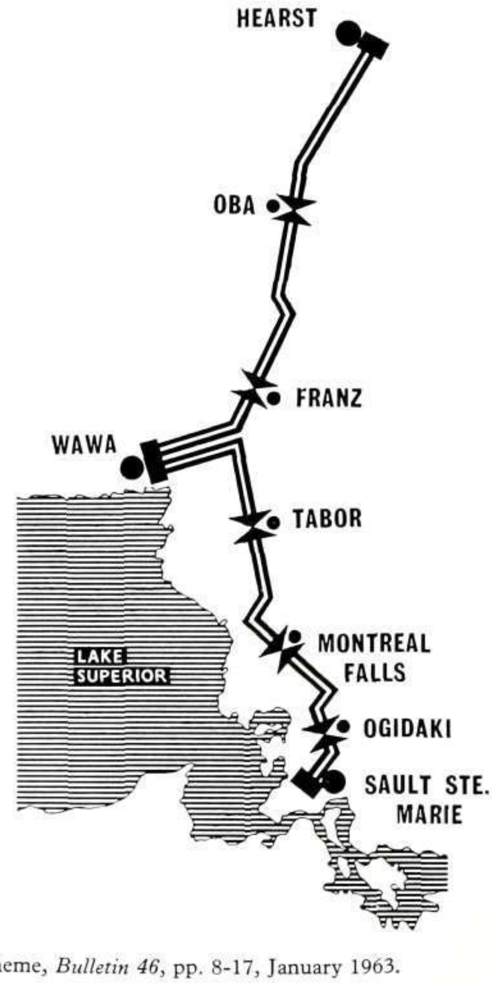


Figure 1—Map showing cable route of Sault Ste. Marie/Hearst scheme

[1]The Khartoum Sennar Cable Scheme, *Bulletin 46*, pp. 8-17, January 1963.

economically by conventional methods such as high-capacity microwave systems. North of this comparatively highly developed belt is a vast sparsely-populated area where, from a trunk-provision point of view, conditions are very similar to those in the Sudan; very long routes with comparatively few circuits required.

The Company has executed several contracts for cable schemes in Canada and in the light of experience gained the ETC 601 system has been modified to some degree, the modifications being incorporated in later equipment supplied to the Sudan P & T Department.

THE SAULT STE. MARIE–HEARST SCHEME

The Sault Ste. Marie–Hearst scheme in Northern Ontario is the largest ETC 601-type installation to date and, apart from a simple 75 mile long scheme between Noranda and Val d'Or in Quebec, was the first balanced cable system in Canada.

The map (see Figure 1) illustrates the cable route. The cables were ploughed into the ballast along the right-of-way of the Algoma Central and Hudson Bay Railway, the plough being part of a self-contained cable-laying train which also included wagons for the cable drums and accommodation for the cable-laying crew (Figure 2). Despite the delays inevitable on a busy single-track line the cable was laid over the whole 350-mile route in three months.

Terminal stations are situated at Sault Ste. Marie, Wawa and Hearst. At Wawa the two terminals are connected back-to-back, with through-group filters being used to make twenty-four circuits available over the whole route. Main repeaters are sited as indicated, those at Ogidaki, Franz and Oba being provided with facilities for circuit extraction.

There are 54 buried repeaters spaced at intervals of approximately six miles along the route. Power for these is fed from Sault Ste. Marie, Montreal Falls, Wawa, Franz and Hearst, and fault-location equipment is installed at Sault Ste. Marie, Montreal Falls, Wawa and Hearst.

There were a number of changes from the original Khartoum–Sennar equipment, the first being occasioned by the fact that the cable physicals were not required for a train control system as they were in the Sudan. This meant that the line filters were unnecessary; they were removed and replaced by line transformers. There were also modifications to the main repeaters, facilities being provided for the addition of blocking filters so that when circuits were

Figure 2—Cable-laying train with plough wagon at rear

Figure 3—North American standard type cable post for connection of successive cable-drum lengths

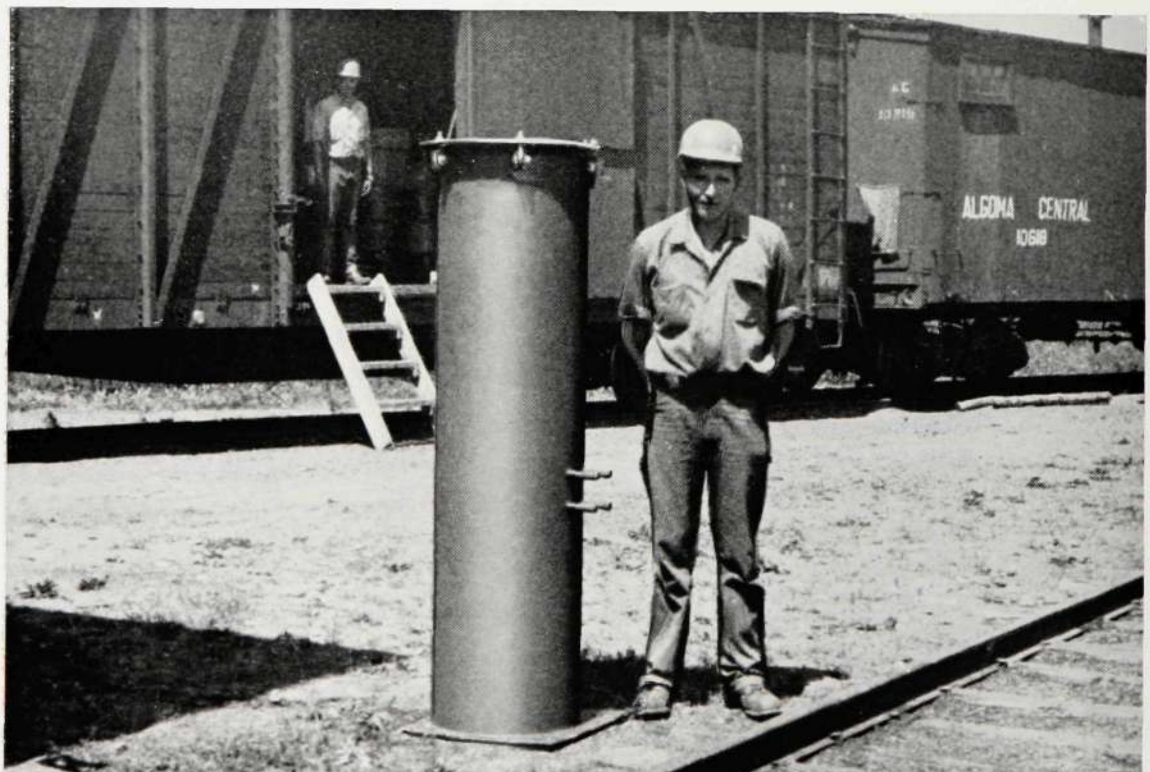


Figure 4—Manhole canister for installation on cable route

dropped from one direction, the same part of the frequency band could be used for circuit dropping from the other direction.

The main changes however were those necessitated by the very different climate. In the Sudan, with the cable buried at a depth of 2 ft., a temperature change of not more than $\pm$ 6°F was encountered; the expected temperature variation of the Sault Ste. Marie–Hearst cable was between 20°F and 65°F. This meant that automatic level regulation became much more important and a variable slope equalizer under the control of the 256 kc/s pilot was added.

In this part of the world the winter cold is intense and the earth is normally frozen to a depth of 4 to 5 ft. This means that in the event of a cable fault it is impossible to dig up the cable, and the Sudan method of an epoxy resin buried joint could not be used. This problem was overcome by use of the North American standard type cable post (see Figure 3) which permitted convenient connection of successive cable lengths. With this equipment the cables are brought up the centre of the hollow post and terminated on a terminal block. Subsequently the terminals and cable ends are enveloped by ' cocooning ' from a plastic spray and added protection is afforded by a weatherproof cover. Because of this terminating method a faulty cable length can be replaced by an interruption cable in the event of a winter cable fault, the interruption cable lying on the surface until such time as the ground thaws and the buried cable can be repaired.

The extremely low air temperatures (—40°F is not uncommon at Hawk Junction) necessitated a more advanced design of manhole canister than the concrete pipe used in the Sudan. The canister employed consisted of a cylindrical metal tube, 20 inches in diameter and six feet long (see Figure 4). Because it is buried with not more than 1 ft. showing above the surface, its bottom is below the frost line and heat is extracted from the ground to provide a comparatively warm column of air which is kept in the manhole by an air-tight lid. A 2 ft. square baseplate is welded to the bottom of the manhole to provide an anchor and so prevent successive freezing and thawing of the surrounding earth from forcing the canister out of the ground. The cable entry is via four short axial tubes halfway up the manhole which are rendered airtight by means of a sealing compound.

In the Sudan the buried-repeater tails were connected to the main cables by an epoxy resin joint. The airtight manhole removed the necessity for this, and connections were made on the open tag strip which can be seen in Figure 5.

Figure 5—Terminating connections on open tag strip during installation of buried repeater

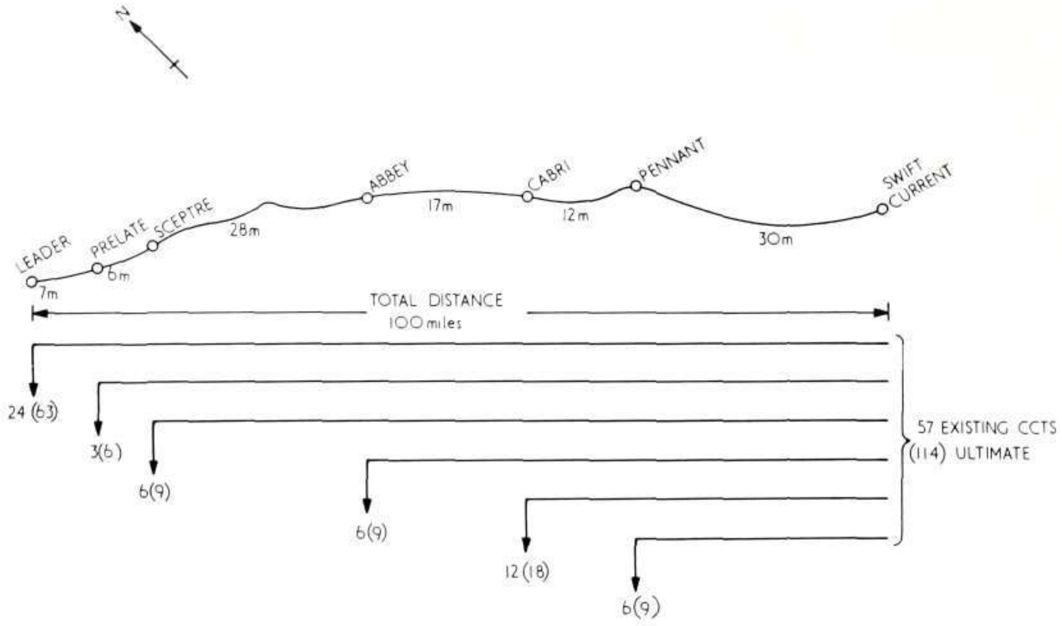


Figure 6—Circuits provided on Leader/Swift Current scheme

Figure 7—Ploughing cables in the highway right-of-way using plough vehicle with caterpillar tracks

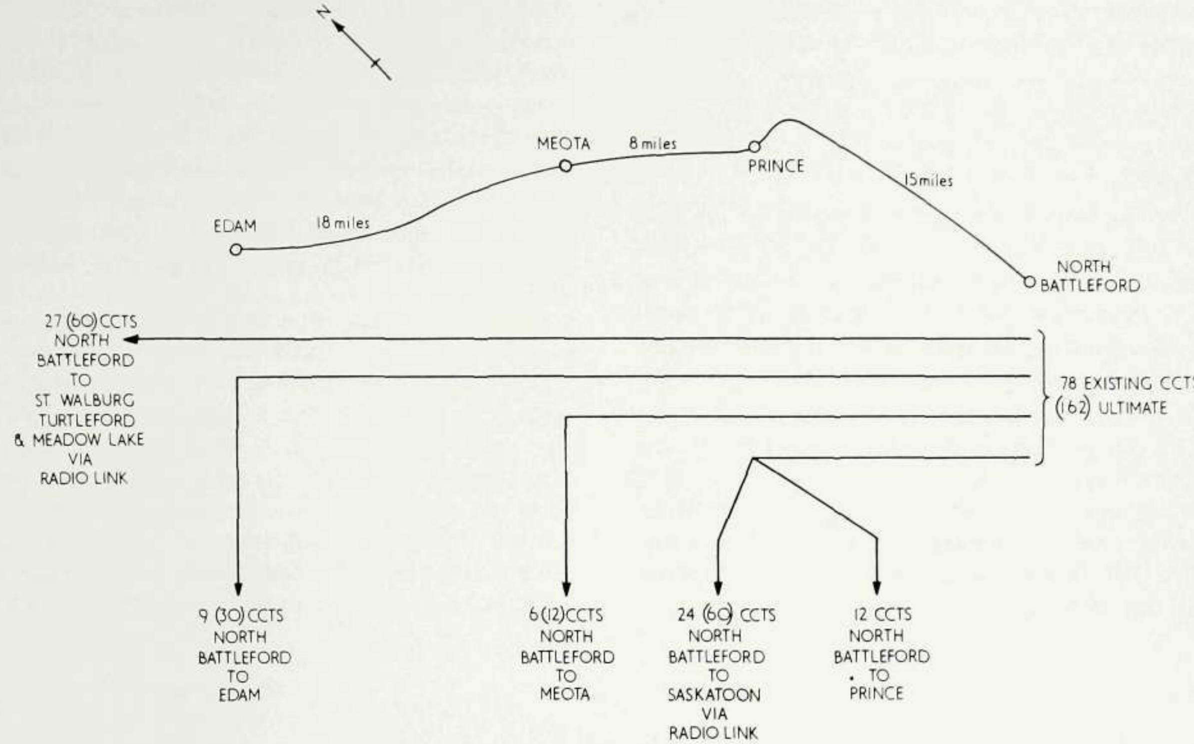


Figure 8—Outline of North Battleford/Edam scheme

The Swift Current–Leader Scheme

In the wheatlands of Saskatchewan there are applications for carrier systems which will provide inexpensive facilities for dropping groups of 12 circuits or less at intervals along a route, rather in the manner of a rural carrier system. The sketch (Figure 6) shows the circuits provided by an ETC 601 system which became operational in October 1964. The cables were ploughed in the highway right-of-way using the caterpillar-tracked vehicle illustrated in Figure 7, the vehicle being equipped with two drums of cable so that two cables could be fed directly to the plough blade.

As on the Sault Ste. Marie–Hearst scheme cable-jointing pedestals were used. The manhole canisters were similar but were a foot deeper and had an improved cable entry aperture. The method of jointing the repeater tails to the main cable inside the manhole was also improved, the open tag strip being replaced by a weatherproof cable-terminating box which also gave facilities for mounting the crosstalk balancing capacitor.

The circuit-dropping racksides installed at the main repeaters are completely self-contained with their own carrier and signalling supplies. These 6 ft. racksides are designated ETG 31, ETG 122 and ETG 123 and used for dropping circuits 10, 11 and 12 of group 5 (12 to 24 kc/s), the 12 circuits of group 4 (60 to 108 kc/s), and 12 circuits of groups 1, 2 or 3 respectively.

Less than half the available circuits are used at present and it is expected that the 100-mile system will be extended in the future by a further 70 miles or so to Golden Prairie. Facilities have also been provided to allow the number of circuits dropped at each main repeater to be increased easily and economically.

The North Battleford–Edam Scheme

The frequency limitations on the use of 40 lb polythene-insulated single-quad cable are largely fixed by the degree of far-end crosstalk attenuation attainable between one pair of the quad and the other. Experience gained in balancing the Swift Current/Leader cable had shown that crosstalk figures of 90 db per mile at 250 kc/s were easily obtainable by the addition of one capacitor only, and in view of this it was decided to carry out further development of the ETC 601 system to double the circuit capacity to 120/240 circuits. This new system, designated ETC 1201, is to be used by Saskatchewan Government Telephones on the North Battleford–Edam Scheme, due to become operational in the autumn of 1965. An outline of this scheme is illustrated in Figure 8.

The frequency spectrum of ETC 1201, re-recommended as the CCITT scheme 4 for a two-supergroup balanced cable system, is illustrated in Figure 9.

The equipment is designed primarily for use over 40 lb/mile polythene-insulated single-quad cables with an attenuation of approximately 8·7 db/mile at the highest transmitted frequency. The fixed equalizer and the amplifier gain give an approximate repeater spacing of 4 miles.

The fault-locating system is similar to that of the ETC 601 system except that the tone band is in a higher frequency range, that is, 15 to 55 kc/s. The fault-locating tones are spaced at 2 kc/s intervals, giving a total of 21 tones against the 16 available on the ETC 601 system; this is necessitated by the closer repeater spacing.

A new feature of the scheme is the use of one of the two phantoms of the ' go ' and ' return ' cables as the bearer of an engineer's order-wire circuit operating between terminals and main repeaters (the other phantom being used for the power feed). An ETL 14 single-channel system is used, suitably modified to work into the low impedance (approximately 75 ohms) of the phantom and to give the extra gain required for the Edam-Meota link (17 miles, approximately 50 db).

Once the possibility of achieving adequate pair-to-pair crosstalk figures is accepted, the two-supergroup system offers other advantages over the 60-circuit system, in addition to the doubling of the ultimate capacity with a comparatively small increase in cost. One of these is that the frequency band used for traffic (60 to 552 kc/s) now covers approximately 3·3 octaves instead of approximately 4·5 octaves. Moreover, the cable impedance is reasonably constant above 60 kc/s, which means that equalization is much

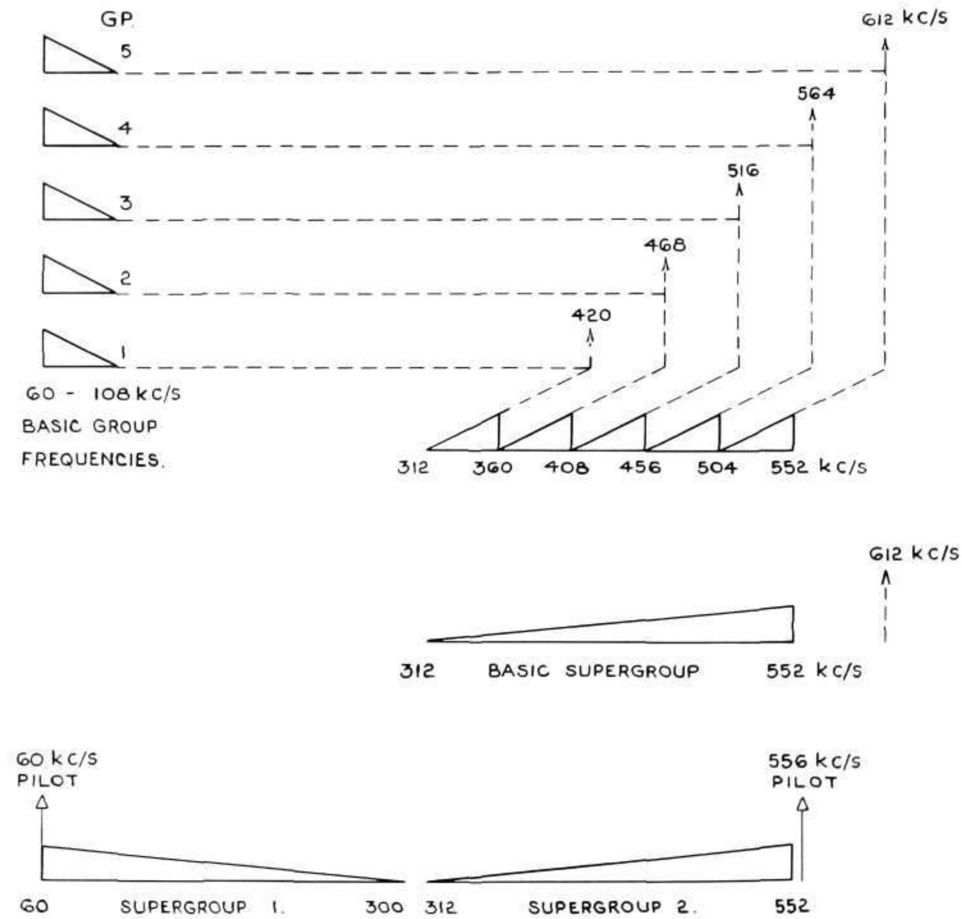


Figure 9—Frequency spectrum of ETC1201 system

easier and correspondingly less 'mopping-up' is required.

The cost of the line equipment for an ETC 1201 system for a given route length is, of course, greater than that for an ETC 601 system owing to the increased number of buried repeaters required. However, this increase is small in relation to the total line cost (in the order of 10% only) because the cable is normally several times more expensive than the repeaters. For a fully equipped system the total line costs could be less than £2 per circuit/mile.

CONCLUSION

The ETC 601 system has proved to be an economical solution to the problem of providing up to 120 long-distance trunks, and the ETC 1201 development promises to be similarly successful where the ultimate requirement of a scheme is up to 240 circuits.

An interesting possibility now under active consideration is the use of modified ETC 1201 equipment over one cable where the ultimate capacity of a link is known not to exceed 60 circuits. Except in the case of a very short link (less than 25 miles), the cost of the actual cable will account for more than half the total line cost of an ETC 601 or ETC 1201 system; very considerable economies could therefore be made if one cable only were used. This could be done simply by transmitting Supergroup 1 in one direction on one pair of the quad, and Supergroup 2 in the other direction on the other pair.

U.D.C.621.395.65 : 182.4

A New Type of Portable Switchboard

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This article describes a portable switchboard of novel design. Composed of separate units it can be quickly assembled and connected on site for use in a variety of situations where telephone service is required at short notice.

IN recent years the holding of conferences in many different parts of the world has been a feature of international and commonwealth affairs. At these times telephone communications, and particularly the provision of additional special lines for delegates and representatives, become an important aspect. To fulfil the conditions demanded in these circumstances, the communications engineers of the Foreign Office asked the Company to consider the development of a switchboard which could be easily dismantled into units of convenient size for despatch by air to any part of the world, to give telecommunication facilities at conferences at short notice. The design of the switchboard had to meet the following conditions:—

Figure 1—Fully assembled switchboards

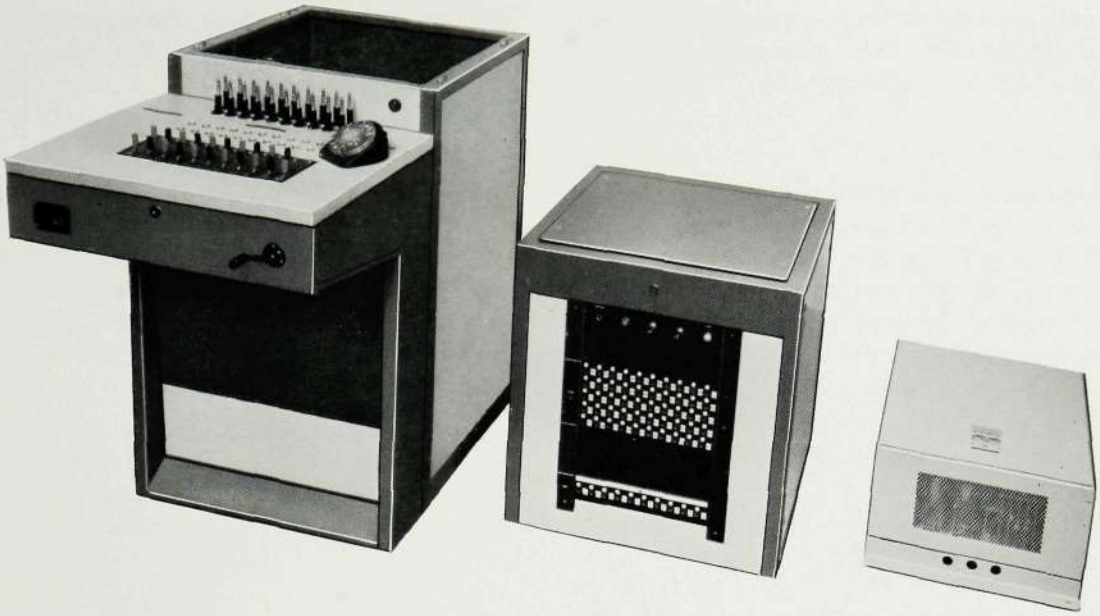

Figure 2—The two separate portions of a single position, together with a battery eliminator

(*a*) No unit should be wider than 1 ft. 9 in. (53 cm) so that when packed in a case, it could be loaded through narrow aircraft doors.

(*b*) Although no limit was set on weight, each unit should be as light as possible.

(*c*) The component units should be easy to assemble with the minimum of interconnection between units.

(*d*) Circuit facilities should be the same as those incorporated in the switchboards normally supplied to the Foreign Office for use in embassies.

(*e*) The switchboard should have capacity for 20 lines to the main exchange and 100 extension lines.

(*f*) The whole switchboard should be robust enough to withstand rough treatment both in use and transit.

It was obvious that the stated number of lines and the circuit requirements could not be accommodated in a one-position switchboard without exceeding the prescribed dimensions. A two-position board was therefore designed, each position normally containing equipment for 10 exchange lines, 50 extension lines and 10 cord circuits, the line equipment being in the upper part, and the cord circuit equipment in the lower part of the board, as shown in Figures 1, 2 and

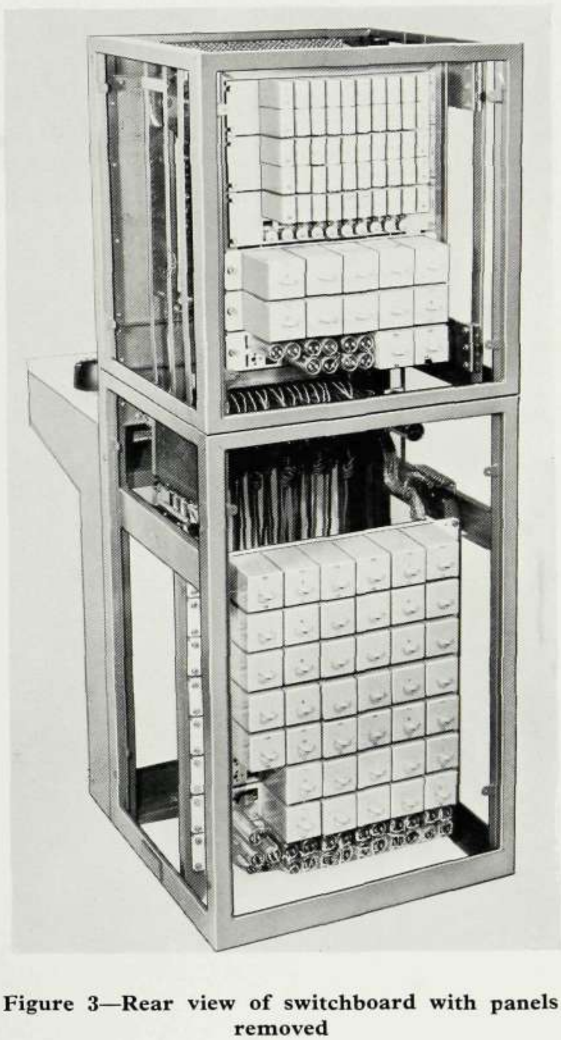

Figure 3—Rear view of switchboard with panels removed

3. Each position is self-contained and could be used independently where the requirements are within its capacity; see under 'Flexibility'.

Framework Design

In order to provide rigid and robust units a welded pressed-steel skeleton is utilized, on to which removable plastic-faced panels are fitted. This arrangement not only makes for easy replacement of panels, if damage occurs, but also affords improved access to equipment for maintenance and adjustment (see Figure 3).

With one relay per extension line and two relays per exchange line, it is necessary to mount the line equipment in the top unit in such a way that access can be gained to both the jack and lamp-strip wiring and the relay equipment. This is achieved by mounting the relay bars on a hinged frame secured by two lock-screws. In this way, the relay frame can be swung out to permit access to the interior of the top unit (see Figure 4). On the lower unit a hinged frame is not necessary because access can be obtained to the wiring by removing the bottom panel and moving aside the cords and weights.

Although the external finish is not of major importance, a durable surface is necessary to minimize damage during operation and handling. For this reason, the ironwork is stove-enamelled elephant grey and the front panel, the key and plug shelf, and the side and rear panels are faced in a buff-coloured hard-wearing plastic. The lower front lift-out panel below the keyshelf is also faced at the bottom with a plastic ' kicking ' strip.

Circuit Facilities

The facilities incorporated in switchboards normally supplied to the Foreign Office for use in embassies are provided in the Portable Switchboard. They include the connecting and supervising of calls between two extensions or between an extension and the main exchange.

If the operator remains in circuit after setting up a call, or enters the circuit during an established call, her presence is indicated by the application of ' ticker tone ' to the line.

On extension-to-exchange calls the equipment is held under the control of the extension loop to provide through clearing.

Calls to the main exchange are made by loop-disconnect pulsing, using a standard dial.

Ringing current can be provided by a ringing machine, hand generator, or transistorized ringing unit.

Audible and visible alarms are provided to indicate when a fuse blows, and coupling facilities are included

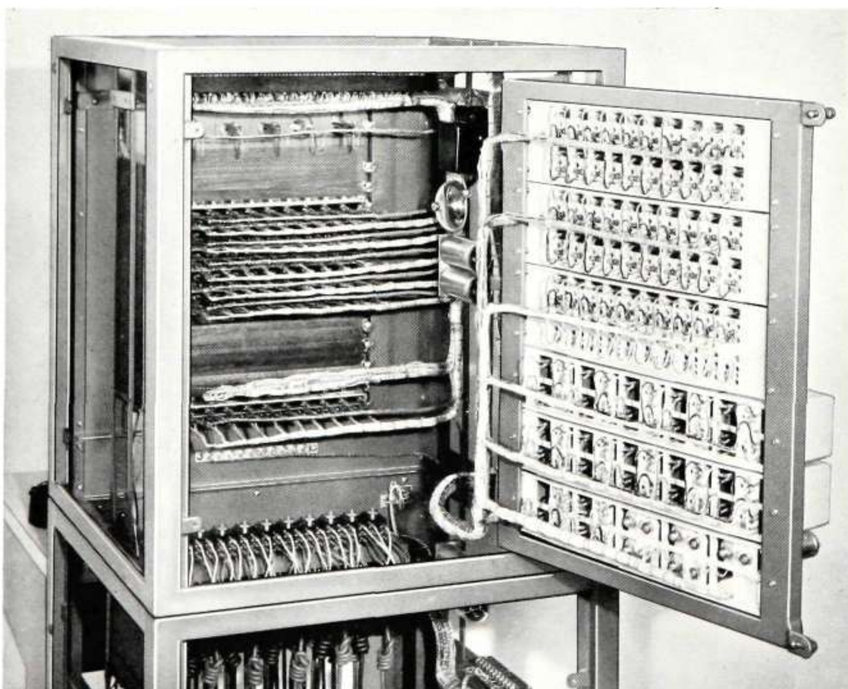

Figure 4—Hinged relay-mounting frame swung out to give access to internal wiring

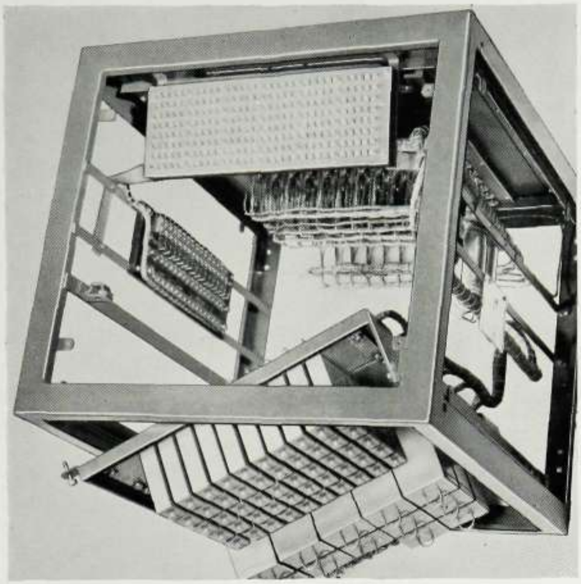

Figure 5—Plan view of upper section of switchboard showing easy access to terminal block

to enable one operator to deal with calls on two positions.

Each cord circuit includes divided battery feed and is arranged to prevent dialling-out on extension lines or ringing-out on exchange lines.

Equipment

To facilitate replacement and interchangeability, standard telephone apparatus is used throughout. All relays except those for extension lines are B.P.O. 3000 type. Extension line relays are B.P.O. 600 type. A transistorized ringing generator is fitted in addition to the hand generator and a transistorized ' ticker tone ' unit provided for the intrusion tone facility. Each section of each position has its own separate fuse panel, thus reducing to three the number of connections between the upper and lower section, i.e. battery, earth and alarm leads.

Connections required between positions are: 7 wires for coupling, 3 for ringing (when an external supply is used), and 2 wires for power. Connection of incoming lines needs to be simple because soldering irons or special tools may not be available. To simplify connection, all the terminals are mounted on a single plastic-faced panel at the top of the upper sections, using screw connections only (see Figure 5). There is ample room for the cable entering at the base of the switchboard to pass vertically through both sections to the terminal panel.

Flexibility

As stated previously, the circuits of the switchboard supplied to the Foreign Office had to conform to those standardized for switchboards installed in embassies. In these circumstances each position has capacity for 10 exchange lines, 50 extension lines and 10 cord circuits, as well as the usual common circuits and 10 auxiliary jacks and lamps which may be used for any special requirements. However, the flexibility of the equipment mounting arrangements makes possible the accommodation of almost any type of circuit, and where this is of simple design, the capacity for extension lines may be increased to 100 per position, although the maximum number of exchange lines and cord circuits remains at 10.

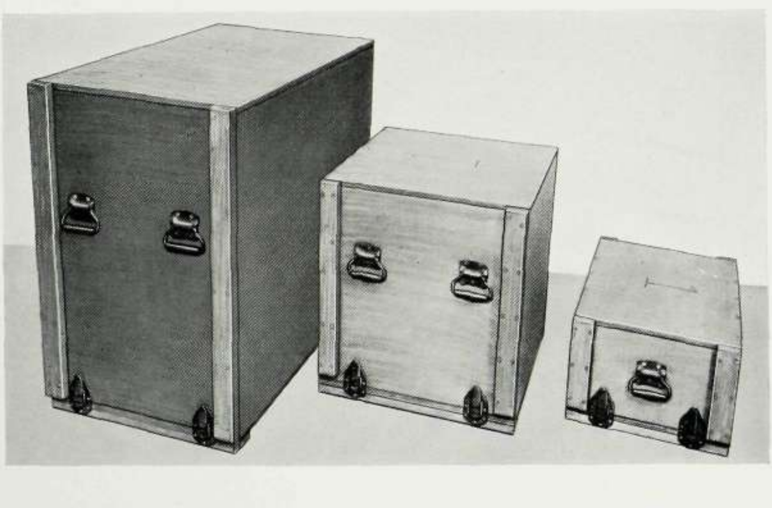

Figure 6—Packing cases for the two sections of the switchboard and the battery eliminator

The circuit flexibility, convenience for transport and ease of installation of this switchboard renders it suitable for a variety of applications such as building sites exhibitions, agricultural or similar outdoor shows of a temporary nature. Its use to meet emergency conditions of various kinds can also be envisaged. In such conditions the convenience for transportation by air in containers of the type designed by the Foreign office and shown in Fig. 6 is particularly advantageous.

Power

The switchboard is designed in its present form to operate from 24-volts d.c. although, of course, circuits operating from 50-volts d.c. could be provided. The most convenient power source in both cases is a mains-operated battery eliminator, but any method of obtaining a 24- or 50-volt d.c. supply could be utilized. The busy-hour load per position will depend upon the circuit employed and in the case of the type supplied to the Foreign Office is 2 amps.

Acknowledgment

The author is indebted to the communications engineers of the Foreign Office for help in the preparation of the article and for permission to reproduce the photographs.

U.D.C.621.387

Cold Cathode Display Tubes

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This article outlines the principle of operation of Digitron display tubes, and the main problems overcome in design. Satisfactory read-out up to 30 feet is possible in any ambient light level other than direct sunlight. Life expectancies of the order of 30,000 hours are now typical.

ONE of the more marked trends in current instrument technology is that towards the digital presentation of readings. In part this is no more than symptomatic of the fact that counting processes play an increasingly important part in instrumentation generally. Potential applications of digital display however go beyond this field; there is a growing recognition that the traditional scale-and-pointer is not always the most practical, elegant, or easily read-out means of presenting many other types of information. The main advantage of digital indication is obvious; the user is relieved of the need to decide 'what is the least significant scale increment?'. In effect the responsibility for this decision is taken once and for all by the instrument designer. From both operating and visual considerations it is advantageous if the display characters are of self-luminous type and of low power consumption. Cold cathode tubes recommend themselves both for these reasons and because they are reliable and long-lived devices, simple in construction and capable of a good conversion efficiency into the visual spectrum.

These advantages have been fully exploited, as the outcome of some five years' development, in the current range of Digitron* display tubes. The design of these tubes is based on the principle that at certain values of gas pressure the visible discharge in a cold cathode tube can be made to 'hug' the cathode surface closely; luminous digits can be formed simply by bending wire electrodes into the required form and applying a suitable voltage between the wanted digit and a common anode placed out of the line of view. The relatively narrow, sharply defined stroke width of the glowing character makes the best use of the available light output, giving good background contrast and maximum legibility when reading the display at a distance.

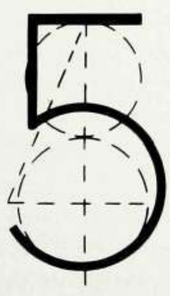
Build-up of Digits

Figure 1(a) shows the method of assembly of a complete Digitron in diagrammatic form. The wire digits are stacked one behind the other in a common enclosure, separate leads being brought out from each digit and from the anode (not shown).

Although this is the type of assembly in widest use it does not, of course, represent the only way of mounting a display. Figure 1(b) shows an alternative type of Digitron in which a matrix of cathodes is employed to build-up the desired digit. A coplanar display is obtained but at the expense of aesthetic appearance in the digits and more complicated switching. This is an earlier type in point of development; at the time of its introduction, switching problems in fact restricted its use to a few specialized

*Registered Trade Mark

(a)



(b)

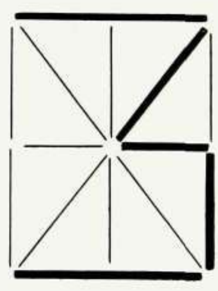


Figure 1—(a) Method of assembly of complete Digitron
(b) Alternative type of Digitron using a matrix of cathodes to build up the desired digit

applications. Recent advances in decoding circuitry however have given the design a much wider potential field of application.

Operating principles and problems in construction are closely similar in both types and for this reason subsequent description is confined to the stacked Digitron. It will be seen that its one apparent disadvantage, namely the non-coplanar nature of the display, can largely be offset by suitable design.

PHYSICS OF GLOW DISCHARGE

Each digit forms with the common anode a simple gas diode, capable of supporting a discharge when individually switched to the supply voltage. As the voltage across such a diode is increased from a low value (Figure 2) the current drawn is initially due to ionization of the gas by external agencies such as cosmic rays and trace radioactivity in the tube material and surroundings. With a further increase of voltage, two other effects arise; electrons accelerated towards the anode acquire sufficient energy to ionize gas atoms by collision, and the positive ions so formed bombard the cathode, producing further electrons still.

This non-ohmic increase of current continues until the 'striking' voltage V_s is reached, when the discharge becomes self-sustaining, that is, independent of the initial ionization in the tube. At the same time, space-charge effects cause a marked distortion of the potential gradient along the cathode-anode path. Much of the potential drop now occurs close to the cathode in the 'cathode fall' region, and the discharge becomes visible at the outer boundary of this region as the cathode glow.

Glow is the result of excitation of gas atoms by electron impact in a range of velocities lower than that required for ionization. In the near-uniform potential gradient before striking, most electrons reach ionizing velocity before collision occurs, and the discharge is therefore 'dark', though this is a relative term. Ionizing collisions likewise predominate in the cathode fall region after striking, but now the electrons, slowed by collision, emerge into the boundary layer where there is a much lower potential gradient. The majority are unable to regain ionizing velocity before new collisions occur and excitation therefore predominates. The depth of the visible glow in the boundary layer is an inverse function of gas pressure; the area of cathode surface covered by the flow depends on the current in the discharge.

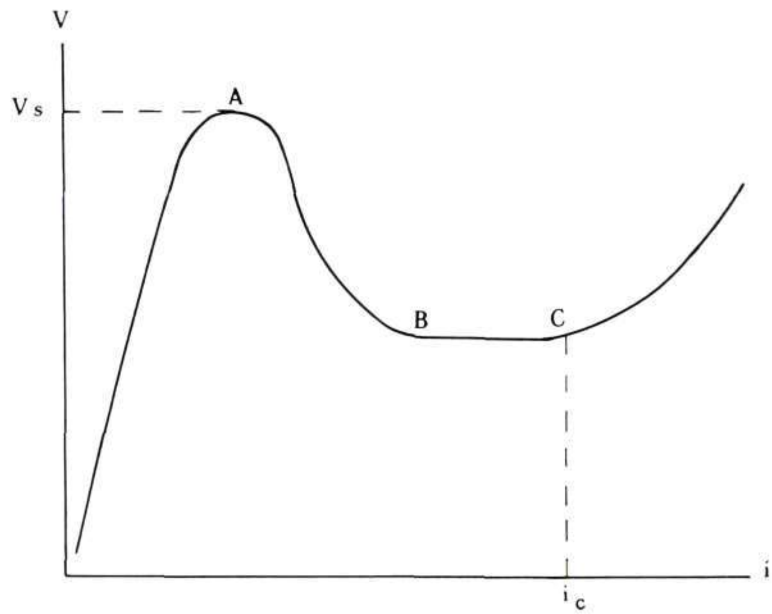


Figure 2—Glow discharge voltage/current characteristics

At point A in Figure 2 this area is minute and a considerable proportion of ions is lost out of the cross-section by diffusion. At point B an appreciable area is covered and the loss-proportion is much less. A steady state can therefore be maintained at a lower rate of ion-production and the voltage correspondingly falls to V_m, the maintaining voltage.

Between B and C the voltage remains constant at V_m and the discharge area increased linearly with current until at C the whole cathode is invested with glow. The current i_c at this point is thus the minimum for satisfactory display. However, as indicated in Figure 3, the actual rated minimum (i_{min}) is somewhat higher than the i_c value to allow for changes in cathode characteristics in operation due to erosion by sputtering, or the deposition of sputtered material from other cathodes.

An increase of current beyond i_c can only be obtained by raising the current density in the discharge. Ionization efficiency falls as a result, and the voltage necessary to maintain a steady state correspondingly rises. A limit is reached when the applied voltage reaches V_{md}, the maintaining voltage of the digit connecting wire or pin-end, and the discharge spreads to these. However a lower limit (i_{max}) is set in practice because of the increasing rate of sputtering (proportional to a power of the current) and of heat generation, which may lead to the release of contaminant from the tube materials and the distortion of digits.

The term ' cold cathode ' is only a relative one; temperatures of 400–500°C have been observed in certain highly-rated tubes and 200°C may be regarded as normal in digitron application. This, with a 1 in. high digit would give rise to a bowing of 0·025 in. towards the next digit if the ends were held fixed and distortion could not take place in the plane of the digit. Tube construction should therefore impose minimum restraint on the free expansion of digits.

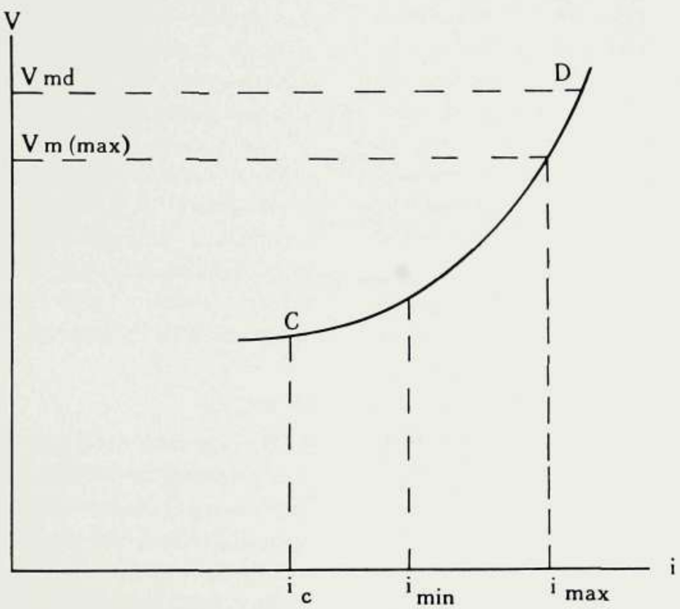


Figure 3—Operating current limits

Visual and Mechanical Considerations

Gas Filling

With the exception of a trace additive to be referred to later the choice of tube filling is for obvious reasons confined to inert gases. Of those available, neon has a spectral emission nearest to the region of maximum visual stimulus. The addition of a small percentage of argon increases the ionization efficiency and substantially reduces the values of V_s and V_m without appreciably affecting the spectral content; such a reduction is particularly valuable in view of the possibility of series operation of digitrons by other cold cathode devices.

Cathode and Glow Width

Cathode width is limited by the need to minimize the obscuring of glowing by non-glowing digits. A width of 0·01 in. (0·25 mm) is chosen, this being found sufficiently small to render the dark areas, where digits cross, almost invisible at normal viewing distances. The coincidence of whole segments of digits, in any direction within the angular field of view, must of course be avoided. It is possible to achieve this by minor changes in digit shape without sacrifice of appearance.

Glow width is restricted by the two complementary considerations of total light output and contrast in high ambient lighting levels. Practically, light output falls as the width is increased, because to achieve this increase the gas pressure must be reduced; i_c becomes less and with it the permissible input to the tube. The compact, bright display is therefore to be preferred from both considerations. The glow width adopted is a comfortable optimum for the range of viewing distances intended, a typical value being 0·045 in. (1·2 mm).

Numeral Proportions

A study of the type faces and letter-spacings used in printing will show that a wide variety of proportions is acceptable from the aesthetic point of view, and a similar choice is available in the design of luminous display digits. Where legibility is considered alone there is an even greater freedom, for printed characters not being self luminous must rely on a considerably greater stroke-thickness to achieve contrast with the background; this to some extent dictates permissible character proportions and spacing.

Figure 4 shows numerals having principal dimensions and spacing around the average of those used in printing. H/W is 1·5, T/H is 0·14 and C/W ranges from approximately 1·1 to 1·3. With digitron characters T/H is of the order 0·05 and H/W can range from 1 to 2 or more without loss of legibility at maximum viewing distance. It is thus possible to set aside other considerations at the outset and adopt values of H and W which make the best use of the available glass envelope, in the confidence that only small modifications of shape will then be necessary to obtain a good aesthetic balance. The optimum value

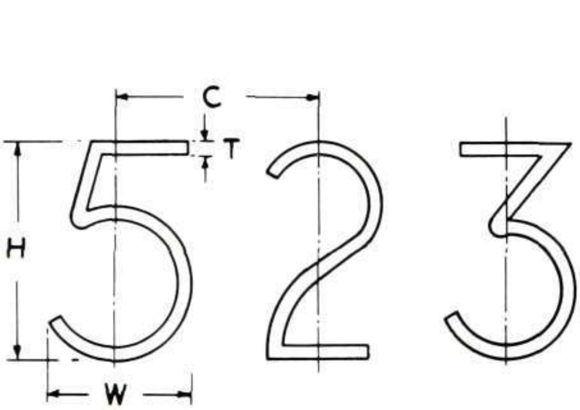


Figure 4—Numeral proportions

of C/W is generally the lowest obtainable, i.e. with the tube envelopes in contact; this however must be consistent with a reasonable viewing angle.

Considerations of availability and cost at present narrow the choice of envelope to the cylindrical type, as widely used in the tube industry, having a pin base at one end with or without a seal-off pip at the other. These two types are employed for side and end viewing as illustrated in Figure 5. In both designs it is necessary to ensure that the portion of the envelope through which the digits are viewed is free from noticeable distortion. The usual mass-produced envelope is satisfactory in this respect for side-viewing use, but some care in manufacture is necessary where the display is to be end-viewed.

A viewing angle of about 25° from square is the most that is required in normal use, and up to this angle serious foreshortening will not be evident even with the side-viewing tube. The angular limit is reached when portions of digits are cut off by the intrusion of adjacent envelopes into the line of sight, digits at the rear of the stack being affected first. The cut-off angle is increased by making the stack as shallow as possible and by mounting it as far forward as the construction permits, although there is an obvious limit to the useful extent of this with the side-viewing tube. Unusually wide angles of view can be accommodated by separating the tubes appropriately.

Operation

The common anode is connected to a source of voltage somewhat higher than V_s and sufficient series resistance included to limit the current to the correct operating value. The regulation of the supply should be such that the voltage is at all times within the two limits defined by i_{max} and the striking voltage.

The simplest means of selectively illuminating digits is by normally open switches in each cathode lead. A more convenient method for use in conjunction with counting and logic circuitry is to place a fixed positive bias on all the cathodes and arrange for an opposing bias to be delivered selectively to the cathode required to be lit. A disadvantage however is that a proportion of the current which should flow to this cathode is diverted as leakage currents to neighbouring cathodes; this may lead to degradation of the display. Leakage can be reduced by raising the gas pressure or increasing the stack separation, but both are undesirable; the first because i_c and hence the sputtering rate is also raised, the second from viewing considerations. The remaining variable is the bias. A sufficiently high bias to give complete 'cut-off' of unwanted cathodes however would be incompatible with the external

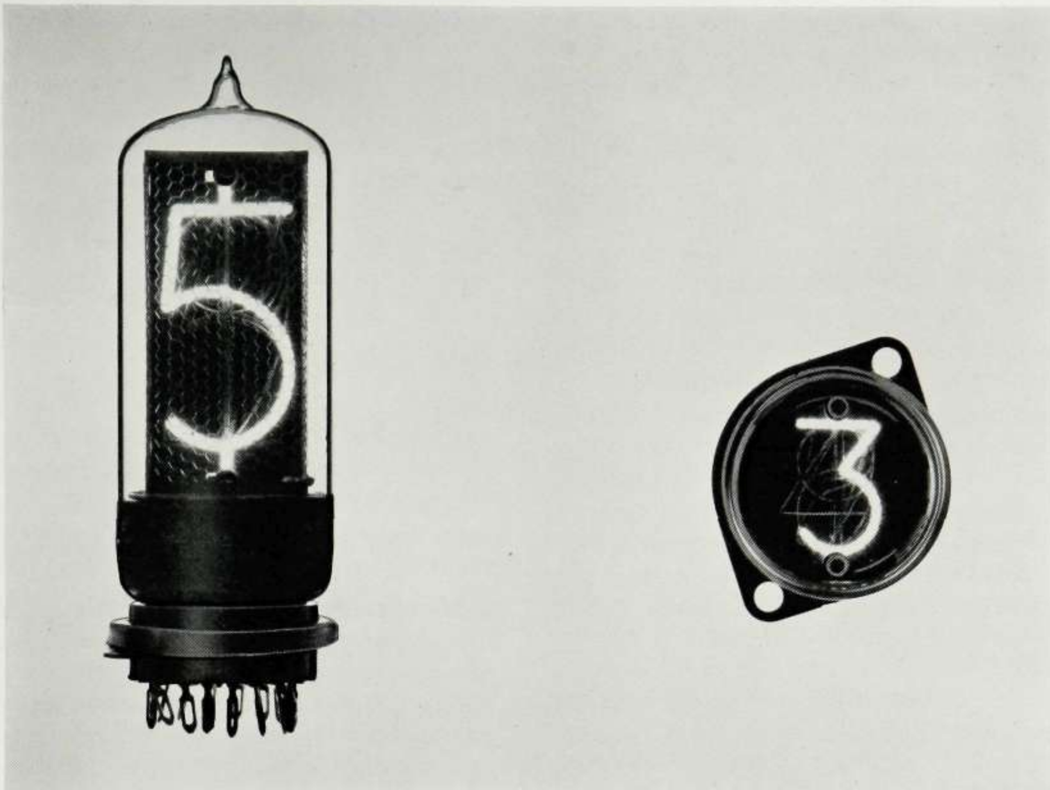


Figure 5—Side-viewing and end-viewing tubes

circuitry, so that some compromise is necessary. It is found that a leakage of between 5% and 20%, depending on the distribution to unlit cathodes, is tolerable, and this can be achieved with a bias of about 60 volts.

Leakage can be further reduced, though at the expense of some ancillary equipment, by providing a pulsed supply to the display. The improvement is due to the fact that leakage takes place by positive-ion diffusion, slow in build-up compared with the main discharge. Either half-wave 50 c/s pulses or square pulses of about 100 μs duration at 1 kp/s have been found suitable.

The negative bias step required to illuminate a digit may be obtained by direct connection to the anode of a trigger tube in, for instance, a ring counter. Transistors capable of giving the required output are now becoming lower in cost, and it is therefore possible to visualize the use of digitrons in otherwise wholly solid-state circuits. Operation is also possible under control of any Dekatron-type selector counter by the interposition of cold-cathode trigger tubes. A type of Dekatron capable of operating a display by direct connection has now been developed and is described elsewhere.[1]

LIFE EXPECTATION

As with any other electrical component, eventual failure in a display may be either catastrophic, or may take the form of a drift in characteristics outside acceptable limits, i.e. relative failure. Catastrophic failure due to weld or envelope defects has been virtually eliminated by careful control of manufacturing processes; the only significant potential cause remaining is the complete erosion of cathodes by sputtering. In the earlier forms of display tube it was possible for this to occur, if the discharge rested on a cathode continuously, in some 1,500 hours.

It was later discovered that the introduction of a small amount of mercury into the filling had a strong inhibiting effect on sputtering, increasing the total-erosion life of a cathode in continuous operation to

[1] 'A New Dekatron for Direct Operation of Digitrons', *Electronic Engineering*, June 1962, pp. 372-376.

some 10,000 hours. This additive is now standard; its only disadvantage being the presence of a slight bluish background haze in the display, an effect which can be removed by optical filtering.

The principal cause of relative failure for a tube operated within the i_{max} rating is the transfer of sputtered material from glowing to non-glowing cathodes, which can result in unevenness of glow when the latter are energized. However a proportion at least of this sputtered material will then be removed again, so that the importance of the effect will depend on the duty cycle of the individual cathodes.

An assessment of the relative incidence of the two types of failure shows that under typical operating conditions an average life of more than 30,000 hours may be expected, provided that tubes are operated within the rated i_{max}. If useful life is terminated by relative failure, deterioration will be gradual and replacement can be deferred until convenient.

Filters

The contrast between the glowing digit and the background may be improved by the use of a suitable filter, this also serving to remove the mercury haze. The origin of the improvement is twofold; ambient light has to pass twice through the filter but light from the display only once, and the latter, being near-monochromatic, is absorbed much less strongly. A simple red or amber filter is effective and its density may be chosen according to the prevailing level of ambient light. Polarizing material is advantageous because reflection is principally from the tube envelope.

Conclusion

The potential application of the Digitron is perhaps best indicated by reviewing the limitations on its use, of which only two are significant; a viewing distance at present not exceeding about 30 feet (for the largest size) and an ambient lighting level excluding direct sunlight.

Apart from direct qualities such as its very favourable life expectation, low cost and maximum legibility, an added recommendation of the Digitron is that a variety of simple, non-critical types of circuitry may be used for its operation.

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Industrial Design

J. E. Blackwell, A.I.B.D.—Industrial Design Engineering Department

Industrial design—sometimes referred to as the bridge between technical design and the customer—plays a significant role in the development of subscribers' apparatus. The author surveys some aspects of his work in this field, with particular reference to telephones and switchboards.

BEFORE the introduction of any new product to the public there must be a complex and often protracted process of research, planning and development. The industrial designer's influence is vital at all stages of this process since he must not only make the outward form of the product attractive to the eventual user but achieve a logical relationship between form and function.

Ideally, when the function has reached perfection, the form is beyond criticism, but only few objects such as the ball and the wheel and perhaps the ploughshare, have attained such excellence. In general, extreme simplicity of design is not feasible; many components are needed for the function, and these must be integrated with a form that is both practical and pleasing. The conviction of the 'rightness' of a finished design for public release is backed by the designer's intuition, resulting from long experience, a recognition of engineering problems, understanding of product usage, an awareness of public taste and, lastly, a sense of timing.

Design Philosophy

The field of telecommunications, as typified by the activities of this Company, affords considerable scope to the industrial designer, particularly in relation to subscribers' apparatus. This is the generic name for all the apparatus seen and handled by the public, and comprises such items as telephone instruments, standard or amplified handsets, PAX cordless cabinets, PMBX and PABX switchboards, dials, keys, plugs and so on. Since these items are complementary to the vast hidden network of automatic exchanges, transmission systems and line equipment that constitutes the public communications network, they have comparable long-life expectation. Because of this the industrial designer is presented with the challenge to achieve a design that will remain aesthetically acceptable to the user for as great a proportion of this service life as possible. He strives, therefore, not merely for acceptance of the design at the point of sale, but acceptance in subsequent use.

To appreciate the extent of his task it must be borne in mind that subscribers' apparatus is almost constantly in sight of the user and is critically appraised in relation to other equipment and furnishings in home or office. The successful design therefore is one that fulfils as far as possible two separate conditions. Firstly, it must be a sufficiently effective common denominator of the best in design trends elsewhere to achieve compatibility with other equipment; secondly, it must establish a design-idiom not only original enough to connect it with a particular manufacturer but sufficiently tractable to link a particular family of products. The fulfilment of these conditions in present-day subscriber-apparatus design represents a complete departure from the past, when apparatus was to be tolerated for its utility, provided that it was unobtrusive or could be installed where appearance did not matter.

This revised attitude to a whole class of technical products has no exact parallel elsewhere and could not have been brought about by designers working in isolation. It is the result of a permeation throughout this industry of a conscious design philosophy, one largely formulated and sustained by this Company. It may be summarized as a search for 'presentability', defined as a compound of the aesthetic and practical qualities that a highly representative body such as the Council of Industrial Design[1] would itself prescribe.

Design Procedure

The procedure in preparing any new design usually takes the same characteristic form, the designer collecting his brief at an initial meeting between engineers, chemists, sales and marketing representatives and possibly production engineers. The designer will commence by producing many varied ideas in rough sketch form, in a number of different media, in order that one avenue of thought can finally be decided upon. From these initial roughs, one or two of the more pleasing forms will be rendered, often in colour so that a more finished visual may be shown to the other persons involved in the design project. After this,

[1]Several examples of the Company's work in the subscriber-apparatus field have been accepted for the design index of the Council of Industrial Design.

further meetings with engineers, sales representatives, etc., take place. The finalized concept, which may possibly be a composite one based on the one or two visuals shown to the interested parties, will be then produced in three-dimensional form. Usually these initial block models are produced in wood and finished to represent the actual material visualized for the ultimate production model. From this point forward, once the design concept has been given management approval, the industrial designer and the mechanical and electrical engineers co-operate to provide the initial working prototype, and finally the production model.

As regards subscriber equipment, requirements in design fall under a number of headings, broadly similar whatever the purpose of the equipment. A review of details under these headings as they affect the telephone is of interest, since this instrument confronts by far the greatest number of non-specialist users.

Functional

Best defined as the ability to give the lowest ratio; time spent manipulating/time usefully employed. Good design reduces this mainly by eliminating points at which misoperation can occur.

Ergonomics

With a telephone the primary consideration is the handset which must be designed to suit the modal distance of the average user, i.e. the distance from ear to mouth and the cheekbone clearance. Correct shape of the handle section is also important to ensure stability in the cradle as well as in the hand.

Among other points for consideration are the position of the carrying handle, legibility of dial markings, push-button shapes and spacings.

Mechanism, Controls, Components

Although perfection in the mechanism, controls and components is largely the concern of the apparatus engineer he must confer with the designer in deciding how they are to be related to the design as a whole.

Construction

This covers factors such as the ability to withstand the maximum amount of rough usage the instrument is likely to meet over the whole period of its expected service life. Particular attention is necessary to vulnerable points such as the case fixing points and cradle area.

Figure 1—Switchboard in laminated plastic

Figure 2—Switchboard with replaceable panels

Resistance to rough usage has been increased in one version of the Etelphone by arranging for the casework and main circuit board to be complementary parts of an internally braced, virtually shock-proof system. In this design, the circuit board, which also carries the dial, is retained in place by the downward pressure of the case and can be detached from the instrument in a few moments.

In other subscribers' apparatus, maintenance is similarly assisted by one-piece cover construction with simplified fixings, but optimum access to individual components is a matter for joint study by the designer and apparatus engineer.

Production

In the past the decision to enter production of a new design often depended ultimately on how far it would make use of existing materials and machines. Few fundamental advances however can be interpreted in production without some breakaway in technique. An example was the adoption of new forms of plastics, specially developed by the plastics industry, and of new moulding methods in the production of the B.P.O.-adopted 706 telephone (Etelphone). These materials and methods were however to prove indispensable to a whole range of other manufactures. General advances of this nature derive much of their initial momentum from the influence of the designer, and his confidence in the projected design.

Evolution of a Design

The current range of cordless switchboards, including the BPO-adopted 2 + 6, 3 + 12 and 4 + 18 were developed as the culmination of a series of design studies over the preceding decade. These adequately illustrate the evolutionary pattern underlying subscriber equipment in general, both by reason of the extreme contrast between the starting and end-points, and the well-defined relationship, evident at each stage, between external form and available materials and manufacturing techniques.

The initial stage was confined to an attempt to improve the external appearance and wear-resistance of the traditional form of cordless switchboard by facing it with plastic laminates. At this time such laminates (thermo-setting melamine-faced materials) were being used on an increasing scale in the interior decoration of buildings and in the construction of furniture. They were available in a variety of attractive colours and designs and possessed great durability and hardness. In such a context the switchboard (Figure 1) gained in compatibility with its

Figure 3—Switchboard of composite form, with miniature keys and indicators

Figure 4—A 2+6 desk-top cordless switchboard—one of a new family (Figs. 4, 5 and 6) having one-piece injection-moulded covers

surroundings but it remained an interim design. The traditional effect, inseparable from the underlying wooden construction, had not been modified.

At this stage the dominant possibilities of the new plastics, namely to liberate design altogether from the limitations imposed by woodworking techniques, had still to be fully explored. Valuable experience was however gained, this proving useful to the design of larger floor-pattern switchboards.

A further step, still within the constraints of the traditional shape, was to provide moulded corner sections which provided protection and enabled the laminate panels to be individually exchanged or replaced if required (Figure 2). The only attempt to advance the styling at this stage was in a few variants with sloping front panels.

It was clear that the only way to a more sophisticated outline lay in shedding the wooden substrate, the necessary strength and rigidity being conferred instead by a metal framework. This would mount the majority of components and give adequate support to the casework, which should be in as few separate parts as manufacturing techniques permitted.

Reference to Figures 1 or 2 shows that two features of the earlier switchboards (the keys and indicators) could not possibly have fitted aesthetically into a unified contemporary design. Consequently, the development around the mid 50's of miniature wedge-handle keys and miniature indicators was a timely and essential contribution to further progress.

The first of the new designs is shown in Figure 3. Among novel features of the equipment was a hinged chassis surmounting a cast aluminium base and mounting keys, indicators and other components. The cover was a composite four-part construction, the ends being compression mouldings of plastic and the transverse plates of enamelled metal. Whilst this arrangement offered the possibility of economic maintenance in that individual sections of the cover could be separately replaced, if necessary, the appearance was less unified than would be given by a one-piece cover construction. It was not however economically possible at the time to produce such a cover using existing compression-forming techniques.

Figure 5—3+12 Switchboard with one-piece cover

Reasonable quantities of this switchboard were produced, mainly for export, experience confirming both the soundness of the new engineering techniques and the acceptability of a design idiom based on similar construction and overall visual effect.

With the introduction of thermo-plastics and vacuum-forming techniques the designer was at last able to experiment with different shapes of moulding

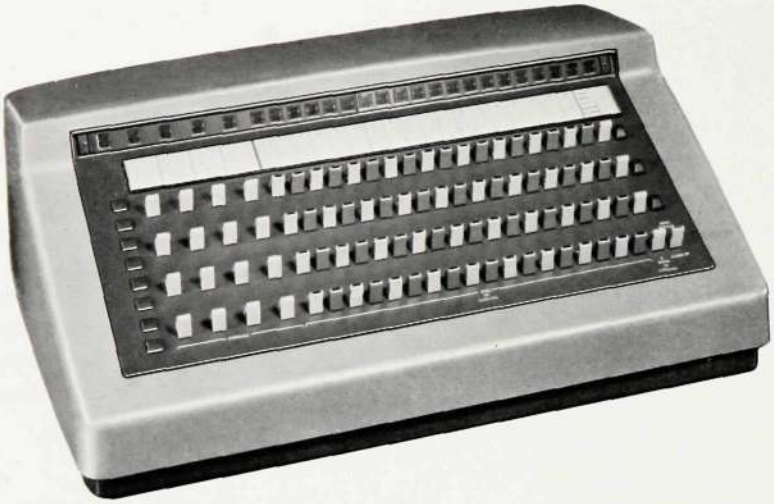

Figure 6—4+18 cordless switchboard with one-piece injection-moulded cover

Figure 7—The 2+10 House Exchange telephone

Figure 8—The 'Etelux' luxury telephone

Figure 9—Floor-pattern, indicator-signalling switchboard (Export series)

with comparative freedom. Moulds or formers could be easily and cheaply modified and the effect on the finished product assessed; also complete prototypes, with casework varied to suit different arrangements of components and controls, could be assembled and compared. It also became practicable to obtain advance data on market reaction by the small-scale distribution of prototype designs.

Following a satisfactory response to these designs a number of switchboards featuring one-piece, injection-moulded covers were produced, three of the final production versions (all BPO approved) being shown in Figures 4, 5 and 6. It is of interest to note that the 4 + 18 switchboard illustrated in Figure 6 is also the basis of the Company's new Ship-to-Shore Cordless Cabinet, developed in collaboration with the Admiralty. These switchboards represent a complete re-statement of design in a class of equipment which had remained virtually unchanged for half a century and may be expected to remain acceptable in the aesthetic sense for many years to come.

The design experience and manufacturing capability accumulated in typical developments such as the above, has led to the appearance of other items which have achieved wide recognition in the subscriber apparatus field. Among these are the 2 + 10 House Exchange and the ' Etelux ' luxury telephone (see Figures 7 and 8). More recently, work has progressed on a new

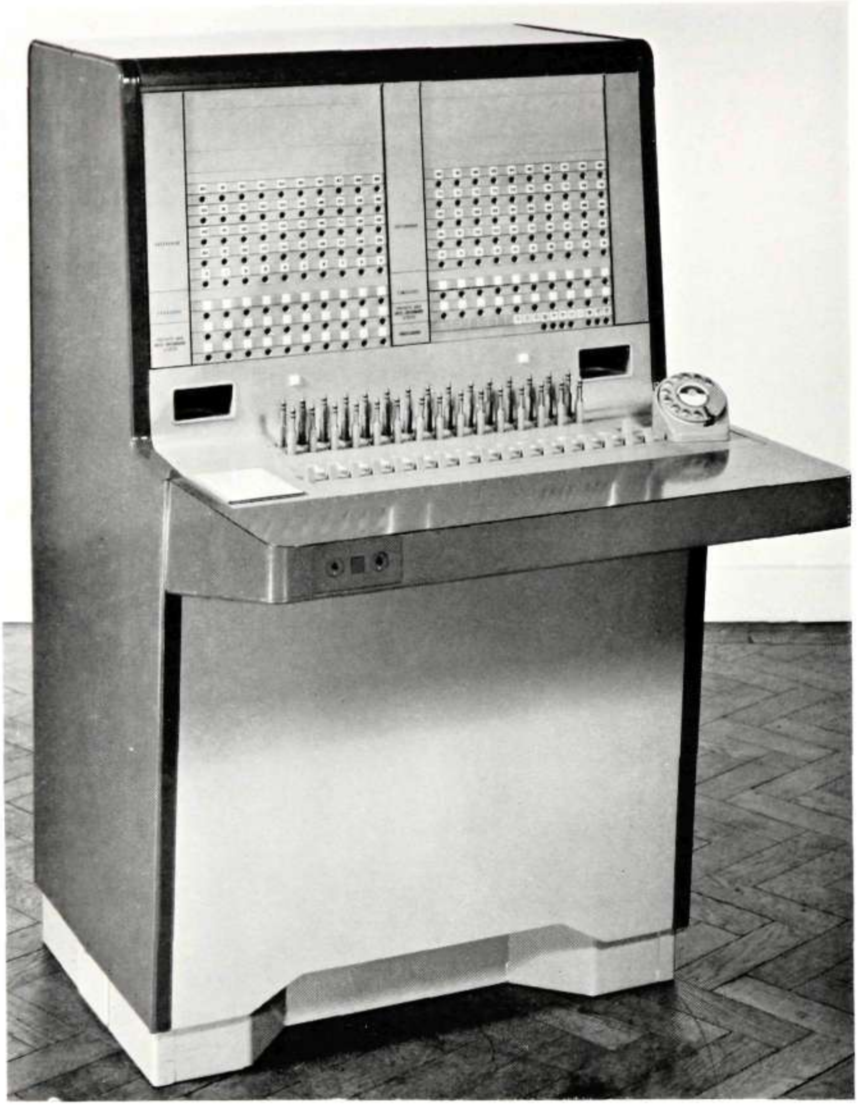

Figure 10—Latest lamp-signalling switchboard approved by the B.P.O. and ready for installation in the B.P.O. Tower Building, London

low-price telephone and a telephone incorporating push-button dialling.

The floor-pattern switchboard is another area of design where the scope for improved appearance has been broadened immeasurably by the use of new materials. Two examples of this class of switchboard, using similar materials and constructional techniques, are illustrated in Figs. 9 and 10. The first is typical of a range designed to meet a variety of signalling requirements for administrations overseas[2]; the second is the prototype of a design that has been developed for and recently adopted as standard by the British Post Office. This prototype is at present being installed beneath the new 620 ft. BPO London radio tower, in the same building that houses the ' Mercury ' trunk exchange.

Other recent developments include the new PABX 4 floor-pattern console-type switchboard and a 7 + 35 alternative table floor pattern switchboard. The latest extension of this range (see Figure 11) is the pedestal-mounted console for the PABX installation at the Plessey Company, Vicarage Lane, Ilford, Essex.

Conclusion

It can be seen from this brief description of some aspects of the industrial designer's function, particularly in this industry, that he has an increasingly important role to play in the creation of new products.

[2]'A New Series of Floor-Pattern PBXs': Bulletin 44, Jan. 1962, pp. 10-15.

Figure 11—Pedestal-mounted console for PABX installation at the Plessey Company, Vicarage Lane, Ilford, Essex

With his specialized knowledge of aesthetics and associated skills he is able to co-ordinate actively the various demands made in the initial product brief, and give the most suitable emphasis according to customer demand which, in the final analysis, is the most important aspect of design after all.

British Registered Designs Nos. 881,787-8-9-90; 898,377; 900,242; 902,938; 916,237 and corresponding foreign registrations

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