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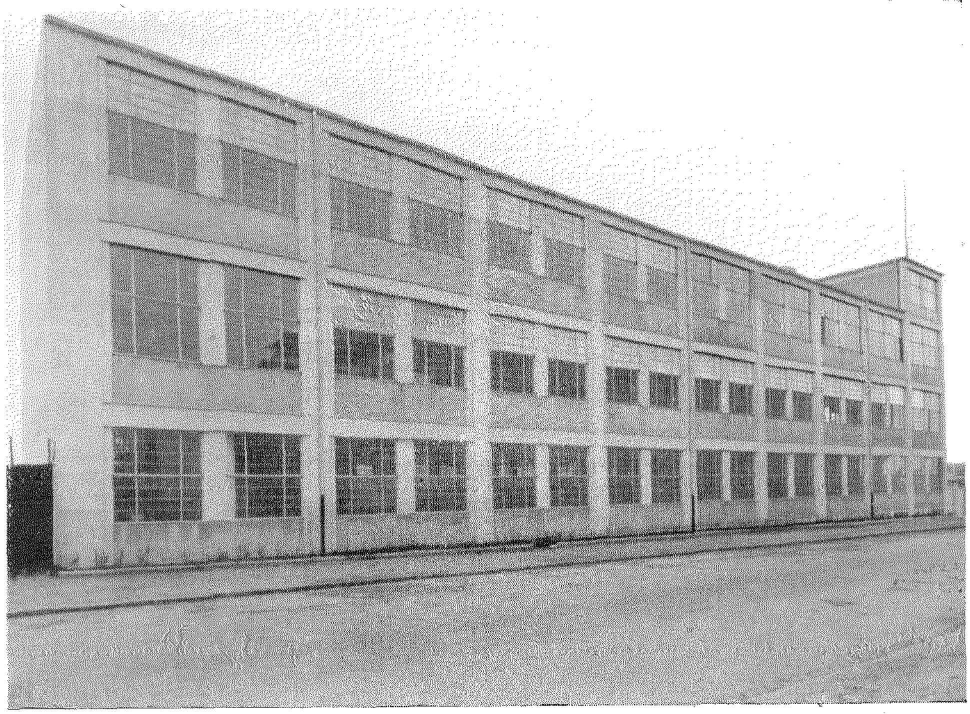


MODERN PLANT OF STANDARD ELECTRIC AKTIESELSKAB, COPENHAGEN, DENMARK, WITH FLOOR SPACE OF 2,860 SQUARE METRES (30,785 SQUARE FEET). CONSTRUCTED IN 1936 PRINCIPALLY FOR THE MANUFACTURE AND ASSEMBLY OF COMMUNICATION EQUIPMENT.

Automatic Ticketing of Telephone Toll Calls

By LESLIE B. HAIGH, M.A., A.M.I.E.E.,

Development Laboratories, Bell Telephone Manufacturing Company, Antwerp, Belgium

A NEW telephone facility known as Automatic Toll Ticketing, the first of its kind anywhere, was placed in public service on December 7, 1936, in the town of Bruges, Belgium. This event, which may have far reaching consequences, marks a further step forward in the evolution of communication systems. It demonstrates the practical possibility of offering to a telephone subscriber the advantages of full automatic dial service for toll as well as local calls, coupled with an individual printed record of every toll call, in which no human agency, save the calling and called parties, has been involved.

The Laboratories of the Bell Telephone Manufacturing Company, Antwerp, have been engaged for some time in studying the problems of introducing national dialing—"automatic toll" service—in several European countries, including Belgium, where the most important towns — Brussels, Antwerp, Liége, Ghent, Charleroi, Tournai, Bruges—and many of the small towns and villages surrounding them, already enjoy automatic service for urban and rural calls. In Belgium, many of the signaling and transmission problems involved in long distance dialing have already been solved by the extensive introduction of operator dialing over toll lines with the aid of the 50-cycle and "two voice frequency" impulsing systems. The second method has been described in a recent article.* One of the difficulties in extending toll dialing in Belgium to the subscribers themselves arises from the prevailing tariff law. Whereas a subscriber is charged for every toll call he makes, he is entitled upon payment of his annual rental to a limited number of local calls without extra charge. To comply with the law, the charges for toll and local calls must be computed separately. It follows that, if toll calls are to be metered automatically, each subscriber must be provided with a second message register for this purpose, a task of some complexity in existing automatic exchanges. Automatic ticketing also offers a solution to this problem.

A Field Trial Installation

The Belgian Régie has followed with interest the steps in the development since the idea of automatic ticketing was first mooted, and has assisted materially by giving the Bell Telephone Manufacturing Company the opportunity to tender upon several practical applications. Acknowledgment is due also to the engineers of The Hague Municipal Telephone Administration for the sympathetic interest they have shown in the discussions which have taken place on this subject.

On April 22, 1936, the Régie placed with this Company an order for a field trial installation of automatic ticketing equipment in the Bruges exchange. This equipment was to permit calls to be established by dialing and without the intervention of an operator, from Bruges subscribers to subscribers in the neighbouring seaside town of Blankenberghe, nine miles away, and therefore outside the local zone.

Both towns have had dial service for local calls for some years. Bruges is the toll switching centre of West Flanders, and the 3000-line

* "The Application of Voice Frequency Signaling to C.L.R. Service in Belgium," by G. E. H. Mönnig, *Electrical Communication*, October, 1935.

automatic exchange, cut-over in October, 1932, was one of the first 7-D Rotary System installations in Belgium (Fig. 1). Blankenberghe has

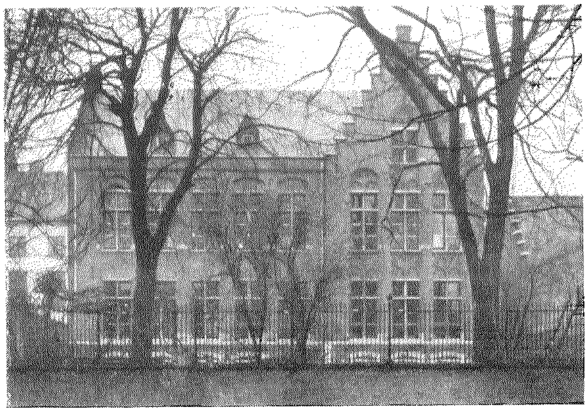


Fig. 1—The Telephone Exchange, Bruges.

a 900-line exchange, also 7-D Rotary, dating from July, 1934, and it was designed at the outset for direct dialing in the direction Blankenberghe-Bruges on a multi-metering basis. Traffic in the opposite direction has hitherto been handled manually, the operators in Bruges dialing the numbers of the Blankenberghe subscribers, and supervising and ticketing the calls.

Requirements of a System of Automatic Ticketing

In any system of automatic ticketing of telephone calls, the absolute minimum of information recorded upon each ticket must be such as to determine directly or indirectly the proper charge for the call and the identity of the subscriber to whom it is chargeable. The latter can evidently be conveniently indicated by his directory number. The charge can be computed in a variety of ways: directly by automatic means and recorded by a code or in monetary values; or indirectly from a record of the directory numbers of the calling and called subscribers (or of the unit tariff), together with the duration of the call (or the time of commencement and termination).

In the installation in question, a record is made upon each ticket of more particulars than are strictly necessary and the ticket is thus both adequate for accounting purposes and acceptable to the subscriber. The record consists of the directory numbers of the two subscribers, the tariff per time-unit of conversation, and the number of such units expended. The date and the time of day (to the nearest 5 minutes) are also recorded for the benefit and satisfaction of the subscriber, together with identification marks useful to the operating staff.

Comparison of Present and Previous Routing

It is interesting to compare the routing of calls since automatic ticketing was introduced with the method by which the same calls were established previously by operators, and thereafter to examine the problems involved in obtaining automatically the information which those operators themselves recorded upon the tickets.

Before the introduction of automatic ticketing, a Bruges subscriber desiring a connection to a Blankenberghe subscriber first dialed special service "02." The Bruges register routed the call over first and second group selectors (see A, Fig. 2) to a jack circuit at one of the rural positions. An operator inserted a plug in the jack and enquired both the number of the caller and the number desired. She then inserted the second plug of the same cord in the calling subscriber's multiple jack. Having verified the correctness of the information given, she released the original dialed connection by a key and transferred the first plug into the jack of a line to Blankenberghe. Another Bruges register attached itself to this line and the operator dialed into it the five digits of the desired number. The register routed the call to the line of the Blankenberghe subscriber and, whilst awaiting his reply, the operator prepared a ticket for record. At the end of the call the ticket was completed and despatched, together with other toll tickets, to the sorting table.

The new service has simplified the procedure whilst involving a minimum of modification of the existing plant. The lines to Blankenberghe, hitherto accessible only to operators, now appear in the arcs of the first group selectors and are each furnished with a printing register and a controlling relay group or "outgoing repeater" containing timing apparatus (see B, Fig. 2). A Bruges subscriber dials, instead of "02," the number of the subscriber he desires to call. The routing register selects a line to Blankenberghe over the first group selector and then routes the call directly to the desired line in that town. A printing register, associated with the outgoing end of the toll line, is supplied automatically with the necessary information for the recording of the call. When the call is finished, the register produces a ticket with the information printed upon it and ejects it through a chute into a container.

Printing the Number of the Called Subscriber

Although the Blankenberghe exchange as yet has less than one thousand subscribers, it is in the Bruges rural area in which all subscribers have five digit directory numbers. It follows that all the Blankenberghe subscribers have numbers beginning with the same two digits, which the routing register recognises as indicating a Blankenberghe call and translates into the single train of impulses required for the selection at the first group selector. The remaining three digits are transmitted without translation to the outgoing relay group, which relays the impulses both to Blankenberghe and to the digit-wheel in the printing register. The latter thus receives the last three digits and prints them upon a paper strip as they arrive, but receives no indication of the first two digits. However, these digits are always the same, as already stated, and the printing register is furnished with a patented device whereby at the first printing operation they are printed in front of the digit received. The strip now carries a record of the called subscriber's number.

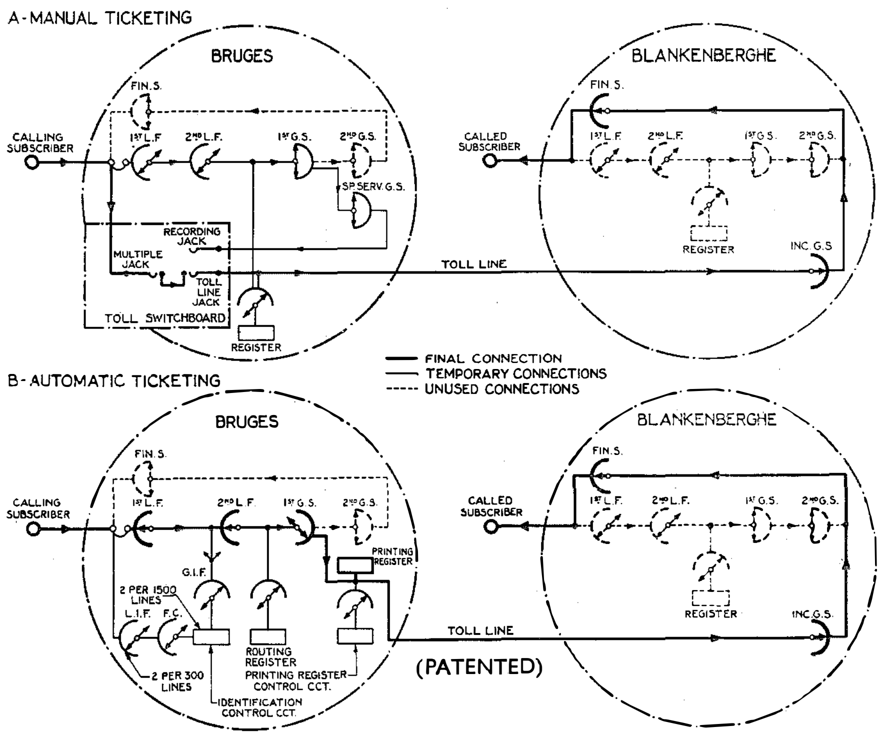


Fig. 2—Routing of Calls from Bruges to Blankenberghe, Before and After the Introduction of Automatic Ticketing.

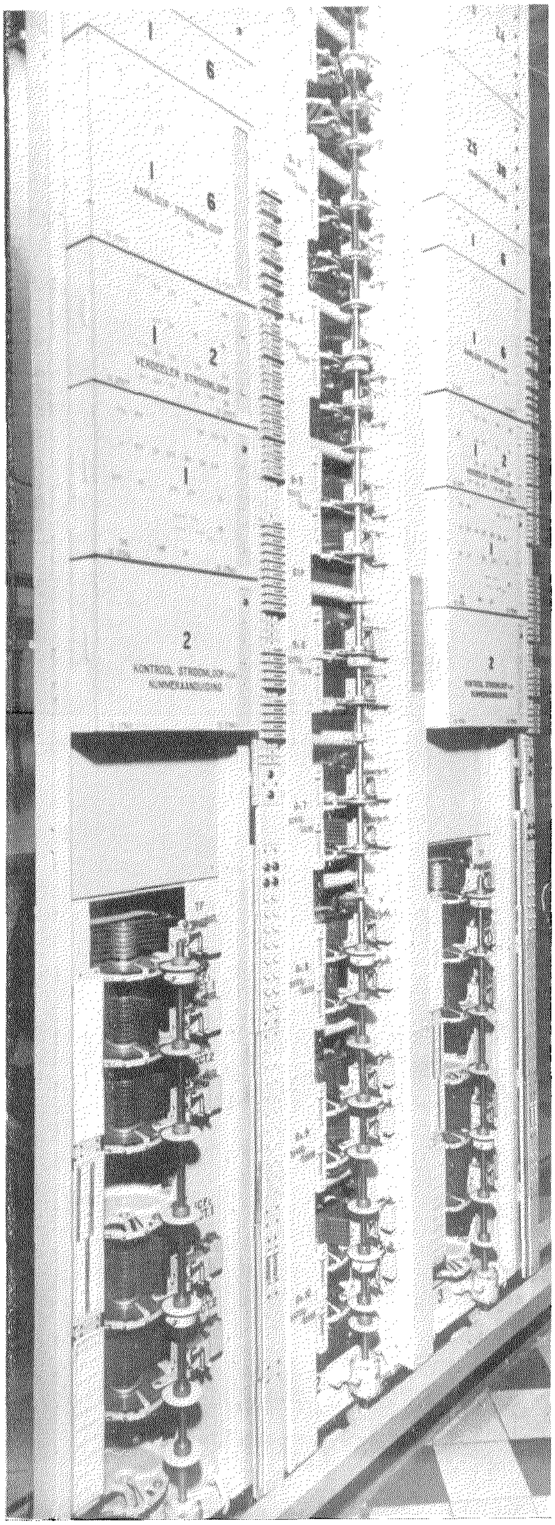


Fig. 3—The Calling Line Identification Equipment.

Printing the Charge per Time-Unit of Conversation

As soon as the selection of the desired line is complete, the routing register disconnects itself, and from this moment two series of operations take place simultaneously. On the one hand, upon the reply of the called subscriber, timing of the call begins in the outgoing relay group and, after the usual six seconds of "free time" have been counted, the call is registered as "effective" and chargeable by the operation of a relay. On the other hand, one of a common group of "printing register control circuits" attaches itself over a finder switch to the outgoing relay group and proceeds to direct the printing of the "tariff" or charge per time-unit of conversation. In the present installation, since only calls outgoing from Bruges to Blankenberghe are as yet ticketed automatically, this operation is quite simple, for the tariff is always Frs. 0.80. The printing register is capable of printing any number composed of four digits and can also print a "dash" when required. The control circuit accordingly creates the requisite trains of impulses and transmits them to the digit-wheel in the printing register for printing at the end of each train of impulses. In order to separate francs and centimes by a "dash," the printing signal is given to the register without any impulses to the digit-wheel, and the strip now carries also the inscription 0-80.

Printing the Number of the Calling Subscriber

The next operation presents greater difficulty. It is necessary, in the first place, to determine the identity of the calling line, which can be achieved only by tracing the call back to the line equipment; and, in the second place, to convey this information from the line equipment to the printing register. Since these two points in the connection are separated by first and second line finders and first group selectors, which were already existing, the provision of a new signaling path by the addition of brushes to these switches was evidently impracticable. The use of alternating currents at voice frequency made an economical solution possible, involving a very small amount of modification and disturbance to existing equipment. In each "link circuit" a condenser is connected between one of the brushes of the first group selector and the "metering" brush of the second line finder. A lead is run from the metering brush of each first line finder through a condenser to new and patented equipment known as the "Calling Line Identification" equipment. Finally, a connection is made from every subscriber's message register to this equipment.

To initiate the identification process, the printing register control circuit connects a 2,000-cycle tone to a lead in the outgoing relay group, whence it passes through the link into the identification equipment. Here it is detected in a starting circuit containing a thermionic valve; and a group identifying finder in one of a group of "identification control" circuits, which has been preselected by an allotter, begins to rotate. This finder has a terminal in its arc reserved for each group of first line finders, and to this terminal are connected the leads coming from the metering brushes of all the first line finders in that group. The calling tone thus finds its way to one of these terminals, and as soon as the rotating finder reaches this terminal, the tone is detected a second time by another thermionic valve and the rotation is arrested. The position in which the finder has stopped now indicates the group of first line finders which has access to the calling line. In Bruges, although jumpering facilities between the first line finder and final selector multiples are provided, all lines are jumpered "straight," that is, they appear in corresponding positions on the line finder and final selector arcs. It follows that, when the group of first line finders having access to a line is known, all the digits of that line's number except the last two are equally known. The first step in the identification of the calling line is thus achieved.

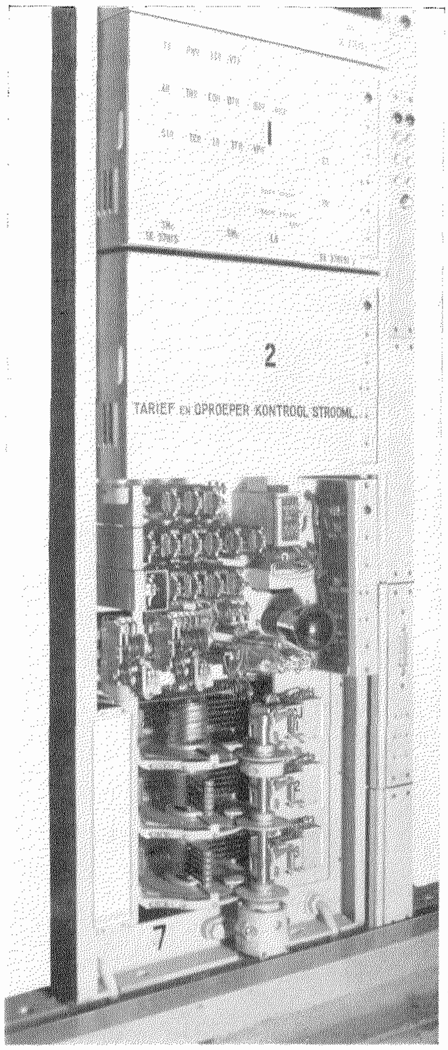


Fig. 4—The Printing Register Control Equipment.

The next step is to determine the position in which the brushes of the first line finder are standing, since this fixes the "tens" and "units" digits of the line number. To this end several groups of line identifying finders are provided. To the arcs of these finders the leads coming from the subscribers' metering wires are connected, one hundred lines to a level. There are three such levels on each finder, which therefore has access to 300 lines. The calling tone thus finds its way also to an arc terminal of each of the finders in one of the groups, the group being already known from the position of the group identifying finder. A finder in this group is accordingly chosen by the identification control circuit, through its finder chooser, and begins to rotate. When the brush reaches the terminal carrying the tone, the valve in the control circuit immediately detects it and the rotation is arrested. The position of the brushes indicates the last two digits of the line number, which has now been completely identified. As soon as this occurs a tone of a different frequency is transmitted in a forward direction from the identification control circuit, to the printing register control circuit, over the same path in which the calling tone is still being propagated in the opposite direction. It is detected by a valve and causes the calling tone to be disconnected.

The final step is to transfer the number of the calling line to the printing register. This is achieved by transmitting, again over the same path and to the same valve, trains of impulses of alternating current at tone frequency, controlled digit by digit in accordance with the positions assumed by the group and line identification finders. The impulses are relayed to the printing register and the digits printed one after the other upon the paper strip. The strip now carries a record of the directory numbers of the lines in communication and of the tariff chargeable, and the printing register is ready to record indications of the duration of the conversation.

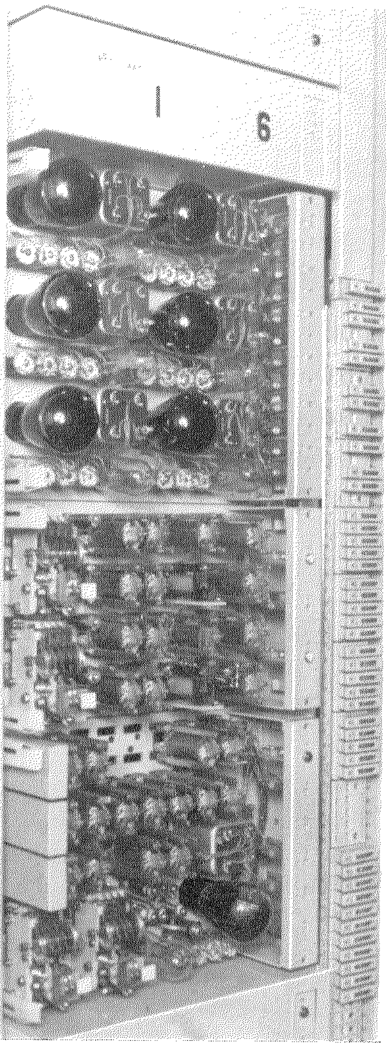


Fig. 5—The Layout of the Relays and Valves.

Recording the Duration of Conversation

By this time, an average of perhaps 15 seconds after the end of selection and the beginning of ringing, conversation may already have begun. If, or when, the call is registered as "effective," a signal is sent to the printing register and three small holes are punched one after the other in the paper strip. The time-unit of conversation in Belgium is normally three minutes; long-distance toll calls are, however, charged per elapsed minute after the first period of three minutes. For the sake of uniformity, the printing register has been designed to punch three holes, each representing a chargeable minute, upon receipt of the first signal and thereafter to punch one hole for each succeeding signal at one minute intervals.

The timing mechanism in the outgoing relay group consists of a step-by-step switch advanced under the control of a master chronometer. It sends signals to the printing register when the call is "effective," as already stated, and at the end of every minute thereafter, except the first two, when signals are unnecessary because three holes have already been punched. During the punching of these first three holes, the opportunity is taken to print the date, the time of day, and the machine's own identification mark and serial number. The three printing operations are spread over the three punching operations to reduce the load on the moving parts. Whilst conversation is in progress, the paper strip thus acquires further records indicating when conversation began and how long it lasted, together with useful identification marks.

Completing the Ticket

When the outgoing relay group receives the signal to release, the printing register advances the paper strip, if this be necessary, until sufficient paper to make a ticket of normal length has passed the knife. It then severs the strip and ejects the ticket into a chute.

The Identification Equipment

Theoretically, the relay and valve equipment composing the identification starting circuit could be common to the whole exchange ; and a single group of identification control circuits would suffice. In order to increase the security of the new service in this trial installation and

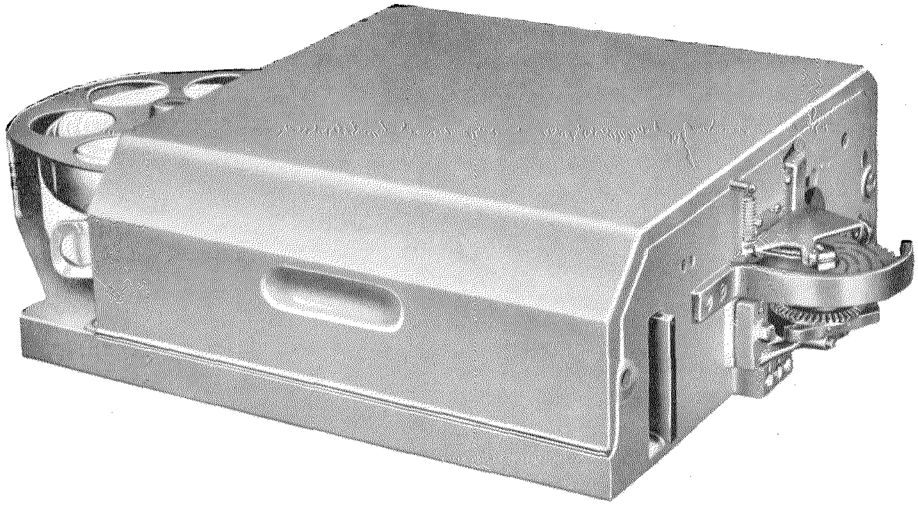


Fig. 6—The Printing Register with Cover in Position.

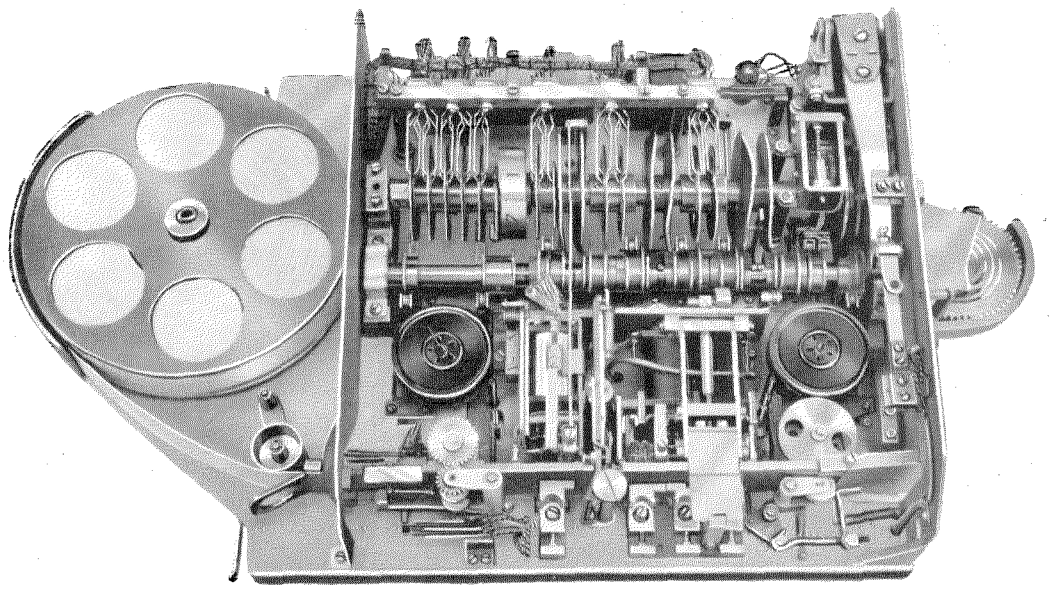
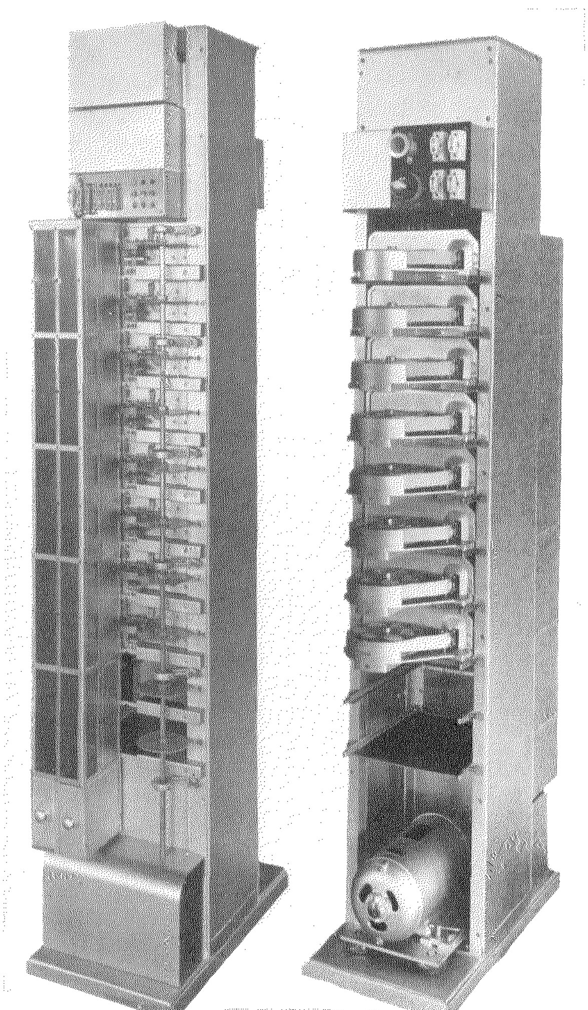


Fig. 7—The Printing Register with Cover Removed.

PATENTED

to avoid any possibility of unforeseen trouble throwing the whole identification equipment out of action, it was deemed advisable to provide a starting circuit for each 300 lines and a group of identification control circuits for each 1,500 lines. Two circuits in each group could easily carry the traffic expected from these lines but, also for reasons of security, space was reserved for a third. A group of identification finders was provided for each 300 lines, two finders being equipped with space reserved for a third. The whole of this equipment is accommodated upon three bays (Fig. 3). The centre bay mounts 30 identification finders and it will be seen that every third space is vacant. The other two bays are of the "combined" type, mounting the finders of the identification control circuits at the bottom, and the relay and valve equipment of these circuits and of the starting circuits above. The top finder on each combined bay is a routine test access finder. The bay is thus a complete unit serving 1,500 lines. (Fig. 5 shows the layout of the relay and valve equipment.)

The printing register control circuits, inasmuch as they contain the valve and relay equipment for converting voice frequency signals into direct current signals, may be considered as accessory to the identification equipment proper. They are mounted on another "combined" bay together with the outgoing relay groups. The bay mounts ten relay groups at the top and three control circuits with their finders at the bottom; Fig. 4 illustrates the lower part of the bay. Figs. 3 and 4 together give an idea of the small amount of rack-mounted equipment added to a 3,000-line exchange, purely for purposes associated with automatic ticketing.



Figs. 8 *and* 9—*Front and Rear Views of the Printing Register Bay.*

The Printing Register and Its Bay

Figs. 6 and 7 illustrate the power-driven printing register, and Figs. 8 and 9 show front and rear views of a patented apparatus bay designed to mount ten such printing registers together with suitable motor control and supervisory equipment.

The register measures 532 by 300 by 118 mm. (21 by 12 by $4\frac{3}{4}$ in.) overall, and is designed to jack-in from the rear of the bay. With the machine properly jacked-in, a flexible gear wheel protruding from the front (see Fig. 7) can be brought into engagement with the rotating vertical shaft of the bay. Through bevel gearing, the flexible wheel drives a shaft carrying mechanical cams. The different printing operations and the punching, cutting, and ejecting operations are controlled by these cams, which are engaged with the shaft in the proper sequence by mechanical means.

A strip of paper is fed from a roll into the rear of the machine, where it is caught between friction rollers, and passes between guides before various type wheels, a punch, and a knife; and the cut tickets are ejected through a deflector-slot into one of two chutes running

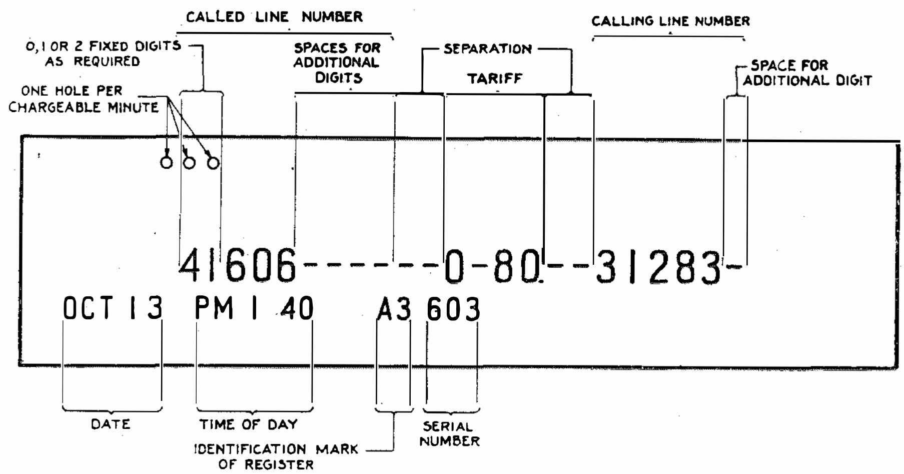


Fig. 10—Illustrating the Arrangement of the Ticket.

down the front of the bay. At the foot of each chute is a container, one for tickets of all kinds recording subscriber calls, and the other for routine test tickets which are separated automatically from the rest by the hinged deflector-slot. The bay is so designed that at a later date, when the traffic has increased sufficiently, the first container can be removed and the tickets conveyed by a belt conveyor direct to the sorting desk.

For each operation the cam shaft makes one revolution and the paper strip is advanced one step. The register has a normal cycle of 36 operations; the normal ticket thus has a length equivalent to 36 steps. The first 21 operations are concerned with the printing of the called and calling parties' directory numbers and the tariff with suitable spacing between them. The next 14 are punching or spacing operations, according to the duration of conversation; and the last is the cutting and ejecting operation. Calls lasting 14 minutes or less are thus recorded on a ticket 36 steps long. For calls lasting longer than 14 minutes, the ticket is extended without limit beyond its normal length. The date and the time of day are printed from type-wheels advanced by impulses transmitted by a master clock. The fixed type, from which are printed the register's own identification mark and the invariable digits prefixed to the called line number, are carried on members arranged to jack-in and are therefore readily changeable. The other numbers are printed digit-by-digit from a type-wheel advanced by current impulses from the associated relay group and restored mechanically after each printing operation. A standard typewriter ribbon supplies the ink for printing and is advanced and reversed automatically.

The Ticket

Fig. 10 is a full size illustration of a typical ticket of normal length. It measures 116 mm. by 30 mm. ($4\frac{5}{8}$ in. by $1\frac{1}{8}$ in.). It will be seen that, although each of the line numbers shown has five digits, the printing register is capable of printing calling line numbers with up to six digits and called line numbers consisting of up to seven variable digits preceded by one or two invariable digits. The discrepancy between the two numbers is explained by the necessity, in the case of long distance calls, of indicating the identity of the area or town to which the called number belongs.

The New System Proves Its Worth in Advance of Cut-Over

The first ticket recording a commercial call bears the date October 6. How it came to be produced two months before cut-over is a story in itself, and illustrates the immense value of the documentary evidence afforded by such a record. Fig. 11 is reproduced from a photograph of this interesting ticket.

On the day in question, testing of the equipment was in progress in preparation for a demonstration arranged for October 8. Amongst the test tickets in the container, a ticket was noticed which carried two regular subscribers' numbers. The calling number was found upon investigation to belong to a railway

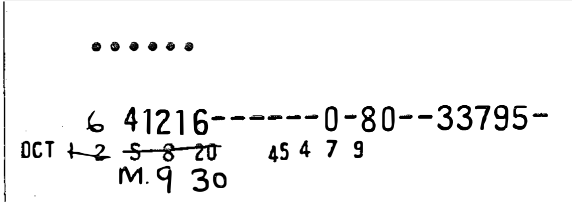

6 41216------0-80--33795-
OCT 1 2 5 8 20 45 4 7 9
M. 9 30

Fig. 11—Record of the First Call Ticketed Automatically.

depot in Bruges. This number was immediately called up by the Administration and the official who replied was informed that a call had been put through automatically to Blankenberghe railway station. This was, of course, contrary to regulations because the new service was not yet open to the public. The call was at first emphatically denied, as might have been expected, since only the person in charge of the depot is allowed to make calls outside the Bruges local area. Eventually, when the overwhelming evidence of the date, time, numbers involved, and duration of conversation was appreciated, the call was reluctantly admitted by an employee—and duly charged.

The Perpetual Clock Circuit (Patented)

An interesting innovation in the new equipment is the arrangement for adjusting automatically the type-wheels in the printing registers from which the date is printed. Precisely at midnight every day an impulse must be sent to all the date counters to advance the day of the month. At the end of the month two difficulties arise. In the first place, any counter constructed with tens and units digit wheels must necessarily have a cycle which is a multiple of ten steps. Actually the date counters have a cycle of fifty steps. At the end of each month, therefore, when a new cycle begins, the counters must be advanced. Secondly, the number of steps varies from month to month, as the number of days in the month varies. A special arrangement for dealing automatically with this situation has been devised. A small relay group and four step-by-step switches receive an impulse at midnight every day, and the switches are advanced according to a combination which is such that their relative positions are repeated only once in four years. The days of each month are counted and the appropriate number of impulses are transmitted to all the printing registers at the end of the month. During this process of adjusting the monthly cycles, the printing registers are prevented from recording non-existent dates, such as the 36th day of the month. The changeover from "summer time" to "winter time" by automatic means is not possible owing to the varying dates when these changes occur, but precautions have been taken to enable the adjustment to be made, without interfering with the service, by a member of the exchange maintenance staff.

Further Developments

Since the day of cut-over the automatic ticketing equipment has functioned smoothly, and the quality of the service has in every way fulfilled expectations. The exchange is being maintained by the regular maintenance staff and no unforeseen difficulties have been encountered. Evidence of the impression the system has made is furnished by the fact that a further order was placed on November 4, 1936 with the Bell Telephone Manufacturing Company for four new automatic exchanges for the towns of Zeebrugge, Heyst, Knocke, and Le Coq, all in the Bruges rural area. For these exchanges, which are to be in service in time for the summer season of 1937, automatic ticketing is specified for all rural calls for which the charge exceeds the local call fee. The centralisation of all printing registers at the toll switching centre, Bruges, represents a further advance in the art and constitutes another advantage over multi-metering, inasmuch as the tedious collection of meter records from outlying localities is avoided. It is intended to give an account of the measures taken to attain this end, and to describe in greater detail, in a separate article, the mechanical features of the printing register.

Automatic Printing Register for Telephone Call Recording

By L. DEVAUX,

Les Laboratoires, Le Matériel Téléphonique, Paris, France

THE trend towards the adoption of full automatic switching systems for toll connections has created a demand for a recording mechanism which can produce automatically a charge ticket for each call, corresponding to the tickets prepared by the operators in manual switching systems. Such an apparatus, known as a printing register, has been developed by Les Laboratoires L.M.T.; it is believed to be new in the telephone art, and has been widely protected by patents.

Function of the Printing Register

The object of the printing register is to produce a separate ticket for each call established through the trunk with which it is associated. On the ticket, the following indications are recorded: the called subscriber's number, the charge per time-unit of conversation, the calling subscriber's number, the date and time of day of the connection, the identification mark of the machine which has made the ticket, a serial number and the number of elapsed time-units of conversation.

The ticket printer is an electro-mechanical apparatus operated by impulses delivered by the automatic central office equipment; its functions are to record all indications delivered to it in sequence by the automatic equipment, and to send alarm and suitable status signals to the latter.

A ticket is made from a continuous strip of thick paper wound on a roll; the numbers are printed, the elapsed time-units are recorded by punched holes, then the tape is severed and the ticket is ejected. The printing of the subscribers' numbers and the charge per time-unit is made digit by digit. The date, the time of day and the serial number are printed in three operations, one for each. The duration of the connection is recorded by punched holes which are made one by one at the beginning of every minute, except that the first three-minute unit is recorded by three holes shortly after the called subscriber answers.

The printing register is necessarily a rather complicated piece of apparatus, and the description which follows is intended to give only a general idea of its principle of operation inasmuch as a complete description would occupy too much space.

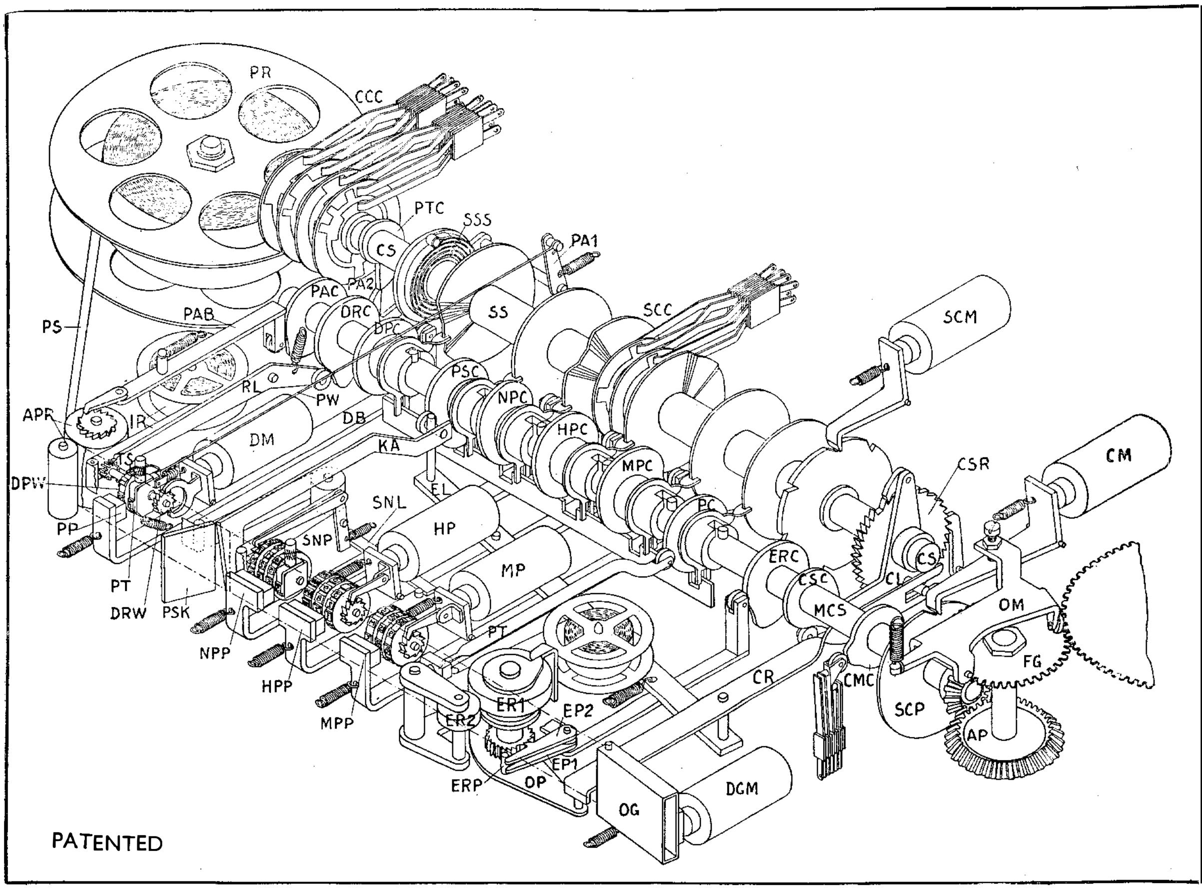
Mechanical Principle

The mechanism is shown schematically in a simplified form in the figure (page 274). In order that certain parts might be illustrated, it has been necessary to depart somewhat from the actual structure of the apparatus.

The mechanical operations of the printing register are controlled by three revolving shafts: main cam shaft MCS, counting shaft CS and shifting shaft SS. Mechanical power is imparted exclusively to the main cam shaft, and is conveyed thence by cams only. The main cam shaft is driven by a continuously rotating vertical shaft through a flexible gear in the same way as in the Rotary Automatic telephone system, a method which more than twenty years of experience has shown to be satisfactory. The flexible gear is shown at FG; it drives the main cam shaft, MCS, through bevel gears AP.

Control of the register from the outside is effected exclusively by closing electrical circuits at appropriate times to operate a series of electro magnets DM, MP, HP, CM and DGM. The function of each is explained later.

The main cam shaft carries a number of cams; some are clutched and perform operations which are repeated at each revolution of the shaft; others are clutched in sequence. These latter cams are mounted on bushings which can slide freely on the shaft, each bushing having a slot acting as a dog for engaging a corresponding pin on the shaft. The sliding motion of each cam unit is imparted by an undulated disc, which is rigidly mounted on



Mechanism of Automatic Printing Register Shown Schematically in Simplified Form.

the shifting shaft SS and which passes between the prongs of a fork carried by the cam unit.

The cams are shown on the figure as follows :

PAC, paper advancing cam, always clutched ;

DRC, digit wheel resetting cam, always clutched ;

DPC, digit printing cam, clutched for printing subscribers' numbers and tariff ;

PSC, paper severing cam, clutched for severing the paper strip when the ticket is complete ;

NPC, identification mark and serial number printing cam, clutched for printing a serial number and a mark proper to the machine ;

HPC, hour printing cam, clutched for printing the time of the connection ;

MPC, date printing cam, clutched for printing the day and month ;

PC, punching cam, clutched for punching holes denoting the duration of the connection;

ERC, ejecting roller spring winding cam, always clutched for winding up the clock spring of the ejecting rollers ;

CSC, counting shaft advancing cam, always clutched ;

CMC, clutch magnet and reverting impulse cam, always clutched for operating contact springs ;

Ink ribbon advancing cams not shown on the illustration, always clutched.

A stopping and centering disc, SCD, is clamped on the main cam shaft ; it contains a notch which is engaged by the tip of the armature of the clutch magnet to fix exactly the home position of the main cam shaft.

Cycle of Operations

The cycle of operations consists of 36 or more revolutions of shaft MCS and one revolution each of shafts CS and SS. In consequence of the latter, CS and SS can be concentric and interrelated by a spring drive. Counting shaft

CS has 36 positions and is rotated step by step, one step for each revolution of main cam shaft MCS, winding up the clock spring, SSS, which drives shifting shaft SS.

A ticket is made from the paper strip, PS, which is advanced step by step by the rotation of cam shaft MCS; the normal ticket, accordingly, has a length of 36 steps.

Shifting shaft SS has seven positions and is advanced by the unwinding of the driving spring under the control of an escapement carried by the armature of a magnet, SCM. It sets the printer to enable it to perform seven distinct and selectable functions in sequence, namely: printing a digit, printing the date, printing the time of day, printing the serial number, punching a hole, advancing the paper without printing or punching and separating the tickets.

The interaction of shafts CS and SS is controlled within the printing register by electrical circuits closed by contact cams CCC and SCC on the two shafts, respectively. Regular Rotary sequence switch cams and spring nests are used.

Printing Numbers

The register, initially, is prepared to print the digits of the subscribers' numbers and the charge per time-unit; the dog of the digit printing cam, DPC, is engaged by a pin of the main cam shaft, MCS, as shown.

The paper strip, PS, wound on a roll, PR, is fed into a channel (not shown in the illustration) and is advanced step by step by a pair of friction rollers, APR, which are controlled by a ratchet wheel and a pawl. The paper first passes in front of the digit printing wheel, DPW, an ink ribbon, IR, being inserted between paper and wheel.

The digit printing wheel is under the pressure of a spring through a pinion and a toothed sector, TS, and is held in position by a ratchet wheel, DRW, engaged by an escapement anchor carried by the armature of a controlling magnet, DM. Besides the digit printing wheel, DPW, there is a prefix type, PT, which at the beginning is in position to be printed on the paper.

The controlling magnet, DM, receives external impulses corresponding to the first digit. The escapement pawl oscillates and the type wheel rotates step by step under the action of the spring of the toothed sector; the first digit is now opposite the paper strip as it is actually shown in the illustration. An impulse is next sent to the clutch magnet, CM, and the cam shaft, MCS, makes one full revolution, driving the digit printing cam, DPC, and the digit wheel resetting cam, DRC, the latter being rigidly fixed on the shaft.

The first cam moves a bar, DB, carrying a printing pad, PP, which applies the paper strip both to the digit type of the wheel and to the prefix type, which are thus printed. Immediately afterwards, the resetting cam, DRC, moves the resetting lever, RL, which drives the type wheel to its home position by means of the toothed sector, TS. During the resetting operation the paper advancing cam, PAC, fixed on the main cam shaft, acts upon a bar, PAB, which drives the rollers, APR, by means of a pawl and a ratchet wheel, and the paper strip is advanced one step.

A fourth cam, CSC, drives the cranked lever, CL, bearing a pawl which rotates the counting shaft, CS, through an angle corresponding to one tooth of the ratchet wheel. This small rotation of the counting shaft disengages the prefix type, PT, so that it will not again be printed. The prefix type is pulled by a wire, PW, secured at the end of an arm, PA1, fixed to a second arm, PA2, the end of which bears upon a spiral cam, PTC, on the counting shaft. When this shaft rotates, the end of arm PA2 escapes from the end of the spiral cam and, under the action of its spring, the arm PA1 pulls the prefix type, which rotates and becomes disengaged.

The same cycle of operations is repeated for all the digits (seven on the first model) of the number to be recorded first; that is, the called subscriber's number, the paper strip advancing each time by one step, and the counting shaft rotating one tooth.

When all the digits of the first number are printed, the counting shaft is in position 8, where a contact closed by one of its cams, CCC, causes the clutch magnet, CM, to become energised. The cam shaft rotates twice, causing the paper to advance two steps and the printing pad to press the paper strip on the digit wheel, but since no digit is displayed, two dashes only are printed and serve to separate the first number from the second.

The counting shaft, CS, is now in position 10, and the printer is ready to receive the digits of the tariff exactly in the same way as for the first number. At this moment a reverting signal is sent to the automatic exchange. Four digits are allotted for the charge per time-unit, and the counting shaft moves to position 14 where it again causes the main cam shaft to make two revolutions, and two dashes are printed.

The counting shaft moves to position 16 and signals again by a reverting impulse that it is ready to register the calling subscriber's number; this latter number of 6 digits is printed in the same way, and the counting shaft moves to position 22.

All numbers are now completely printed and the digit printing mechanism is placed out of action as explained subsequently.

During the printing of the numbers the paper strip passes between the blades of a cutter, PSK, and, when these operations are completed, it arrives in front of the date (month and day), the time of day (hour and minutes), and the serial number of the printer which are shown, respectively, at MP, HP and SNP.

The printer must now be set to register the first chargeable period of conversation.

Printing the Date, Time of Day, etc.

The shifting of the mechanism is accomplished by the shaft, SS, which, as already stated, carries undulated discs which control the clutching of the operating cams of the main cam shaft.

The contact cams of the counting shaft close the circuit of the shifting shaft controlling magnet, SCM, which operates an escapement pawl, causing the shifting shaft to rotate under the action of a clock spring, SSS. Consequently, the digit printing cam, DPC, is declutched and two other cams are clutched: the punching cam, OC, which drives a punching tool, PT, and the date printing cam, MPC, which drives a pad, MPP, for applying the paper strip to the type wheels of the month and day printer, MP. This latter apparatus resembles a message register; it is controlled by a master clock which sends an impulse at midnight every day for advancing the wheels.

The printer now sends a reverting impulse for signaling that it is ready to receive an impulse, indicating the beginning of a chargeable period. When this latter impulse arrives and energises the clutch magnet, CM, the main cam shaft makes one revolution: the date is printed, a first hole is punched, the paper is advanced one step, and the counting shaft is driven to position 23.

In this position, the circuit of the shifting shaft controlling magnet, SCM, is again closed locally and the shifting shaft rotates, freeing the date printing cam, MCP, and clutching another cam, the time of day printing cam, HPC, controlling the printing pad, HPP, in front of the wheels of the time of day printer, HP. This latter is similar to the date printer and its type wheels are operated every five minutes by impulses delivered by a master clock.

As soon as this cam shifting operation is completed, the contact cams of the shifting shaft close the circuit of the clutch magnet and the cam shaft makes another revolution for printing the time of day and punching a second hole.

A cycle of operations, similar to the preceding one, occurs for shifting the cams: the hour printing cam, HPC, is freed, the serial number printing cam, NPC, is clutched, after which the cam shaft makes a third revolution. The pad, NPP, applies the tape to the fixed types and type wheels of the serial number printer, SNP, for printing identifying marks denoting the machine printing the ticket and a serial number set by number wheels. These wheels are advanced by one unit for every ticket made by the machine by means of a pawl driven by an oscillating lever, SNL, controlled by the printing bar of the time of day printer.

The counting shaft has been advanced each time for the two last operations and is now in position 25. All printing operations are now finished: serial number printing cam, NPC, is freed by the rotation of the shifting shaft, but the punching cam, PC, remains clutched.

Registering Duration of Conversation

The printing register is now ready to record the duration of the conversation. For this purpose, an impulse is sent at the beginning of every minute (after the first three minutes) by the automatic exchange equipment in order to energise the clutch magnet, CM, and to rotate the main cam shaft once, causing a new hole to be punched each time, as well as the paper and the counting shaft to be advanced.

As the normal ticket is made in 36 steps, there is room for 11 holes in addition to the first 3, corresponding to a conversation of 14 minutes' duration. After this time, the counting shaft is in position 36 in which the driving pawl bears upon a part of the rim of the ratchet wheel, CSR, where a tooth has been removed ; thus, if more time punching impulses are received, the paper is punched and advanced, but the counting shaft is no longer driven, remaining in position 36. A ticket longer than the normal dimensions may thus be made for a practically unlimited conversation.

Frequently the time allowed for a toll connection is limited to 6, 9 or 12 minutes, according to the intensity of the traffic. The printing register provides a simple method of interrupting the conversation after the maximum allowed time has elapsed. The position of the counting shaft denotes the duration of the conversation ; it is in position 25 during the first three minutes. It passes to position 26 at the beginning of the fourth minute when the time impulse is received, and so on. The contact cams of the counting shaft are arranged to send a reverting impulse either in position 28, 31 or 34, at the beginning of the 6th, 9th or 12th minute of conversation, so that the automatic exchange equipment may send at the proper moment a signal over the line informing the subscribers that the connection will shortly be broken, and may then make the disconnection.

Completion of the Ticket

At the end of the conversation, when the automatic equipment releases, the printing register advances the ticket up to 36 steps, provided this position has not already been reached as a result of the duration of the conversation. If the counting shaft is already in position 36, the conversation has lasted 14 minutes or more and the ticket is of normal length or longer.

In the first case, when the clearing signal is received, the shifting shaft is rotated to declutch the punching cam, PC, without clutching another cam. Then the clutch magnet, CM, is energised and the main cam shaft rotates continuously until the counting shaft reaches position 36. During this operation the paper is advanced step by step without being punched. Since the counting shaft is then in position 36, the shifting shaft, SS, rotates one position and the paper severing cam, PSC, is clutched.

In case the disconnection occurs when the counting shaft is already in position 36, the shifting shaft, SS, rotates two steps and the paper severing cam, PSC, is clutched.

The rotation of the main cam shaft occurs immediately afterwards ; the paper strip is pressed against the knife, PSK, by lever KA, driven by cam PSC, and is severed. The ticket is now detached ; it must be ejected into a chute. This operation is achieved by a ticket ejector composed of two friction rollers, ER1 and ER2. One of them, ER1, is provided with a clock spring which is wound up step by step by a pawl, EP1, and a cam, ERC, of the main cam shaft during the preparation of the ticket, but the roller, ER1, is prevented from turning back by a second pawl, EP2. The knife armature, KA, drives a long lever, EL, which, by means of bar CR, oscillating plate OP and pin ERP, disengages both pawls, EP1 and EP2, just after the ticket is separated and, at the same time, it acts on a spring (not shown in the illustration) to apply the second roller, ER2, to the first one, the ticket being pressed between them. Under the action of the clock spring, both rollers rotate rapidly and throw the ticket through the oscillating guide, OG, into an appropriate chute.

The lever, EL, has another function : it drives the counting shaft out of its 36th position to reset it at its starting position. For this purpose, a double operation is imparted to the driving pawl, which is thus carried beyond the dead position of the missing tooth in the ratchet wheel, CSR ; the pawl being actuated through the agency of the connecting rod, CR, which links lever EL with the cranked lever CL. After this, the shifting shaft rotates one step more to free the paper severing cam, PSC, and to clutch again the digit printing cam, DPC.

The printing register is now in its starting position ready to print another ticket. The associated trunk, kept "busy" during the interval required to complete the ticket, is now free.

Special Tickets

The above sequence of operations takes place for a regular "effective" connection, but means have been devised to have the machine take care of "premature release" and "no reply calls." In both cases, when the disconnecting signal is received, the shifting shaft is rotated to unclutch all cams; then the main cam shaft is rotated to complete the ticket to the normal length exactly as in the case of a regular ticket, but without any further recording. Severing and ejection are accomplished exactly as for a normal ticket.

In accordance with automatic telephone practice, a routine test circuit is associated with a set of printing registers. Test tickets are made to check the operation of the apparatus; but, in order to facilitate maintenance, it has been found advisable to prevent the test tickets from being associated with the regular tickets. The oscillating guide OG, in its normal position, directs the tickets into the chute of the regular tickets; when a test ticket is to be made, the test equipment closes a circuit to energise magnet DGM which deflects the guide, OG, so that test tickets are thrown into a separate chute.

Additional Features

The above description gives an idea of all the essential features of the printing register; however, mention should be made of some of the patented refinements and safeguards which have been added to ensure satisfactory and reliable operation :

1. Alarm contacts signal when the paper roll is exhausted and when, for any reason, the printing register fails to accomplish its full cycle of operations.
2. A push button is provided to allow test tickets bearing only the date and the time of day to be produced for checking the position of the wheels.
3. The date and time of day printers may be advanced by push buttons in case they are late.
4. Interlocking devices prevent the disturbance of the relative positions of the counting and switching shafts.
5. The printing register is jacked-in on the bay and can be easily removed; it is put in action and the corresponding trunk is rendered free only when it is fully jacked-in and clamped in position.
6. If the shafts of the printing register are not in their normal positions when it is placed on the bay, it resets itself automatically as soon as it is clamped.
7. When a new roll of paper is inserted, the printing register automatically makes a first blank ticket so that the next ticket will commence exactly at the right place.
8. When a printing register is engaged in recording a connection, it cannot be disturbed : date and time of day checking tickets cannot be made until this printer is free, the push-button being locked.

Field Trial

The automatic printing register above described is no longer in the experimental stage. A number of these machines are in service in the toll exchange in Bruges, Belgium. Particulars of the equipment used are given in another article in this issue of *Electrical Communication*, including views of the printing registers and the equipment bay on which they are mounted.

Application of Lorenz Communication Technique at the Olympic Games, Germany, 1936

By H. DEWALD,

C. LORENZ, A.G. Berlin-Templehof, Germany

THE great Olympic Games in Germany not only brought the finest sportsmen in the world to the arena and demanded from them the last ounce of bodily strength and athletic ability, but also imposed the highest demands on a large number of others who were engaged on the organization of the Games and who were responsible for their running smoothly. Not least amongst those who contributed to the solution of the important problems involved, was the Engineer.

The organizing committee to a special degree, entrusted C. Lorenz, A.G., with many and important technical problems. The following Lorenz communication equipment was installed, i.e.:

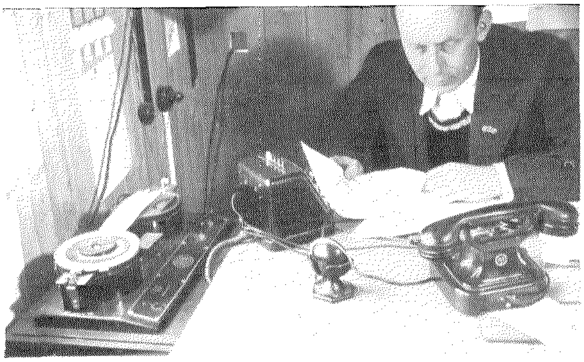
16 Teleprinters, model 15.
220 Speech input amplifiers, V.35.[1]
4 Short-wave broadcast transmitters (Olympic World transmitters), each of 40 kW output.
5 Microphone amplifiers.
1 40 watt commentator's transmitter with modulation amplifier.
1 Steel band tape machine.
46 Steel wire machines ("Textophone").

It was essential that the different and widely separated playing fields be interconnected for co-ordination purposes. Accordingly, the Lorenz page teleprinter was utilized at the Olympic Winter Games held at Garmisch-Partenkirchen (February 1936).

Lorenz Teleprinter in the National Sports Field, Berlin.

[1] This equipment was installed by the Reichs-Rundfunk-Gesellschaft.

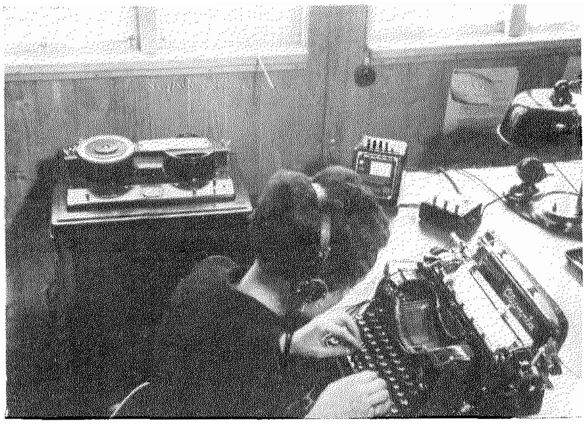
Here the Press Office was connected to the Ski Jumping ground, the Ice-stadium and the Riessersee Ice-rink. The Lorenz page printers, which were available for local service in Garmisch-Partenkirchen, were connected in series, so that all communications from any one station were simultaneously received at all stations and could immediately be read from the complete manuscript for further transmission over loud-speakers. Results which were, for example, announced at the Ski Jumping ground, immediately appeared at the Press Office, the Ice-stadium and on the Riessersee. Thus the press representative, located at the Ice-stadium, was furnished with information on events taking place elsewhere.



Lorenz Steel-tone Wire Machine ("Textophone") installed in the Office of the Director of the Organization Committee in Garmisch-Partenkirchen (Control Station).

Duplicating apparatus placed alongside of each page printer provided means for quickly reproducing any desired quantity from the ten copies delivered by the page printer. These copies then immediately became available to the press agents.

The Press Office also had two additional Lorenz page printers. One machine was connected with the Government Office of German Correspondence, Berlin, Zimmerstrasse, whilst the other was connected with the office of the "Münchener Neueste Nachrichten" which printed the programme.



Lorenz "Textophone" Listening Station.

The service was rapid and efficient. The assignment of experienced and expert operators from the Reichspostdirektion München ensured correct and reliable transmission of news.

The teleprinters were equipped with an automatic call-back device which, when the appropriate key was depressed, printed the name of the place where the communication originated. In the case of the apparatus at the Ski Jumping ground, for example, when the key was depressed the words "Ski Jumping ground" appeared at the transmitting point and, simultaneously, it was printed by all the interconnected printers. A great deal of time was thus saved since the release of the identifying word was accomplished by depressing a single key.

At the XIth Olympiad in August, 1936, in the Reich sports-field, Lorenz teleprinters were installed in the Führer's box, the Government box, the Judges' box, and in the Olympic World Broadcast Transmitting Room. All were connected with the teleprinter-exchange, and from it received pertinent news items. Lorenz teleprinters were also installed in the show-windows of important business houses and newspapers, in order that passers-by might receive news of the Olympic competitions transmitted by the teleprinter-exchange in the sports-stadium.

Of the 220 speech input amplifiers (V35) supplied to the Reichs-Rundfunk-Gesellschaft, 50 were installed at Garmisch-Partenkirchen and 170 in various locations, such as the Reich sports field, the Deutschlandhalle, the bicycling track, and the regatta river banks in Grünau, near Berlin, and Kiel. Thirty-three foreign broadcasting companies in co-operation with the Reichs - Rundfunk - Gesellschaft, transmitted news of the Olympiad in thirty-two countries. Sixty-seven foreign radio stations distributed this news in twenty-five languages throughout the world. Such figures show very clearly the interest and the world participation in the Berlin Olympic Games. At the same time, the tremendous requirements imposed on German radio facilities will be apparent. These could only be met with the aid of the most modern technical equipment.

A series of fixed speech input points was provided, equipped with type V35 amplifiers. Sports fields from which a large number of commentaries had to be sent were provided with sub-stations which, in some cases, as regards size and scope, exceeded the amplifier-equipment of an ordinary broadcasting station. These sub-stations totalled 17, the largest being placed in the underground room of the principal competitors' stadium. The latter functioned as the principal amplifier-station and, also, as the main switching station. Here all the lines from the sports fields, from the Avus, the Deutschlandhalle, the bicyling stadium and the regatta waters in Grünau and Kiel terminated. In addition to these fixed speech input points, a number of mobile stations were provided on lorries containing Lorenz built-in apparatus.

By means of this speech input equipment it was possible to meet all the requirements of the organization engineers involving the selection of the microphones set up at various points, regulation of sound volume and the mixing of several microphone circuits. The equipment is of the transportable type and is furnished with the usual broadcasting valves which amplify the speech currents to values comparable with those supplied to cable circuits when normally sensitive condenser-microphones are employed. Facilities were provided for measuring the input voltage of the cable, and supervising the transmission at the entrance to the cable, as well as for transmitting an interval signal between broadcasts. The speech input equipment consists of regulator-panels (regulator and mixing equipment), amplifiers proper, monitoring amplifiers, the modulation tester and the interval signaller. Each equipment unit comprises four regulator panels which, at their input, permit selective connection of any two condenser-microphones by means of a switch.

The monitoring amplifier stage serves for supervising the outgoing modulation voltages at the speech input equipment itself. It is coupled through a volume regulator directly to the anode of the output valve. The output amounts to about 0.6 watts and suffices to modulate the permanent dynamic loudspeaker serving as a monitoring speaker.

An 800 cycle note, keyed by a relay arrangement, was selected for the interval signal. The note itself is obtained from a valve generator. The complete electrical separation of the interval-signaller from the amplifier enables an interval signal to be transmitted on the cable whilst a transmission test is being made at the transmitting-end.

As a special extension of the German Reichspost's largest short-wave broadcast system, Lorenz supplied 4 short-wave transmitters, each with a 40 kW output. The new transmitters, representing the results of lengthy development, had to comply fully with the following requirements: telephone output 40 kW[2]; maximum frequency stability; modulation 80 per cent.; and rapid wavelength change-over. The first requirement not only involves a valve problem, but also a question of circuit practice and construction from a high frequency aspect. In the short-wave range, the most favourable waves are close together. In order, therefore, to avoid mutual interference, it is of great importance that the theoretical frequency of the transmitter be maintained as accurately as possible. For this reason, the new transmitters, each of which has 7 stages, were equipped with quartz control at a frequency precision of 10^{-6}. Tests made thus far have shown that the new transmitters, in consequence of their ample output when class B amplifiers are used, permit of a modulation of nearly 100 per cent.

A medium-wave broadcast transmitter operates uninterruptedly on the same wave length with the same antenna. In the case of short-wave transmitters, on the other hand, the antenna and wave are often changed during the day. In order to facilitate tuning, the new transmitters are constructed with duplicate tuning equipment. While the transmitter is operating on one wave, the other tuning equipment is prepared for the next wave. The switching-over period, which in the case of older short-wave transmitters takes from 20 to 30 minutes, is thus decreased to seconds.

The output stages of the short-wave transmitter have water-cooled valves. An extensive cooling system with a large number of pumps, copper-pipe cooling coils and enormous water-conditioning tanks ensures the necessary cooling water supply at all times.

The four short-wave transmitters form the centre of a directional antenna system. The antenna systems radiate electric waves to North, Central and South America, to Africa and to South and East Asia. In order to obtain the most favourable conditions for short-wave transmission, depending on the time of the year and the day, two or three waves must be provided for each direction.

The distributor-amplifier, developed by Lorenz in co-operation with the Reichs-Rundfunk-Gesellschaft, was also installed for the Olympic Games. In the case of high-power transmission the plurality of microphones used in connection with broadcasting and tone films often causes interference. As a result of the arrangement of the technical equipment, architectural problems were encountered; and further, conflicting technical requirements were

Olympic Transmitter at Garmisch-Partenkirchen with the Lorenz Speech Input Amplifier (*V* 35).

[2] According to the recommendations of the C.C.I.R., the term telephone output should be understood to mean antenna-output in the case of non-modulated transmitters.

difficult to avoid. As a general rule, therefore, only two microphones, a main pair and a reserve pair, were used; and distributor-amplifiers were installed for supplying the individual amplifier equipment of all the connected sound transmission and sound recording systems.

To avoid interference as far as possible, these amplifiers were constructed with special care and with high grade components. A separate spare amplifier was also provided, each amplifier having duplicate batteries for filament and plate currents, so that uninterrupted transmission and maximum possible reliability were secured.

A convenient monitoring control at the individual outputs of the distributor amplifier was provided by an amplifier stage equipped with head telephones. A step-by-step switch was used for the necessary switching operations. The "O" stage was shunted over a 200 ohm resistance so that the listener might control the operation of the monitoring stage.

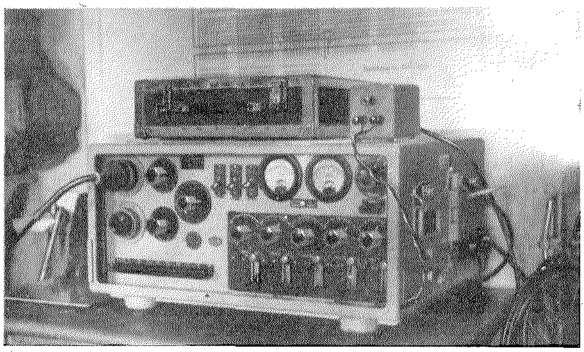
The whole amplifier was installed in a chassis consisting of a frame and front plate. The chassis was inserted in a light weight metal case projecting beyond the front plate and thus protecting components mounted on the latter. The batteries were housed in a second similar

Olympic Transmitter Hut at Garmisch-Partenkirchen.

case made of iron sheeting to resist corrosion from the caustic potash contained in the Edison batteries.

Of special interest was the introduction of a Lorenz commentator's transmitter which the announcer carried about with him. Commentaries were transmitted to a conveniently placed receiver, and then conveyed to a transmitter or recorded on gramophone records. Practically all communications could be conveyed to the broadcasting system by means of such commentators' transmitters.

In the Olympic Games held in Berlin, the



Lorenz Distributor Amplifier.

"steel sound car" of the Reichs-Rundfunk-Gesellschaft, equipped with two Lorenz steel-tone tape machines for recording and subsequent transmission purposes, was utilized. For the Winter Olympic Games at Garmisch-Partenkirchen, Lorenz provided a steel-tone tape machine for use in connection with the Bob Sleigh Track. Events in this section, therefore, could be announced quickly and satisfactorily at other points, such as at the Ice-stadium and the Ski Jumping ground.[3]

This steel-tone tape machine, developed by Lorenz to a high degree of perfection, was installed at a control tower on the Bob Sleigh Track, and was operated through a microphone by an observer in the tower. During intervals between events, the record on the steel tape was reproduced at the Ice-stadium and Ski Jumping ground by loudspeakers.

Lorenz steel-tone wire machines, called "Textophones," were installed in the office of the Organization Committee in the Hardenbergstrasse, in the Schillersäle, in the Deutschlandhalle, in the Sports House and, particularly, for the National Sports Organizer, Herr von Tschammer und Osten, and in the National Sports Field.

During the Olympic Winter Games in

[3] See *Electrical Communication,* "The New Steel Tone Tape Machine," Vol. 15, No. 1, p. 62.

Garmisch-Partenkirchen, "Textophones" were used by the Olympic Committee and proved highly satisfactory. They enabled all the Sports Organisers to furnish their colleagues with necessary instructions regarding individual arrangements over ordinary telephone lines. The machines also were especially useful in recording important conversations for certain persons who were temporarily absent.

A "Textophone" switchboard, which consisted of a combination of several "Textophone" machines with a switchboard connected in parallel to the exchange lines, was installed in the Hardenbergstrasse in Berlin. It was thus possible also to record urgent telephone messages for an absent subscriber. On his return he could listen to the conversation direct from the machine ; or, if it were known that his absence would be prolonged, the conversation could be recorded from the machine by a typist in written form.

In addition to these "Textophone" exchanges, whereby it was possible to record conversations from ten exchange lines, important members of the Organization Committee had "Textophone" machines connected to the telephone as a substitute for a second receiver. Telephone conversations could consequently be recorded on the steel wire. With the aid of the "Textophone" every important telephone conversation could thus be recorded and listened to again at any desired time.

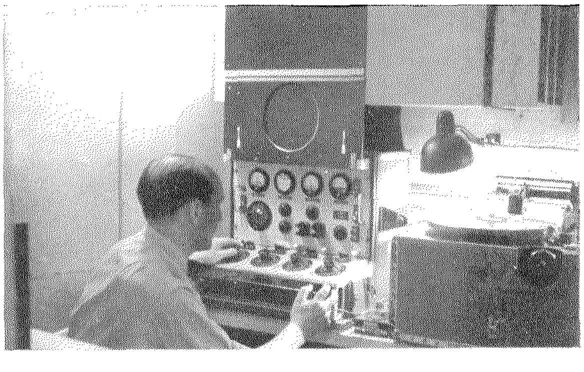
For quicker reference to any individual conversation or dictation recorded on the "Textophone" wire, the time of such conversation or dictation is marked on a ruler-type writing block on the right-hand side of the coil carrier. The edge of the block is also correspondingly subdivided in twenty minute intervals. The return to the desired listening point occupies only a very short time, inasmuch as the wire reversing operation is twice as fast as the forward movement during recording.

The "Textophone" control set can be in a separate room from the recording apparatus. It consists of a small desk type cabinet with 5 push buttons, a table microphone and a special control headphone.

The listening set itself is preferably set up close to the "Textophone." Associated therewith is a switch box with 3 keys, a volume regulator and a pair of headphones. For listening to the recorded text, the switch which is marked accordingly is thrown to "Listening Position." The indicator signal at the control station then drops out of sight, indicating that the set is no longer connected with the "Textophone." The key marked "W" (Reproduction) is then pressed and the volume adjusted to the required degree by a knob. During the recording process, the sound carrier movement of the "Textophone" is disconnected. This is accomplished at the listening point by pressing the key marked "H" (Stop). The special wire used as a sound carrier then runs back a little way so that, during further listening, by pressing down the key "W," the last part of the recorded text is repeated, thus aiding in securing continuity of the text.

The foregoing indicates the extent to which C. Lorenz, A.G., participated in providing communication facilities on the occasion of the Olympic Games in Berlin and in Garmisch-Partenkirchen. As a result of high standards of development in the communication field, Lorenz were able to provide high grade apparatus and equipment in the great numbers required within a comparatively short time, thus contributing to the success of an outstanding achievement.

Acknowledgment is due to the Press Agent of the IVth Olympic Winter Games in Garmisch-Partenkirchen and to the Organization Committee of the XIth Olympic Games in Berlin, for expressions of appreciation to C. Lorenz, A.G., emphasising the satisfactory operation of the Lorenz Communication Equipment.



Lorenz Speech Input Amplifier (V35) for Gramophone Recording Reception in the National Sports Field, Berlin.

The Carrier Telephone and Telegraph Equipment of the New Bass Strait Submarine Cable System

By F. RALPH, B.Sc., A.M.I.E.E., and R. L. HUGHES, B.Sc., A.M.I.E.E.,

Standard Telephones and Cables, Limited, London, England

The submarine telephone cable system between the Australian Mainland and the island State of Tasmania is described. The cables are of the type employing a single non-loaded central conductor with coaxial return. Six telephone circuits and a programme circuit are provided together with telegraph facilities. The terminal and intermediate circuits and equipment are described, and the land line extensions on the mainland and in Tasmania are dealt with. The system represents the first case in which reversed feedback type amplifiers have been used in commercial practice. Overall transmission results are given.

Introduction

THE first public telephone service between the mainland of Australia and Tasmania was inaugurated on March 25, 1936, by the Prime Minister of the Commonwealth, the

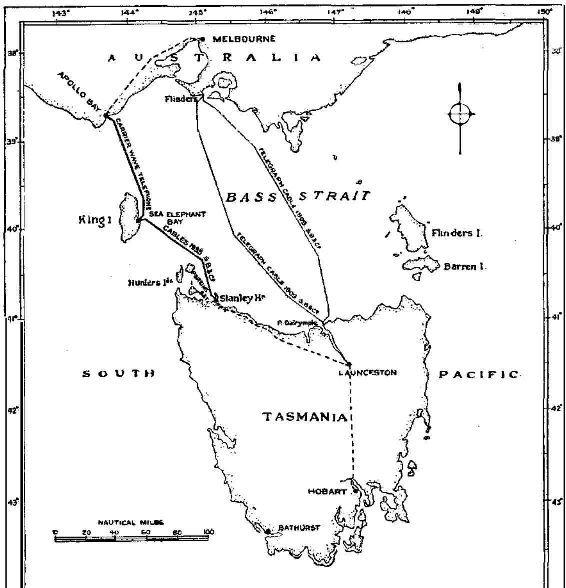


Fig. 1—Map of Route.

Rt. Hon. J. A. Lyons, M.P., who declared the service open in an address from Canberra, which was transmitted to Tasmania over the new cable and broadcast throughout the Commonwealth.

The need for telephone communication between Tasmania and the mainland had been keenly felt for many years, but in spite of its desirability, having regard to the telephone facilities existing between the other States of the Commonwealth, technical difficulties had hitherto made its realisation at a reasonable cost impracticable.

The number of channels of communication which it was estimated would be required would have made the use of radio channels expensive, both in initial and maintenance costs, while considerations of fading and the need for secrecy were important factors.

As the shortest practicable routes for a direct cable were of the order of 145 nautical miles, and the depths rendered the use of a multiconductor lead-covered cable inadvisable, the problem of providing a number of channels by means of a cable was a considerable one. In recent years, however, improvements in the dielectric materials used in submarine cables have made it possible so to improve the transmission properties of such cables at high frequencies that the Bass Strait problem was brought within the practicable economic range. It was finally decided to employ a submarine cable to provide the desired facilities; also, to lay the cable on a route calling at King Island, about half-way between the mainland and Tasmania, and by establishing a repeater station on the island, to increase the total number of communication channels obtainable and, at the same time, to provide a telephone service for the population of King Island.

Tenders were called for and the system designed by Standard Telephones and Cables, Ltd., was accepted, arrangements being made for the cable to be provided by Siemens Bros.

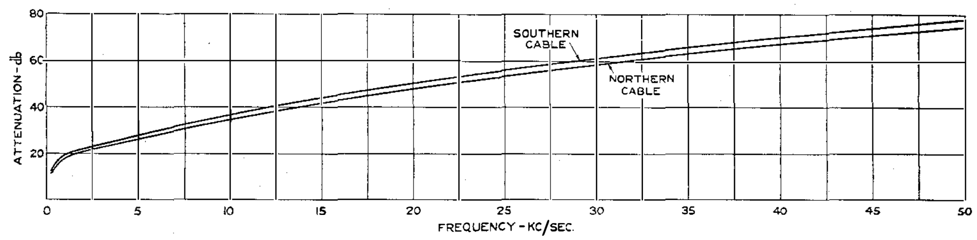


Fig. 2—Attenuation-Frequency Characteristics of Cable Sections.

to the design necessary for this system. The present article describes the system and the equipment supplied by Standard Telephones and Cables, Ltd., to provide the extensive communication facilities required on the cables and associated land line extensions.

Fig. 1 shows the route followed by the complete system. It is of interest to note that the submarine cable system is longer, and is operated with higher frequencies than any other submarine telephone cable system in the world.

Cable Route

The two cable sections are laid as follows. The first or northern section runs from Apollo Bay, on the coast of Victoria, to Naracoopa (Sea Elephant Bay) on the East coast of King Island. The southern section runs from Sea Elephant Bay to Perkins Bay, near Stanley, on the North-West coast of Tasmania.

The laid lengths of the two cable sections are :

Northern Section =78.92 nautical miles.
Southern Section =82.05 nautical miles.

Type of Cable

The type of cable employed is similar in general design to the Key West-Havana No. 4 cable[1] consisting of a single central insulated conductor with a coaxial uninsulated return conductor. No loading is used.

This type of cable is intended for the transmission, without excessive attenuation, of a wide range of frequencies such as are employed on carrier telephone and telegraph systems. The attenuation-frequency characteristics of the two cable sections are shown in Fig. 2.

[1] "A New Key West-Havana Carrier Telephone Cable," by H. A. Affel, W. S. Gorton and R. W. Chestnut, *Bell System Technical Journal*, April, 1932.

Circuit Requirements

The total circuit requirements on the submarine cable were as shown in Table I.

TABLE I

Type of Communication Channel.	No. of Circuits Required.
Duplex Telephone	5
Duplex Telegraph (capable of a speed of 50 bauds)	7
Broadcast Programme (one way but reversible in direction of transmission) (Range 35 to 7000 p : s) ..	1

All of the communication channels were to be extended to Melbourne on the mainland and to Launceston in Tasmania ; at the Tasmanian end some channels were to be extended still further to Hobart.

Some only of the ultimate number of circuits were required initially, traffic estimates having suggested that the full number would not be needed until about 1940.

Table II shows the terminating points for the various circuits required for the initial installation and also for those to be provided later.

Further requirements, which cannot be readily indicated in a table, were as follows :

(1) With regard to the broadcast programme channel between Melbourne and Hobart, it was specified that Launceston should have access, for local use, to programmes passing in either direction, and alternatively should be able to transmit Launceston programmes to Melbourne and Hobart simultaneously, thus forming, as it were, a triangular system in which any one of the three stations could transmit simultaneously to the other two.

(2) One of the telephone channels between Melbourne and Launceston was to be arranged

so that Currie, on the West coast of King Island, should be an intermediate station—Currie to be provided with facilities for using the Melbourne-Currie and Currie-Launceston sections simultaneously.

CHOICE OF METHOD OF MEETING CIRCUIT REQUIREMENTS IN THE CABLE

In examining alternative methods by which the above circuit requirements could be met over the route as a whole, the following were important factors of which it was necessary to take account:

(*a*) In view of the high cost of submarine cables, it was important that the frequency spectrum available for transmission should be exploited as fully as possible. As the number of communication channels to be provided was fixed, this problem, therefore, resolved itself into the provision of these channels in the smallest possible frequency range, thus leaving as much as possible of the total usable range free for later exploitation as traffic requirements might demand.

(*b*) The frequency bands employed by any carrier telephone or telegraph systems operated on the land line sections of the routes must be such as to co-ordinate suitably with systems already in use or likely to be used over part or all of the same pole routes, so as to avoid excessive inter-system crosstalk.

(*c*) For economic reasons it was important that the equipment should be so far as possible of standard design, although this aspect could not be subordinated unduly to the broader issues covered by (*a*) above.

An important technical factor affecting the choice of a method of operation over the submarine cable, was the degree of uniformity which could be economically obtained in the characteristic impedance of the cable. When carrier channels are operated on open wire lines, it is not, in general, possible to employ the same frequency band in both directions owing to unavoidable irregularities in line construction, and variability due to weather changes rendering balance conditions and freedom from crosstalk impracticable.

TABLE II

	Type of Communication Channel.	Melbourne-Launceston.	Melbourne-Hobart.	Total.
Initial Installation	Duplex Telephone	3	–	3
	Duplex Telegraph	3	2	5
	Broadcast Programme (reversible channel)	–	1	1
Later Additional Installation	Duplex Telephone	–	2	2
	Duplex Telegraph	1	1	2

In the case of a submarine cable of the type employed in the present system, however, it is possible, by suitable methods of manufacture, to produce a cable whose impedance-frequency characteristic is very smooth, so that a network may be devised to give a high degree of balance over a wide frequency range. Furthermore, as the temperature at sea bottom does not vary greatly from time to time, a cable well constructed from stable materials may be expected to exhibit very stable electrical properties; and a high degree of impedance balance, once achieved, should endure within close limits, for a long period.

The degree of balance required to permit of balanced operation is, of course, a function of the attenuation of the cable and hence, in a given cable, of the operating frequency. In a given case, therefore, the degree and stability of balance obtainable will determine the frequency range over which balanced operation is possible.

In the present case it appeared that, for design purposes, balanced operation might be assumed to be possible at all frequencies up to approximately 10 kilocycles per second. Above 10 kc.

all duplex channels would require different frequency bands for the two directions of transmission.

From the above considerations, it was clearly uneconomic to employ any part of the frequency range below 10 kc. for the broadcast programme channel, since only a unidirectional channel was required and the advantages of balancing the cable impedance would be wasted.

The following further points arise from a consideration of the circuit requirements:

(1) The number of telegraph channels required is such that they clearly cannot be provided by direct current circuits, so that either high frequency carrier telegraph channels must be employed or a voice frequency carrier telegraph system must be operated over a carrier telephone channel. The latter alternative is much the more economical in the frequency band required, owing to the simplification of the filtering problem. This scheme was, therefore, chosen, and the number of telephone channels to be provided was increased from five to six.

(2) As only one telephone channel was to be available at King Island, the natural one to select was the voice frequency channel, using the normal commercial range from say, 200 p : s to 2800 p : s, thus avoiding the use of modulators and demodulators at this station.

Allocation of Frequency Bands

In the frequency range below 10 kc. it is possible to obtain three telephone channel bands of commercial width; and, operating on a balanced or "two-wire" basis, these bands will provide three duplex channels (one of which is, of course, the voice frequency or physical channel).

Six other channel bands, giving three duplex channels with different frequency bands for the two directions of transmission, may be located between 10 and 31 kc., giving the required total of six telephone channels below 31 kc.

At the time at which the Tasmanian Cable scheme was designed, a carrier system for the unidirectional transmission of broadcast pro-

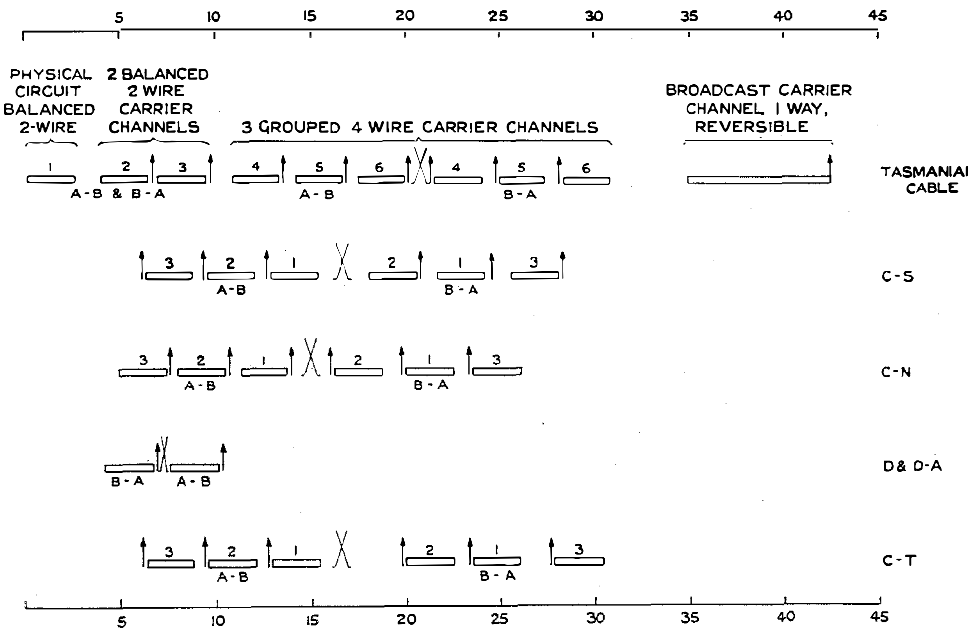


Fig. 3—Frequency Allocation Diagram of Cable Equipment and Relationship to Standardised Land Line Systems Already in Use in Australia.

grammes had already been standardised. This system employs a frequency band extending from 34 to 42.5 kc., and therefore fits in naturally and economically with the above allocation of telephone channel bands.

It was, therefore, apparent that such an allocation of frequency bands would represent the maximum economy in the utilisation of the available transmission range of the cable. This frequency bands employed by systems operating on that route are so arranged that excessive inter-system crosstalk does not occur. The systems most commonly used in Australia employ the frequency bands used in the "Standard" systems types "D" and "D.A." (single channel) and "C-N," "C-S," "C-T" (three channel). The frequency bands employed by these systems are shown in Fig. 3 in relation to those already

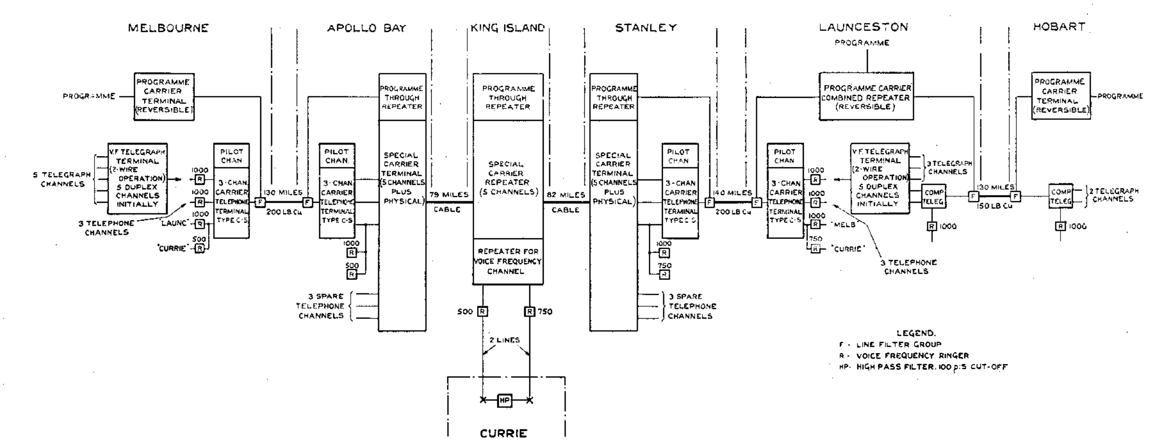


Fig. 4—General Diagram of Transmission System.

allocation of bands is shown diagrammatically in the top line of Fig. 3.

Co-ordination with Standardised Land Line Systems

It would seem, at first sight, that the channels in the cable could be extended to Melbourne and Launceston by land line without any change of the carrier frequencies. The "go" and "return" sides of the balanced cable channels would, of course, have to be carried in separate open wire pairs as it is not practicable to work balanced channels on open wire lines. The use of the same carrier frequencies throughout was, however, ruled out for the following reasons. Carrier telephone systems of various types are already in extensive use throughout the Commonwealth, and in order that such systems may be utilised to the fullest possible extent on a given pole route, care is necessary in planning installations to ensure that the referred to for the cable equipment. From this diagram there are clearly two features of the proposed frequency allocation for the cable equipment which render it an unsuitable one for co-ordination with systems of existing design.

Firstly, the bands of the two balanced carrier channels coincide fairly closely with those of the single channel systems, and as the cable equipment would employ both these frequency bands in both directions, serious mutual crosstalk would occur. As there were such systems already operating between Melbourne and Geelong on the Melbourne-Apollo Bay route, this was an important factor.

Secondly, the upper channel of the "A to B" group of the cable frequencies coincides approximately with, and is transmitted in the opposite direction to, that of the lowest channel of the "B-A" group of the C-S and C-N system. This also would lead to serious crosstalk.

It is clear that no rearrangement of the frequency bands of the cable equipment could possibly avoid these crosstalk difficulties without reducing the number of channels obtainable.

General Scheme Finally Adopted

It was therefore decided to employ for the cable section of the route the general arrangement of channels already shown in Fig. 3 and to install terminal equipment (modulators, demodulators, channel band filters, etc.) at Apollo Bay and Stanley so as to make this section of the whole system complete in itself. Extension of the channels from Apollo Bay to Melbourne and from Stanley to Launceston and Hobart could then be achieved by using standard land-line carrier systems such as were already in extensive use in the Commonwealth. The choice of the particular systems to be used could then be made entirely on the basis of the requirements of the particular land line routes.

This scheme offered the further advantage of great flexibility, since at a later date the equipment on the land line sections of the route could be modified as general developments might demand, without in any way affecting the equipment on the submarine cable.

Fig. 3 indicates the actual band used for each direction of transmission on each of the six channels in the cable system. It will be observed that the balanced channels and the lower group employ the lower sideband. The use of the lower sideband rather than the upper is desirable for channel No. 2 as it prevents certain third- and fourth-order products of modulation from occurring within the range of the transmitted sideband.

A general examination of the frequency distribution of inter-channel modulation products, such as would be produced by an overload condition in a common amplifier, showed that little, if anything, was to be gained by a special allocation of the bands to individual channels. The upper sideband was chosen for the upper group as the maximum carrier frequency to be used was thereby slightly reduced.

The land-line system chosen in each case to provide the initial three through circuits was the type C-S three-channel system inasmuch as it may be operated on the same route as a type D system. For the later extension to six channels, type C-T systems will be used. The carrier programme system operates on the same pair of wires as the three channel system and is provided with straightforward reversible repeaters at the three cable stations.

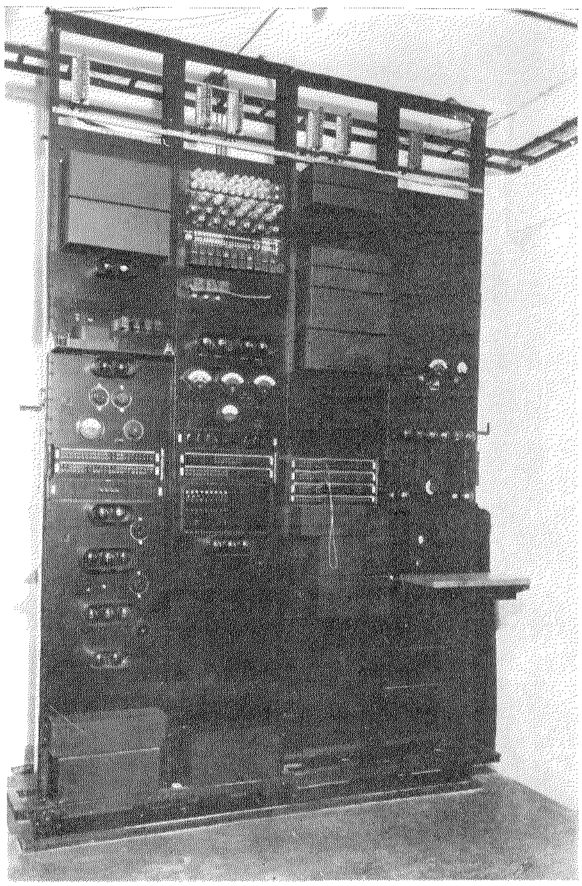


Fig. 5—Programme Carrier Terminal, Melbourne.

Fig. 4 shows the general scheme as finally planned for the initial installation. To simplify the ultimate extension of facilities the full number of six channels was provided initially on the submarine cable section of the route.

It will be observed that no use is made of the physical circuits on the land line sections of the route. These circuits were in fact already in use for purposes outside the present scheme.

Signalling Facilities

The carrier terminals at Melbourne and Launceston are equipped with the usual type of 17–1000 p : s interrupted voice-frequency ringers. In the case of the channel looped to

Currie, however, some selective ringing scheme was necessary. That adopted was as follows:

At Melbourne, this channel was equipped with two voice frequency ringers, employing frequencies of 1000 p : s and 500 p : s. On the side facing the carrier terminal (i.e., the voice frequency side) the two ringers were connected in parallel, but on the local or 17 p : s side the two ringers were led through separate pairs to jacks on the trunk switchboard, labelled "Launceston" and "Currie" respectively.

At Launceston, two ringers operating on frequencies of 1000 p : s and 750 p : s were similarly arranged.

At King Island repeater station, a 500 p : s ringer was included in the Melbourne side of the voice frequency loop to Currie, and a 750 p : s ringer in the Launceston side. On the Currie switchboard the two pairs of the loop terminate on separate jacks, labelled "Melbourne" and "Launceston," respectively, the jacks being normally connected through to each other to complete the through circuit. Thus Melbourne, for example, can ring Currie or Launceston as required by applying 17 p : s ringing current to the appropriate switchboard jack, operating either the 500 or 1000 p : s ringer. The two ringers at King Island are prevented from operating one another with 17 p : s current by the inclusion of a 100 p : s high pass filter between the switchboard jacks at Currie.

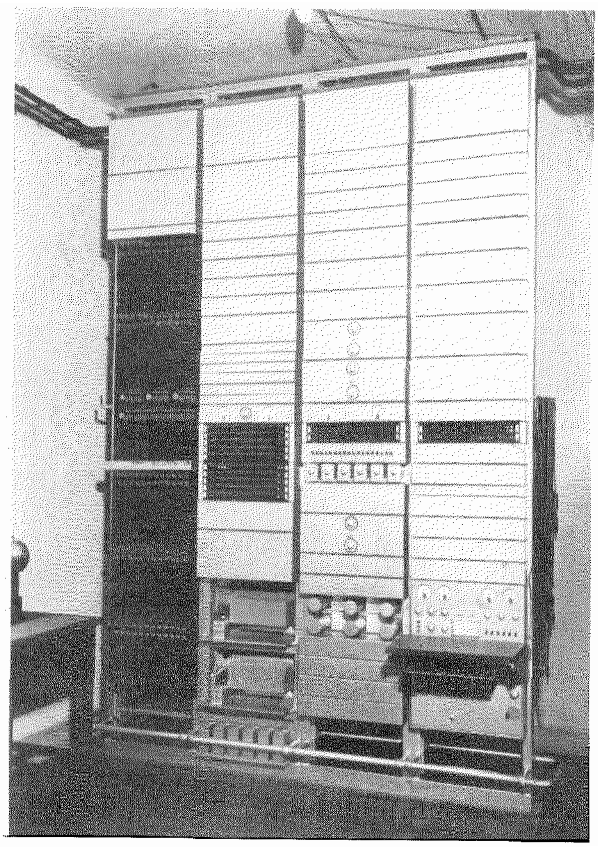


Fig. 6—V.F. Telegraph Terminal, Melbourne.

In order to provide suitable communication facilities between all stations along the route, similar ringers to those at Melbourne and Launceston were equipped at Apollo Bay and Stanley, respectively. These ringers were arranged with their voice frequency sides bridged across the physical circuit of the cable, suitable keys being arranged for ringing in either direction with the appropriate frequency. A delay circuit was used to prevent a normal short ring, such as occurs during traffic, from calling in the maintenance staff. A simple coded ring must be applied when it is desired to operate the calling devices at the repeater stations.

The ringers at Apollo Bay and Stanley were arranged so that they could be readily converted to operate as terminal ringers if it were desired to terminate the physical cable circuit at either or both of the cable terminal stations.

As the traffic on the circuits has proved to be heavier than anticipated, it has, in fact, been found desirable to employ three of the carrier channels in the cable for the through circuits, and to terminate the physical cable circuit at Stanley, the other end being temporarily extended from Apollo Bay to Melbourne via a separate single channel carrier system. For this purpose, the selective ringing equipment at Melbourne has been transferred to the single channel system.

There are at present, therefore, three through circuits from Melbourne to Launceston (one of which is in fact normally extended to Hobart by means of a single channel carrier system), and one circuit from Melbourne to Stanley, serving North-West Tasmania—this circuit being also available at Currie. As these modifications are to some extent temporary ones made as a result of traffic requirements,

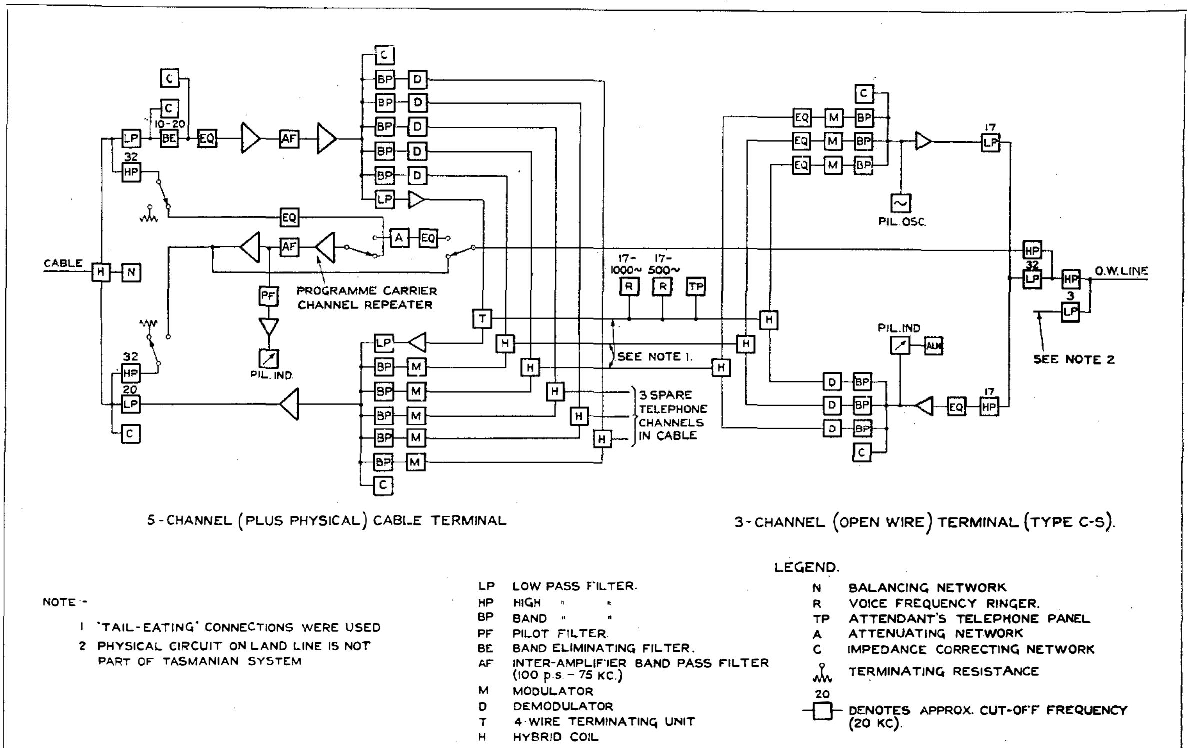


Fig. 7—Block Schematic—Stanley.

and may be subject to further change as circumstances demand, no further reference is made to them and the description is restricted to the system as originally planned.

Extension of Telegraph Channels from Launceston to Hobart

The number of telegraph channels to be extended to Hobart was not considered sufficiently large to warrant the use of voice frequency operation, and it was decided to obtain these channels by means of composite circuits derived from an existing physical telephone circuit. The actual line used, as indicated in Fig. 4, is the same as that employed for the programme carrier channel.

LAND LINE EQUIPMENT

3-Channel Systems

Except for minor modifications, the two type C-S three-channel carrier telephone systems are of standard design. Each system is supplied with pilot channel equipment for its own particular section of the route in order to facilitate the maintenance of a suitable transmission equivalent under varying weather conditions.

As the attenuation of the submarine cable is not liable to short period changes, no pilot equipment was considered necessary over this section.

Programme Carrier System

This system is similar to that described in an earlier issue of *Electrical Communication.*[2] Briefly, it is a single-sideband suppressed-carrier system, employing the lower sideband of a carrier frequency of 42.5 kc. A feature of the system is that a pilot frequency of four-fifths of the carrier frequency, i.e., 34 kc., is employed not only to indicate changes in transmission equivalent but also to maintain synchronism between the carrier frequency oscillators at the transmitting and receiving stations.

The equipment at Launceston is capable of operating either as a receiving repeater or as a terminal transmitting simultaneously in both

[2] "The Standard Carrier Broadcast System," by K. G. Hodgson, F. Ralph and B. B. Jacobsen, *Electrical Communication*, January, 1935.

directions, and thus provides the facilities outlined previously.

Fig. 5 is a view of the Melbourne Programme Carrier terminal, together with the heterodyne oscillator and volume indicator used for maintenance purposes.

Voice Frequency Telegraph Equipment

This equipment operates on any one of the channels between Melbourne and Launceston. Its design follows the general lines of the 18-channel system widely used by the British Post Office,[3] the carrier frequencies employed being odd harmonics of 60 p : s. The system used in the present scheme differs from the standard system in the following respects :

(1) In order that it shall be capable of operating on either a "grouped" or a "balanced" channel in the submarine cable, the system is arranged for operation on a two-wire basis, and employs different voice frequencies in the two directions of transmission.

The system is initially equipped for five duplex channels, but is wired for eight channels.

(2) Different methods of carrier current supply are used at Melbourne and Launceston. At Melbourne, carrier current supply is obtained in the standard manner from a multi-frequency motor-generator set operating from a 24-volt battery. The carrier frequency generator is designed to supply up to ten 18-channel systems ; and, as it is not likely that there will be a large extension of voice frequency telegraph systems at Launceston, this terminal is equipped with valve oscillators for its carrier frequency supplies.

Telegraph distortion measuring equipment is supplied at both stations.

Fig. 6 is a view of the equipment at Melbourne. The distortion measuring set is seen at the bottom of the right-hand bay. The Launceston equipment consists of two bays only.

Composite Telegraph Equipment

This equipment, accommodated on a single 10 ft. 6 in. rack at Launceston and Hobart, provides initially two duplex direct-current channels over one pair of wires with earth return. Provision is made for later extension to four duplex channels.

[3] "A New Voice Frequency Telegraph System," by J. A. H. Lloyd, W. N. Roseway, V. J. Terry and A. W. Montgomery, *Electrical Communication*, April, 1932.

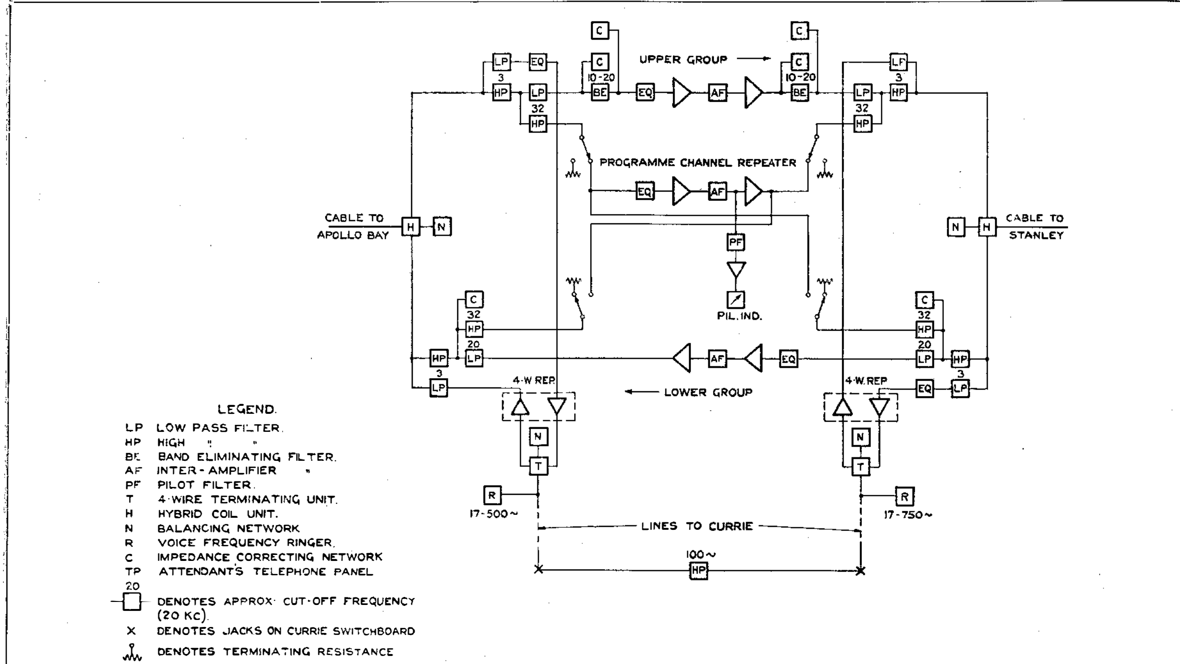


Fig. 8—Block Schematic—King Island.

The local circuits of the two initial channels are directly connected at Launceston to those of two of the channels of the voice frequency system, giving direct working between Melbourne and Hobart.

SUBMARINE CABLE EQUIPMENT

General Considerations

In addition to the general considerations common to all types of multi-channel carrier telephone systems, factors affecting the design of the submarine cable terminal equipment at Apollo Bay and Stanley, and the repeater equipment at King Island, included the following:

(1) The attenuation of each cable section at 42.5 kc. is of the order of 70 decibels and there are two such sections. At 31 kc. the attenuation per section is 60 db and, at 20 kc., it is approximately 50 db. The terminal and repeater gains required were therefore much higher than those necessary on land line carrier systems. It was desirable that the amplifiers used to provide these high gains should be such that their gain was not unduly susceptible to changes in battery supply voltages.

(2) The number of telephone channels contemplated, if handled by amplifiers common to all channels, called for amplifiers having considerable power handling capacity with low

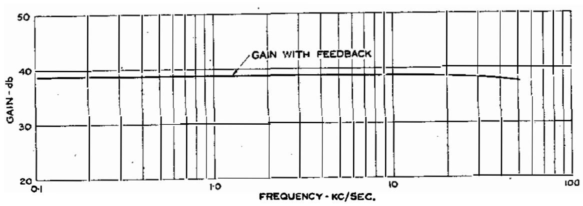


Fig. 9—Gain Frequency Curves of Reversed Feedback Amplifier.

harmonic distortion, in order to avoid interchannel crosstalk due to intermodulation.

(3) The use of a combination of balanced and grouped channels necessitated a hybrid coil unit which would carry all channels at the required power level without producing objectionable intermodulation products. The combination of the two types of channel also resulted in some complication of the directional filtering problem.

(4) The large differences between transmitted and received levels called for some care in the disposition and screening of apparatus on the bays, and in the layout of wiring between bays. Care was also necessary to prevent coupling between units via their respective battery supply circuits. The desirability of bringing

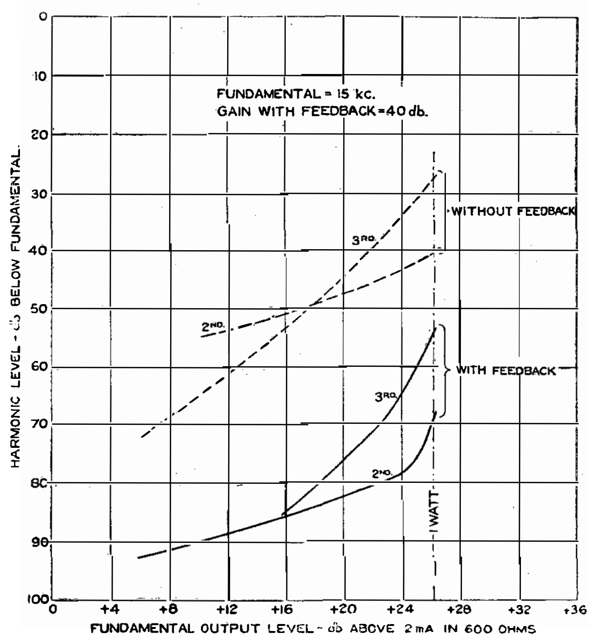


Fig. 10—Harmonic Levels in Reversed Feedback Amplifier.

these circuits in close proximity to one another for convenience in checking plate and filament currents contributed to this problem.

(5) It was necessary to devise a suitable electrical configuration for the network used to balance the impedance of the cable and to arrange this unit in a form which was mechanically convenient for the final accurate adjustments to be made. As in all cases the cable was brought directly into the repeater station, a suitable unit on which to terminate it was required.

(6) Some form of level limiting device was necessary to prevent abnormal speech input levels on one or more channels from producing overloads and consequent crosstalk in common amplifiers. This was of particular importance in view of the use of voice frequency telegraphs on one of the channels, as interference on such channels would produce incorrect signals.

(7) The problem of designing equalisers to correct for the attenuation-frequency charac-

teristics of the cables and having a suitable latitude of adjustment for final setting in the field was one of some importance. The difficulty of forecasting exactly the attenuation of the laid cable at the lower frequencies was a factor here.

The circuits and equipment at the cable stations will now be described and discussed in relation to the above design factors.

Transmission Circuit at Stanley and Apollo Bay

The complete transmission circuit of the equipment at Stanley is shown diagrammatically in Fig. 7. That at Apollo Bay is identical except for the disposition of certain filters affected by the different frequencies employed in the two directions of transmission.

Considering this diagram first in relation to transmission on the telephone channels in the direction from land line to cable, the voice frequency band, the programme carrier channel band and the carrier telephone sidebands are first separated by two sets of high- and low-pass filters. The telephone channel sidebands then pass through the receiving side of the 3-channel C-S carrier terminal. An equaliser, common to all channels, is included to compensate for the attenuation-frequency characteristic of the line. The hybrid coils of two of the three channels are connected to similar hybrid coils of two of the channels on the cable carrier terminal. The third is connected to a four-wire terminating set associated with the physical or voice frequency channel in the cable. The connections are arranged to give what has been referred to as a "tail-eating" connection in each case. That is, the "line" and "net" sides of the hybrid coil of the C-S system are joined respectively to the "line" and "net" sides of the corresponding hybrid coil (or four-wire terminating set) of the cable system. In this manner if the "line" and "net" connections are arranged in suitable phase relationship, all the energy output of a demodulator of one system is, in the ideal case, transferred to the input circuit of the corresponding modulator of the other. This gives effectively a four-wire connection between the two channels and avoids the three decibel loss normally associated with each hybrid coil.

In the cable equipment, speech from the hybrid coils passes via modulators to band filters which select the required side-band. The cable system, like the C-S system, employs the single sideband and suppressed carrier principles, the modulators and band filters being of a similar type in both systems.

For the physical circuit, an amplifier, which is in fact half of a standard four-wire repeater panel, takes the place of a modulator, and a low-pass filter that of a band pass filter.

All channels, including the physical channel, then pass via a common transmitting amplifier to the output filter group. The transmitting amplifier is of the reversed feedback type and is described later.

Stanley is arranged to transmit the lower group of frequencies for the grouped channels, and so all the channel bands lie below approximately 20 kc. The transmitting group output filter is, therefore, a low-pass filter with a cut-off frequency of approximately 20 kc. From this filter the sidebands pass via a hybrid coil unit to the submarine cable.

In parallel with the low-pass filter is a high-pass filter, with a cut-off frequency of approximately 32 kc., through which the programme system sideband is applied to the hybrid coil when this system is operating in the direction from land-line to cable.

On the receiving side, Stanley receives the upper group of sidebands, together with the sidebands of the two balanced carrier channels and the voice frequency band.

These bands are first separated from the programme sideband by a high- and low-pass filter group having a cut-off frequency of 32 kc. The telephone channel sidebands then pass through a band-eliminating filter arranged to pass only frequencies below 10 kc. and above 20 kc. This filter, together with the 20 kc. low-pass filter on the transmitting side of the circuit, serves to provide an adequate singing margin for the station equipment. In determining the attenuation requirements for these filters, both from considerations of singing margin and possible near-end crosstalk due to modulation in the transmitting amplifier, a considerable loss across the cable hybrid coil could be assumed over the frequency range of the grouped channels, since although the hybrid coil balance does not of itself provide a sufficient margin of loss for these channels, its minimum value is nevertheless of the order of 40 decibels.

Compensating networks shown in parallel with the band eliminating network, and with the low-pass (20 kc.) filter, serve to improve the impedance-frequency characteristics of the filters over the transmission range, particularly in the neighbourhood of the cut-off frequencies. For convenience, they take the form of simple band pass filters, terminated in suitable resistances, and having pass bands which coincide with the attenuating range of the filters with which they are associated. This arrangement incidentally results in the impedance-frequency characteristic of the station, as seen from the cable, being much more uniform than would otherwise be the case, as both the transmitting and receiving sides of the equipment present a more or less uniform impedance to the hybrid coil unit at all frequencies lying in the range of the various channels.

It will be observed that the hybrid coil unit is directly adjacent to the cable and its balancing network. As a result, the hybrid coil carries all channels including the programme channel. This necessitates care in the design of the hybrid coil to avoid modulation crosstalk, but offers the great advantage that the problem of balancing a network against the cable is not complicated by the presence of filters between it and the hybrid coil. Effort in network design can, therefore, be concentrated on the reproduction of the impedance characteristic of the cable itself, without the addition of subsidiary networks to balance filters on the cable side.

From the receiving filter group, the sidebands pass through an equaliser compensating for the attenuation-frequency characteristic of the cable and then to the first of two receiving amplifiers operated in tandem. Both these amplifiers are of the reversed feedback type. As on the transmitting side, the receiving amplifiers are common to all channels, including the voice frequency channel. The sidebands are then separated and demodulated in the usual manner and the speech from three of the channels passes to the transmitting side of the land-line system. Immediately preceding each modulator of the land-line system is an equaliser. The need for this equaliser arose as follows. The complete circuit between Melbourne and Launceston consists of three carrier telephone channels in tandem. The gain-frequency characteristic of each of these channels alone is well within generally accepted limits for such

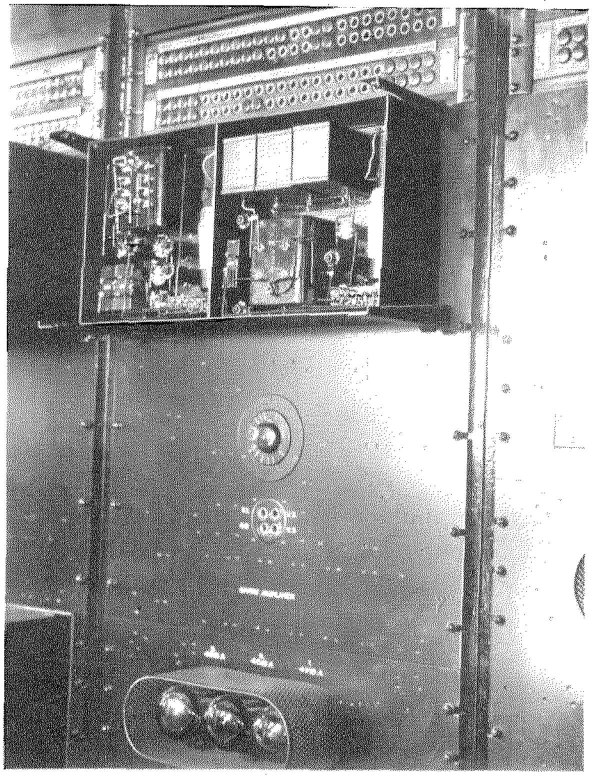


Fig. 11—Front View of Reversed Feedback Amplifier.

channels, and is determined largely by the loss characteristic of the modulator and demodulator band filters at the terminals. When two or more such channels are connected in tandem, the overall transmission characteristic becomes progressively worse and in the present case would not have been satisfactory. The cable system by itself provided a satisfactory margin on the transmission quality limits aimed at for the system as a whole, and it was decided to equalise each channel of the land-line systems so as to make the transmission-frequency characteristics substantially flat over the required frequency range. Such equalisation could most readily be achieved at voice frequencies, and each of the equalisers shown is arranged to compensate both for the loss characteristic of the modulator band filter following it and for that of the demodulator

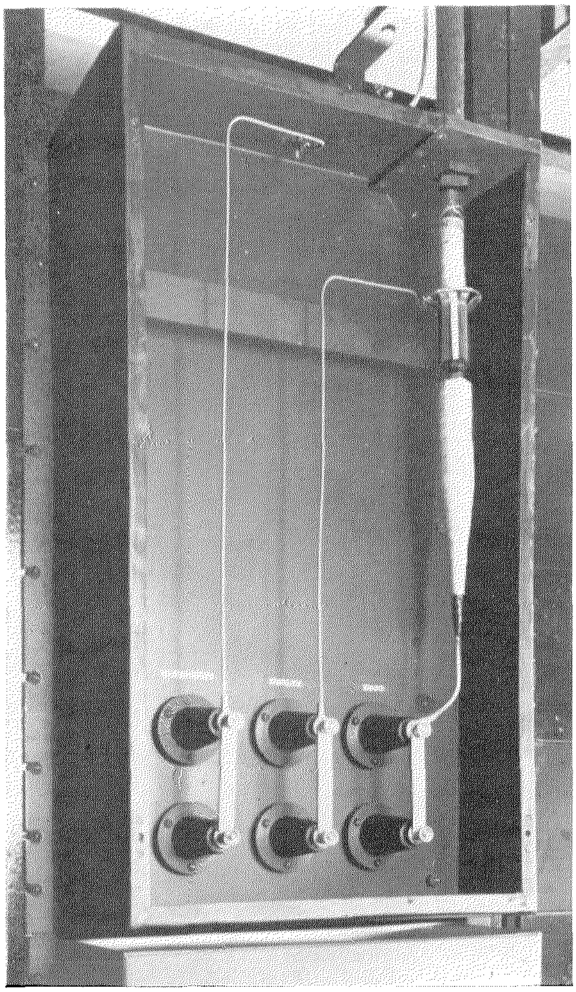


Fig. 12—Front View of Cable Terminating Unit.

band filter at the distant end. The equaliser is described in a later section. Each of the land-line terminals was fitted with equalisers, and similar units could, of course, be used on the cable equipment to obtain still greater improvement in the overall transmission characteristic, but in practice this was unnecessary.

The reversible repeater for the programme carrier channel is shown in Fig. 7, with the directional switching keys set to operate in the direction from cable to land line. From the receiving side of the hybrid coil, the sideband passes via an equaliser to the first of two amplifiers operating in tandem. These amplifiers are again of the reversed feedback type. From the second amplifier the circuit continues via high-pass filters to the land line. The method of operation in the reverse direction is clear from Fig. 7. As the attenuation of the cable is much greater than that of the land line, and the general shape of its attenuation-frequency characteristic is different, separate equalisers are used for the two directions of transmission; the attenuating network "A" is adjusted so that the gain required is approximately the same in both directions. The pilot filter has a very narrow pass band including 34 kc., the pilot frequency. The pilot equipment shown is similar to that at a normal programme-channel repeater station, and is described in an earlier issue of *Electrical Communication* to which reference has already been made.

Transmission Circuit at King Island

The transmission circuit at King Island is shown in block schematic form in Fig. 8.

By comparison with that for Stanley, this diagram is practically self explanatory. It will be observed that the voice frequency channel is amplified separately at King Island, and that the amplification is performed in two stages. This was necessary in order to loop this channel to Currie and to control the levels in the Currie loop.

For the telephone channel repeater, two reversed-feedback amplifiers are operated in tandem, as on the receiving side at Stanley. For the programme channel the arrangements are similar to those at Stanley and Apollo Bay, except that as the two cable sections are of substantially the same length and attenuation, alternative equalisers are not necessary.

GENERAL EQUIPMENT FEATURES

Amplifiers

The amplifier requirements outlined in an earlier paragraph were met by employing amplifiers of the reversed-feedback type described in an article by H. S. Black.[4] Reference should be made to this article for a discussion of the operation of this type of amplifier. The amplifiers used in the present system are generally similar to the example described by Black. This cable system represents the first case in which reversed-feedback type amplifiers have been used in commercial practice. Only two

[4] "Stabilized Feedback Amplifiers," by H. S. Black, *Bell System Technical Journal*, January, 1934.

different types of reversed feedback amplifier were employed. These both employed three valves, giving three stages of amplification, and differed only in the type of valve employed in the output stage. One type, employing a simple triode in the output stage is used as the first or input amplifier when two amplifiers are operated in tandem. The other design embodies an output valve of the coplanar grid type,[5] a feature of which is the large power output obtainable with moderate anode battery voltages. This amplifier is used as the second or output amplifier when two are operated in tandem, and also as the transmitting amplifier at the cable terminal stations. It will give single tone output of approximately one watt with a total harmonic level approximately 55 decibels below the fundamental.

Both types of amplifier have an operating frequency range from 200 to 50,000 p : s and a maximum gain of approximately 50 db. Gain control is effected by means of a potentiometer which varies the extent of the feedback coupling, and the gain may be reduced to 30 db by this means. When lower values of gain are required attenuating pads are included in the input circuit. The gain of the amplifiers without feedback always exceeds 75 db over the above frequency range so that the reduction in gain

[5] "A Study of the Output Power obtained from Vacuum Tubes of Different Types," by H. A. Pidgeon and J. O. McNally, *Proceedings of the Institute of Radio Engineers*, February, 1930.

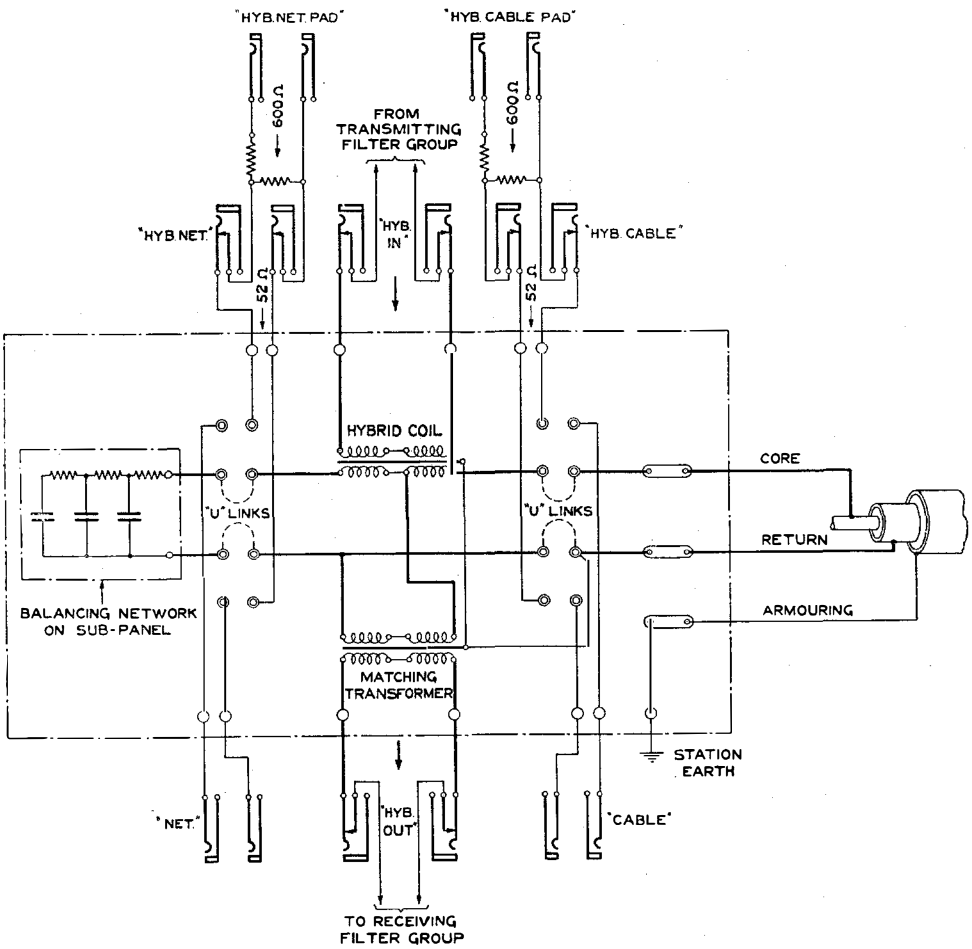


Fig. 13—Circuit of Cable Terminating Unit

due to feedback is always at least 25 db. As shown by Black, a considerable reduction in harmonic distortion and improvement in gain stability with variation in power supply voltages is therefore achieved.

Fig. 9 shows a typical gain frequency curve, for the high level amplifier, i.e., the type employing the coplanar grid valve. The gain with feedback as shown is constant to within ± 0.6 db between 200 and 50,000 p : s.

Fig. 10 shows, for the same amplifier, the variation of second and third harmonic levels with fundamental output, with and without feedback.

Two amplifiers in tandem will give a maximum gain slightly in excess of 100 db. The maximum gain actually employed at any station is approximately 80 decibels.

It will be realised that with such high gains precautions were necessary to prevent distortion or self-oscillation due to coupling effects between input and output circuits of the various amplifiers, and between amplifiers operating in tandem.

Fig. 11 is a front view of one of the high level amplifiers with the covers removed from the screening boxes of the first two stages. The screened grid valves employed in these stages are just visible on the right of each screening box. The output valve is mounted at the rear of the panel.

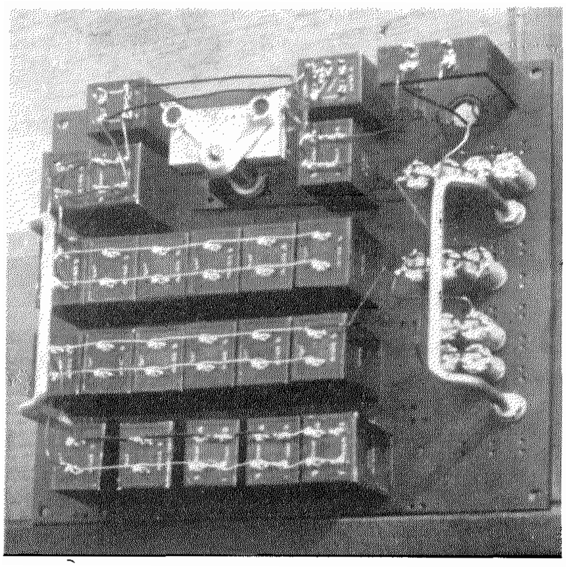


Fig. 14—Balancing Network Sub-panel.

Equalisers

All equalisers are of the constant resistance type, and in general are contained in sealed screening boxes. As the equalisation required could not be accurately predetermined, it was necessary to allow some latitude for adjustment in the field. It was found possible when designing these equalisers to obtain an adequate range of characteristics by varying only resistance components in the networks. Adjustments in the field were therefore made by strapping resistances in accordance with data collected during factory tests. The sealed cases were opened for this purpose and resealed when the final settings were obtained. In the case of equalisers for the programme carrier channel, it was known that a "straight-line" equaliser was required, but the slope was not accurately known. A number of networks of various slopes was therefore provided and the required combination of these could be selected by making connections external to the units themselves.

CABLE TERMINATING UNIT

At all cable stations, the end of the submarine cable is brought into the repeater station and joined directly to the station equipment. After a certain allowance of slack outside the station, the cable is brought up through the floor of the apparatus room and connected to terminals mounted on insulating pillars in a dustproof terminating box. From these terminals the core, return conductor, and armouring are connected via detachable links to the station circuit proper. Fig. 12 shows a front view of this terminating unit with the front cover removed.

The hybrid coil and balancing network, together with the transformer necessary to match the impedance of the terminating circuit to the impedance of 600 ohms presented by the station equipment, are mounted at the back of the unit. The complete circuit of the terminating unit is shown in Fig. 13. It will be observed that with the connections shown, the relatively high transmitting levels produce flux in the core of the hybrid coil, but not in that of the matching transformer. The core of the hybrid coil is therefore made of fairly generous dimensions to avoid intermodulation between channels.

In planning the details of the terminating unit, it was desired to make the hybrid coil, cable and network reasonably accessible for testing, but it was considered inadvisable to include jack contacts in the cable and network for this purpose owing to the danger of the balance being disturbed by faulty contacts. The arrangement shown, employing "U-links," which have generous contact surfaces and can be easily inspected, provides a convenient solution. The jacks shown are mounted on the main jack field of the bay and may be readily connected up as required for test purposes by removing the rear cover of the terminating unit and rearranging the U-links.

The jacks marked "HYB. NET PAD" and "HYB. CABLE PAD" with their associated impedance transforming resistance networks, have been found useful when making local station tests, as a 600 ohm plug serves as a network and the "HYB. CABLE PAD" jacks present the same impedance (600 ohms) as all other portions of the station equipment.

The balancing network is mounted on a separate sub-panel at the back of the terminating unit and is readily detachable for test, adjustment, or replacement by a spare in emergency.

Fig. 14 shows a view of a network sub-panel with its circuit elements strapped ready for insertion on the main panel.

Volume Limiters

The volume limiters employed on the telephone channels to prevent overload and interchannel crosstalk being caused by very loud speech are of a simple type. The primary winding of a transformer is connected in parallel with the transmission circuit at a suitable point in the voice frequency part of the circuit. This transformer has a very high step-up ratio, and across the secondary winding is connected a small neon-filled discharge lamp. The step-up ratio is so arranged that if the peaks of speech exceed a predetermined value, the lamp glows, the shunting effect produced effectively limiting the level in subsequent portions of the circuit. Although it would be imagined, at first sight, that such a device would produce serious distortion effects, tests have shown that in practice this is not the case.

Such a limiter is fitted on each channel of the three channel systems, at a point between the hybrid coil and the modulator. Limiters are also fitted in a similar position on those channels of the cable equipment which will, for the present, remain as spares, so that these channels may be extended without further attention to this problem unless demanded by the nature of the extending circuits themselves. Limiters are also arranged to be included at Currie when the circuit is interrupted at this point.

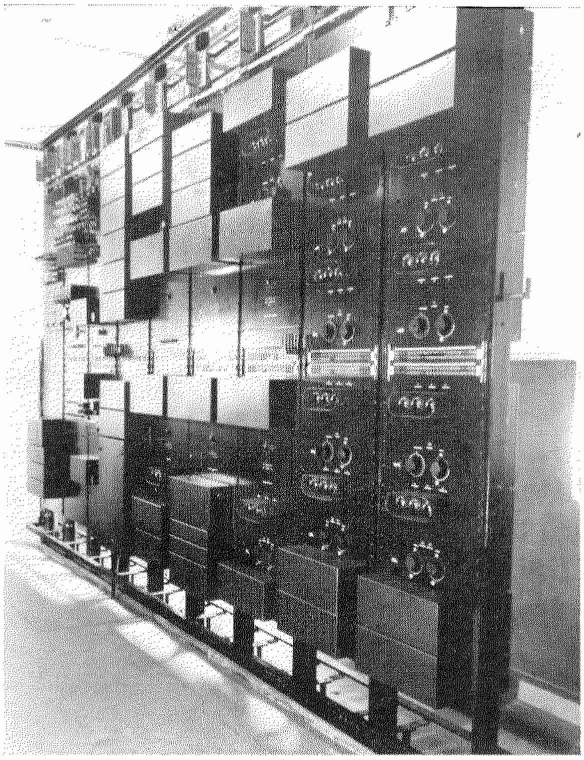


Fig. 15—Cable Equipment—Stanley.

LAYOUT OF EQUIPMENT

As in the case of the land-line equipment, the cable equipment was mounted on 10 feet 6 inch racks. Fig. 15 shows the cable equipment at Stanley, that at Apollo Bay being similar. The bays from left to right are as follows: Fuse, Battery Supply, Ringer, Cable Terminating, Carrier Programme Repeater, Receiving Amplifier and Voice Channel, Transmitting Amplifier and Channel 6, and two channel bays carrying modulators, demodulators, etc. for channels 2 and 3, and 4 and 5, respectively.

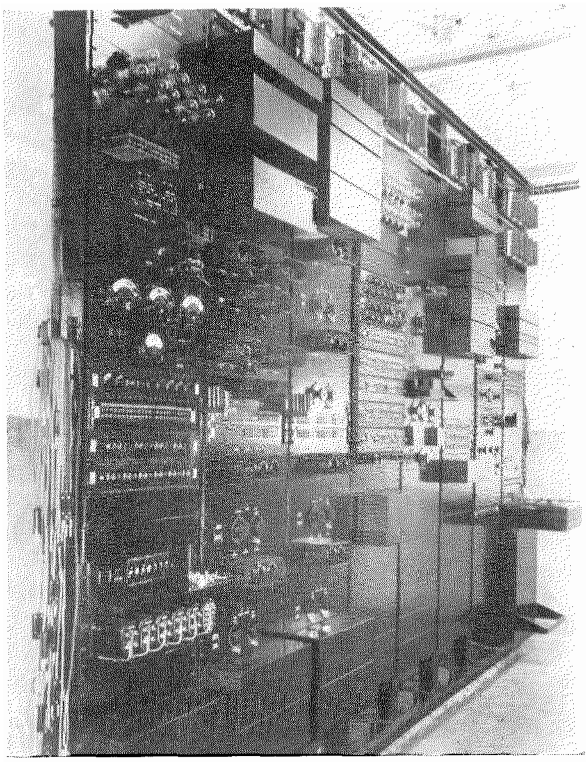


Fig. 16—Land Line Equipment—Stanley.

The cable may be seen coming up through the floor to the terminating unit.

Bay and interbay wiring largely followed standard carrier practice, jacks being included in the circuit to make most panels accessible for test purposes. Shielded twisted pair was widely used, and in many cases the sleeves of testing jacks were earthed to the shields of the leads to these jacks, so that, by using shielded cords for test purposes, continuity of earthing connections was ensured and undesirable looping of earth connections was avoided. Gain and loss measuring equipment employing a thermocouple was provided on the battery supply bay. With this equipment gains up to 100 decibels at 40 kc. could be measured with sufficient accuracy for field purposes.

The land line equipment at Apollo Bay and Stanley was mounted in a line facing the cable equipment, and is shown in Fig. 16.

At King Island the bays were mounted in a single line, the two terminating bays being kept as far apart as a logical circuit layout would permit. The equipment at King Island consisted of nine bays as follows: Battery supply and fuse; Cable terminating (Apollo Bay side); Amplifier A to B; Voice frequency and ringer; Carrier programme; Amplifier B to A; Cable terminating (Stanley side); Test oscillator; Trunk test board.

At each cable station a spare reversed feedback amplifier is provided. This is of the high output level type, and as it covers the frequency range of all channels (200 p : s to 50 kc.) it may be substituted for any amplifier in the system including, at Apollo Bay and Stanley, the three-channel system.

TESTING EQUIPMENT

In addition to a testing circuit for gain and loss measurements, the following testing equipment is provided at each of the cable stations.

Variable Frequency Oscillator

This, with its associated amplifier, will give an output of 240 milliwatts at frequencies from 35 p : s to 50 kc.

Volume Indicator

This is a 2-stage instrument and will record over a range from minus 25 db to plus 25 db referred to a zero of 6 milliwatts.

Impedance Bridge and Detector Amplifier

The impedance bridge is intended primarily for measurements on the cable and balancing network, but is also applicable to some extent to general measurements. The bridge has inductive ratio arms, and the unknown is measured in terms of a capacity in parallel with a resistance.

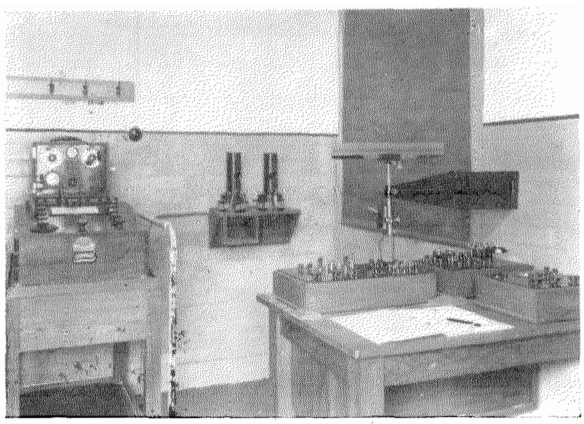


Fig. 17—Cable Test Set and Impedance Bridge.

As a detector for use with the bridge, the detector amplifier is used. This operates as a tuned amplifier from 200 p : s to 3000 p : s and as a heterodyne-detector from 3 kc. to 50 kc. It has a gain of the order of 60 db. Either headphones or a visual indicator in the form of a rectifier meter may be employed as the final indicating device.

The bridge and detector amplifier are mounted together on a portable test-waggon. Battery supply for the detector amplifier is obtained via cords and plugs from jacks located in a number of positions in the jack fields of the apparatus bays. The complete unit is shown on the left of Fig. 17.

Cable Test Sets

As the three cable stations were new, it was necessary to equip them with sets for making the usual direct current tests on submarine cables, and for localising any faults which might develop.

The equipment supplied is shown on the right in Fig. 17. The conductor resistance set incorporates a Wheatstone bridge of normal design with battery reversing key, galvanometer shunt and key, all mounted as one unit. A separate resistance box is supplied for use in overlap tests and for other purposes, and a two range milliammeter is included to enable the testing current to be measured when required.

Owing to the high dielectric resistance of the cables (between 500 and 1000 megohms for the whole cable) the dielectric resistance testing set had to include some special shielding features, as otherwise surface leakage would have rendered the cable tests very inaccurate. For the same reason the use of any form of combined set enabling the conductor and dielectric resistance to be obtained with the same equipment, was deemed inadvisable, as the inevitable wiring complication would have increased the surface leakage. The dielectric resistance set includes a Rymer-Jones battery reversing key, galvanometer shunt and key and a standard condenser and high resistance.

Separate galvanometers are used for the two sets as the sensitive type necessary for the insulation tests would be unsuitable for use with the Wheatstone bridge.

Testing current is obtained from large dry batteries with suitable tappings, and the galvanometer lamp is lighted from the 24 volt supply.

The sets are mounted on a suitable table with a cupboard for the batteries and test records, etc., underneath.

The whole of this d.c. testing equipment was made by Messrs. Muirhead & Co., who have had long experience with this type of apparatus.

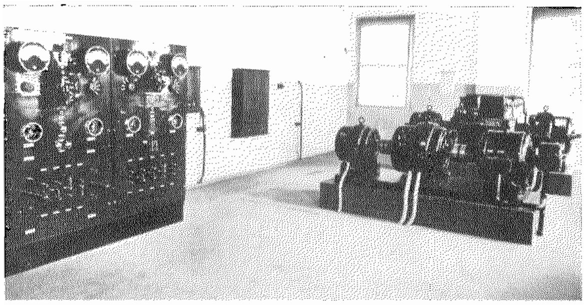


Fig. 18—Power Room—Stanley.

POWER PLANT

At Melbourne, Launceston and Hobart, all equipment is operated from existing station battery supplies. The cable stations, however, are new buildings so that complete power plant was supplied. Filament and anode supplies are provided from "Exide" storage batteries of 24 volts and 130 volts, respectively. Both batteries are duplicated at each station, and are operated on a charge-discharge basis. At Apollo Bay and King Island the 130 volt battery also serves to provide lighting for the repeater station and attendants' dwelling. At these stations, as no local power supply is available, power is provided by "Parsons" petrol engines of 20 and 8.5 B.H.P., respectively. These engines run at 1000 R.P.M. and are direct coupled to the two charging generators, one at either end of the engine, on a common bedplate. Two sets are provided at each station.

At Stanley a 415 volt slip-ring induction motor operating from the local supply drives one pair of generators, a petrol set similar to those at Apollo Bay being supplied for emergency use.

Fig. 18 shows the power room at Stanley. Fig. 19 is a general external view of the Apollo

Bay station, with the repeater building on the right. The tanks form part of the cooling systems of the petrol sets.

DESIGN OF CABLE BALANCING NETWORK

The cable balancing network is intended to present an impedance as nearly as possible equal

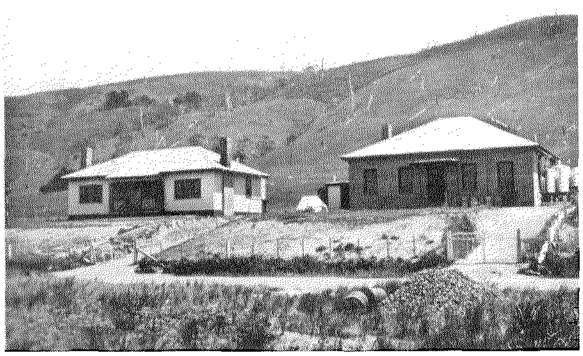


Fig. 19—*General View of Apollo Bay Station.*

to that presented by the cable at all frequencies in the working range, i.e., from 200 p : s to 42.5 kc./sec.

After the cable was laid a series of measurements of its characteristic impedance had been made, in which the cable was always terminated at the far end in its characteristic impedance, the termination being adjusted for each frequency. In actual use, however, the cable is not terminated in its characteristic impedance, but in the impedance of the equipment to which it is connected. As has been explained, special measures were taken to make the impedance of the equipment as seen from the hybrid coil as nearly as practicable a pure resistance of 600 ohms, and a transformer associated with the hybrid coil was used which made the impedance of the equipment as seen from the cable about 52 ohms, this being an approximation to the high frequency impedance of the cable.

Accordingly a series of measurements was made with the cable terminated in the hybrid coil with the "HYB. IN" and "HYB. OUT" jacks (see Fig. 13) each terminated in 600 ohms. In cases where the installation had not advanced far enough for the cable to be connected to the hybrid coil, the cable was terminated in 52 ohms, and check tests later showed that there was hardly any perceptible difference between results obtained by the two methods.

The cable impedance thus measured differed from the characteristic impedance and oscillated about the characteristic impedance curve with frequency, but this oscillation could only be detected at very low frequencies; and the same smooth curve could be drawn through the measured impedance results whether they were characteristic impedances or impedances measured with the cable terminated in 52 ohms. If the network could be made to simulate the smooth curve perfectly, the maximum singing point obtainable would be determined by the deviation of the actual impedance from the smooth curve and the following statement of an extreme case will show that the procedure was satisfactory.

On the King Island-Apollo Bay cable, as measured at King Island, at a frequency of 300 p : s, the characteristic impedance and the "smooth curve" impedance both had the value 78.9–*i* 49.9 ohms, while that obtained with the cable terminated in the equipment at Apollo Bay was 75.84–*i* 51.34 ohms.

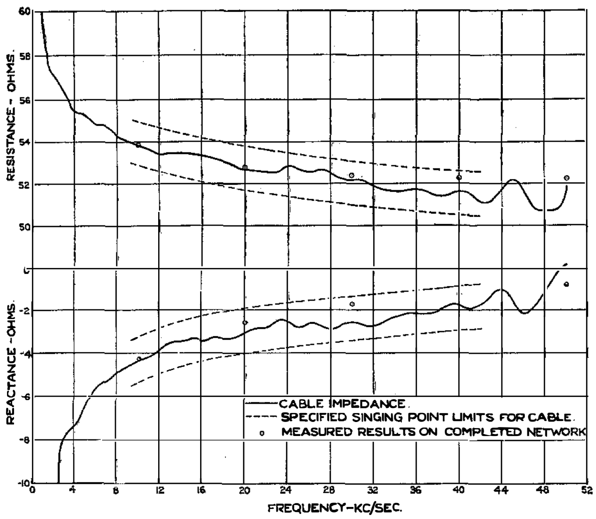


Fig. 20—*Impedance of King Island–Apollo Bay Cable at King Island up to* 50 *kc./sec.*

If the network were a perfect match to the "smooth curve" impedance, the actual singing point at this frequency would be 35 decibels, and when it is noted that the corresponding cable attenuation is only about 13 decibels, it can be seen that the margin is ample. As the frequency rose, the differences rapidly vanished and from 1000 p : s upwards they could hardly be distinguished from experimental error. At 1000 p : s the cable attenuation is 18.6 db.

Fig. 20 shows the impedance of the King Island end of the King Island-Apollo Bay cable up to 50 kc./sec. measured with the Apollo Bay end terminated in the equipment. The scale is unsuitable for showing the small impedance variations and Fig. 21 shows the portion up to 10 kc./sec. on an enlarged scale—with the smooth curve and the specified singing point limits drawn in. Fig. 22 shows the very low frequencies on an exaggerated scale to reveal the oscillation about the smooth curve referred to above.

It can be seen from Fig. 20 that at the higher frequencies the impedance approximates to a pure resistance, and owing to the fact that balanced channels were only being operated up to 9.6 kc./sec., it was evident that the networks should be primarily designed to balance the cable up to about 10 kc./sec. as accurately as possible. Previous work had suggested that the resulting network would also be satisfactory for the higher frequencies.

The type of network adopted was that shown in Fig. 23 as this form lent itself to direct computation. The previous work had shown that a six element network, as indicated, would be satisfactory. Networks with eight or more elements could have been designed if necessary, but the calculation would have taken considerably longer.

Network Results

Networks were designed for each of the four cable ends and made up on the sub-panels previously referred to, of which one is shown in Fig. 14. This sub-panel is so arranged that components can also be mounted on the back. The actual values obtained for a typical network are as follows :

$R_1=52.02$	$R_2=10.83$	$R_3=84.73$ ohms.
$C_1=$ 2.73	$C_2=$ 4.39	$C_3=$ 7.78 microfarads.

Considerable accuracy is necessary in adjusting the resistances and capacities, particularly in the first two sections of the network.

Fig. 24 shows the actual measured singing point curve obtained in the case corresponding to the data in Figs. 20, 21 and 22, and it can be seen that a very satisfactory margin is obtained for the balanced channels, and that the loss across the hybrid coil at the higher frequencies is still considerable.

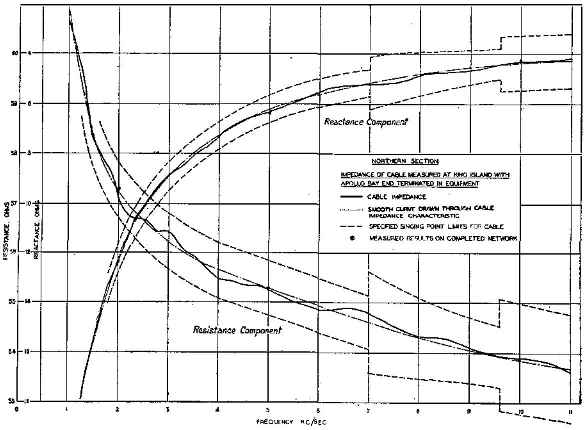


Fig. 21—Impedance of King Island–Apollo Bay Cable at King Island up to 10 kc./sec.

Fig. 24 is typical of the curves obtained in all four cases, and in general the singing point is greater than 50 decibels at all frequencies in the balanced channel range (except the very low frequencies) and greater than 40 decibels over the rest of the range.

INSTALLATION

The whole of the equipment, including power plant, was installed and wired by the staff of the Postmaster-General's Department. Some idea of the magnitude of this task may be obtained from the fact that, in addition to power plant, the equipment consisted in all of no less than seventy-four 10 feet 6 inch bays. These were distributed between the various stations as follows :

Melbourne	13	Apollo Bay	17	King Island	9
Stanley	17	Launceston	12	Hobart	6

That these were installed and wired, tested, and the telephone channels cut into service within four months of the arrival of the first bays in Australia, is an indication of the speed and efficiency with which the installation work was performed.

OVERALL RESULTS

Operating Levels

The telephone channels were required to have an overall transmission equivalent of 6

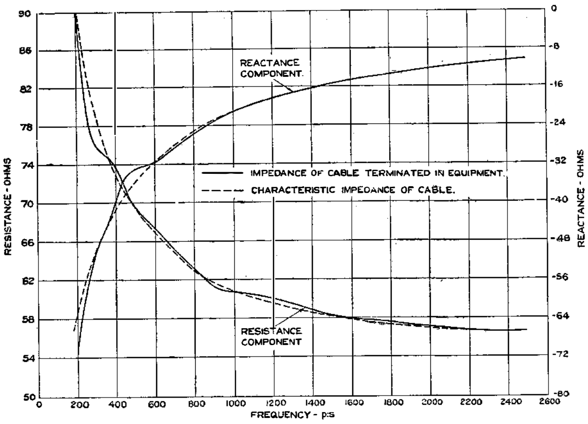


Fig. 22—Impedance of King Island–Apollo Bay Cable at King Island up to 2.5 kc./sec.

decibels at 1000 p : s. Each of the three separate carrier links was, therefore, adjusted to give a 2-wire circuit equivalent of 6 db. The use of "tail-eating" connections then eliminated 6 db loss at Apollo Bay and Stanley, giving the required overall equivalent. The approximate levels existing at each end of each cable and land-line section are indicated for the direction Melbourne-Launceston on Fig. 25. This shows the levels at the mid-band frequencies of the highest and lowest frequency carrier channels of each of the three systems, and for the physical channel in the cable. The power levels into the various line or cable sections were the same for all channels, except in the case of the physical channel at King Island, where the lower load capacity of the four-wire repeater compared with the reversed feedback amplifiers necessitated a lower output level. It is to be understood, of course, that this diagram does not represent the manner in which the various channels of the three systems were connected together.

Owing to the fact that the voice frequency equalisers before the modulators of the three channel systems correct for the distortion in the distant demodulator band filter as well as that in the local modulator filter, the levels transmitted to the land lines at the upper and lower voice frequencies are several decibels higher than those in the middle of the band.

The level diagram for the carrier programme channel is also shown in Fig. 25. It will be observed that the input levels to the two cable sections are less than those to the land line sections. This resulted from the loss in the cable hybrid coils, the levels at the output of the main amplifiers being substantially the same at all stations. Assuming these levels to be maximum R.M.S. levels in the programme transmitted, the amplifiers have a load margin of two or three decibels. The actual level of the programme into the system was controlled by observing a volume indicator. In practice it was found that over periods of several hours the average programme level was subject to considerable variations, and it was found desirable to keep the peak input level down to about 10 db below 6 milliwatts in order to avoid risk of short period overloads. As the noise level on the programme circuit was sufficiently low to permit this somewhat uneconomical use of the load capacity of the amplifiers in the system, it was in fact a convenient solution, although technically a better solution would have been provided by a close control of the level from the broadcast studio.

Transmission Quality

For the telephone channels a transmission band approximately 2500 cycles wide was aimed at on a basis of 10 decibels distortion relative to the transmission equivalent at 1000 p : s.

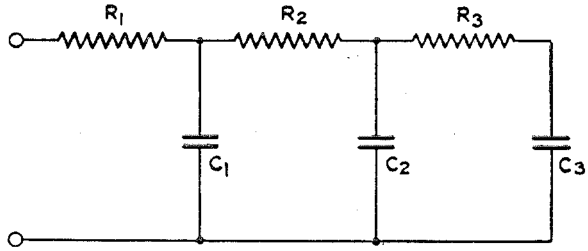


Fig. 23—Balancing Network—Form Adopted.

Fig. 26 shows a typical transmission quality curve for the complete system between Melbourne and Launceston. The corresponding curves for the constituent carrier links are also shown. The dotted curves are displaced for the sake of clarity, each link actually having been adjusted to give a transmission equivalent of approximately 6 db at 1000 p : s. It will be observed that the overall curve is substantially that of the cable link, as each of the land-line systems is equalised to give an almost flat response. As already stated, similar equalisation

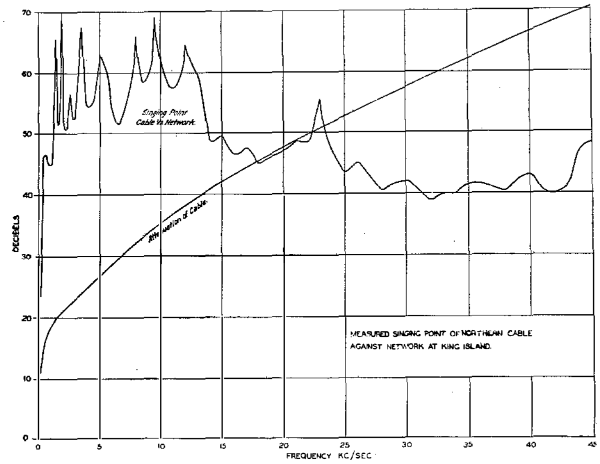


Fig. 24—Measured Singing Point Curve.

could have been applied to the cable system also if desired, but the circumstances of the present project did not warrant it.

The equaliser employed on the land-line systems is perhaps of some interest. It was of the constant resistance type, and was arranged to give a resonance peak of minimum loss at either end of the voice frequency range. Each of the resonance peak frequencies could be adjusted to a number of values by means of tapped coils and condensers, while the basic loss of the equaliser was also made variable. A wide range of adjustment was, therefore, available to allow for differences between channels. On the actual equaliser used a total of ninety different curves may be obtained, although the components occupied only one side of a mounting plate $3\frac{1}{2}$ inches by 19 inches.

The overall quality characteristics of the carrier programme channel between Hobart and Melbourne are shown on Fig. 27. It is seen that the quality limits aimed at are adequately met.

Interchannel Crosstalk

With the system as a whole adjusted to operate in accordance with the level diagrams given in Fig. 25 no crosstalk between channels has been observed of sufficient magnitude to warrant the somewhat elaborate arrangements which would be necessary to measure it reliably. It will be remembered, however, that two of the channels of the cable equipment are not yet in service, so that crosstalk conditions are not severe. Laboratory measurements involving all channels do, however, suggest that all channels may be operated with the level distribution indicated in Fig. 25 without undue crosstalk. In this connection, it will be seen from the amplifier harmonic curves in Fig. 10 that in the high level amplifier harmonics remain at a very low level up to a fairly sharply defined overload point. With the aid of volume limiters, the maximum level occurring in each channel can be readily controlled so as to ensure that a safe load for the common amplifiers is not frequently exceeded.

Noise

Both the telephone channels and programme channel were remarkably free from noise. Some noise measurements were made on some of the reversed feedback amplifiers used in the cable equipment. In these tests, which were made after installation was completed, two amplifiers were arranged in tandem, separated by an inter-amplifier filter in the manner described earlier. The input terminals of the first amplifier were terminated in a suitable resistance, and both amplifiers set to maximum gain, giving a total gain of approximately 104 db. The noise output from the second amplifier was then passed through a filter passing the frequency range to be examined, and was afterwards further amplified and recorded by means of a thermocouple or a suitably calibrated rectifier instrument. The noise measured was then expressed as an equivalent input level to the

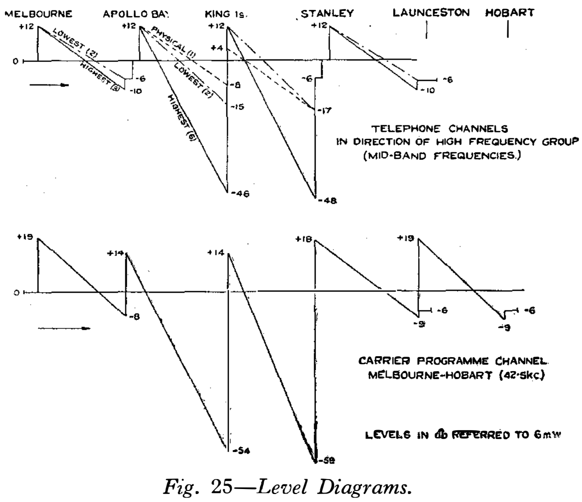


Fig. 25—Level Diagrams.

first amplifier. It was found that the noise energy was uniformly distributed over the frequency scale, except that the band below 3 kc. contained somewhat more noise than a

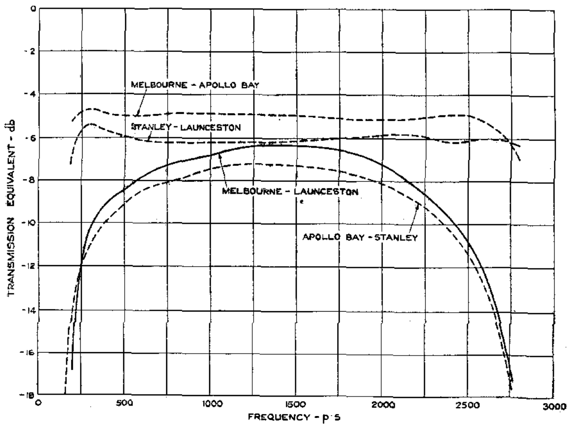


Fig. 26—Quality Curve—Telephone Channel.

band of similar width elsewhere in the spectrum. Typical results were as shown below:

Conditions.	Equivalent Input Noise Level referred to 1 milliwatt.
Noise in any 2500 p : s band between 3 and 30 kc. (measured through filter giving 5 db distortion at 2500 p : s band width)	– 128.5 db
Noise below 2900 p : s.. ..	– 126 db
Total noise below 32 kc. ..	– 116.5 db

The above figures varied approximately ± 3 db for various amplifiers.

For an input level of 6 milliwatts at the terminal station, the lowest level existing on any telephone channel at the input of an amplifier on the present system is approximately 58 db below 1 milliwatt. This occurs at King Island and at Stanley in the Melbourne-Launceston direction. In the reverse direction, the lowest level existing is 47 db below 1 milliwatt at King Island. The ratio of signal strength to amplifier noise is therefore ample. On the programme channel, for an input 10 db below 6 milliwatts, the lowest level occurring is approximately 66 db below 1 milliwatt, the levels at the three cable stations ranging from 54 to 66 db below 1 milliwatt. As the programme channel should transmit efficiently a volume range of 40 db, the above figures, for the weakest programme input, become 94 and 106 db, respectively.

It is seen from the above that the amplifier noise does not enter seriously into circuit conditions in the present system. In the case of the programme channel, however, owing to the large volume range to be reproduced, it probably would not be practicable to operate with minimum levels much lower than those existing. As already mentioned, however, close regulation of maximum transmitted level would, if this were necessary, permit the input level at the terminal station to be raised considerably above the value of 0.6 mW assumed in the above discussion, with consequent further improvement in the signal to noise ratio.

Telegraph Channels

The telegraph channels will not, for the present, be used for traffic, as existing telegraph cables to Tasmania are able to meet present requirements. For purposes of test, however, the voice frequency telegraph system was applied to one of the Melbourne-Launceston channels, the actual channel employed being one involving a balanced channel in the cable equipment. Distortion measurements made with the representative word "PARIS" at a speed of 50 bauds in either direction gave distortions averaging rather less than 10 per cent. With each channel looped at Launceston, distortion measurements from Melbourne to Launceston and back gave values up to 12 per cent.

Measurements between Melbourne and

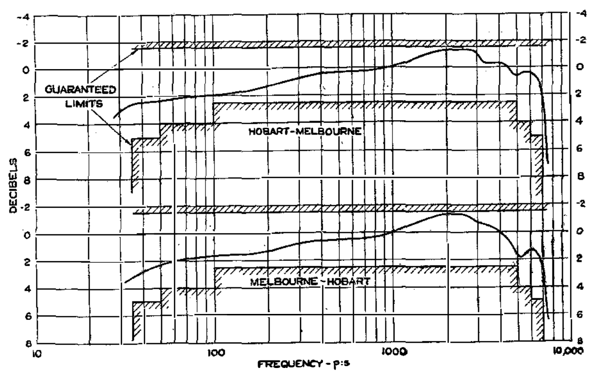


Fig. 27—Quality Curve—Programme Channel.

Hobart, including the composite telegraph extensions between Launceston and Hobart, gave distortions at 50 bauds up to 16 per cent.

As the guaranteed maximum distortions on the Melbourne-Launceston and Melbourne-

Hobart channels were, respectively, 20 per cent. and 25 per cent., the results obtained were very satisfactory.

Traffic

The establishment for the first time of telephone communication between two areas having a large community of interest, each of which had already its own telephone network, gave rise to an unusual situation from the traffic point of view. It was naturally impossible to estimate accurately what the traffic density would be, and some figures may therefore be of interest.

It is the practice in the Commonwealth to base the charges for trunk calls on the air line distance between the points connected, and this principle is applied to the Tasmanian link, in spite of the heavier initial cost of establishing the circuits. The charges for the various periods of the twenty-four hours are at present as follows :

	9 a.m.– 6 p.m.	7 a.m.– 9 a.m. 6 p.m.– 9 p.m.	9 p.m.– 7 a.m.
Melbourne-Launceston	3s. 6d.	2s. 8d.	1s. 9d.
Melbourne-Hobart ..	4s. 6d.	3s. 5d.	2s. 3d.

During the first week after the service was opened, the daily average number of calls for a week-day was 313, while the corresponding figure for the first three months in service was 252 calls. As the average for the third month of service (June) was 237, it would appear that the initial rush of business arising from the novelty aspect has died out and that traffic is likely to be maintained at the high level indicated. In this connection it is of interest to note that the additional land-line systems for bringing the remainder of the cable channels into service have already been ordered.

CONCLUSION

The authors wish to express their sincere appreciation of the work of the engineering, installation and maintenance staffs of the Postmaster-General's Department throughout the work of installing and testing the equipment, and, in particular, for the spirit of willing co-operation in which that work was carried out. The authors also wish to thank the Department for permission to publish the various photographs and other data contained in the paper.

Two Kilowatt Broadcasters in Bulgaria

By I. GANTCHEFF,

Chief Engineer, Bulgarian Postal Administration,

and

G. DE CZEGLÉDY,

Standard Electric Company, Limited, Ujpest, Hungary

A FEW years ago, in order to furnish good broadcasting service to the largest possible number of listeners, the Bulgarian Postal Administration decided to provide an up-to-date broadcasting system.

Owing to the peculiar geographical nature of the country, it was from the very outset obvious that for a satisfactory distribution of field strength more than one broadcaster would be necessary. Bulgaria extends from West to East, and by the ragged range of the Balkans the oblongly shaped country is divided into two sections. Preliminary studies showed that three stations at least would be required for an efficient broadcasting service.

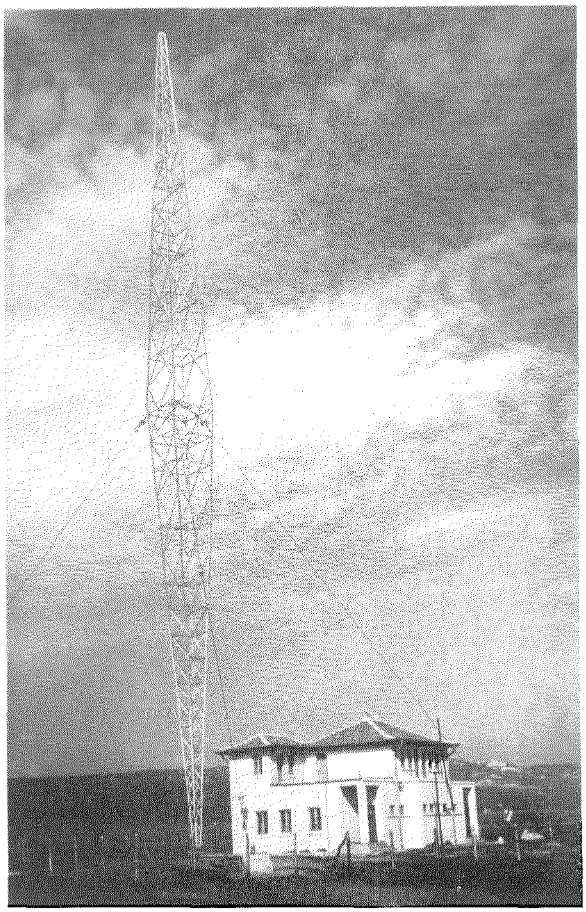


Fig. 1—Transmitter Building and Antenna at Varna.

The first stage in the execution of the programme of the Administration was the erection of two small broadcasters.

The determination of the site of these stations required much effort on the part of the Radio Department of the Administration. A portable radio transmitter was stationed at various points of the regions which, based on previous geographical studies, had been roughly chosen. The best results were obtained in the vicinity of Varna and Stara Zagora, towns which were then definitively made the sites of the two broadcasters.

At first—at the beginning of the year 1936—the station of Stara Zagora was installed. Then, in about a month and a half, Varna followed. Trial transmissions took place at both stations in April, while regular service was started in May, 1936.

Both transmitters are equipped with complete speech input equipment installed at the respective studios located in Varna and Stara Zagora.

The broadcasters, which were ordered from Standard Electric Company Ltd. (Hungary), are of the full mains operated type having an unmodulated output power of 2 kW. The wavelengths are 235.1 metres for Varna and 214.0 metres for Stara Zagora.

In this system, the carrier frequency of the transmitter is generated by means of a master oscillator at low power level. The oscillator provides the sole drive for the subsequent stages of the transmitter, and the frequencies are maintained within close limits by means of crystal control. Modulation occurs at a considerably higher level in order to prevent the carrier frequency from being affected by it.

Modulation of the carrier by the audio frequency input suitably amplified is performed in the output of the modulated amplifier stage, the anode circuits of the modulator and modulated amplifier valves being coupled by means of a transformer. To ensure high degree, distortionless modulation, the modulator stage has a relatively large power handling capacity. All amplifiers use balanced push-pull circuits. This system practically eliminates reaction and thus secures a straight line characteristic for the amplifiers; it also renders the tuning of the various circuits mutually independent.

The transmitters are about six to seven kilometres distant from the two towns. For the transmitting buildings, separate three-phase 6000-volt transmission lines are required. The voltage is transformed into 380 volts 3-phase; and, on account of the frequent voltage fluctuations in the mains, this secondary voltage is stabilised by a rotary voltage regulator.

The transmitter building and antenna at Varna as well as the general layout are shown in Figs. 1 and 2. The latter represents the plan view of the ground floor in which the transmitter and all power supplies are installed.

The 6000/380-volt 3-phase transformer is in room "T" of the figure. The secondary voltage is stabilised by the rotary regulator in room "R."

All radio frequency and power supply equipment is installed in the large central hall. At the left is the line amplifier and by its side, a little to the rear, the high frequency stability master oscillator. From left to right are: the low voltage rectifier, the oscillator-modulator unit and the power amplifier. The high voltage rectifier is located on the right side.

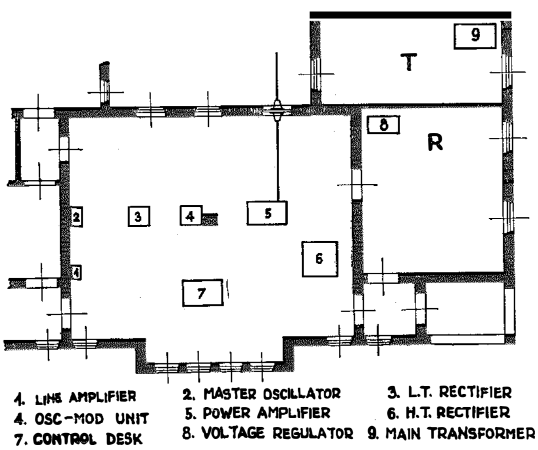


Fig. 2—Plan of Ground Floor Layout, Varna.

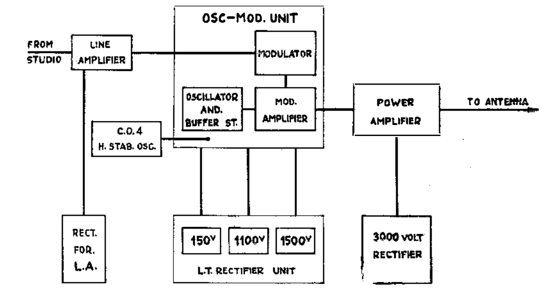


Fig. 3—Transmitter Circuit, Block Schematic.

Press buttons for start and stop and monitoring jacks are mounted on the desk situated in the middle of the transmitting hall.

The transmitting buildings and the city studios are connected by two 2-wire open wire lines. The line amplifier, to which one of the lines is connected, is provided with a volume indicator. By means of the volume indicator the incoming transmission level is checked daily, and thus it is possible to free the level from temporary fluctuations of the attenuation of the open wire line.

The maximum amplification of the line amplifier is 45 decibels; its frequency characteristic is adjusted so as to equalise the distortion of the open wire line.

The output of the line amplifier is connected to the two-stage modulator, the first stage of which incorporates two 50-watt, the second stage two 250-watt valves.

The outgoing circuit of the modulator is connected in series with the anode circuit of the modulated amplifier. The Heising method of modulation is employed.

The input circuit of the modulated amplifier is fed by the type C0.4 master oscillator, which produces the carrier frequency of the transmitter with a stability of 5×10^{-6}. For stabilisation a quartz crystal is used. The crystal is mounted in a special thermostat

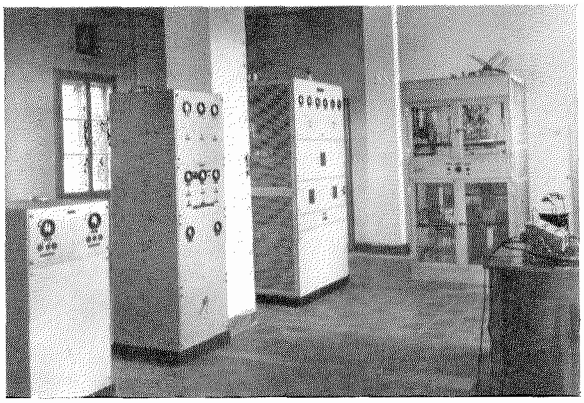


Fig. 4—Transmitter Room at Varna. From left to right : Low Voltage Rectifier, Oscillator-Modulator Unit, Power Amplifier and High Voltage Rectifier.

with a temperature variation of not more than 0.1° Centigrade.

There is another, a spare crystal oscillator installed in the oscillator-modulator unit. The frequency stability of this unit is 25×10^{-6}.

The 250–watt modulated amplifier drives the power amplifier stage, which consists of four parallel and push-pull connected 1.2 kW. air-cooled valves with the necessary output and antenna tuning circuits.

Power supply equipment consists of rectifiers exclusively ; no rotating generators or storage batteries are used.

The following voltages are produced by the low voltage rectifier by means of hot cathode mercury vapour rectifier valves :

150 volts grid for the various units,
1100 volts anode for the oscillator, modulated amplifier and the first stage of the modulator,
1500 volts anode for the second stage of the modulator.

The 1.2 kW. valves are heated by 10 volts a.c. The necessary grid bias is supplied by a dry rectifier installed in the unit itself.

The 3000-volt anode voltage of the power amplifier valves is supplied by a 3/6–phase grid controlled mercury vapour rectifier with glass bulb. This rectifier is placed in the unit itself together with all auxiliary circuits. The mercury vapour rectifier is ignited automatically.

The transmitter (Figs. 3, 4 and 5) is centrally controlled by three press buttons mounted on the monitoring desk. With the aid of a remote control circuit, the station may also be started or stopped from the studio in the city. Alarms inserted in the starting circuit signal failure of both antenna and mains current.

An interval of less than a minute is required for starting the complete transmitting equipment. The proper sequence of switching is safeguarded by a set of automatic delay relays. All voltages and currents may be read on meters on the front panels of the units.

Removable turn-dials serve for tuning in and adjusting the transmitting equipment.

Adequate protection is provided both for personnel and apparatus. The apparatus is assembled in totally enclosed units with "dead" front panels. Access to apparatus in the various units is obtained through a door at the rear of each unit. The doors are fitted with safety switches which ensure that all high tension supplies are removed from the units before the doors are opened.

To protect the valves and other expensive pieces of apparatus from damage due to faulty operation, the switching arrangements are such as to prevent the various voltages from being applied in the wrong order, and provision is made for the automatic disconnection of the high tension supplies in the event of failure of the grid supplies.

The equipment is characterised by safety, simplicity and ease of operation.

The antenna is at a distance of about fifteen metres from the transmitting building. A simple transmission line connects the two.

The excellent quality of the transmitter is best shown by a few data from the Minutes

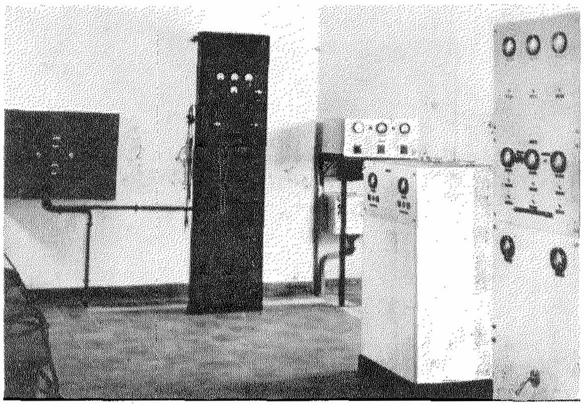


Fig. 5—Transmitter Room at Varna—Line Amplifier and High Stability Master Oscillator.

taken on the occasion of the acceptance tests. For Varna, the following data were obtained :

Output Power : The unmodulated radio frequency output was 2.07 kW.

*Klirr factor :** (measured at 400 p : s)

Modulation per cent.	*Klirr Factor per cent.*
70	2.99
80	3.70
90	4.56
100	7.31

Audio frequency characteristic (measured between 35 and 10,000 p : s) : The maximum variation was 1.66 db.

Carrier noise :
55 decibels, below the level of 100 per cent. modulation.

Power consumption :
When unmodulated, 11.15 kW.

Efficiency : 18.5 per cent.

Acceptance tests were made with the very accurate General Radio Monitoring Assembly, with due regard to all corrections.

The speech input equipment (Fig. 6) installed at the studio in the city is also of the entirely mains operated type. It is provided with three pre-amplifiers for the moving coil microphones.

A four-channel mixer panel is used for mixing the different microphones or other pick-up circuits. By means of the main amplifier, the level is raised to the suitable value.

In this system, the total gain between microphone and line is divided into two parts. The pre-amplifier used between microphone and mixer has a gain of about 20 decibels. After the mixer, the main amplifier follows with a maximum gain of about 60 decibels, giving—for normal modulation—an average of 1.2 volts to the 600-ohm transmission line.

The design of the jack strip of the amplifier equipment allows of transmission of various broadcast plays. As switchings must be performed in logical order, errors are almost entirely excluded. The circuits of three microphones and of a gramophone may be mixed in all possible combinations ; and, in addition, outside broadcast facilities have been provided for. The incoming and outgoing lines are connected through a separate jack strip.

* Coefficient of non-linear distortion.

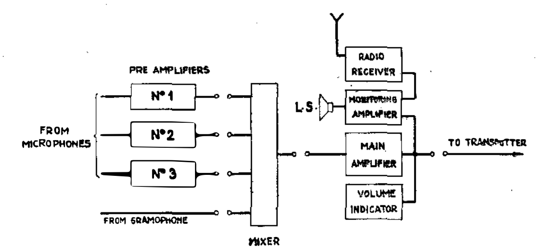


Fig. 6—Speech Input Circuit in Studio—Block Schematic.

Special attention was given to the elimination of noise due to mechanical and acoustical shocks to the valves.

Standard moving coil microphones are used. This type is most suitable for both studio and outside broadcasts.

A volume indicator connected to the output circuit of the main amplifier has been provided for adequate control of the programmes. This indicator, which shows the average value of the programme level, is of the low speed type.

Transmissions of programmes may be listened to with headphones or through the monitoring amplifier by means of a loud speaker. The radiated programme is received with an inbuilt receiver ; and, by means of a key mounted on the monitoring amplifier, the reception may be checked against the actual transmission.

The excellent quality of the speech input equipment is indicated by the following data taken from the Minutes of the acceptance tests for Varna :

Frequency response characteristics between 30 and 10,000 p : s. Maximum variations measured :

(*a*) Three pre-amplifiers : 0.86, 1.06 and 1.06 db.

(*b*) Main Amplifier : 1.9 db.

(*c*) Line Amplifier : (at the transmitter) 1.0 db.

Klirr factor (measured at 400 p : s) :
Line Amplifier : 0.8 per cent.

No measurements have as yet been taken of the radiating quality of the transmitters. However, good quality broadcasts, for example, are received from Stara Zagora even several hundred kilometres beyond the frontiers of the country, such as in Budapest and in Alexandria.

History and Application of Piezoelectricity

By M. TOURNIER,

Les Laboratoires, Le Matériel Téléphonique, Paris, France

NATURE, which endowed man with the power of doing mechanical work with his muscles, did not furnish him with an obvious means of producing electricity. It was only in the 17th Century that Volta, by inventing the battery, gave humanity the first source of electrical energy.

After Faraday and Ampère, engineers learned to devise machines for transforming energy for distribution in electrical form. In these machines, iron or magnets were always found; and ferro-magnetism, that mysterious molecular property of iron, has been basic in the development of the electrical arts: it is the transformation medium between electrical and mechanical energy. For about half a century, this link between matter and electricity seemed unique and irreplaceable.

Then came the notable studies of Becquerel and Gauguin on pyroelectricity. The theories formulated by the Curie brothers to explain this strange phenomenon led them to foresee a new property of matter: piezoelectricity, the specific attribute of certain crystalline substances. Langevin showed subsequently that piezoelectricity made it possible to create a new branch of electro-technique whereby the exchange of mechanical and electrical energy may take place in both directions without the intervention of ferro-magnetism. Quartz made its entry in this technique; and in a very few years, a large number of applications were developed, thanks to the work of Curie and Langevin.

History of Piezoelectricity

Piezoelectricity is the property of electrical polarization possessed by certain crystals when subjected to mechanical deformation. The kindred phenomenon, pyroelectricity (the polarization of certain crystals when heated), had been known for a long while. In the *Annals of Chemistry and Physics* there exists a paper of Becquerel on this subject dating from 1828, and an important paper of Gauguin in 1856.

In 1881, Pierre Curie studied pyroelectricity and gave an interpretation of it deduced from theoretical and philosophical considerations. The development of these theories led him to foresee, before he was really able to observe it, the new phenomenon—piezoelectricity. In the history of science, this discovery is one of the rare examples of a new physical fact which was of capital importance for the future of scientific research and which was completely foreseen before it was found by experiment.

The discovery of the planet Neptune has been largely quoted and admired for the efficiency of the Cartesian method of reasoning. It is well known that after observing the perturbations of Uranus, Le Verrier foresaw the existence of a planet, until then unknown, for which he published the constants and coordinates. Galle, a German astronomer, discovered it at the appointed hour in that part of the sky which Le Verrier had indicated. Almost at the same time, Adam, an English astronomer, who was not aware of these studies, announced the existence of this planet in the same place and by almost the same calculations. Such facts illustrate the power of the scientific method created by Descartes and developed and formulated by Claude Bernard, the operations taking place in the following order: observation, hypothesis, and experiment, contradicting or corroborating the hypothesis.

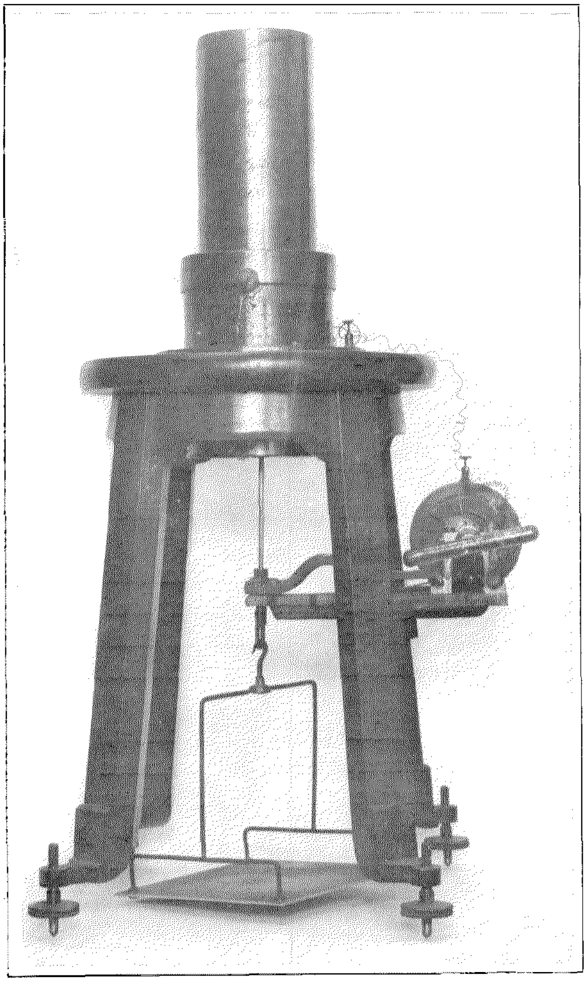
In the discovery of piezoelectricity, we again find these three stages. Here the analysis of facts by the scholar's mind is singularly original and powerful. After crystallographic studies, Curie enunciated the principle of symmetry, which may be summarized as follows:

When a phenomenon *A*, which presents special characteristics of symmetry is the cause of a phenomenon *B*, we find, in the symmetrical elements of *B*, those which are the special characteristics of *A*. Conversely, if we observe in a phenomenon "effect" B special characteristics of symmetry, we may be sure that they exist also in the "cause" phenomenon A.

Example

The magnetic field has a symmetrical character completely represented by the properties of an axial vector. A mass of iron placed in an electro-magnetic field becomes magnetized. This effect can be represented and measured by the knowledge in each point of the solid of the magnetizing vector, which is, itself, also an axial vector.

The application of a force (symmetry of a polar vector) to a free material mass produces an acceleration of this mass. The acceleration also has the symmetry of a polar vector.

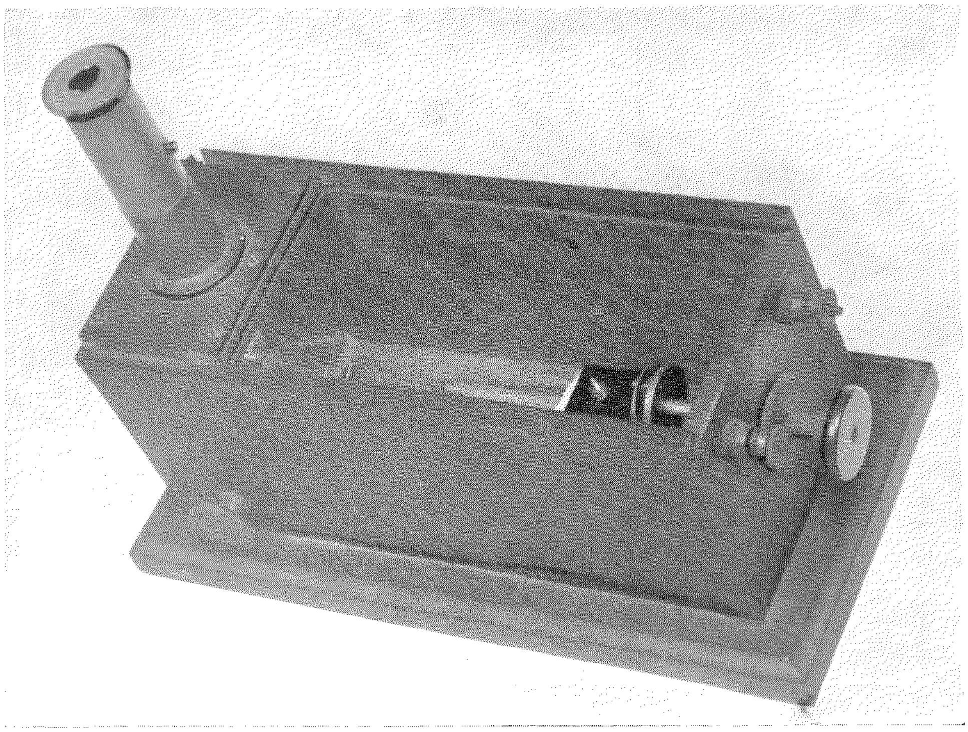


Curie "Piezoelectric Quartz" Apparatus.

The electric field has the symmetry of a polar vector. When one places in it a dielectric substance, this polarizes itself electrically. The electrical polarization vector, which permits the representation of this modification of the space property, also possesses the symmetry of a polarization vector.

Pyroelectricity seemed to have escaped this law. The apparent cause of the elevation of temperature phenomenon may be represented by a scalar quantity. The "effect" phenomenon, which is here the electrical polarization, should be represented by a polarization vector. The principle of symmetry seems to be at fault. Curie remarked that pyroelectricity is not a general phenomenon and that it is only observed in certain crystals endowed with special elastic properties. The symmetrical type, which it is impossible to discover in the initial physical agent, must exist in the crystal.

The action of heat in the crystal determines the tensions distributed in space by reason of its elastic properties. When these tensions are distributed in space with the symmetry of a polar vector, the substance may be pyroelectric. Such is the case of the hemimorphic hemiedrie of the tennary system (tourmaline), of the hemimorphic hemiedrie of the orthorhombic system (calamine, resorcine), and of the enantiomorphic hemiedrie of the clinorhombic system (sugar, tartaric acid, tartrate of potash). The action of an exterior force also determines the appearance of tensions in an elastic and unisotropic substance. When the elastic properties of the substance are such that the application of an exterior force determines the internal tensions regulated according to the character of the symmetry of the electrical field vector, polarization may appear. It is, obviously, impossible to apply a single force to an isolated substance. One can only imagine that the substance is submitted to two equal and opposing forces (the pressure of a clamp) between which one cannot distinguish a predetermined direction. In order that these opposing forces may produce an effect which can be represented by a single vector with fixed orientation, the crystalline substance must be deprived of its center of symmetry. Among the twenty-one classes of crystals deprived of this center, we find twenty which are piezoelectric. These facts, enunciated by Curie in



Curie Electrometer.

several papers, were experimentally verified by him, but his principal study was made on quartz. The laws of Curie are the following: First law: Whatever be the direction of the pressure applied to the crystal, the polarization is always normal to the optical axis; Second law: A uniform pressure parallel to the optical axis does not produce polarization; Third law: The charge dQ is proportional to the force dF when the latter is directed according to the electrical axis, that is,

$$dQ = KdF.$$

When the force dF is applied in a perpendicular direction to the electrical and the optical axes, the quantity of electricity liberated on the electrode is $dQ = K(L/e)dF$. The first equation must be completed by the consideration that the charge may be modified by variation of the potential imposed on the electrode. In other words, for a condenser of piezoelectric dielectric, the charge is the function of two independent variants, the applied force F and the potential V. The final equation is, therefore:

$$dQ = KdF + CdV \quad \text{(Curie's equation)},$$

where C represents the electrostatic capacity of the condenser of constant force.

Curie was interested in electrometrics as well as in crystallography, and he thought of utilizing the property of quartz, which he had just discovered, to evaluate electric quantities in terms of force.

In collaboration with his brother, Jacques Curie, he constructed the apparatus known under the name of "Piezoelectric Quartz." In this apparatus, a sheet of quartz cut perpendicularly to the electrical axis is fixed between two jaws; the upper jaw is fixed to a rigid support, the lower to a scale which permits the application of a force by means of a known weight. The direction of the force is perpendicular to the optical and electrical axes.

The sheet is covered with tin for receiving the charges. One of the tin sheets is connected to ground, the other to an insulated pair of quadrants of an electrometer mounted heterostatically. The sheets are dimensioned so that one kilogramme of traction corresponds to an absolute C.G.S. electrostatic unit of electrical quantity.

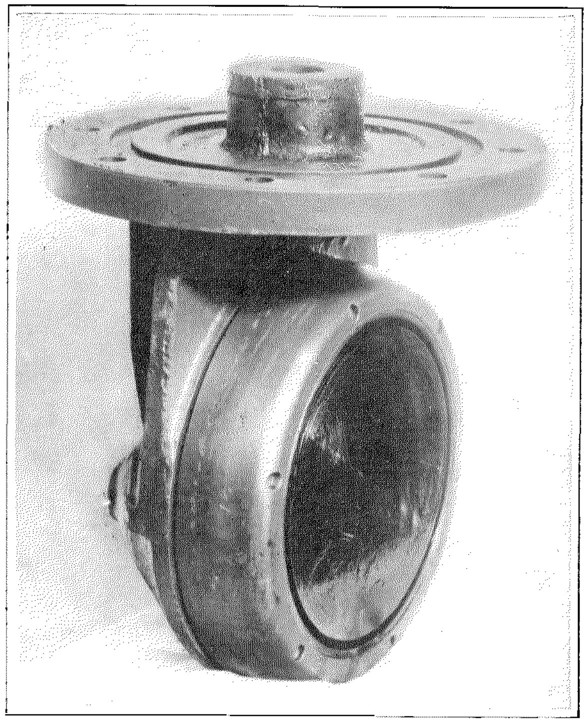
One may demonstrate by the electrometer the charge released by 0.5 gramme of quartz, and the sheet has sufficient power of resistance to support the traction of 5 kilogrammes. Thus an instrument capable of measuring quantities of electricity proportionate to the weight varying from 1 to 10,000 is available. This apparatus was shown at the Electrical Exhibition held at the Paris Observatories in 1885.

After Curie's discovery of the direct piezoelectric phenomenon, Lippmann published a theoretical work on the converse phenomenon: the geometrical deformation of the crystal when it is placed in an electrical field. Lippmann, founding his conclusions both on the principles of the conservation of energy and of electricity as well as on the properties of the direct phenomenon, was able to foresee and demonstrate in advance the special properties of the converse phenomenon.[1] He even gave the means of calculating beforehand the crystal size for a predetermined potential difference when the quantity of electricity released by a predetermined pressure is known.

The two converse phenomena are connected by the general law (enunciated by Lippmann), which is nothing but a generalization of Lenz's law. In effect, the converse phenomenon always tends to oppose the production of the earlier phenomenon.

The initial form of the apparatus foreseen by Curie for illustrating these phenomena was the following:

Several discs, cut perpendicularly to the axis, are provided with metal electrodes and superimposed by being separated by isolating blocks. The whole pile is tightly squeezed in a press, one of the discs being connected to the isolated quadrant of an electrometer and to the earth. One surface of the other disc may be placed in connection with a source of potential difference,



Ultra-sonic Transmitting Apparatus.

the other surface of the same disc being connected to ground. After equilibrium has been established, the difference of potential may be applied. Because of the converse effect, the disc undergoes deformation; and, since the press holds it rigidly, it exerts supplementary pressure on the disc connected to the electrometer. This pressure is made evident by the appearance of a charge on the quadrant.

A second and more sensitive arrangement allowed Curie to make the deformation of the crystal directly evident.

Two very thin plates of quartz are cut parallel from the same block of quartz and normally to an electrical axis. Their contour has the form of an elongated rectangle. The width of the sheet is parallel to the optical axis and the length is normal both to the optical and electrical axes.

The two identical sheets are ground until they are only some hundredths of a millimeter thick. They are glued together with Canadian balm so that the electrical axes are in opposite directions in the two sheets and the external surfaces of the double sheet are silvered. If a difference of potential is established between the two silvered

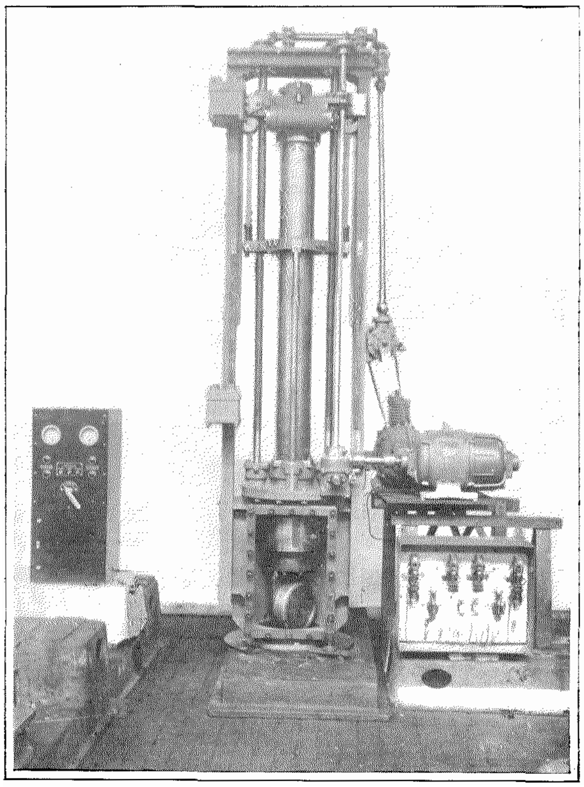
[1] "The Principle of the Conservation of Electricity," *Annals of Chemistry and Physics,* 1881, p. 145.

surfaces, one of the sheets tends to elongate itself in the direction of its length and the other to shorten itself. Since they are stuck together, the double sheet bends and the convexity is on the side of the sheet which elongates itself. The phenomenon is amplified by fixing to the free extremity a long light needle.

These very delicate sheets (1/30 millimeter for each sheet with 80 centimeters of length) have been cut by Werlein, an optician of great talent. There are thus obtained instruments which are sensitive to 5 volts and may serve up to 1,000 volts. They have permitted measurements of the piezoelectrical constant corresponding to the deformation under the influence of a field. The deformation foreseen by Lippmann's theory is an elongation in the direction of the electrical axis of the crystal, this elongation being proportional to the difference of potential:

$$dx_F = KdV.$$

The theory permits determination of the fraction dx/dV when the elastic force is constant, and it



Ultra-sonic Transmitter with a Device for Submerging and Electric Control of Movements.

is exactly equal to the piezoelectric modulus K of Curie's formula, where,

$$dQ = KdF \text{ and } K = 6.36\ 10^{-8}.$$

The Work of Voigt—1890-1892

Some years later Voigt published some very important papers wherein he gave a complete theory of the piezoelectric properties of crystals. In reality, by reason of the anisotropism of the substance, the application to a crystalline sheet of a force directed other than along the optical axis, also produces piezoelectrical phenomena. One may find a relation between the electrostatic polarization of the substance and the component parts of the force which provoke this polarization.

From a purely elastic point of view, Voigt stated that the pressure components are linear functions of the differential quotients which represent the deformations. If an element of thickness dx is displaced by u, following the direction x, one can write $x_x = du/dx$. This term represents the contraction in the direction x.

In the same way: $y_y = \dfrac{dv}{dy}$ and $z_z = \dfrac{dw}{dz}$,

but the molecular displacement in the direction of the axis x changes from one point in the crystal to another in all directions. One may express the deformations of shearing by the quantities:

$$y_z = \frac{dv}{dz} + \frac{dw}{dy}, \qquad z_x = \frac{dw}{dx} + \frac{du}{dz}, \qquad x_y = \frac{du}{dy} + \frac{dv}{dx}$$

and Voigt's relation between the components: X_x, Y_y, Z_z, Y_z, Z_x, X_y, and the differential quotients are the following:

$$-X_x = C_{11}\,x_x + C_{12}\,y_y + C_{13}\,z_z + C_{14}\,y_z + C_{15}\,z_x + C_{16}\,x_y,$$
$$-Y_y = C_{21}\,x_x + C_{22}\,y_y + C_{23}\,z_z + C_{24}\,y_z + C_{25}\,z_x + C_{26}\,x_y,$$
$$-Z_z = C_{31}\,x_x + C_{32}\,y_y + C_{33}\,z_z + C_{34}\,y_z + C_{35}\,z_x + C_{36}\,x_y,$$
$$-Y_z = C_{41}\,x_x + C_{42}\,y_y + C_{43}\,z_z + C_{44}\,y_z + C_{45}\,z_x + C_{46}\,x_y,$$
$$-Z_x = C_{51}\,x_x + C_{52}\,y_y + C_{53}\,z_z + C_{54}\,y_z + C_{55}\,z_x + C_{56}\,x_y,$$
$$-X_y = C_{61}\,x_x + C_{62}\,y_y + C_{63}\,z_z + C_{64}\,y_z + C_{65}\,z_x + C_{66}\,x_y.$$

Conversely, the components of the deformations x_x, y_y, z_z, y_z, z_x, x_y, may be expressed by the function of the components of the pressure:

$$-x_x = S_{11}\,X_x + S_{12}\,Y_y + S_{13}\,Z_z + S_{14}\,Y_z + S_{15}\,Z_x + S_{16}\,X_y,$$
$$-y_y = S_{21}\,X_x + S_{22}\,Y_y + S_{23}\,Z_z + S_{24}\,Y_z + S_{25}\,Z_x + S_{26}\,X_y,$$
$$-z_z = S_{31}\,X_x + S_{32}\,Y_y + S_{33}\,Z_z + S_{34}\,Y_z + S_{35}\,Z_x + S_{36}\,X_y,$$
$$-y_z = S_{41}\,X_x + S_{42}\,Y_y + S_{43}\,Z_z + S_{44}\,Y_z + S_{45}\,Z_x + S_{46}\,X_y,$$
$$-z_x = S_{51}\,X_x + S_{52}\,Y_y + S_{53}\,Z_z + S_{54}\,Y_z + S_{55}\,Z_x + S_{56}\,X_y,$$
$$-x_y = S_{61}\,X_x + S_{62}\,Y_y + S_{63}\,Z_z + S_{64}\,Y_z + S_{65}\,Z_x + S_{66}\,X_y.$$

In these expressions :

$$C_{iK}=C_{Ki} \text{ and } S_{iK}=S_{Ki},$$

the relations are entirely general in any elastic substance, but the particular supplementary relations between the numerical coefficients characterise the type of symmetry in a given crystalline substance.

For quartz, choosing for optical axis the axis of Z, we have the following table for the coefficients C and S:

$$\begin{array}{cccccc} C_{11} & C_{12} & C_{13} & C_{14} & 0 & 0 \\ & C_{11} & C_{13} & -C_{14} & 0 & 0 \\ & & C_{33} & 0 & 0 & 0 \\ & & & C_{44} & 0 & 0 \\ & & & & C_{44} & C_{14} \\ & & & & & C_{66} \end{array} \qquad \begin{array}{cccccc} S_{11} & S_{12} & S_{13} & S_{14} & 0 & 0 \\ & S_{11} & S_{13} & -S_{14} & 0 & 0 \\ & & S_{33} & 0 & 0 & 0 \\ & & & S_{44} & 0 & 0 \\ & & & & S_{44} & 2S_{14} \\ & & & & & S_{66} \end{array}$$

The relations of elasticity thus simplified, there remains :

$$\begin{aligned} -X_x &= C_{11}\,x_x+C_{12}\,y_y+C_{13}\,z_z+C_{14}\,y_z \\ -Y_y &= C_{11}\,y_y+C_{13}\,z_z-C_{14}\,y_z \\ -Z_z &= C_{33}\,z_z \\ -Y_z &= C_{44}\,y_z \\ -Z_x &= C_{44}\,z_x+C_{14}\,x_y \\ -X_y &= C_{66}\,x_y \end{aligned}$$

$$\begin{aligned} -x_x &= S_{11}\,X_x+S_{12}\,Y_y+S_{13}\,Z_x+S_{14}\,Y_z \\ -y_y &= S_{11}\,Y_y+S_{13}\,Z_x-S_{14}\,Y_z \\ -z_z &= S_{33}\,Z_x \\ -y_z &= S_{44}\,Y_z \\ -z_x &= +S_{44}\,Z_x+2S_{14}\,X_y \\ -x_y &= S_{66}\,X_y \end{aligned}$$

where

$$C_{66}=\tfrac{1}{2}\,(C_{11}-C_{12}) \text{ and } S_{66}=2\,(S_{11}-S_{12}).$$

In addition, in a general way, we have the following relations between the coefficients C and S,

where h, i and $K = 1–2 \cdot \cdot \cdot 0$

$$\Sigma\, C_{hi}\, S_{hi} = 1 \text{ and } \Sigma\, h\, C_{hi}\, S_{hK} = 0\; i/K$$

For quartz, we have :

$$\begin{aligned} C_{11} &= 85.46\ 10^{10}\ \text{Dyn cm}^2, & S_{11} &= 12.95\ 10^{-13}\ \text{cm}^2/\text{Dyn}, \\ C_{33} &= 105.62\ 10^{10}\ \text{Dyn cm}^2, & S_{33} &= 9.88\ 10^{-13}\ \text{cm}^2/\text{Dyn}, \\ C_{44} &= 57.12\ 10^{10}\ \text{Dyn cm}^2, & S_{44} &= 20.05\ 10^{-13}\ \text{cm}^2/\text{Dyn}, \\ C_{12} &= 7.25\ 10^{10}\ \text{Dyn cm}^2, & S_{12} &= 1.69\ 10^{-13}\ \text{cm}^2/\text{Dyn}, \\ C_{13} &= 14.35\ 10^{10}\ \text{Dyn cm}^2, & S_{13} &= -1.54\ 10^{-13}\ \text{cm}^2/\text{Dyn}, \\ C_{14} &= 16.82\ 10^{10}\ \text{Dyn cm}^2, & S_{14} &= 3.81\ 10^{-13}\ \text{cm}^2/\text{Dyn}. \end{aligned}$$

The direct piezoelectric effect represents the dependence between the deformation of the crystal and the electrical polarization of the substance :

$$\begin{aligned} P_x &= E_{11}\,x_x+E_{12}\,y_y+E_{13}\,z_z+E_{14}\,y_z+E_{15}\,z_x+E_{16}\,x_y, \\ P_y &= E_{21}\,x_x+E_{22}\,y_y+E_{33}\,z_z+E_{24}\,y_z+E_{25}\,z_x+E_{26}\,x_y, \\ P_z &= E_{31}\,x_x+E_{32}\,y_y+E_{33}\,z_z+E_{34}\,y_z+E_{35}\,z_x+E_{36}\,x_y. \end{aligned}$$

The converse piezoelectrical effect, i.e., the deformation by an external electrical field, obeys the following linear equation :

$$\begin{aligned} x_x &= d_{11}\,E_x+d_{21}\,E_y+d_{31}\,E_z, \\ y_y &= d_{12}\,E_x+d_{22}\,E_y+d_{32}\,E_z, \\ z_z &= d_{13}\,E_x+d_{23}\,E_y+d_{33}\,E_z, \\ y_z &= d_{14}\,E_x+d_{24}\,E_y+d_{34}\,E_z, \\ z_x &= d_{15}\,E_x+d_{25}\,E_y+d_{35}\,E_z, \\ x_y &= d_{16}\,E_x+d_{26}\,E_y+d_{36}\,E_z. \end{aligned}$$

For the crystalline system of quartz, the piezoelectric modulus and the constants are simplified :

$$\begin{array}{cccccc} e_{11} & -e_{11} & 0 & e_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -e_{14} & -e_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ d_{11} & -d_{11} & 0 & d_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -d_{14} & -2d_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{array}$$

$$e_{11}=4.77\ 10^4 \qquad d_{11}=6.36\ 10^{-8}$$
$$e_{14}=1.23\ 10^4 \qquad d_{14}=1.69\ 10^{-8}$$

The general simplified equations are :

$$\begin{aligned} X_x &= d_{11}\,E_x, & P_x &= e_{11}\,X_x-e_{11}\,Y_y+C_{14}\,Y_z, \\ Y_y &= d_{11}\,E_x, & P_y &= e_{14}\,Z_x-e_{11}\,X_y. \\ Y_z &= d_{14}\,E_x, \\ Z_x &= d_{14}\,E_y, \\ X_y &= -2d_{11}\,E_y, \end{aligned}$$

These equations, besides the effects shown by Curie, express the possibility of obtaining piezoelectric effects by shearing.

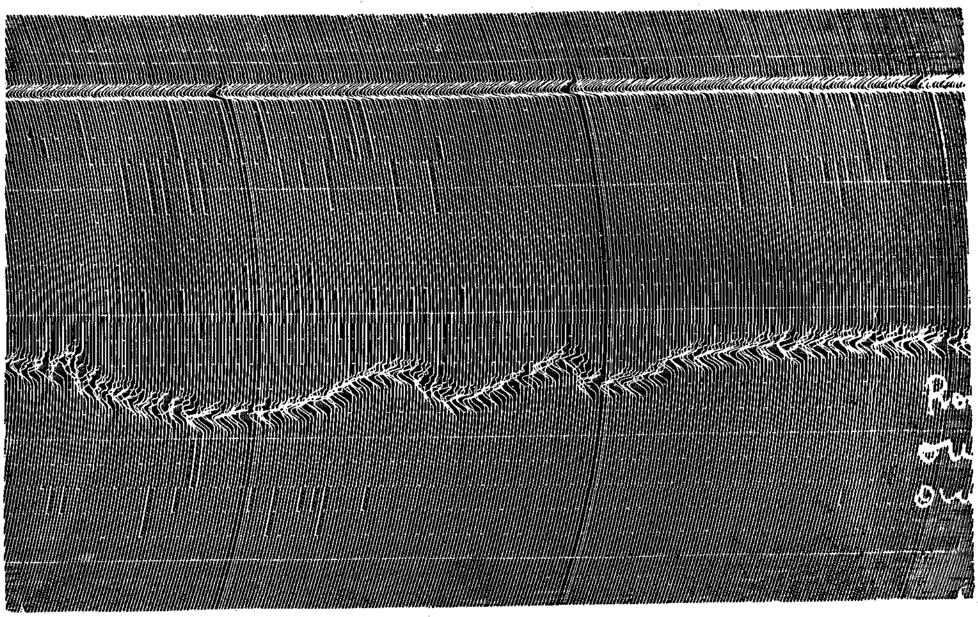
If a sheet is cut parallel to the surfaces, i.e., to the electrical axis, and if a field is applied in the direction y, there will follow a deformation of the type Z_x and another of the type X_y.

In the same way, there will here appear a polarization directed according to y, if the sheet is sheared in a perpendicular sense.

During many years, the widely known piezoelectric effects were neglected except for measuring charges.

Work of Langevin

In 1914, on the invitation of the French Ministry of Marine, work was begun which was destined to make progress in methods of defence. It was proposed to find a way which would enable a ship to detect the presence of a dangerous submerged object—a submarine or a mine. The use of echoes was suggested, the searching ship emitting a sound-wave into the water. This wave, reflected by the obstacle, would be retransmitted towards the ship which would be provided with a microphone system. The measure of the time taken by the signal to go and return would



Recording of Echo Signals on the Floor of the Sea. The Upper Recording Corresponds to the Transmission Signal, the Lower to the Floor Sounds (Echoes) Which Move as the Vessel Travels and Which Trace, Vertically to the Ship's Path, the Profile of the Sea Depths.

furnish the distance of the obstacle. If it were possible, in addition, to detect the direction, it would be possible to localize the obstacle. By reason of the great speed of sound propagation in water, however, the wavelength, which corresponds to average musical frequencies, is very great, being about 3 metres at 500 cycles, and of the same order as the dimensions of the objects to be detected. One may be sure that diffraction will play an important part and that the greatest part of the energy received by the obstacle will travel around it, only a small proportion returning to the observer.

If, on the contrary, short wavelengths are employed, the energy received by the obstacle may undergo the regular reflection and be remitted towards the observer under conditions defined by the form of the object and the laws of geometrical optics. The problem was put in a new form by Chilowsky who had observed that these interesting frequencies were commonly employed in wireless. The wavelength in water, as for instance 1.5 centimeters—very small in comparison to the dimension of a dangerous submarine obstacle—is that which corresponds to a frequency of 100,000, or 3,000 meters of electromagnetic wavelength. At the beginning of these researches, facilities for the production and reception of electrical oscillations of this frequency were already available. The problem thus resolved itself into finding a physical phenomenon which would permit the realization of the transformation of electrical energy in the form of oscillations of high frequency into elastic energy, and conversely. In the first experiments, Langevin employed electrical condensers capable of deformation for emission, and a microphone for reception. He thus obtained very remarkable results, both in communications from a distance and in the case of echoes. The apparatus, however, was fairly delicate and gave poor results. It was not until Langevin thought of utilizing the properties of quartz for the transformation of energy that the new technique achieved its definite form. Imagine a submerged sheet of quartz covered with conducting electrodes. If U

be the potential difference and a the amplitude of deformation, we have $a = KU$, where K is the piezoelectric modulus equal to 6.5×10^{-8} when a is expressed in centimeters and U in electrostatic C.G.S. units.

Calculations show that for fairly strong emissions, immense differences of potential are necessary. It is easy to determine the amplitude of displacements transmitted to the water in order to emit a given power value in the form of a wave.

Let us fix the emitting power at 1 watt per square centimeter. A displacement of 0.4 micron is sufficient for a frequency of 40,000 cycles. By reason of the smallness of the piezoelectric modulus, this amplitude leads to a very high value of the potential difference. Nevertheless, the problem may be solved by having recourse to the same process for the reception, viz., the utilization of electrical resonance. By placing a circuit in resonance on the applied e.m.f., the potential difference is amplified to its limit and, further, it is possible to amplify the displacement by making use of elastic resonance. In effect, if we imagine a flat wave propagating itself parallel to the surfaces of the sheet, the time it takes to go and return after two reflections on the surfaces is $T = 2e/V$, where e is the thickness of the sheet and V the speed of the propagation of the elastic waves in the quartz, i.e., about 5,000 meters per second.

For 40,000 periods, it is necessary to have 6 centimeters of travel in the quartz. We thus excite a sheet of quartz 6 centimeters thick with an alternating current of 40,000 cycles per second and realize the resonance of the excitation under the vibrations of the sheet, also the amplification of these vibrations. Unfortunately, this amplification is limited by the fact that the piece of quartz is in water and cannot vibrate without damping. Calculation shows that the amplification under these conditions is only 5 ; that is to say, instead of 250,000 volts, it is possible, by making use of resonance, to employ 50,000 volts, which is still too high. This same calculation shows that when the sheet vibrates in air instead of water, the amplification is 10,000.

To illustrate the effectiveness of resonance in producing in water important transmissions of energy from an electric source of high frequency, an experiment conducted at the Laboratory in Toulon may be cited. With a power of 1 kW. in ultra-sonic waves, the quartz sheet being 1 centimeter thick, which corresponds to a frequency of 160 kilocycles, there was produced in the water a phenomenon of radiation pressure shown by a curling movement. This movement was of a peculiar nature in that if an obstacle were interposed in the water, the curl formed again on the opposite side of the sheet. Fishes placed in a basin have been killed by these ultra-sonic waves. The vibrations at the indicated frequency correspond to an intracellular pressure of five atmospheres. Even with such amplitudes, a very large surface of quartz is required to radiate great power, the crystal employed in the preceding experiment being a specimen unique in its dimensions.

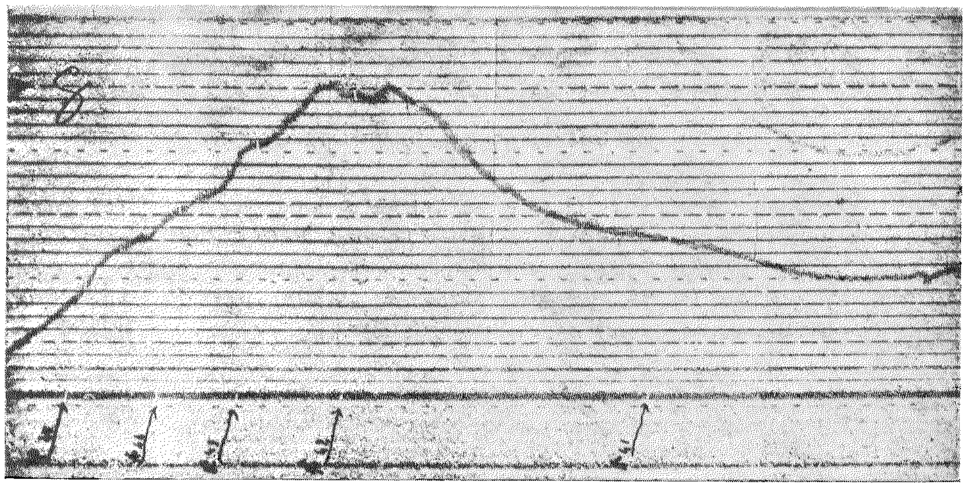
Langevin then had the idea of forming a mosaic of quartz of some millimeters in thickness into a surface of 400 square centimeters, the mosaic being glued between two steel slabs with total thickness of 6 centimeters and vibrating at 40,000 cycles per second. The substitution of steel for quartz presents the great advantage of increasing the power of amplification. When the whole is in resonance and vibrates in half waves, the quartz sheet in the center is in the region of maximum pressure, and is then subjected to stronger pressure than the neighbouring regions of the surface in contact with the water. Its efficiency is thus increased. Thanks to this arrangement, 10,000 volts are sufficient to radiate 1 watt per square centimeter instead of 50,000 volts.

The phenomena of emission and of reception are thus realized at one and the same time. The apparatus is adapted to ultra-sonic waves just as the antenna in radioelectricity is applicable to Hertzian waves. It is the submarine antenna which is both the beacon and the eye.

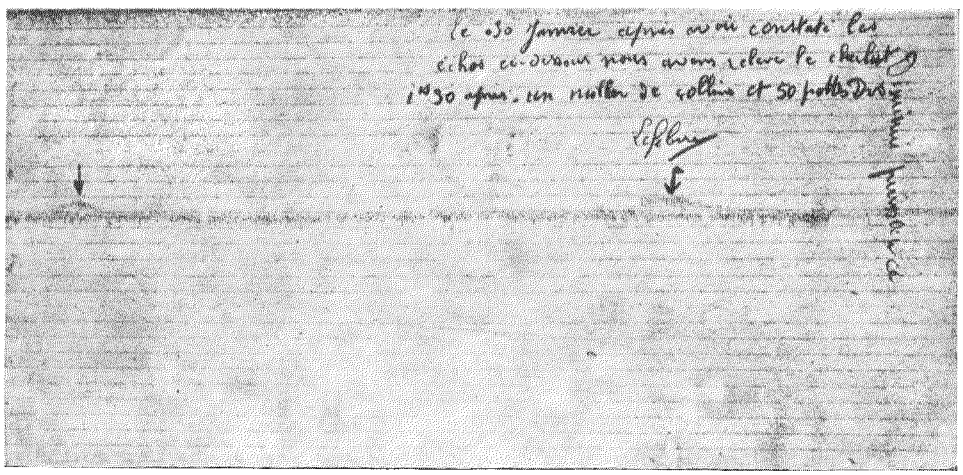
The smallness of the amplitude above calculated, which arises from the lower power of compression of water, can only be compared with the smallness of the amplitudes necessary for reception. Experiment has shown that excellent reception can be obtained when, at the frequency of 40,000, the amplitude of the ultra-sonic waves impinging on the projector is only a millionth of the amplitude of the emitted waves, i.e., an amplitude of the order of 10^{-11} centimeters. This fact is remarkable, since these amplitudes are greatly inferior to the dimensions of the molecules, which are of the order of 10^{-8} centimeters.

The ultra-sonic transmitter possesses another highly important property : the power of direction. In effect, the free surface in contact with the water functions like a flat piston in which all the points are displaced symmetrically by the alternating movement, and the vibrations in the water are transmitted in phase and in a direction perpendicular to the flat surface of the transmitter. The reflected waves are similarly in phase and an addition in amplitude occurs.

Contrariwise, in an oblique direction with an inclination of α from the perpendicular to the surface, the paths traversed on the straight line



Recording by a Chemical Photographic Process of the Ocean Contour, Indicating the Presence of a Wreck.



Duplication of the Depth Sounds (Echoes) Indicated at the Two Points Marked by Arrows and Caused by the Presence of a School of Fish. Their Presence was Checked by the Trawler Carrying the Ultra-sonic Apparatus.

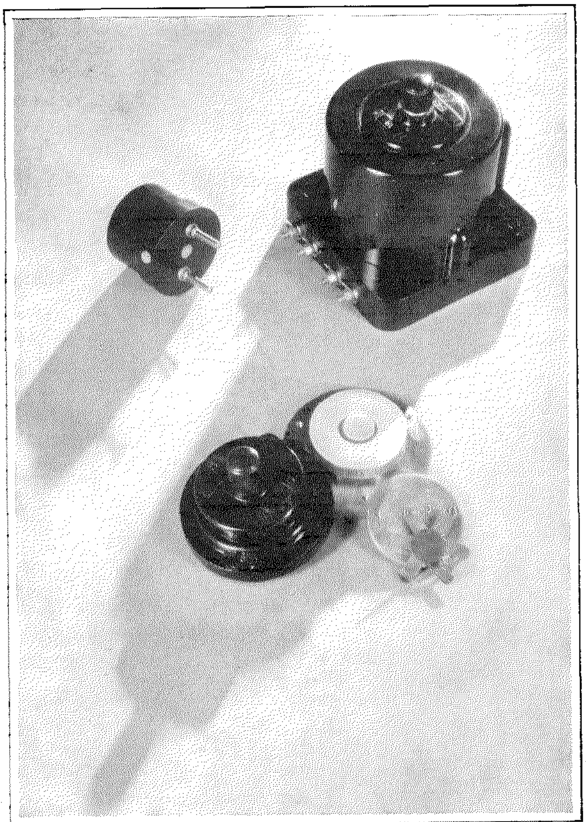
parallel to this direction are not the same. The difference between the lengths of these paths grows with the distance from the point of emission considered as the point A, and reaches the value $D \sin \alpha$. Let us suppose that $D \sin \alpha = \lambda/2$; the vibration emanating from A is opposite in phase to that of the point of origin. If the surface of emission be circular, we have a direction of minimum zero for:

$$\sin \alpha = 1.2 \frac{\lambda}{D}.$$

If $\lambda = 5$ cm. and $D = 30$ cm.,

$$\sin \alpha = 1.2 \frac{5}{30} = 0.2.$$

The emission, which is intense in the perpendicular direction, is annulled in all directions which form an angle of 10 degrees. Beyond this angle we find an amplitude noticeably diminished and there is no more concordance of phase. A little more than 90 per cent. of the energy emitted is found concentrated in a cone with an angle of 2α at the apex, and this angle becomes more acute in proportion as the wavelength diminishes.



Thermostat and Le Matériel Téléphonique Quartz Holder.

The directivity of emission is accompanied by directivity of reception. Let us suppose that a flat wave arrives parallel to the surface. It impinges at all points symmetrically with respect to the amplitude, and the resulting movement is maximum. On the contrary, if the wave arrives obliquely, it is not in phase at all points. The effect of directivity is as marked at reception as at emission.

Application of Ultra-Sonic Waves

1. APPLICATION TO SOUNDING DEPTHS AT SEA

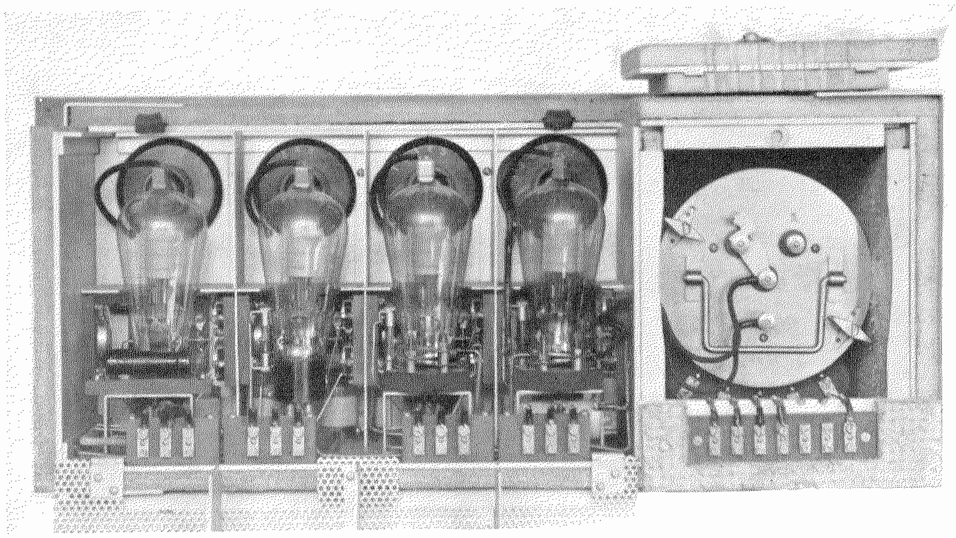
The horizontal projector placed beneath the ship emits a ray which is reflected from the ocean bottom. A very short signal, 1/100 millisecond, is transmitted and the interval of the time between the departure and return $d = Vt/2$ is measured. The times of departure and arrival of the signal are recorded on the same strip of paper. Since the signals are regularly spaced, the profile of the bottom of the sea along the ship's course may be measured.

2. APPLICATION TO SIGNALING AND HORIZONTAL DETECTION

A projector with a mobile vertical axis enables brief signals to be sent successively in all directions. When a submarine obstacle exists in the direction in which a ray has been emitted, an echo signal is received at the end of a period, depending on the distance of the obstacle. The position of this obstacle in relation to the ship is thus defined in polar co-ordinates. In effect, the support of the projector carries a mobile graduation.

Such a projector has been proposed for discovering the position of icebergs, submarines, and mines.

The entrance to the Port of Calais has been furnished with an ultra-sonic projector. The signals emitted are received on the boats coming from Dover and permit the entrance to the harbour to be found with ease, even in the case of fog. The arriving boat turns its projector in the direction of



Master Oscillator and Thermostat.

maximum intensity, thus furnishing it with the direction of the station of emission. In addition, a radio antenna transmits a signal simultaneously with the submarine signal. The entering ship possesses an antenna regulated to the same wavelength. It, therefore, registers two successive signals: the first, Hertzian; the second, ultra-sonic. The interval of time between the two permits the distance to be known. Finally, the ultra-sonic apparatus, modulated to the frequency of the voice, makes two-way submarine telephony practicable.

The Use of Quartz for Frequency Stabilization

Up to 1922, one may say that in the realm of alternating currents of high frequency, only electrical oscillations of circuits containing self-inductance and capacity were employed. In this system the energy accumulated in the condenser passes alternately from the electrostatic to the electromagnetic form, the period of the circuit, according to Kelvin, being:

$$T = 2\pi \sqrt{\frac{LC}{1 - \frac{CR^2}{4L}}}.$$

All these quantities can change with temperature; the accuracy of a good triode oscillator is not higher than one part in ten thousand.

In the ultra-sonic apparatus of Langevin, the alternating phenomenon is the successive reflections of flat waves on the surface of a steel block with a frequency defined by the thickness of the block and by the rate of propagation of elastic waves. These two physical quantities being completely constant, the time of the double journey of the wave is rigidly fixed.

This particular stability of the natural period of a vibrating bar had been observed by Langevin who had given a complete theory of the vibrations of a quartz sheet with parallel surfaces, and of a quartz sheet glued between two steel slabs.[2] The paper on this subject was submitted at the Washington Congress of June, 1917. In 1922,[3] Cady published a simple theory, permitting consideration of the crystal in the neighbourhood of a resonance as an oscillating circuit of which the constants L C R may be calculated by functions of the physical constants of quartz and its dimensions.

[2] Sound Transmitter for Underwater Signaling, British Patent 145691, 1921.

[3] "Theory of Longitudinal Vibrations of Viscous Rods," *Physical Review*, 1922, p. 191.

One may thus, in a manner familiar to electrotechnicians, take account of the interaction between a source of alternating current and a sheet of quartz. Cady and Pierce subsequently published papers wherein they indicated the simple means by which the oscillations of the crystal may be maintained by association with a triode.

Cady, in his first publication, showed the absorption of energy in a very narrow frequency band, thus opening the path for future study on crystal filters.

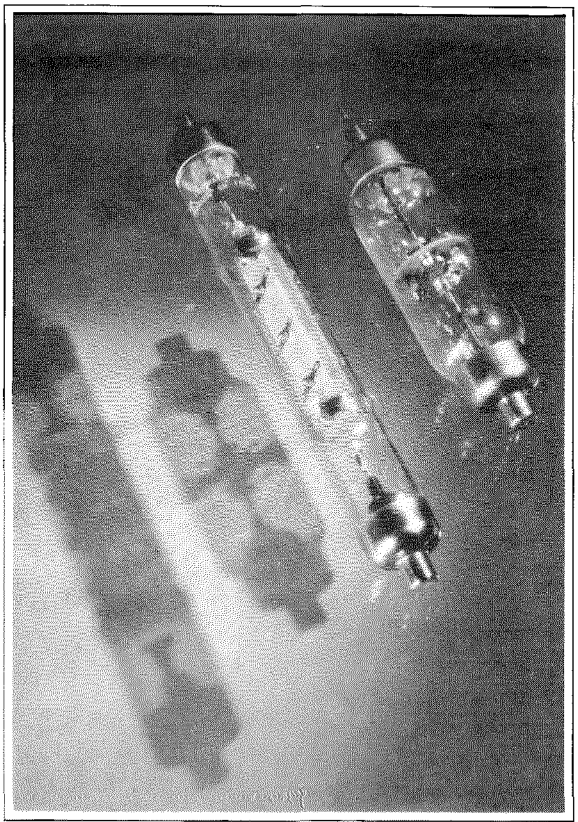
In January, 1920, when filing his first patent application (now United States Patent 1,450,246), Cady was working with crystal plates provided with the usual tin foil coatings. In neither this patent nor patent 1,472,583 (filed May, 1921) did he consider the influence of an air gap between the plate and either of its electrodes.

Dye demonstrated the influence of the air-gap contained between an oscillating quartz and its electrodes. He was able to put in evidence the existence of stationary waves in the air. Thanks to its extraordinarily weak decrement, the quartz sheet, whose oscillations are easily maintained by a triode, preserves a frequency which varies only very slightly with changes in the holding condition. As soon as this important fact was realized, the use of crystals was proposed for defining exactly the frequency of master oscillators of commercial transmitters.

It may be said that, at the present moment, radio emission is merely the translation amplified in electrical form of the mechanical movement of a thin piezoelectric sheet which is both fragile and precious, which is breakable by a force of a few grammes, and which, nevertheless, controls, in the case of certain emissions, a power of several hundred kilowatts.

Every electrical oscillator functioning periodically may be compared to a clock. The transmitters of 20 years ago with arcs, sparks or triodes, in relation to the modern crystal transmitters, had the irregularity of the clepsydrae or hour-glasses compared to the perfect working of an astronomical clock.

This wonderful frequency stability has permitted the simultaneous operation of a very large number of radio transmitters. Each transmitter emits a frequency-spectrum, restricted to a narrow, strictly limited band, with a rigidly constant carrier frequency. All the emissions of one country constitute a complete spectrum whose individual narrow bands are separated from the neighbouring bands as sharply as possible. Without stability, all these frequency bands would be changing continuously, and interference and superposition would render the stations unintelligible. Thanks to crystal control, the graphs published monthly by the International Office of Control at Brussels register variations of frequency which are very small for the majority of stations, and, for certain ones, do not exceed a few cycles. It has thus been possible to multiply the number of stations of emission without confusion ; also, to transmit simultaneously from several distinct stations with the same modulation and wavelength, but with different master oscillators.



A Vacuum-Mounted Crystal Oscillating on Partial 3 *for the Crystal-Controlled Clock of the Laboratoire National de Radioélectricité* (*Le Matériel Téléphonique Product*).

This triumph of skill has been made possible by the use of master oscillators especially adapted to very high precision, the maximum variation during an interval of 6 hours being of the order of one part in ten millions. It may be noted that this precision is of the same order as that of an astronomical clock.

Frequency-Measurement Apparatus

All frequency measurement is merely a measure of time. To measure high frequencies is, indeed, to measure very short intervals of time. The unit of time, common to all, or almost all the systems of measurement, is the second, the 1/86,400 part of the average solar day. The second is in reality only an auxiliary unit. The solar year alone can be defined by astronomical measurements, which enable our unit of time to be linked to the course of the stars. It is the solar year which is the true physical unit of time. The solar year lasts about 31,000,000 seconds.

Let us suppose that we wish to measure, approximately within the precision of one part in a million, the period of an electrical oscillator, the frequency of which is 5,000 kilocycles. This means that we must measure the time interval of 2×10^{-7} seconds to the nearest fraction of 10^{-6}. In other words, we must be able to determine a time interval of 2×10^{-13} seconds by disposing of a physical unit of the value of 31,000,000 seconds. The unit here is 1.5×10^{20} times greater than the quantity to be measured.

In the domain of measurements of length, the problem would be to determine a length of one millimeter by employing a ruler of which the length was 1.5×10^{20} millimeters. For the light to traverse this ruler, a period of 5×10^{8} seconds, i.e., about 16 solar years, would be necessary.

Most fortunately, in the case of measurements of time, we benefit from a rigid physical phenomenon. It is the isochronism of the oscillations of the pendulum affording a means for adding an immense but well determined number of brief, similar time intervals and comparing this sum with the standard of time. The astronomical clock is in reality only a meter which enables us to know how many oscillations are made in a year by means of a pendulum which is, as far as possible, independent of external circumstances in its movement. By admitting the necessary postulate of the isochronism of oscillations, our unit of time becomes that period of the pendulum which is 1/31,000,000 of the solar year. This unit is, of course, convenient for measuring purposes.

To continue the preceding example, when it is necessary to demonstrate a variation of one part in 10 millions in the frequency of an oscillator of 5,000,000 cycles per second, it still remains for us to determine a very small time interval with a unit which is 5×10^{12} times greater.

In the domain of measurements of length, the problem would be comparable to that of the measurement of one millimeter with a ruler of 5×10^{12} mm., i.e., 16 light seconds or about nine times the distance from the earth to the moon.

To resolve this problem we here admit once more the postulate of the isochronism of the oscillations of quartz, and we set up a quartz clock which resembles in many ways an astronomical clock or, more precisely, a chronometer. Here the fundamental period will be that of the crystal, and is solely defined by the elastic properties of the crystal and its linear dimensions, similar to that of the balance-wheel of a chronometer.

To complete the clock, we require a meter comprising an electrical demodulator system. If the period of the crystal be 1/100,000 part of a second, it is arranged so that the quartz at the end of each group of ten periods sets up a secondary electrical phenomenon (charging a neon lamp, for instance) ; then this first neon lamp will act on a second after ten of its own charges, and so on, and we end by disposing of a periodical current which presents 100 maxima per second.

With this current a synchronous motor would be turned, and henceforth the demultiplication will take place by mechanical processes, as in ordinary clocks. It only remains to compare the working of the quartz clock with the working of an astronomical clock. A quartz clock in reality furnishes us with an auxiliary unit of time shorter than the astronomical clock, i.e., 1/100,000 second.

This time or unit is on the scale of the periods of the oscillations to be measured. The postulate, on which the accuracy of the measurements is based, is the isochronism of the quartz oscillations. The probabilities are that this isochronism is much more rigid than that of the oscillations of the pendulum of the astronomical clock.

The period of the astronomical pendulum may be influenced by many secondary phenomena, i.e., variations of atmospheric pressure, of temperature and, especially, of variations in the intensity of the field of gravity. Thus we may hope that, thanks to the use of quartz clocks, it will be possible to demonstrate more clearly certain anomalies of the earth's movement.

Temperature Coefficients

The period of a crystal is, nevertheless, dependent on a certain number of external physical agents, among which temperature plays a preponderant part. To avoid the inconvenience due to this phenomenon, thermostatic ovens have been constructed with a temperature as constant as possible and, in certain cases, it has been possible to obtain a temperature stability of the order of 1/100 of a degree. Recently, Lack and Marrisson have proposed the coupling of crystals so as to take advantage of different modes of vibration, propagating in different directions and having temperature coefficients of opposite signs. Thanks to this coupling, for a given quartz specially cut, there exist fairly extensive regions in which frequency is independent of temperature. By a suitable choice of the ratios of different dimensions, very small temperature coefficients are obtainable.

The accompanying illustration shows a quartz constructed at the L.M.T. Laboratories, Paris, for the National Laboratory of Radioelectricity. This quartz is an elongated bar, Curie-ground. Its length is parallel to the optical axis and its thickness to the electrical axis. It vibrates on the third partial by means of three pairs of electrodes cross-connected. Wires, knotted along the nodal lines, suspend the bar in a moulded quartz frame in the evacuated center of a sealed bulb. The bulb is placed in a thermostatic oven. Electrical mounting, connected with the crystals, permits one to obtain simultaneously 50,000 oscillations of different frequencies, all known with the same accuracy as the fundamental quartz frequency. By means of recording systems, it is possible to obtain a permanent comparison between this quartz clock in the National Laboratory and all the clocks of mean time in the Paris Laboratory, each clock being compared during 5-minute periods by rotations of about a half hour. This crystal has oscillated continually for several years.

The subsequent studies of Marrisson, Straubel, Koga, and Bechmann (thanks to the advanced study of the elastic properties of quartz in the light of Voigt's equations) led to the discovery of angles for cutting the crystalline sheets in which the temperature coefficient of the rate of wave propagation parallel to the external faces of the specimen under consideration, is very small and may become nonexistent. Further, angles of cutting may be found in which the deformation in the direction of the propagation is not accompanied by deformation in the perpendicular direction. In this case, the principal movement of the sheet is isolated and is no longer coupled to a secondary movement whose period and temperature coefficient fall between the period and the coefficient of the whole.

As a consequence of these studies, we now know how to grind crystalline sheets whose period is practically independent of temperature and which may be employed without thermostatic ovens.

Different Applications of Piezoelectricity

Measurement of Pressure

In the measurement of pressure with the aid of crystals, no use is made of the phenomenon of elastic resonance at high frequency.

By means of an electrometer tube, followed by an amplifier and an oscillograph, the succession in the time of electrical polarizations produced in the crystal by external pressure is registered. Apparatus of this type makes possible the study of widely differing phenomena. The order of magnitude of the forces which may thus be measured and registered varies between 1 gramme and 30 tons.

Applications of these manometers have been made by André Langevin in the study of hydrodynamical and physiological mechanical phenomena. With these manometers he has been able to obtain accurate records of discontinuous phenomena which are produced in water pipes.

The records show the exact physical nature of the phenomena, indicate the theory of the formation of discontinuities, and help to explain the laws of the united motion of the liquid column which fills the pipe and which is provoked by these discontinuities of pressure.

A manometer of a similar type makes possible the study of the very slight pressure on the veins and arteries which the circulation of the blood produces in the human organism.

A variant of this apparatus permits the recording of the strain produced by railway carriages on the rails. The same method is applied to the study of the vibration of bridges and other metallic structures.

Finally, by means of these manometers, it has been possible to measure the explosive pressure in the cylinders of combustion motors and in guns.

Electric Filter Crystals

If the use of quartz in radio transmitters, by assuring the stability of the carrier wave of each station, permits the frequencies of different stations in the same country to be placed more closely together, it is at the same time necessary to make the receivers very selective.

The ideal selectivity characteristic of a receiver should allow the free transmission of all frequencies, without amplitude distortion, within the selected band and completely suppress all other frequencies falling outside the desired range. For the most efficient use of the frequency spectrum, the abrupt frequency discrimination between the passed frequency range and the attenuated frequency range must be realized in the narrowest possible frequency space.

Even the employment of the most improved types of coils and condensers in the construction of such sharp cut-off selecting circuits leaves much to be desired. W. P. Mason has shown that it is possible to quite closely approach the ideal by the use of crystal elements in resonant type, selecting networks that have small percentage band widths and which attenuate in small percentage separation ranges.

Here also success is due to the extremely low damping rate of the mechanical oscillations of the solid. The piezoelectric properties of quartz make it possible for damper circuits to benefit in certain domains of frequency from the properties of mechanical resonators with which they are coupled.

Application to Acoustics

Quartz, little capable of deformation but very sensitive to pressure, is specially well adapted to the reception of sound waves transmitted by water. It is thus that piezoelectric microphones have been constructed to listen to underwater sounds (noises of ships, propellors, and submerged submarines).

For uses of this kind, when very slight damping of the elastic solid is not necessary, and the piezoelectrical effect needs only to be a qualitative translation of external pressure, it is possible to replace the fairly weighty quartz by Rochelle salt, double tartrate of sodium, and potassium, which is more economical and, besides, more sensitive, since its piezoelectric modulus is greater.

Minute fragments of Rochelle salt, properly cut, constitute very good, light pick-ups for gramophone records.

Finally, the converse piezoelectrical effect enables the construction of telephones with a membrane worked by a piezoelectric motor and of loudspeakers better fitted than the electromagnetic loudspeakers to the reproduction of very high frequencies ("Tweeters").

In these last applications we see that in high frequency and other applications piezoelectric phenomena tend to be substituted for the ferromagnetic property as an intermediary between the two forms of energy—the electrical and the mechanical.

Conclusion

Too much emphasis cannot be placed on the extreme importance of the discovery of the piezoelectric properties of quartz from the viewpoint of electrical high frequency technique. As in the case of ferromagnetism, known of old, this discovery yielded additional facilities for the conversion of mechanical to electrical energy, and vice versa.

In iron and steel, magnetic polarization may be localized either permanently, as in the case of magnets, or intermittently, as in the case of soft iron. To obtain good results in the transformation of energy, the displacement between the magnetic and the electrical conductive systems must be relatively slow. In the case of ferromagnetism, the elasticity of matter is not relevant, and the frequencies involved are relatively low and the energy great. In a crystal, however, the average dielectric polarization is always zero, and molecular displacement is imposed on the mass by an external force which disturbs equilibrium and gives rise to dielectric polarization, which is a direct consequence of the force and which vanishes simultaneously with that force.

In reality, a molecular electromagnetic phenomenon analogous to piezoelectricity exists in iron, i.e., the magnetostriction or molecular deformation of iron when magnetized under the influence of an external magnetic field. When desiring to apply this property to high frequency phenomena, one perceives that the loss through Foucault currents or through magnetic hysteresis is considerable and that the resulting exchange of energy is small. Quartz, on the contrary, is well adapted to high frequency work. Its losses due to dielectric hysteresis are negligible, its electric conductivity is strictly zero, and its internal molecular friction is very slight. Actually, the damping of crystalline resonators is due for the most part to the friction of the quartz against its supports.

If this friction be diminished by suspending the specimen from its nodal points and if the air-damping be suppressed by placing an oscillator in a vacuum, decrements lower than 10^{-6} are obtained. This means that in a sheet of say, 5 centimeters length, a flat isolated wave, propagating itself parallel to the faces, traverses 100 kilometers by undergoing two million successive reflections before its amplitude is diminished in the ratio of ε to 1.

Quartz, more useful than the diamond, which for man has always been a symbol of perfection in matter, is one of the most valuable substances with which nature has endowed us. Purely scientific and disinterested research was at first necessary for the discovery of its piezoelectric properties. Born of the pure genius of Curie, this new knowledge was soon revealed to be rich in unsuspected uses.

Budapest Automatic Telephone Network Reaches Stage of Six-Digit Dialling

By DEZSÖ VÉGHELY,

Chief Technical Director of the Royal Hungarian Postal Administration

A NOTEWORTHY event took place on June 27th, 1936, when the six-digit dialling system was introduced in the Budapest automatic telephone network. The transition from five- to six-digit dialling was an important stepping stone towards an unprecedentedly rapid development of telephony in Budapest, and prompts a review of the stages passed in the growth of the Budapest telephone system from the cut-over of the first automatic telephone exchange at that date.

The first section of the Budapest automatic telephone system was cut over on April 28th, 1928. When automatic service was introduced, the former manual network had, of course, to be decentralised. The traffic that previously was handled with three manual exchanges was in course of the process of automatization distributed over seven automatic exchanges. The advantages of automatic service soon became an incentive to large portions of the public, which had kept away from the telephone, to join the fold of telephone subscribers. Soon after the cut-over of the first exchange a rapid increase occurred in the number of subscribers, principally during the years 1928 to 1930, when the glamour of the novelty still continued to attract. The rapid increase is clearly indicated by the steep, ascending curve of Fig. 1. Moreover, it was due mainly to the automatic service that, in the years 1931 and 1932 when business dropped to an alarming level, few subscriptions only were lost. In 1933, the situation again changed for the better.

This change in the trend of development in effect was an admonition to the Post Office that, sooner or later, transition from five- to six-digit dialling might become necessary. The idea of introducing six-digit dialling was suggested also by the circumstance that there was no proportion in the growth of the number of subscribers in the sections allotted to each automatic exchange. While certain parts of the city developed rapidly, there was a standstill or even a retrograde tendency in others. Thus the mountainous region on the right bank of the Danube, called Buda, grew faster than other regions of Budapest. The number of telephone subscribers in that region increased from 3,000 in 1928 to 15,000 in 1933, a development unforeseen when the automatic network was planned. Consequently, certain number groups of the exchanges in this region soon became saturated.

Another reminder that five-digit dialling would not suffice any longer was the rapid growth of party-line subscribers. Party-lines soon became very popular with the Budapest public, primarily on account of the individual calling numbers and message registers at the exchange, and the secrecy of service, the outstanding features of the Budapest party-line system. As a result, party-lines have increased much to the disadvantage of main station lines.

Owing to the adoption of the individual calling number feature, a two-party party-line reduced the capacity of the exchange by an amount corresponding to two normal subscribers' stations. On the other hand, from the point of view of traffic, a party-line subscriber does not represent the traffic value computed for a single line at the time when the exchanges were planned. As a matter of fact, the traffic ratio of a party-line subscriber is about one half of that of a normal line. Consequently, it was at first considered that a party-line should take a single location only on the final and the first line finder arcs instead of the two as at present. In this case, party-line subscribers might be connected to vacant locations of the present exchange equipments at a comparatively low cost. This object, however, may be best obtained by the adoption of the six-digit dialling system. According to the 200-unit final switch system of the original 7-A Rotary System, the final capacity of the Budapest area is $200 \times 10 \times 10 \times 10 = 200{,}000$ when the 1st, 2nd, 3rd and final selecting stages are fully exploited. This means that, by adopting the six-digit dialling system, only the numbers ranging from 100,000 to 299,999 may be used instead of a full million, which six-digit dialling would at first glance suggest. Consequently, 3 and 4 as first digits may be used for indicating the second party to a two-party party-line. As shown in Table I, the first group selector is selected by digits 1 and 2. Accordingly, digits 152819 and 352819 may be paired in a way such that the register transforms both numbers to the same effect, with respect to the first group selector, by simultaneously marking by means of relays whether the first digit was a 1 or a 3. At final selection, when a 3 has been dialled, the trip spindle makes a complete additional turn, whereby a relay is energised in the final selector circuit and legs "a"—"b" are reversed, ringing thus taking place over leg "a" instead of leg "b." This is the well-known method of ringing the second station of a two-party party-line system. Further, the same point of the arc of the final selector corresponds to both stations marked by two numbers differing only in the first digit.

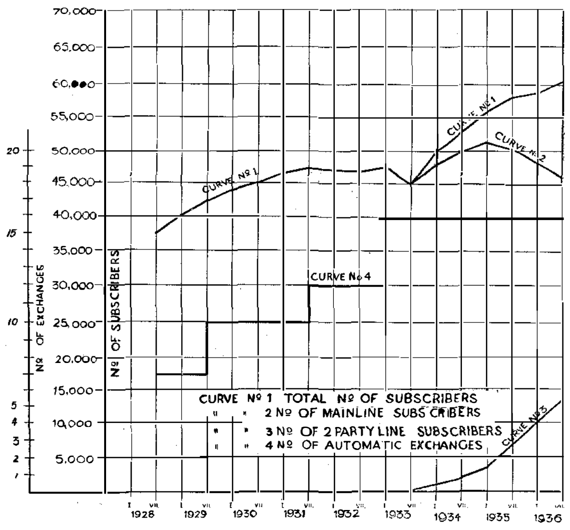


Fig. 1—Increase in Subscribers.

Similarly, numbers of the 200,000 field may be paired with numbers of the 400,000 field. Thus the numbers of the 300,000 and 400,000 fields are reserved exclusively for the second stations of two-party party-lines, and separate final and group selectors may be dispensed with. As the 300,000 and 400,000 fields are reserved for the second stations of two-party party-lines, it follows that these fields will be exploited only to the extent required for party-line purposes. Accordingly, an adequate number of final and selector circuit groups will require modification for the purpose of partial exploitation of the 300,000 and 400,000 fields.

The digits dialled by a calling subscriber are registered by the registers of the automatic exchange in order that they may control the selectors in due course. Therefore, to carry through the change from the five- to the six-digit dialling system, the register circuits had to be modified first. Of the sixteen exchanges of the Budapest automatic telephone area, only eight are provided with registers; the other eight, being satellites, use the registers of their respective main exchanges. There are altogether 1,442 register circuits in the eight main exchanges. The cut-over had to take

TABLE I

Selection	Digits	
	At 5 digit selection	At 6 digit selection
1st Gr. Select.	First	First and Second
2nd ,, ,,	Second	Third
3rd ,, ,,	Third	Fourth
Final	Fourth and Fifth	Fifth and Sixth

place simultaneously at all exchanges, and, as a matter of course, at a time of minimum traffic. The time selected was midnight, June 27, 1936, a Saturday, followed by Sunday, the 28th, and Monday, the 29th, a holiday. This choice was made in order that the modification of all registers might be completed in due course for handling increased traffic requirements on the following working-day, June 30th. Preparatory work had started several months previously.

The following is a brief sketch of the programme as laid down at the beginning of the work. Two stages may be distinguished in the complete process :

(*a*) The preparatory stage, comprising the insertion of four new relays in each register circuit, the change-over of two relays (change of contact) and the connection of additional wires of the registers ;

(*b*) The cut-over stage involving the cutting of 30,000 wires on the terminal strips and the connecting of 62,000 wires in the total network.

While this work was in progress, the circuits were placed out of service by means of the busy jacks.

Since the performance of the operations necessitated by (*b*) for each register circuit consumed the comparatively long period of about an hour, a few of the 1,442 registers were modified before the actual cut-over had taken place. For such registers the cut-over proper consisted merely in extracting the plug from the busy jack.

Inasmuch as the time available for the cut-over of the still unmodified registers was short, the terminal strip wires and the terminals ready for cut-over of this portion of the registers were connected to auxiliary jacks. The latter were used for the change-over to six-digit dialling, which took a very short time only and which was made by extracting and/or inserting a short circuiting brass plug. This secondary preparation was preceded by a long installation period. This installation work, however, was necessary in order to have available an adequate number of registers at the time of actual cut-over. All such temporary apparatus installed for the occasion was gradually dismounted and the final modification of the registers completed. The rest of the register circuits, forming a third and additional group, were at the time of cut-over placed out of service by inserting plugs into the busy jacks, the plugs remaining there until the operations of stage (*b*) were fully carried through.

Handling of the cross connecting arrangements was adequately provided for by :

(1) A staff of trained help,
(2) Formers used as auxiliary tools,
(3) Systematic routine tests,
(4) Constant supervision of the work by a staff of engineers.

Preparatory arrangements made it possible that, from the first day of normal traffic, all register circuits were serviceable and capable of handling a traffic larger even than the normal. The great increase of traffic on the first days of the new system was mainly due to the momentary forgetfulness of subscribers, who instinctively dialled five digits instead of six. Calls of such subscribers were attended to partly by plugging them into the line jack of the registers and partly by routing them to a special board by means of the so-called wrong number feature. During the first few days of the new system there was a daily average of twenty to twenty-five thousand wrong number calls.

The Cunard White Star R.M.S. "Queen Mary" Radio Installation

By Commander F. G. LORING, O.B.E., M.I.E.E.,
W. L. McPHERSON, B.Sc. (Eng.), A.M.I.E.E., and
W. H. McALLISTER

EDITOR'S NOTE: *The following has been extracted from a Paper, "A Survey of Marine Radio Progress, with Special Reference to R.M.S. 'Queen Mary,'" presented on 3rd March, 1937, before The Institution of Electrical Engineers, London. It forms a technical supplement to the general description of "The Radio Installation on the Cunard White Star, R.M.S. 'Queen Mary,'" published in "Electrical Communication" of July, 1936. In extracting from the original I.E.E. Paper, the sequence of subjects and the reference numbers of the illustrations have been changed to conform with the more restricted scope of the present article as compared with the I.E.E. Paper.*

The radio equipment of the "Queen Mary" was almost entirely manufactured by companies in the International System, and was supplied and installed and is operated by the International Marine Radio Company, Limited, under contractual agreement with the Cunard White Star Limited.

Principal Requirements

THE two primary considerations in deciding on the equipment to be fitted in a large passenger vessel are, firstly, navigation and safety of the ship, and secondly, the public radio-telegraph and -telephone service. While the first is still the most important function of the radio station on board, it presents no real problem and can be amply catered for by quite orthodox and standardized arrangements.

The second consideration, that of the public radio service, becomes of greater importance as the size of the ship and the passenger accommodation increases, and, in the largest transatlantic vessels, is the real deciding factor as to the equipment which is to be supplied to the ship. The volume of radio traffic handled is considerable, and it is of great importance that it be cleared with the minimum of delay.

For the R.M.S. *Queen Mary* it was calculated that four transmitting channels and four receiving channels would be required—two on the short waveband for simultaneous eastbound and westbound communication, one on the medium waveband and one on the long waveband. Automatic transmission and reception at moderately high speeds on at least two or three channels was also considered necessary.

The above remarks apply primarily to telegraph traffic. In order to provide for the radiotelephone service the conclusion was reached that simultaneous communication with both London and New York would certainly be required at times and that the most efficient and economical arrangement would be to incorporate radiotelephony in both short-wave transmitters rather than to install separate equipment.

Having determined the number of operating channels required, the next question to be settled was how to obtain them. The chief problem was the provision of multiplex working, which, in the confined space of a ship, presented no little difficulty. Not only was operation on four different wavebands required without mutual interference, but duplex working in each of these wavebands was also aimed at, up to the limits of practical working range of the transmitters.

Based upon previous experience it was clear that the primary requirements for efficient multiplexing were, firstly, separation of the transmitters and receivers with their associated aerials by as large a distance as possible; secondly, the provision of receivers having considerable selectivity and ability to withstand high voltages picked up by their aerials from the local transmitters; thirdly, the provision of transmitters as free as possible from harmonic radiation. A number of other relatively minor difficulties, such as interference between adjacent operating positions due to key-clicks, and receiver inter-action, "stay noises," etc., also had to be overcome.

Some separation of the transmitters and receivers was not a difficult matter to achieve in so large a ship, and suitable sites for the transmitting and receiving stations 400 feet apart were obtained.

and have to carry the whole of the telegraph load at times when the short-wave channels are both occupied for telephony, or when short-wave communication is poor, it was considered necessary to provide the highest power practicable. A power of 3 kW in the aerial circuit was finally decided upon, the limiting factors being space available for installation and the maximum

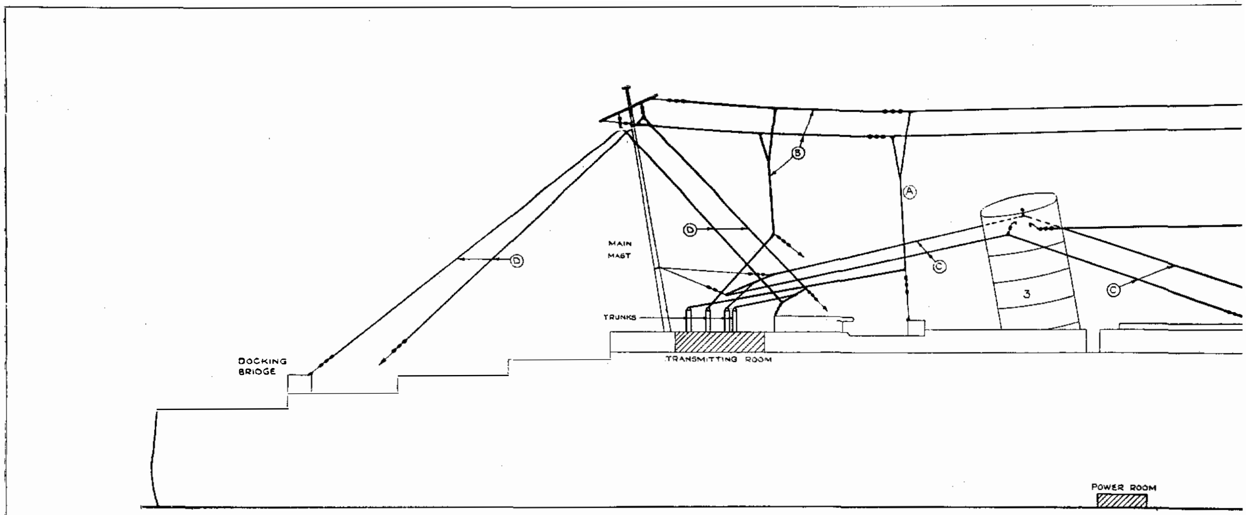


Fig. 1—Outline of R.M.S. "Queen M

(A) Long-wave Transmitting Aerial.
(B) Medium-wave Transmitting Aerial.
(C) Short-wave Transmitting Aerial (No. 1).
(D) Short-wave Transmitting Aerial (No. 2).
(E) Emergency and Long-wave Receiving Aerial.
(F) 13-Mc Double Doublet.
(G) 17-Mc Doublet.

One of the most important features in the rapid handling of traffic is the ability to change wavelength quickly. This especially applies to the short wavebands when combined telegraph/telephone equipments are used, since special wavelengths are allocated to each of these services, and in order not to delay either service it is necessary to be able to change from the one to the other very quickly. Consequently it was decided to provide complete remote control not only for keying and power but also for rapid selection of any one of a number of preselected wavelengths.

The power and frequency ranges of the transmitters remained to be decided. For the medium and long wavebands the factor limiting good communication is as a rule the signal/noise ratio. Since these frequency bands are part of the main communications of the ship, voltage permissible on the aerials. The transmitting aerial constants were of considerable importance in this connection, since any brush discharge would give rise to damped waves which would shock-excite the receiving aerials and prohibit multiplexing.

For short-wave communication, conditions are somewhat different. While the limiting factor, especially for telephony, is again the signal/noise ratio, experience has shown that the borderline cases are not the general rule; that is to say, for any particular frequency, conditions are generally either good or bad with the average powers in use. When conditions become bad it is better to change frequency rather than to increase power. Experience gained in the *Aquitania* and *Berengaria* showed that, with the aerial powers in use in those ships, well over 90 per cent. of radiophone calls could be satisfactorily completed. Increasing the power by 10 times, giving an increase in signal/noise ratio of some 10 db, would have added about another 5 per cent. to the total—a desirable feature, but scarcely worth the corresponding disadvantages of extra space and power supply required, greater difficulty of control, higher "stay noises," and higher initial and maintenance costs. On the other hand, it was estimated that by providing suitable directional aerials an effective increase in signal/noise ratio of between 5 and 10 db could be anticipated, equivalent to an increase in power of some 3 to 10 times. This was confirmed by preliminary experiments carried out in the *Berengaria*, when even greater increases in signal/noise ratio were reported. It was consequently decided to use an aerial power of approximately 400 watts, and to concentrate on providing the most efficient aerial system possible.

A similar argument holds good for the receiving aerials, and experiments were carried out with different types of these in order to obtain the maximum signal/noise ratio. In this case, besides providing as much directivity as possible, interference from ship's machinery had to be avoided by suitably arranging the planes of the aerials, providing shielded feeders, etc.

LOCATION OF EQUIPMENT

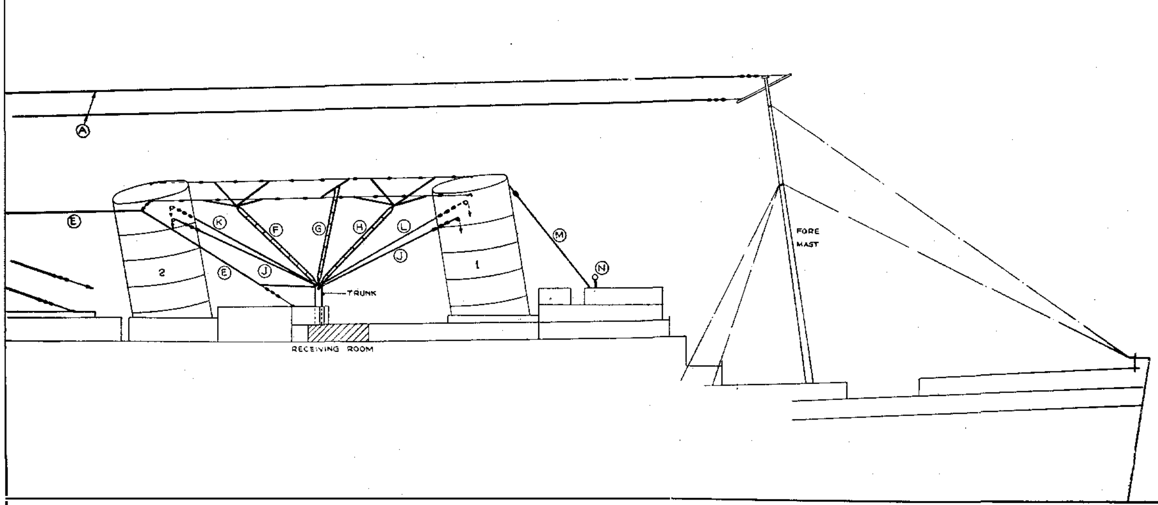
The communication equipment of the *Queen Mary* is housed in three separate places on the ship, viz:

(*a*) The power room, situated near the engine room of the ship, containing the two 45-kVA motor-alternators for supplying all power to the transmitting and operating rooms.

(*b*) The transmitting room on the sun deck, containing the four main transmitters and the power control and distribution board.

(*c*) The operating room, also on the sun deck, about 400 feet away from the transmitting room, containing all receivers, telephone terminal equipments, remote-control apparatus, transmitting keys, high-speed transmitting and receiving apparatus, and a complete emergency station.

Fig. 1 shows an outline of the ship, giving the respective positions of these rooms and of the aerial system.



Showing Position of Radio Plant and Aerials.
(H) 8-Mc Double Doublet.
(J) 4-Mc Dipole.
(K) Medium-wave Receiving Aerial.
(L) Broadcast Receiving Aerial.
(M) Direction Finder Sense Aerial.
(N) Direction Finder.

TRANSMITTING ROOM

This is situated at the after end of the sun

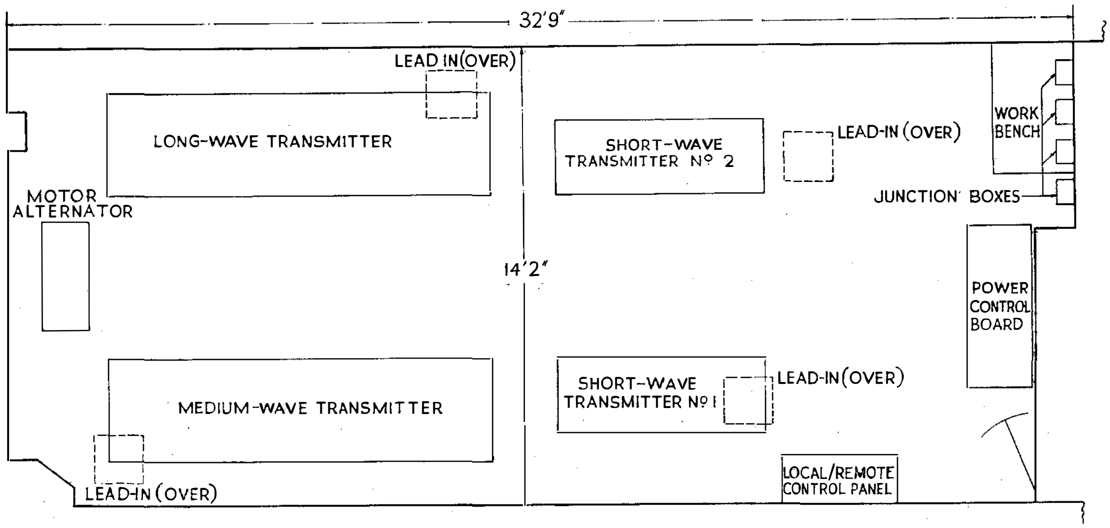


Fig. 2—Transmitting Room of R.M.S. "Queen Mary."

deck, just forward of the mainmast, and measures some 30 ft. by 14 ft. by 9 ft. in height; the layout is shown in Fig. 2. The equipment in this room weighs about 11 tons and comprises:

(*a*) *A Power Control and Distribution Board.*—This board, which is of steel throughout and measures approximately 7 ft. by 5 ft. by 2 ft. 6 in. deep, carries duplicated stop-start motor and alternator control arrangements for the two main motor-alternators (which are seven decks below), together with the necessary pilot lamps, voltmeters, ammeters, frequency meter, and an automatic voltage regulator which keeps the 3-phase a.c. supply at a constant voltage irrespective of the load or temperature conditions. The board also carries the control for the modulating motor-alternator used with the medium-wave transmitter. The 50-cycle 3-phase a.c. supply is distributed to 6 output circuits, each having its own switch and pilot lamp—one to each of the four transmitters, one to the receiving room, and a spare.

(*b*) *A Medium-wave Telegraph Transmitter* [described hereinafter].—This transmitter utilizes five spot frequencies. The transmitter works into a 700-$\mu\mu$F "T" type aerial giving an aerial current of about 21 to 25 amperes on full power, according to wavelength.

A 2-kW motor-alternator used for modulating is mounted beside the transmitter.

The transmitter is mounted on a special shock-absorbing base comprising two heavy channel-iron plinths, one floating elastically on top of the other and allowing universal motion of the transmitter, to protect the valves and control relays against any vibration which might exist.

(*c*) *A Long-wave Telegraph Transmitter* closely resembling the medium-wave transmitter but restricted to C.W. operation, M.C.W. not being permitted on these wavelengths. It utilizes 7 out of the 10 available spot frequencies and works into an "L" type aerial having a capacitance of 2,000 $\mu\mu$F, giving an aerial current of about 25 amperes at full power.

(*d*) *Two Telegraph/Telephone Short-wave Transmitters* [of the type described hereinafter].—These transmitters furnish the two short-wave links of the vessel, one being used normally for communication to Great Britain and the other to the United States. Each has 10 crystal-controlled frequencies between the limits of 3 and 17 megacycles (17 to 100 m.), the frequencies of course being selected so that no mutual interference exists and so that neither the transmitted frequencies nor their harmonics are likely to interfere with reception in the operating room.

These two transmitters stand upon shock absorbers similar to those used for the medium- and long-wave transmitters.

(*e*) *Auxiliary Control Panel.*—An auxiliary control panel is provided at a small desk near the door to the transmitting room. This panel carries switching arrangements allowing of local keying of any of the four transmitters, monitoring any of the receivers in the operating room, and for putting any of the operating room remote-control arrangements completely out of circuit if required, when overhauling the transmitter concerned.

OPERATING ROOM

General Arrangement

The operating room forms the central control point of the entire station, all incoming and outgoing telegraph and telephone traffic being handled here.

Extensive precautions have been taken against interference from the ship's electrical machinery. In addition to the shielding of the receivers themselves, the operating room is lined with copper sheet forming as nearly as possible a closed tank, earthed at one point only to the upper deck. All electrical wiring inside the room is shielded, the shielding being bonded to the copper lining of the room. Every wire entering the room, including lighting, power, telephone, and control lines to the transmitting room, terminates at one or other of several shielded junction boxes, situated in a small compartment immediately external to the copper lining, the main object of this being to ensure that noise brought in by wiring can be rapidly located and the offending lines suitably filtered. All lines from the junction boxes to other parts of the ship are also shielded, the shielding being earthed.

As a further precaution against noise, the ship's d.c. mains are normally excluded altogether from the operating room, and all power for lighting this room, operating the receivers and high-speed apparatus, and battery-charging, is derived from the 3-phase a.c. supply provided by the motor-alternator through a 7-kVA 3-phase transformer situated in the same compartment as the junction boxes mentioned above. The primary of this transformer is mesh-connected and the secondary star-connected, with earthed copper shields between the primary and

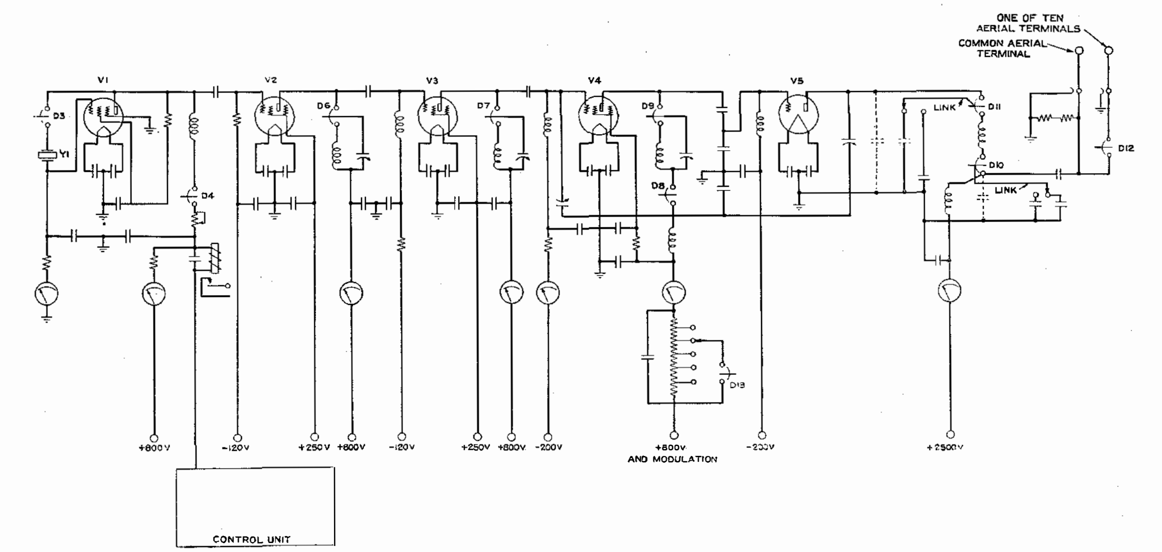


Fig. 3—Simplified Circuit Diagram of Short-wave Transmitter, R.M.S. "Queen Mary."

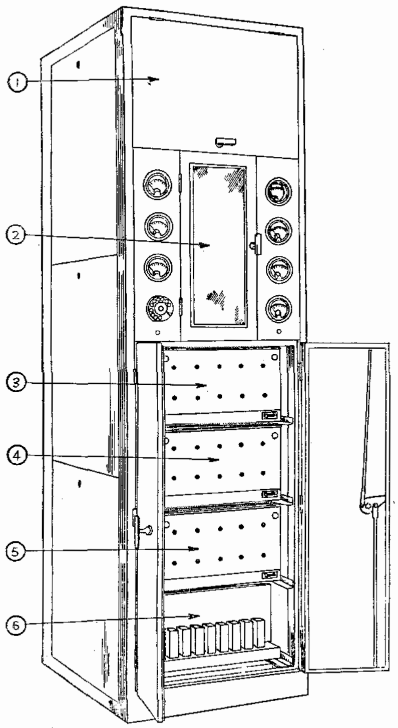


Fig. 4—Radio Frequency Cabinet of Short-wave Transmitter, R.M.S. "Queen Mary."

(1) Output Stage.
(2) Output Valve Compartment.
(3) Modulated Amplifier Stage.
(4) Second Buffer Stage.
(5) First Buffer Stage.
(6) Oscillator Stage.

secondary. The star point of the secondary is also earthed, the three outlets giving separate single-phase supplies used for (*a*) lighting, (*b*) power supply to receivers, terminal equipment and high-speed equipment, and (*c*) battery-charging. The transformer design precludes the possibility of any noise due to the motor-alternator itself reaching the receivers. A change-over switch external to the room allows the lighting system to be transferred to the ship's mains if required, while a second change-over switch allows of an alternative source of a.c. supply for the receivers from a small motor-alternator used for other services on the ship.

Further precautions against noise interference include the fitting of noise suppressors to the four passenger lift motors just outside the receiving room, and to some 200 fan motors ranging up to 10 h.p. on the upper decks, together with the running in earthed conduit of all cables on the upper decks within 200 feet of the receiving aerials.

Operating Positions

The four operating positions are situated at a single bench about 20 feet long and provided with a typewriter well at each position. All telegraphic reception at low speeds (up to 40 words per minute) is carried out aurally, the message being typed out on the appropriate form by the operator. At the side of each typewriter well is a morse key for hand transmission.

All receivers, control units, telephone terminal control equipment, and operators' key panels, are of the rack-mounting type and are mounted in a set of steel cabinets each measuring 3 ft. 4 in. high by 22 in. wide by 12 in. deep, standing at the back of the operating table and facing the operators. Ten such cabinets in all are provided, two to each operating position, plus an extra cabinet between positions 1 and 2 (the short-wave telegraph/telephone positions) and another between positions 3 and 4 (the medium- and long-wave telegraph positions), these additional cabinets containing apparatus common to the positions on either side. The 10 cabinets are bolted together side by side, and are supported by special shock-absorbers to guard the components against vibration. Doors at the back of each cabinet give access for changing valves, etc. The special construction of the panels, known as the "depressed panel system," allows of any repairs being readily carried out after removing the front panels of the cabinets, which are simply cover-plates for the wiring.

Positions Nos. 1 and 2 are identical, each containing a short-wave telegraph/telephone receiver (described hereinafter), the remote control unit for one of the short-wave transmitters, the telephone terminal equipment for one link, and other units as mentioned above. A medium long-wave telegraph receiver is mounted between these two positions, in case either position is required as an additional long-wave telegraph channel. This equipment provides all that is necessary for normal telegraph and telephone communication. Between the two positions is the additional telephone

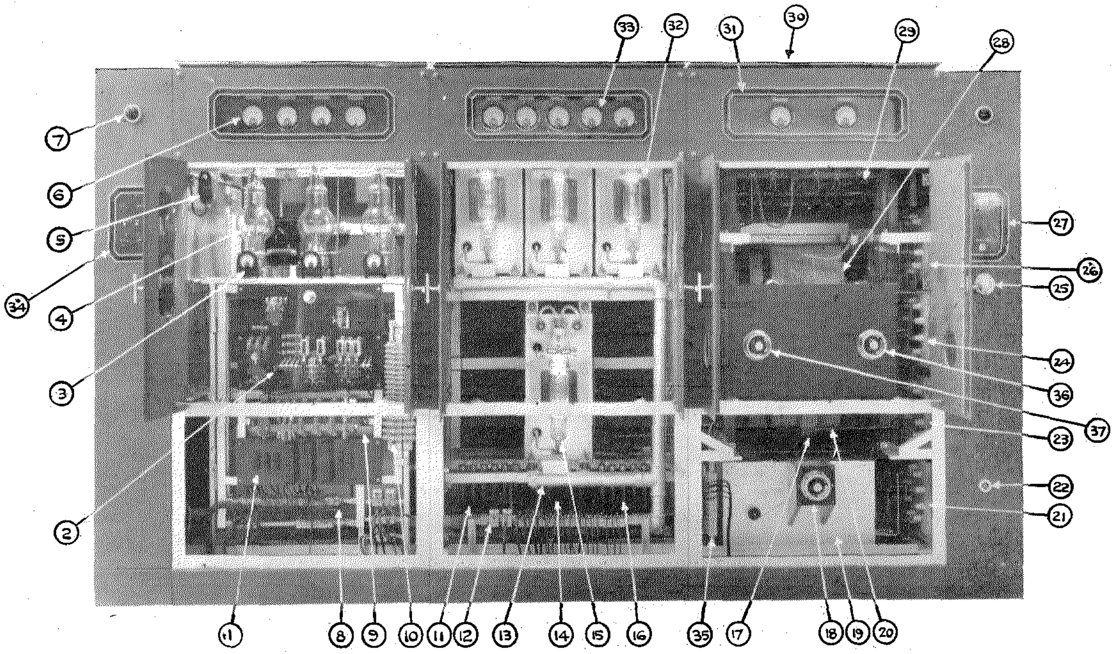


Fig. 5—Front View of Medium-wave Transmitter, R.M.S. "Queen Mary" (Cover Panels Removed).

(1) Rectifier main fuse panel.
(2) Rectifier power-control contactor panel.
(3) Rectifier valve-filament ammeters.
(4) Rectifier valves.
(5) Thermostatic air control.
(6) Rectifier meter panel containing anode ammeters and H.T. voltmeter.
(7) H.T. indicating lamp.
(8) Rectifier main terminal strip.
(9) Main contactor.
(10) Power-control panel strip connectors.
(11) Power amplifier quarter-power resistances.
(12) Valve unit, main terminal strip.
(13) Air supply.
(14) Master oscillator and power-amplifier filament centre-pointing resistances.
(15) Master-oscillator valve.
(16) Power amplifier auto bias resistances.
(17) Aerial coupling coil.
(18) Master-oscillator variometer.
(19) Master-oscillator coil box containing variometer and Selsyn motor.
(20) Amplifier closed-circuit coil.
(21) Master oscillator wave-change switch.
(22) Entry for emergency wave-change handle.
(23) Amplifier closed-circuit wave-change switch.
(24) Aerial coupling-coil wave-change switch.
(25) Wave-change dial.
(26) Aerial tuning-coil wave-change switch.
(27) Wave-change repeater dial.
(28) Aerial tuning coil.
(29) Aerial loading coil (when required).
(30) Aerial lead-out insulator.
(29) Aerial loading coil (when required).
(30) Aerial lead-out insulator.
(31) Aerial and closed-circuit ammeters.
(32) Amplifier valves.
(33) Valve unit meter panel containing master-oscillator and amplifier plate meters and amplifier grid meter.
(34) Local control panel.
(35) Coil unit, main terminal strip.
(36) Aerial tuning variometer.
(37) Amplifier closed-circuit variometer.

terminal equipment allowing either telephone circuit to be put on a "full singing suppressor" basis should communication conditions demand it, the normal condition being only "half singing suppressor." A spare short-wave receiver is also mounted at each of these positions; this is constantly in circuit and is available for immediate use in the event of a valve or other failure in either receiver.

The two privacy equipments, additional singing-suppressor equipment including a delay network, together with their associated power supply rectifiers, are mounted in telephone-type racks bolted to the bulkhead behind the receivers. These are entirely controlled from the two short-wave operating positions and can be cut in or out of circuit as required.

The two short-wave positions, for telephony, normally connect through 2-wire extensions to the ship's telephone switchboard which connects to the 500 cabin staterooms equipped with telephones and to 2-wire phone booths in various parts of the ship, as well as to the ship's official services. In addition, a number of 4-wire extensions are taken to certain of the principal staterooms, through a special 2-wire to 4-wire sub-switchboard at the ship's exchange, to allow of 4-wire working when desirable. In the case of these staterooms, when 4-wire communication is necessary the operator at the ship's exchange disconnects the subscriber from the 2-wire central exchange and connects him direct to the radio terminal equipment on a 4-wire basis. A 4-wire telephone is also provided in a telephone booth near the radio accepting office and is connected directly to the terminal equipment.

Operating positions Nos. 3 and 4 are somewhat simpler, handling only telegraph communication. The general arrangement is somewhat similar to that of positions 1 and 2, except that the transmitter remote controls are situated in the cabinet between the two positions. This allows an operator at either position to control either the medium-wave or long-wave transmitters. Each of these positions carries a medium-wave receiver (500–3,000 m) and a long-wave receiver (1,800–20,000 m). In addition, a spare receiver is carried between positions 3 and 4, for use in the event of breakdown of one of the other receivers.

High-speed Position

Two high-speed tape transmitting keys, together with their associated perforators and a morse undulator, are mounted on a separate table in the operating room. The driving motors of all high-speed apparatus are of the inductor type to avoid commutator noise. Each of the high-speed keys can be connected to operate any one of the four radio transmitters, and can be controlled either locally or from the operating positions.

Satisfactory transmission and reception of messages at speeds of up to 80 words per minute have been carried out with the above apparatus.

Supervisory Position

The supervisor sits at a desk overlooking the rest of the operating positions, his duties being to route accepted telegrams to the proper operating position for transmission, to monitor any of the circuits if required, to keep an additional loud-speaker listening watch on the 600 m wave and on three other circuits, and to perform various circuit-switching duties.

Special provision is made to give the supervisor direct telephone communication with the navigating bridge and with the transmitter room.

Emergency Position

The emergency position resembles the normal equipment of an ordinary cargo ship and comprises (1) an I.C.W. transmitter having three "spot" wave-lengths of 600, 705, and 800 m, and delivering some 4 amperes to the emergency aerial, and (2) a 5-valve receiver covering a waveband of 110–2,000 m. The transmitter is operated through a motor-alternator from a 120-volt emergency battery which also provides H.T. for the receiver. The receiver filaments are supplied from a 24-volt battery, which can also be used in the very last resort to operate the transmitting motor-alternator, which is double-wound for 120 and 24 volts input. The batteries are charged from the a.c. supply through a dry rectifier.

POWER ROOM

The power plant is situated in a small fireproof compartment adjacent to the ship's engine room, and is in duplicate. It comprises two 45-kVA, 220-volt, 50-cycle, 3-phase a.c. motor-alternators, driven off the ship's 220-volt d.c. mains, with automatic starters remote-controlled from the power board in the transmitting room.

The a.c. supply here generated feeds not only the transmitters, but also all the receivers and terminating equipment; it furnishes in addition the normal lighting supply for the operating room, and battery-charging supply for the emergency equipment.

AERIAL SYSTEM

In designing the aerial system, the principal points borne in mind were that (*a*) both the transmitting and receiving aerials should have the maximum possible efficiency, and (*b*) the transmitters should interfere as little as possible with reception. These conflicting requirements are difficult to reconcile on a small ship, but fortunately the great size of the *Queen Mary*, allowing of comparatively wide separation between the transmitting and receiving points, materially assisted matters.

Fig. 1 illustrates the general aerial arrangement finally adopted. It will be seen that, with the exception of the long-wave aerial, the transmitting aerials are kept to the after part of the ship, and the receiving aerials between the first and second funnels, over the operating room.

The medium- and long-wave transmitting aerials were the easiest to arrange, the requirements being that they should be as high as possible and should have large capacity so as to insure low working voltage and reduce any tendency to brush discharge. Accordingly, twin-wire aerials were provided in both cases. These are suspended between spars at the foremast and mainmast heads, the top spans of the one being shackled to those of the other through insulator chains. The medium-wave aerial is of the "T" type, with top span 150 feet long and a downlead 80 feet long dropped almost vertically to a steel "trunk" (or protective conduit) leading to the transmitter room below. The long-wave aerial is of the inverted "L" type, with its down-lead at the after end leading to another trunk over the transmitting room.

The two short-wave transmitting aerials are of the inverted "V" type, giving an appreciable directive effect. That for one transmitter comprises two inverted V's in parallel, the apices being suspended one from each end of the mainmast spar, the far end of each "V" being taken aft to the docking bridge and splayed out to the sides of the ship. The other aerial similarly consists of two wires, the apices of the "V" in this case being suspended one from each side of No. 3 funnel. A number of tests were carried out during the construction of these aerials to determine the best lengths and angles of suspension for the legs of the "V," both by field-strength measurements on a launch cruising at various distances from the ship, and by simultaneous measurements taken by a number of observation stations in different parts of the world during the trials, with the ship swung at various angles. For the first aerial mentioned above, the following gains relative to a half-wave vertical aerial were observed in the fore-and-aft direction:

Frequency Mc	Gain db
4	0
8	5
13	8
17	6

The major lobe of transmission was approximately 60° wide at 17 megacycles, gradually widening until there was practically uniform coverage at 4 megacycles. It is interesting to note that preliminary tests, using only a single-wire "V" suspended on one side of the ship, showed a displacement of the major lobe by some 20° from the fore-and-aft line of the ship; this was corrected by adding the second wire. The other aerial has slightly less directivity, but is still markedly superior to a plain vertical aerial.

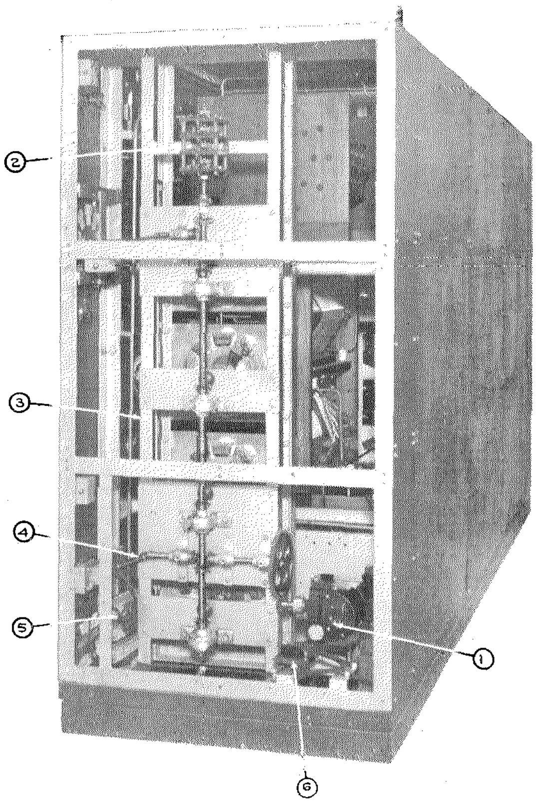


Fig. 6—End View of Medium-wave Transmitter, R.M.S. "Queen Mary" (Cover Panel Removed), Showing Wave-change Gear.

(1) Wave-change Motor.
(2) Control Switches.
(3) Complete Assembly of Wave-change Switchgear.
(4) Hand-control for Emergency Wave-change.
(5) Wave-change Unit Main Terminal Strip.
(6) Wave-change Motor Fuse.

The results shown above are in accordance with requirements; during the greater part of the voyage, when the higher frequencies are required, great-circle bearings between the ship and the shore stations in this country and the United States respectively are within 20° of the fore-and-aft line of the ship, and the directive effect is therefore most useful. When the ship is nearing land and requires the 4-megacycle transmission, the great-circle bearing from the ship tends to alter considerably and therefore non-directive transmission is preferable.

Four short-wave horizontal-doublet receiving aerials are fitted, known as the 4-, 8-, 13-, and 17-megacycle aerials respectively, though the actual frequency response of each extends considerably on either side of the nominal frequency. The 8- and 13-megacycle aerials, being the most used, are double-doublets to increase the frequency coverage.

From each of these aerials a balanced open-wire transmission line runs down to the top of a trunk above the operating room, and thence through impedance-matching transformers and concentric transmission lines to a switching panel equipped with screened jacks and patch cords, from which in turn concentric cables run to the four short-wave receivers. Any aerial may be connected to any receiver at the switching panel. The use of concentric transmission line is very advantageous in eliminating local interference.

For medium- and long-wave reception two aerials are provided. One of these is of the inverted "L" pattern, suspended between the first and second funnels, and can be switched over to the emergency position in the operating room for use as emergency transmitting and receiving aerial. The other is a relatively short inclined aerial, and is used for reception only, principally for duplexing on long waves and for Press reception. All the medium-wave receivers can be connected to one of the aerials, while all the long-wave receivers can be connected to the other aerial, the connections being made through screened patch cords and jacks and then through a concentric transmission line and rejector circuit. The rejector serves to cut down to a safe value the high voltages induced by the long-wave transmitting aerial which runs directly above the receiving aerials, any residual interference being eliminated in the receiver preselector circuits as subsequently explained.

Finally, a separate aerial is provided for the reception of broadcast programmes. This aerial is quite short (60 feet in length) and runs from No. 1 funnel to the receiving aerial trunk, from whence it is fed, through impedance-matching transformers and a rejector unit, to the high-fidelity receiver mentioned below.

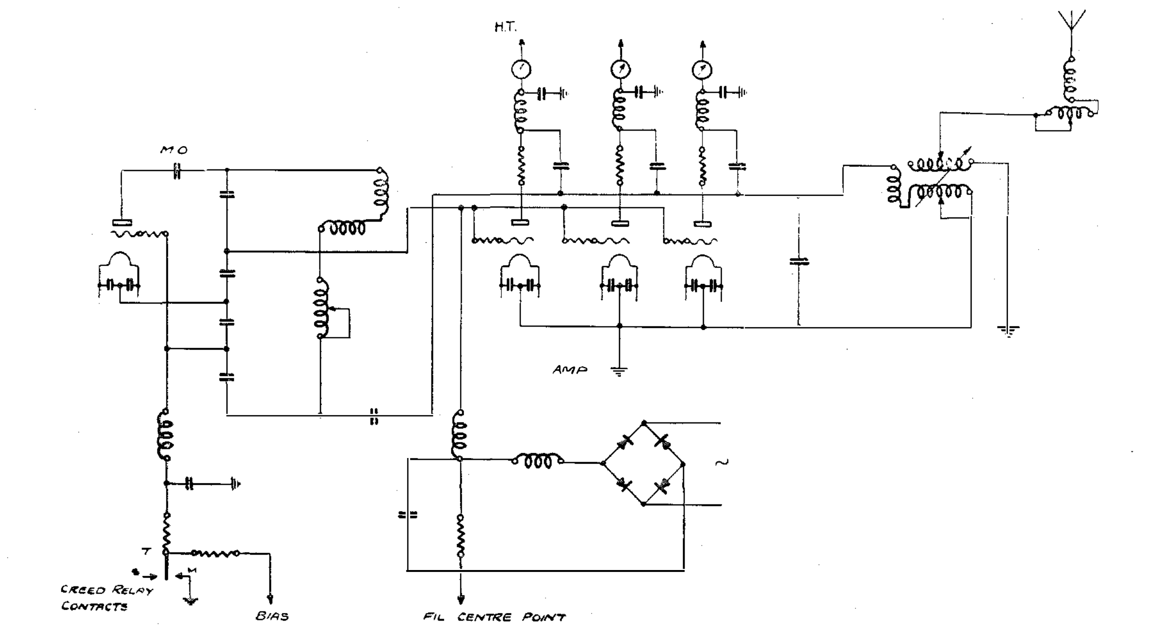


Fig. 7—Simplified Circuit Diagram of Medium- and Long-wave Transmitters, R.M.S. "Queen Mary."

Broadcast reception suffers no interference from the ship's transmission on either short, medium, or long waves.

SHORT WAVE TRANSMITTER (TYPE 14-B)

In the case of the short-wave transmitter the factors chiefly influencing the design are the provision of (*a*) very stable carrier; (*b*) quick change from one spot wave to another; (*c*) moderate output power of approximately 400 watts. The stable-carrier requirement is met by the provision of a separate quartz crystal for each wavelength, followed by five amplifying stages in order to reach the required output level. This involves a number of tuned circuits, each requiring adjustment by tappings or otherwise for each spot wavelength. The use of tappings on short wavelengths is practicable only to a limited degree, and accordingly the wave-change principle embodied in this transmitter is the provision of entirely separate tuning units at each stage for each of the 10 spot wavelengths, the valves being connected to the appropriate tuning units through switches operated simultaneously under the control of a telephone dial. Fig. 3 shows a simplified circuit diagram of the radio-frequency stages with all the tuning units for one wavelength, D1, D2, etc., being the switches connecting the permanent valve circuits to the tuning units. The latter are of plug-in pattern, and are available for a waveband of 16.6–150 m (frequency 2–18.1 megacycles).

The transmitter consists of two cabinets, each of dimensions approximately 24 in. wide, 30 in. deep and 83 in. high, mounted side by side. One cabinet contains the radio-frequency valves and circuits, while the second contains the audio-frequency amplifiers together with the rectifiers and other apparatus. Both cabinets are of the enclosed type with access to apparatus through doors. A ventilating fan is included in the radio-frequency cabinet. The entire equipment is designed to operate from a 3-phase 50-cycle 220-volt source, and has a power consumption of approximately 3.5 kW at full load.

As can be seen from Fig. 4, the radio-frequency cabinet includes a number of subunits of chassis construction. Starting from the bottom, these are: oscillator stage, first buffer stage, second buffer stage, modulated amplifier stage, output-valve compartment, and output stage. Each chassis mounts a total of 10 plug-in tuning units, while the bottom chassis in addition mounts up to 10 quartz crystals. Adjustment of any of the tuning units can be performed, while the equipment is in operation, by means of a tool inserted through an aperture in the grounded front cover-plate of the chassis. All the chassis are quickly removable for examination of components, and are automatically disconnected at all terminals as they are withdrawn from the cabinet.

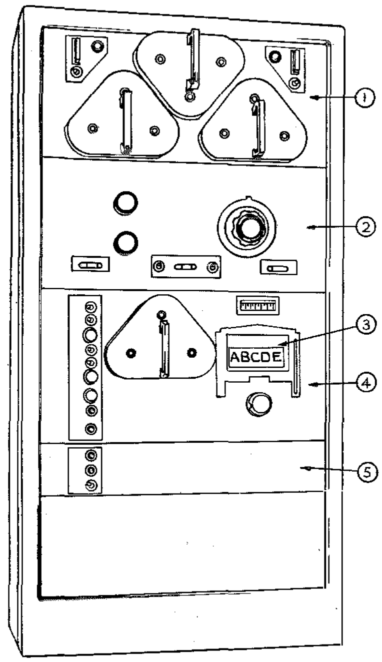


Fig. 8—Rack-mounted Short-wave Receiver used on R.M.S. "Queen Mary" (*Waveband* 13.5–550 *m*).

(1) Combined Power Panel and Spare Coil Rack.
(2) Preselector Unit.
(3) Five-track Tuning Condenser Scale.
(4) Receiver Unit.
(5) Note Filter.

Both the first and the second buffer stages may be used either as straight amplifiers or as frequency doublers, according to the relation between the crystal frequency and the required frequency. For telephony or M.C.W. the modulating voltage is applied in series with the

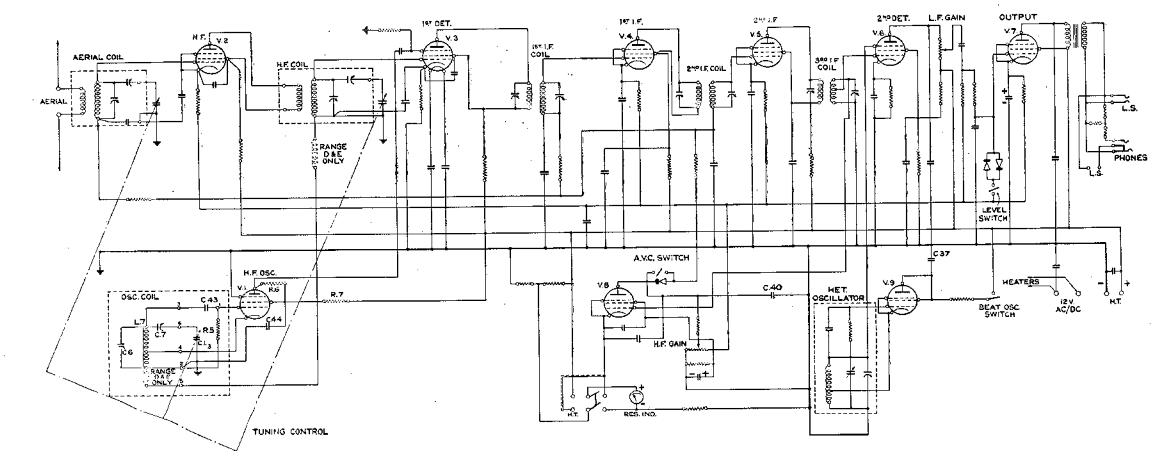


Fig. 9—Circuit Diagram of Short-wave Receiver Unit.

high-tension supply to the penultimate valve, and modulates both plate and screen-grid voltages. Keying is effected at the plate of the oscillator, which is earthed through a key-controlled relay system during the spacing periods. When the transmitter forms part of a radiotelephone link circuit the carrier is, by means of the terminating equipment described later, automatically switched on while the ship subscriber is speaking. In this case the actual switching removes the earth from the plate of the oscillator, as during keying, but the train of relays involved is adjusted so as to provide a short "hangover" period of 150 milliseconds to prevent the transmitter being switched off in the intervals between words.

The wave-change system employed is relatively simple. At the back of the transmitter is a row of 10 vertical rods, one for each wavelength; at the foot of the transmitter is a horizontal shaft equipped with 10 cams which are normally free on the shaft. On dialling the single digit number allocated to the wavelength or "channel," the appropriate cam is locked to the horizontal shaft which then rotates the cam, raising the corresponding vertical rod, the latter operating a number of bell cranks which close switches connecting into circuit the crystal and all the pre-set tuning units for the particular wavelength required. The time required to change wavelength depends almost wholly on the dialling operation, and varies from about 1 to 2 seconds according to the digit dialled. The wave-change system is interlocked with the protective system to remove the high-tension supplies during the circuit change.

The output circuits of the transmitter are designed to work into an impedance of 500 ohms; each output circuit is connected (through a switch forming part of the wave-change system) to its own aerial terminal and also to a common aerial terminal. Each wavelength may therefore have its own aerial directly connected to the transmitter, or alternatively the transmitter may always work into a common 500-ohm transmission line connected to one or more aerials through a separate tuning and coupling unit. In the latter case the coupling unit is equipped with the requisite number of plug-in type tuning circuits, together with a wavechange system of the same pattern as that used on the transmitter, and controlled simultaneously therewith. By means of this arrangement it is possible to use either open-wire or tubular feeders to the aerials, and to use the same aerial on more than one wavelength.

The power supply required for the transmitter circuits is derived from the second or rectifier cabinet. All filaments are heated by alternating current, while three hot-cathode mercury-vapour rectifiers—two of the 3-phase half-wave type and one single-phase full-wave—give the d.c. supplies for anodes and screen and control grid bias. The same cabinet contains a 2-stage audio-frequency amplifier to supply the modulating voltage; this amplifier will give full modulation with an input of 23 db below reference level (5.9 milliwatts). The relay trains used for keying or voice-controlled carrier switching are also fitted in this cabinet, on a removable chassis mounted in the top section.

Remote control of the transmitter is centred on a special panel mounted on the same "operator's position" rack as one of the receivers in conjunction with which the transmitter is used. This remote panel provides for selection of any of the three possible types of communication — C.W. telegraphy, M.C.W. telegraphy, or radio-telephony. It is also equipped with a dial for wave selection, an 800-cycle oscillator to supply tone for M.C.W. modulation, a voltmeter which measures the speech-level supplied to the transmitter (and can be considered as a modulation indicator) and with controls for the depth of modulation, etc., as required for radio-telephone link working (dealt with in a following Section).

MEDIUM- AND LONG-WAVE TRANSMITTERS (TYPE M.20 and 21)

Taking first the medium-wave transmitter, this covers a band of 585 to 822 m with dial-controlled switching to any one of up to 10 spot wavelengths within this band, and aerial circuit power of 3 kW on C.W. or 3 kW plus 80 per cent. modulation on M.C.W. Power input is from a 3-phase, 50-cycle source, with the transformers and any rectifiers required to furnish the various filament, anode, and grid supplies, etc., included in the transmitter. The main H.T. rectifier uses hot-cathode mercury-vapour valves, but all other rectifiers are of the dry metal type.

Views of the general assembly are shown in Figs. 5 and 6. During operation the transmitter is completely enclosed, except for ventilating louvres, cooling being aided by a built-in blower system. Access to the interior is obtainable through doors which, when opened, operate gate switches to cut off the H.T. supply.

The basic circuit of the transmitter is shown in the simplified circuit diagram, Fig. 7. A single-valve self-biased master-oscillator drives a neutralized power-amplifier group of three parallel valves, the output of which is inductively coupled to the aerial through a tank circuit. Keying is performed through a high-speed polarized Creed relay which biases back the grid of the master-oscillator valve. Excellent signal wave-form is obtained up to key speeds of over 100 words per min. For M.C.W. operation the power amplifier is anode modulated by tone derived from a 700-cycle, 2-kW alternator. Provision is also made for low-power grid modulation of the power-amplifier stage, to give either telephony or M.C.W. of other than 700-cycle tone.

The main H.T. rectifier is of the 3-phase half-wave type with one hot-cathode mercury-vapour valve per phase. A spare valve is fitted in position and can be switched as a replacement into any of the three phases; its cathode is kept heated to half brilliancy during the period when it is not in use so as to avoid the serious loss of time otherwise involved in "conditioning" a valve which has been lying idle for some time. When first starting up the transmitter at the commencement of a voyage an automatic time delay ensures that high tension is not applied until the rectifiers are properly warmed up by having their filaments alight for 5 minutes.

The long-wave transmitter is identical in design, power, and facilities, with the medium-wave transmitter, except for the electrical values of tuning condensers, etc., and the addition of an aerial loading coil. It covers a wave-band of 1,875 to 3,000 m, on which, by regulation, transmission is confined to C.W.

As can be seen from the illustrations, the transmitter includes two narrow end-bays flanking three large bays assembled together to form a single unit. The first (end) bay from the left (Fig. 5) contains the air blower, Creed relay equipment, remote-control relay rack, and local-control circuit equipment. In the second bay are housed the main H.T. mercury-vapour valve rectifier with its associated transformers and other power supply gear, together with the dry metal rectifiers for circuit control and grid bias, etc. The third or centre bay contains the master-oscillator and amplifier valves, together with their blocking and tuning condensers, high-

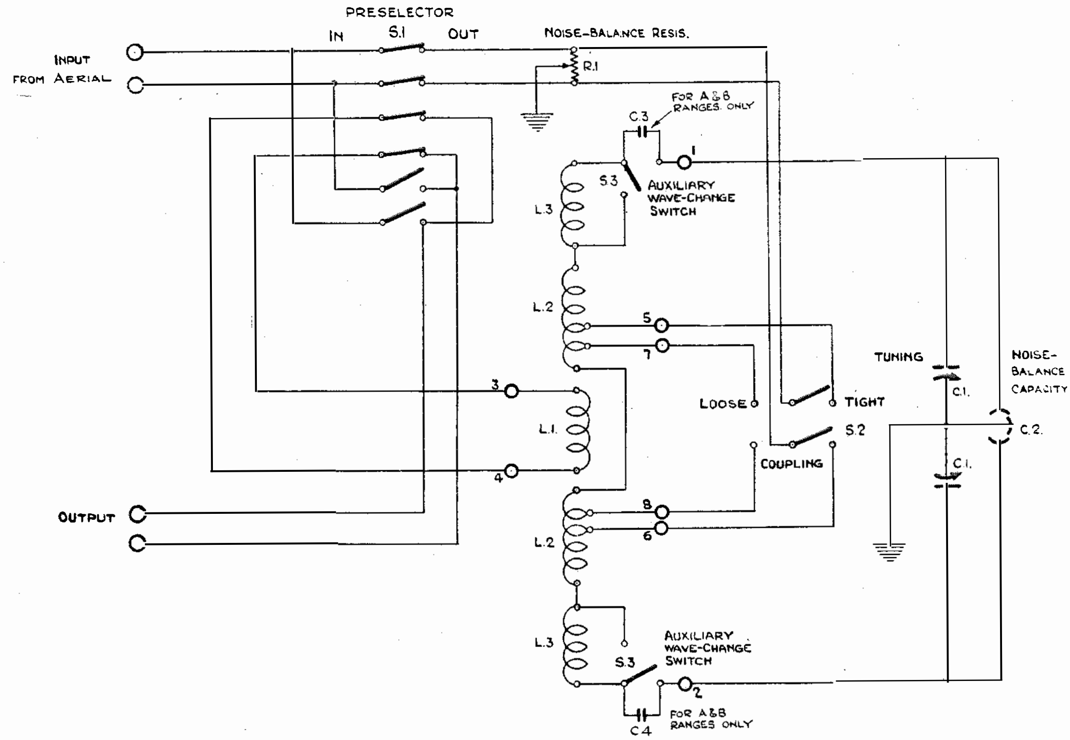


Fig. 10—*Circuit Diagram of Short-wave Receiver Preselector Unit.*

frequency chokes, and protective resistances. The fourth bay contains all the tuning coils for both master-oscillator and amplifier circuits, together with a remotely-controlled mechanism associated with the master-oscillator tuning circuit. The remaining end bay (Figs. 5 and 6) is devoted to the wave-change mechanism.

The method of wave-change used is as follows. The same tuning coils and condensers remain in circuit on all wavelengths, but the active tappings on the tuning coils are changed. In the case of the medium-wave transmitter there are three tuning coils involved—master-oscillator, power-amplifier output, and aerial tuning; while for the long-wave transmitter there is one additional coil for aerial loading. Associated with, and mechanically close to, each tuning coil is a 10-point rotary switch, whose studs are connected to tappings on the coil corresponding to the desired wavelengths. An unusual feature of the switch is that contact between brush arm and stud is made through a special spring-loaded metallized carbon brush with pigtail connection to the brush carrier, the assembly closely resembling the brush gear used on ordinary electrical machinery. All these 10-point switches are operated simultaneously from a common vertical power shaft to which the rotating brush-arms are individually coupled through bevel gears. This common power shaft is itself driven through reduction gear by a small motor which, when idle, has its rotor clamped by a powerful brake and whose starting and stopping is governed by a telephone dial and relay system on principles similar to those used in the design of an automatic telephone exchange.

In addition to the switches just referred to, another group of four 10-point rotary switches are driven from the vertical power shaft. One of these is a pilot switch connected into the relay circuits to complete the motor-stopping circuits when the switches have travelled to the correct tap-contact position ; another ensures that high tension is not applied to the valves unless the h.f. circuits are complete ; the third switches auxiliary tuning condensers through a contactor system ; while the fourth is used to "indicate back" the position of the switches to the remote-control position.

The common power shaft also furnishes drive to an illuminated indicator disc marked for each position with the frequency and dial number of the wavelength to which the transmitter is then set. In the event of failure of the shaft-driving motor it is possible to operate the shaft through a free-wheel device by means of manual control from the front of the transmitter.

The control circuits are so arranged that if a new wavelength is dialled while the transmitter is running, i.e. with anode H.T. "on," in order to safeguard the valves the H.T. supply is automatically disconnected before there is any movement of the power-driven wave-change group of switches, and is restored when these switches have reached the position corresponding to the number dialled. The time taken to change wavelength depends on the amount of travel of the rotary switches, and in the extreme case of changing, say, from wavelength "3" to wavelength "2," which involves the maximum travel (since the switches always rotate in the same direction, and must therefore traverse 9 positions for the case quoted) this total time does not exceed 10 seconds. For changing in the opposite direction, i.e. from wavelength "2" to wavelength "3" the time is about 2 seconds. The control mechanism embodies a storage feature whereby it is impossible for a second operation of the dial to have any effect unless the changes governed by the first operation have been completed. If the dial is operated to give the same wavelength as that on which the transmitter is already set, there is no movement of the rotary switches, the only effect of the second dialling being a momentary interruption of the H.T. supply. Dialling may be done either on the "local control" dial mounted on the front of the right-hand bay of the transmitter (Fig. 5) or on another dial located at a distance on a remote-control unit.

It sometimes becomes desirable to change a wavelength very slightly from its pre-set value, say by a few hundred cycles, in order to avoid interference with or from other stations working on the same wavelength. To meet this possibility a small auxiliary variometer is included in the master-oscillator circuit, and is varied at the remote control through a "Selsyn" system to give the desired small frequency change, the switch-selected taps and the master-oscillator and other coils being left unaltered. This system consists, in effect, of two small a.c. synchronous-motor mechanisms, electrically inter-connected so that the rotor of the "receiving" end, coupled to the variometer, does not rotate but takes up a steady position corresponding to the hand-controlled position of the rotor at the transmitting end, i.e., on the remote-control panel.

On the front of the left-hand end bay (Fig. 5) are switches of the telephone pattern which operate through relays to give the following controls : "H.T. on-off," "Full, half, or low power," "C.W. or M.C.W.," and "Local" or "Remote" control. This last switch provides for the transfer of all the other switch facilities just mentioned, together with the signalling key and wave-change dial circuits, to a remote-control unit. In the case of the *Queen Mary* this remote-control unit is situated in the operating room 400 feet from the transmitter.

The remote-control unit is of panel type and is mounted on one of the "operators' position" racks in the operating room. It is equipped with a telephone dial for wave selection, wavelength number repeater to indicate the wavelength on which the transmitter is set, and switches for H.T. supply, etc., as on the "local control" position on the transmitter. It also includes the control for the "Selsyn" system, which governs the position of the master-oscillator auxiliary variometer, and permits fine regulation of the transmitting frequency on either side of its normal value.

SHORT-WAVE RECEIVER (RM. 10)

The receiver units from which the *Queen Mary's* equipment is built up consist of the "short-wave" receiver, wave-range 13.5–550 m, primarily used for short-wave telegraphy and telephony ; the "medium-wave" receiver, wave-range 500–3,000m, for medium- and long-wave telegraphy; and "long-wave" receiver, wave-range 1,750–20,000m, for long-wave telegraphy. These receivers are all of the rack-mounted type and have the following features in common:

(*a*) Power supplies drawn from an a.c. power unit.

(*b*) Single-control tuning with large indicator drum (8 inch diameter) calibrated directly in kilocycles, the calibration track covering 280°.

(*c*) Auxiliary note filters for heterodyne reception.

(*d*) Auxiliary preselector circuit which can be switched in or out as desired.

(*e*) Output circuits arranged for loud-speaker monitoring, operating a tape recorder for morse telegraphy, and direct feed to the terminating equipment for telephony. For ordinary reception of morse signals a fixed 13-db attenuator is inserted before the headphones, so that both headphones and loud-speaker or tape recorder can be energized simultaneously at their suitable different levels.

Fig. 8 shows a single short-wave receiver mounted on a rack, together with its associated preselector and power supply units, while Figs. 9 and 10 show the circuit diagrams of the receiver and preselector units respectively. The circuit is of the superheterodyne pattern, requiring 9 valves for the following functions; one h.f., 1st detector, separate beating oscillator, two l.f. stages, 2nd detector, l.f. output valve, separate heterodyne oscillator, and separate automatic gain-control valve. This receiver is particularly designed for use on large liners, and possesses accordingly a number of rather special features. These are:—

(1) The short-wave receiving aerials must be so situated as to be as free as possible from the numerous sources of electrical noise which are normally encountered on board such vessels. This in general means that the aerial is at a fairly large distance from the receiver room, and must be connected thereto by a transmission line, which if of the open wire pattern is itself liable to pick up noise. It is therefore necessary to provide special circuits for coupling the receiver through the transmission line to the aerial. In the present case the required coupling circuits are included in a separate preselector panel unit, which serves simultaneously to match the receiver proper to the aerial transmission line, to give extra selectivity against transmissions on a neighbouring frequency, and to give almost complete suppression of medium and long wave voltages picked up by the aerial. It will also give an accurate balance against any noise currents which may be picked up in the transmission

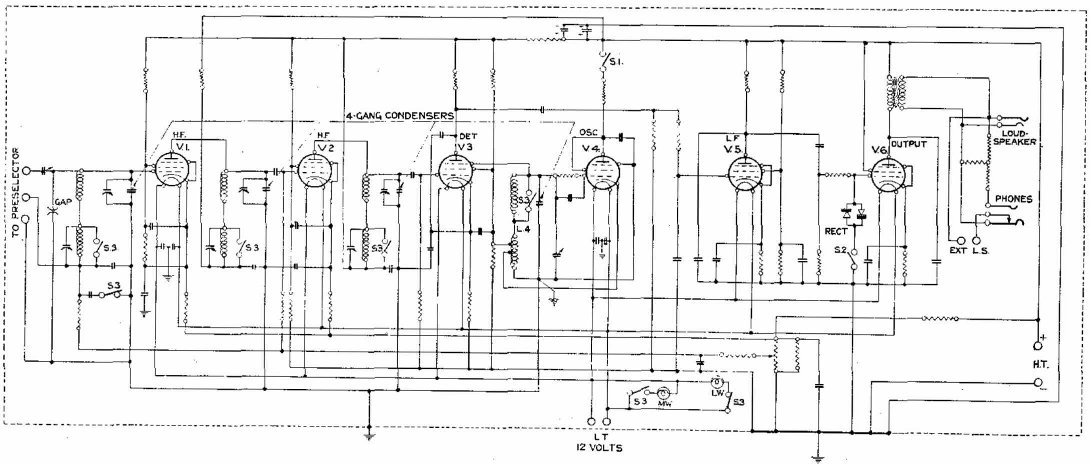


Fig. 11—Circuit Diagram of Medium-wave Receiver Unit.

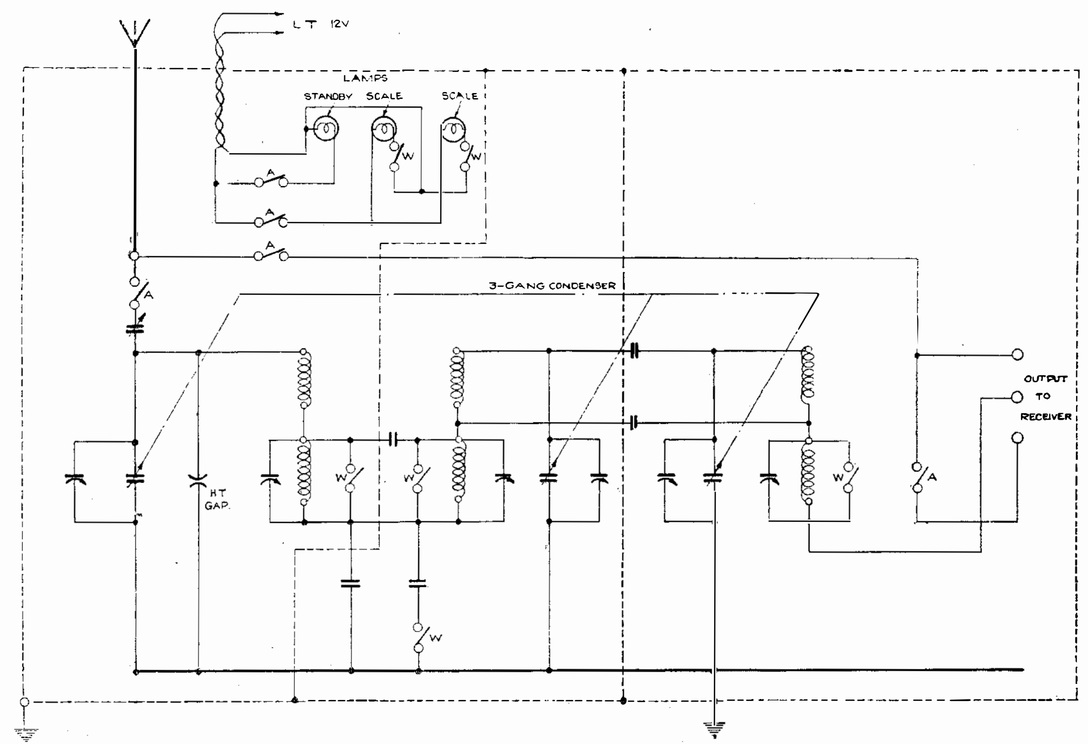


Fig. 12—Circuit Diagram of Medium-wave Receiver Preselector Unit.

line if the latter is of the balanced open-wire type.

(2) A single high-efficiency h.f. stage is provided. High efficiency is necessary to ensure that valve noise shall be low compared with the signal, and to give adequate second-channel suppression.

(3) For heterodyne reception with note filter it is necessary that the h.f. beating oscillator remain very constant in frequency. The high-tension supply voltage for the whole receiver is therefore held constant by a "stabilovolt" gas tube, which gives a stable heterodyne note despite changes in the settings of any control other than tuning and also despite large fluctuations in field strength of the incoming signal.

(4) In order to obtain maximum efficiency, plug-in coils are used. Five sets cover the complete wave-range of 13.5–550 m, the range of a set on the shorter wave-lengths not exceeding a 2/1 ratio. Speed and correctness of handling is ensured by ganging each set of coils, while the appropriate directly-calibrated track on the large indicator drum is automatically illuminated when a coil unit is inserted.

(5) The automatic gain control can be set to operate with either of two time-constants, one being symmetrical and suitable for telephony, the other asymmetrical and suitable for telegraph reception. It is extremely efficient, a signal variation of 1 μV to 100,000μV (100 db) of constantly modulated carrier input being stabilized to 8 db variation of audio output.

(6) Tuning is facilitated by a resonance meter operative on either telephony or telegraphy.

(7) An output limiter is provided to attenuate powerful static crashes.

(8) The intermediate frequency is 350 kc, this being the least likely to experience any form of interference during ocean service.

(9) The sensitivity is such that a 30 per cent. modulated signal of 0.5 μV in the aerial transmission line can give at least 50 mW of low-frequency output from the receiver at all frequencies.

(10) The band width is 8 kc for 6 db loss, and 30 kc to 35 kc for 60 db loss.

Medium- and Long-Wave Receivers (RM.11 and RM.12)

The general appearance of the medium- and long-wave receivers is similar to that of the short-wave receiver, except that no plug-in coils are used. The medium-wave receiver covers a waveband of 500–3,000 m in two ranges, with switch selection, while the long-wave receiver covers a waveband of 1,750–20,000 m in three ranges. Both sets are of the straight type, using 6 valves arranged for two stages of h.f. amplification, detector, two l.f. amplification stages, and separate heterodyne oscillator. (The tuning condenser of the heterodyne oscillator is ganged with the other tuning circuits.) Figs. 11 and 12 show the circuit diagrams of the medium-wave receiver and preselector units. Some of the more important considerations affecting the design of both these receivers are as follows:—

(1) The choice of the "straight" circuit is due to the extreme amount of pre-selectivity which is necessary to permit satisfactory medium- or long-wave duplex operation on frequencies differing by less than 10 per cent. In these receivers about two-thirds of the overall selectivity precedes the first valve for duplex operation. Incidentally, as these receivers are used only for telegraphy there is no need that they should pass a definite or constant band width, and note filtering increases still further the effective selectivity.

(2) Both the receiver proper and its associated preselector panel are provided with adjustable input coupling condensers. Following the con-

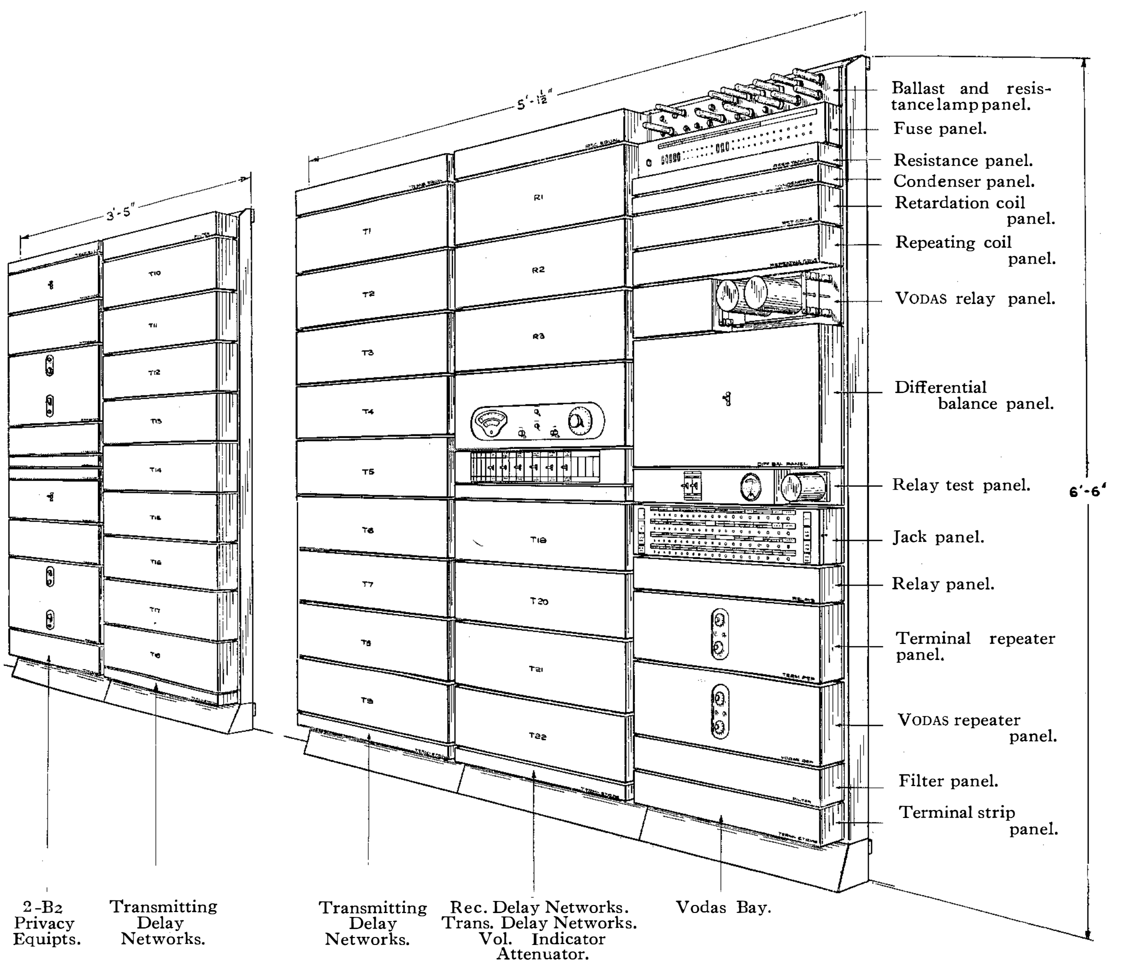


Fig. 13—Rack Assembly of Terminating Equipment on R.M.S. "Queen Mary."

densers are vacuum-gap arresters set to break down at 1,000 volts in the case of the preselector, and at 500 volts in the case of the receiver. By means of the input condensers the signal coupling can be increased up to the point where voltages induced by the local transmitters become prohibitive.

(3) The preselector units contain three tuned circuits. The first valve is therefore preceded by a total of four tuned circuits, and followed by two others. The preselector units are built throughout with components which can withstand approximately 2,000 volts (r.m.s.) at radio frequency, since the aerial vacuum-gap arresters must not operate continuously and so set up interference to adjacent receivers on all frequencies. Continuous operation of the arresters following the preselector is not usual, and in any case could set up only very small external interference on other frequencies than that to which the receiver is tuned.

(4) When the preselector is thrown out of circuit a lamp is lit to indicate that the band width passed is suitable for stand-by reception. This feature is of special importance for the 600-m watch.

(5) Wave-change switching is provided on both receivers and preselectors, and the correct tracks on the frequency-calibrated indicator drum are automatically illuminated.

(6) "Crash limiting" is provided as in the short-wave receiver.

(7) In order to permit of simplex (break-in) operation on a common wavelength, an overload bias device is provided on the first valve.

(8) The sensitivity of each receiver is such that on C.W. telegraphy the low-frequency output is 50 mW for under 5 μV input. Satisfactory headphone operation is possible with signals of less than 1 μV.

(9) When combined with its preselector, each receiver has a signal frequency selectivity equivalent to an attenuation of more than 100 db at 10 per cent. off signal frequency. The note filter, of course, still further augments the total selectivity.

TERMINATING EQUIPMENT (TYPE T.O.P.5)

With the advent of the subscriber's ship-to-shore radiotelephone service a new item has had to be added to the types of equipment required for ship installation. This new item is the "terminating equipment," which in one form or another is a regular part of all radio-link telephone circuits. The primary function of terminating equipment is to prevent local interaction between the radio transmitter and radio receiver, despite their being deliberately coupled together through the subscriber's apparatus and also unavoidably coupled together by induction from aerial to aerial. In the absence of terminating equipment the effect of these couplings is, in extreme cases, to set up actual "singing" round the circuit, and in less extreme cases to reduce the effective sensitivity of the receiver and to impair the quality of both transmitted and received speech. In addition to preventing this local interaction, terminating equipment may also include some "privacy" system which renders the radiated speech unintelligible to unauthorized listeners.

Although ship-to-shore telephony has been established for some years, it has been customary to keep the terminating equipment down to the minimum consistent with a good speech circuit, and the privacy feature has not been a regular part of the service. In the case of the *Queen Mary*, however, it was considered that the service should be of the same nature as that furnished on the transoceanic links, and the terminating equipment is accordingly not only rather more complete than that hitherto fitted in ships but also includes a privacy system. Since the underlying principles are the same in all cases, the following notes on the *Queen Mary* equipment may be taken as including the main features of the more limited equipment used in older ships.

Fig. 13 shows the rack assembly of the complete terminating equipment, including the privacy portion. Its construction follows normal telephone practice, the only special mechanical feature being in the fixing of the rack to the ship members through a rubber anti-vibration mounting. The privacy portion of the equipment includes five indirectly-heated valves, the remainder, i.e., the terminating equipment proper, using a total of 17 repeater valves of the 0.25 A filament type. All power supplies are derived from the a.c. supply to the station.

The fundamental operation of terminating

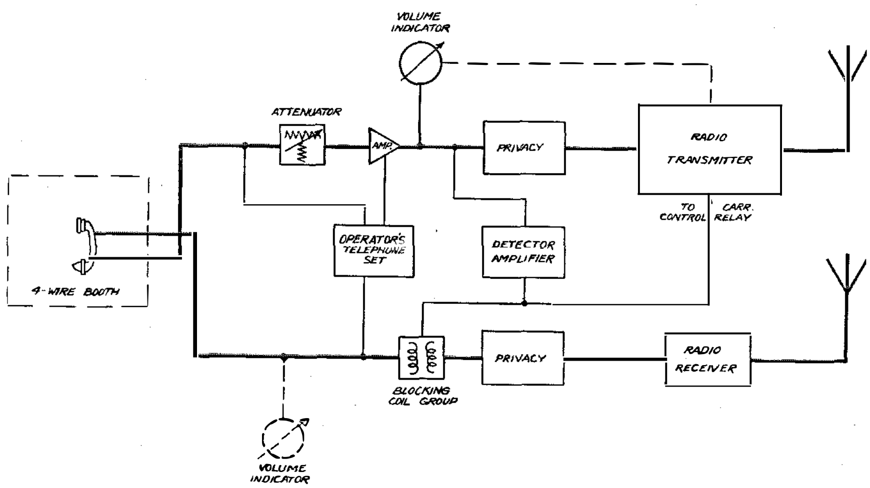


Fig. 14—*Block Diagram of* 4-*wire Radiotelephone Circuit with Half Singing-suppressor Equipment on R.M.S. "Queen Mary."*

equipment is automatic switching of the transmitter carrier, and of the receiver, under the influence of the subscriber's voice, the transmitter being switched "off" and the receiver left "on" at full sensitivity when the subscriber is listening to the distant point, while the reverse action occurs when the subscriber speaks to the distant point. In other words, the radio circuit is effectively operated on a simplex basis, preventing the formation of a "singing path." The switching is performed by means of a voice-operated detector amplifier (see Figs. 14 and 15) operating a fast relay train in the radio transmitter. At the same time as the carrier is switched on, a blocking device is inserted in the receiving circuit so that no singing path can exist (in the case of 2-wire P.B.X. working) round the local loop consisting of hybrid coil, radio transmitter, radio receiver, hybrid coil. The relay train is arranged to have a "hangover" of about 150 milliseconds, i.e. the relays do not release until the lapse of that time after the speech has finished. This prevents any unpleasant echo effects, due to the reflections at the far end, from reaching the speaker.

The voice-operated detector-amplifier controlling the carrier is fitted with a sensitivity control which can be set to suit the conditions existing at any given moment. The sensitivity should be such that the relay train is just operated by the initial weak parts of the speech, and thus "clipping" is prevented. If the sensitivity is made too great, false operation due to room or line noise will occur, causing the local carrier to come on, and cutting off the received speech. After a little experience the operator is able to adjust the sensitivity correctly without any difficulty.

A voice-frequency amplifier and a manually-operated gain control are also provided, so that allowance can be made for varying subscribers' levels. This enables the detector-amplifier to be operated at the correct level and thus prevents possible "clipping," and also enables the modulation of the transmitter to be kept at the correct value.

When the ship's transmitter is setting up a very strong field at the shore receiver, the action of the carrier-suppressor device will cause slight "plops" to be heard by the land subscriber when the carrier comes on, due to the action of the A.V.C. on the receiver. These are not sufficiently loud to be objectionable, but they cause trouble when the circuit is being extended via another radio link. Under such conditions, the transmitting and receiving frequencies must be separated sufficiently to enable the carrier-suppressor device to be removed.

An equipment of the type shown in Fig. 14 is known as a "half" V.O.D.A.S. (voice-operated device, anti-singing) equipment, and covers the essentials in cases where the ship terminal is operated on a 4-wire basis. The usual telephone supervisory and monitoring facilities of course are also provided, but these are purely auxiliary features.

When the ship subscriber is connected in the normal 2-wire manner, additional complications arise, since this means the introduction of a hybrid coil to effect the junction between the transmitting and receiving paths. A hybrid coil is a special type of differential transformer whose windings, in conjunction with the subscriber's line and a balancing network of equal impedance to the line, furnish an a.c. bridge the diagonals of which are connected, directly or inductively, one to the transmitting path and one to the receiving path ; the two paths are thus effectively separated if the bridge is perfectly balanced, although both are connected to the subscriber's line. It is, however, fundamental in the use of a hybrid coil that (the balance between line and network never being perfect) there remains a certain transference of energy across from the "receive" path to the "transmit" path. This is a source of trouble, for two reasons. Firstly, if the received level is allowed to become too high, the fraction of signal which is transferred across the hybrid coil may be sufficient to operate the transmitting detector-amplifier, with consequent re-transmission of the received signal and, in certain circumstances, the setting-up of an undesirable echo at the far end. Secondly, this retransmission may actuate the blocking device in the receiving side, thus cutting off the received signal.

Now, although a good hybrid balance is obtainable on a ship, re-transmission can easily occur if the received signal is fading to a greater extent than the receiver A.V.C. can control. The second effect also occurs if the radio noise-level is very high, since a proportion of this noise will be transferred across the hybrid coil and will cause a similar false operation.

The possibility of such re-transmission occurring is therefore guarded against on the *Queen Mary* by the installation of a full singing-suppressor equipment. This equipment is so arranged that it can be switched instantly into either of the two radiotelephone channels, it being assumed that conditions will nearly always be good enough to allow of one circuit being operated satisfactorily with the half singing-suppressor equipment.

The equipment consists essentially of two

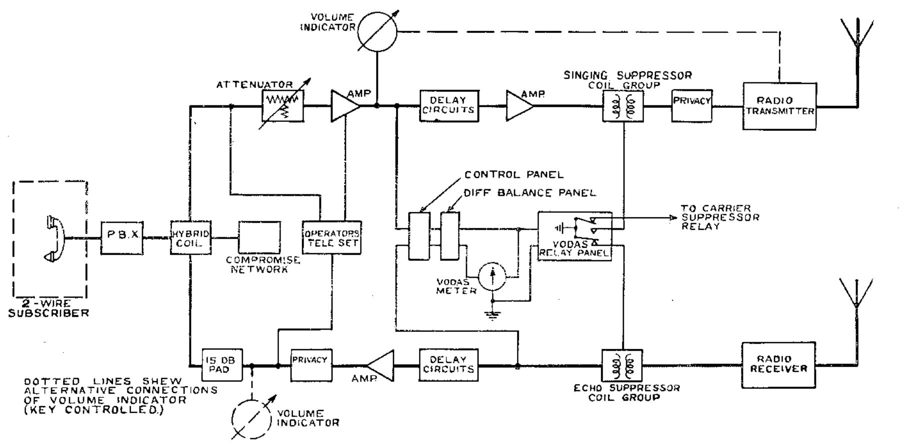


Fig. 15—*Block Diagram of* 2-*wire Radiotelephone Circuit with Full Singing-suppressor Equipment on R.M.S. "Queen Mary."*

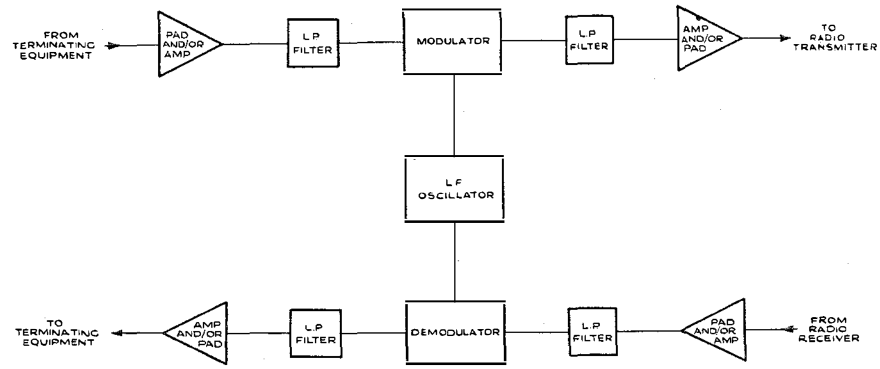


Fig. 16—*Block Diagram of Privacy Equipment on R.M.S. "Queen Mary."*

detector-amplifiers (one in each side of the circuit) with their relay trains and suppressing devices, delay networks to hold up the speech long enough for the relays to operate, and an amplifier to make up the various losses in the circuit. The control of the carrier-suppressor relays is transferred from the original detector-amplifier to the detector-amplifier in the full singing-suppressor when the latter is switched into circuit.

The operation of the equipment (see Fig. 15) is then as follows. Speech from the passenger passes across the hybrid coil and through an attenuator and amplifier. By means of the manually-operated gain control the operator adjusts the passenger's speech to zero level (i.e. 5.9 mW) at the output of the amplifier. The speech then passes through a number of filter sections, so designed that they produce a delay of 22 milliseconds in the speech, irrespective of frequency. These delay filters have a loss of approximately 30 db and are followed by a further amplifier to make good this loss.

Bridged across the main circuit ahead of the delay filters is the transmitting detector-amplifier, of input impedance such that it introduces no appreciable loss. This detector-amplifier takes a small part of the speech currents, amplifies them in a 3-stage amplifier, and then rectifies them. The resulting direct current is used to operate a train of three very sensitive polarized relays mounted on anti-vibration pads. Operation of these relays opens the transmitting path to the outgoing speech, blocks the receiving path, and switches on the carrier in the same manner as in the half singing-suppressor system. The circuit is so arranged that the delay introduced by the special networks also covers the switching-on of the carrier, rendering the possibility of "clipping" still more remote than in the case of the half singing-suppressor, where freedom from "clipping" is governed by the sensitivity of the detector-amplifier and the "quick-starting" properties of the radio carrier.

Consider now incoming speech being received on the ship. This passes through the receiving side of the singing-suppressor and in doing so operates the receiving detector-amplifier, which paralyses the transmitting detector-amplifier so that any speech being transferred across the hybrid coil does not operate it. The existence of the receiving detector-amplifier thus renders it possible to work the circuit on a 2-wire basis when the hybrid unbalance and the noise-level would otherwise make it impossible. The two detector amplifiers, transmitting and receiving, are made up as one unit known as the "differential balance panel."

The full singing-suppressor equipment is set up to work at zero equivalent (i.e., introducing neither gain nor loss) on both sides, so that its insertion or removal does not disturb the circuit.

The circuit is, of course, permanently monitored by the operator, who has a volume indicator in front of him which enables him to check outgoing and incoming levels, both of which can be adjusted by controls conveniently located. In addition, by the operation of a switch, the volume indicator acts as a modulation meter connected to the output of the radio transmitter so that the operator can occasionally check that the modulation depth is remaining at the correct average level. When the full singing-suppressor equipment is in use, an additional meter indicates that it is working satisfactorily. This meter, which is a centre-zero galvanometer, deflects to the right on outgoing speech and to the left on received speech.

Provision is made for the operator to talk either to the ship subscriber or to the distant operator, or to both simultaneously. He also has ring-back facilities to the ship subscriber. For the initial lining-up of the circuit the operators' control positions are equipped for either C.W. or M.C.W. telegraph operation as alternatives to speech. A special "weighted" amplifier, i.e., one whose frequency response curve instead of being flat is adjusted to resemble that of the human ear, is provided for measuring signal/noise ratios ; its gain control is calibrated directly in decibels.

The whole of the voice-control equipment, with the exception of the controls which are located at the receiver control positions, is mounted on four 6-feet single-sided racks carrying standard 19-inch panels (Fig. 13).

PRIVACY EQUIPMENT (TYPE B.2)

The privacy portion of the terminal equipment is, in the case of the *Queen Mary*, supplied in duplicate so as to provide for two simultaneous radiotelephone channels. The two equipments are mounted on a common rack, the layout of which is shown in Fig. 13. The principle of operation (see Fig. 16) is to invert the speech at the sending end so that low frequencies become high, and vice versa, the speech being re-inverted at the receiving end. This inversion is obtained by modulating the speech with a fixed frequency lying outside the voice range, and then selecting by filters the appropriate sideband.

The system is operated on a 4-wire basis, i.e., a separate modulator, together with its associated amplifiers and filters, is used in each direction of transmission. A constant-frequency oscillator supplies the necessary carrier to the modulator and demodulator in the two sides of the circuit, the three units being combined in practice into an "oscillator-modulator" panel. In addition to this panel there is an amplifier, a filter panel, and a mains supply panel. The amplifier enables the privacy equipment to be operated at zero equivalent, while input filters limit the voice frequency range to 2,750 cycles, and output filters cut out unwanted higher modulation products.

The insertion of the privacy equipment is controlled by two keys, one for the transmitting side and one for the receiving side, so that the system can be used in either or both directions of transmission as required. At the same time as the transmitting inverter is switched on, an a.c. motor in the transmitter is started up. This motor drives a subsidiary tuning condenser, which causes the carrier frequency to "wobble" through a certain predetermined band width ; without this "wobbling" it might be possible for speech to be received, despite the inversion, on a simple heterodyne receiver.

PERFORMANCE OF STATION

The results obtained under the heavy traffic conditions of her maiden voyage fully justified the elaborate equipment with which R.M.S. *Queen Mary* was fitted. The simultaneous demands made by telegraphy, telephony, and broadcasting, kept the four transmitters and at least four of the receivers in continuous operation for the greater part of the time she was at sea. Without the independent operation of several lines of communication, rapid wave-change, and automatic transmission, it would have been quite impossible to handle the traffic that was presented.

The results have shown that in spite of the difficulties peculiar to ship installations of this character, by careful engineering a good approach can be made to the operating efficiency of a large land station, where normally the transmitting and receiving sites are some distance apart, and where space is available for extensive aerial arrays.

Condenser Cones for Cable Testing

By J. K. WEBB, M.Sc., A.M.I.E.E.,

Standard Telephones and Cables, Limited, London, England

SINCE the inception of the Condenser Cone as a practical solution of the cable termination problem some three years ago, the use of this device has steadily increased. It

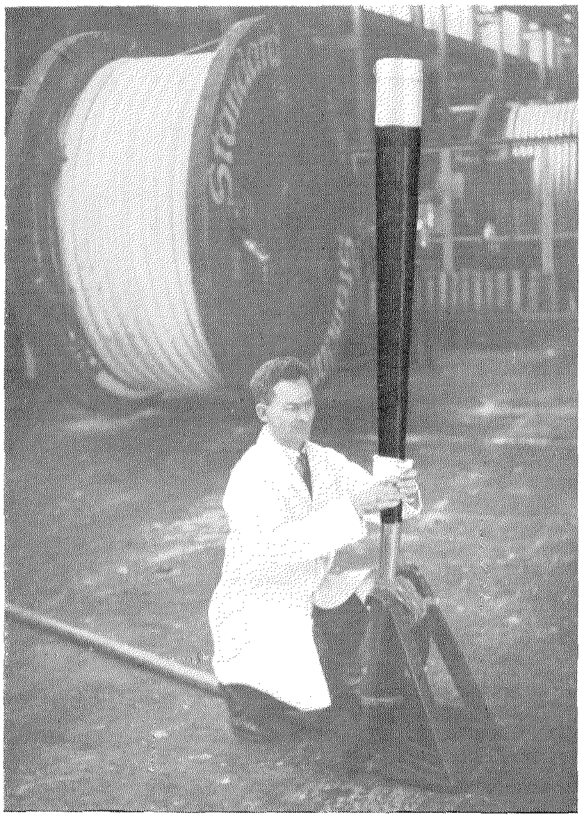


Fig. 1—Mounting a 50-inch Cone on a Cable End. The Cone should be adjusted by gripping with Rag near its Base as shown, and should not be pressed down from the Top.

now finds widespread application in three distinct categories:

(i) For the electrical testing of cables in the factory or the laboratory, the ends being in air.
(ii) Under general service conditions, for the potential grading and, hence, strengthening of cable terminations in endbells or boxes.
(iii) For use in joints, to grade leakage surfaces.

In end boxes, as in case (ii), cones have been successfully used to provide capacitative leakage to the high voltage conductor to operate protective relays, and they may also be adapted as carrier current coupling condensers for communication purposes.

A general description of the Condenser Cone has been given[1] and it is sufficient now to say that it has proved both economical and effective in practice. The present article is solely concerned with the use of cones for testing cable ends in air, Fig. 1, since this case involves special problems which have only been overcome by further development work.

For the successful operation of condenser cones under such circumstances, there are three distinct conditions which must be satisfied from the user's point of view:

(i) The length of the cone should be adequate to avoid external flashover. The maximum test voltage is approximately proportional to this length and may be estimated from the values given in Table I. These values, on which there is a certain factor of safety, refer to standard cones under average conditions, and the assumption is made that the cable to which the cones are attached is quite sound. Poorly impregnated or deteriorated cables are liable to initiate surges along their lengths, thus lowering the flashover value. In these doubtful cases, proportionately larger cones should be used.

TABLE I

Total Length of Cone, Inches.	Flashover Voltage kV.
16.5	90
25	140
50	270

It has been found quite practicable to connect two or more cones in series, one above the other, with the inner former of the upper cone connected to the outer foil of the lower cone. In this case, the total flashover voltage of the combination is only slightly under the sum of the separate flashover voltages. This method results in a smaller overall diameter than when a single cone is used, but requires rather longer preparation. It should be noted also that, with two cones, the voltage between the conductor and former of the upper cone is about half of that in the case of the lower cone. The arrangement is illustrated in Fig. 2.

(ii) The radial thickness of the insulation between the inner former and the outer foil on the cone must be

[1] "The Condenser Cone," by J. K. Webb, *Electrical Communication*, October, 1933.

sufficient to withstand the test voltage. In general, oil-impregnated cones to standard design will withstand indefinitely the test voltage set out in Table I, so that they may be used over and over again, provided that they remain dry and are normally stored immersed in cable compound. The cones, accordingly, are supplied in specially designed tins filled with compound; they are attached to the lid of the tin, and thereby remain suspended during transport. This system is also convenient for the removal of the cone for test. Fig. 3 illustrates these features.

(iii) The filling compound must withstand the stress resulting from the test voltage. The compound is most frequently the limiting factor in over-voltage tests, and it is mainly the purpose of the present article to show how this difficulty may best be overcome. This subject has already been briefly referred to in a previous publication[2] but a recapitulation with further details will now be given in order that the subject may be adequately covered.

The stress on the filling compound is greatest at the base of the cone and is equal to the radial stress at the outside of the cable (i.e., minimum cable stress) multiplied by the ratio of the permittivities of the cable paper and filling compound. If ordinary cable oil is used, this stress must be kept below about 9 kV/mm., a figure which corresponds with the normal breakdown value of the oil. Cable oil has a permittivity of 2.3 while that of the cable dielectric is 3.8, so that the stress on the oil will be 1.65 times the minimum cable stress at the voltage considered. Thus the use of ordinary oil for filling cones is normally limited to those cases in which this minimum cable stress does not exceed a value of about 5.5 kV/mm. Referring to Table II, this value is seen to correspond to voltages of 3 to 4 times the working voltage depending on the cable design.

A reduction of the stress on the oil may be achieved by building up the radial thickness of solid insulation in the vicinity of the base of the cone which must then be of diameter large enough to slip over the added insulation. This building up may be effected with impregnated tapes or a continuous paper roll. There should be chamfers between the ends of the roll and the original cable insulation as illustrated in Fig. 4, and an earth screen made up, say, of lead wire or foil wrapped tightly over the lower chamfer and extending for about 1 inch over the parallel portion. Since in this case the cone will be large enough to slip over the lead sheath, the amount of the latter which should be removed for the cable end equals the length of the inner cone, plus 1 inch, plus the length of chamfer.

This building up of insulation, if skilfully carried out, often effects a considerable improvement in the general characteristics of the end. There is always a risk, however, of leaving an air space between the added roll and the cable dielectric, to avoid which both care and experience are necessary. The best thickness of paper for the roll is 5 mils, and it is advantageous to have the inner end of the paper bevelled. With some practice this may be achieved by tearing. Suggested dimensions for these rolls are given in Table III. There

TABLE II

Rated Voltage kV. (3 phase)	Radial Thickness of Dielectric in Inches.	Section of Conductor in Square Inches.	Maximum Working Stress kV/mm.	Minimum Working Stress[3] kV/mm.	Working Stress at Surface of Added Roll Increasing Cable Diameter by 50 per cent.
33	.325	.25	3.3	1.67	0.7
		.75	2.91	1.86	0.653
66	.650	.25	4.16	1.41	0.685
		.75	3.45	1.61	0.703

[2] "Recent Developments in connection with Joints and Terminations"—T. R. Scott and J. K. Webb, *Conférence Internationale des Grands Réseaux Electriques à Haute Tension—Session* 1935, *No.* 209.

[3] The minimum stress in kV/mm is calculated from the formula,

$$S_{MIN} = \frac{E}{R_1 \times 2.3 \log_{10} \frac{R_1}{R_0}}$$

where E = Voltage in kV. between conductor and lead sheath.

R_1 = Outer radius of dielectric in mm.

R_0 = Conductor radius.

may be a case for using impregnated textile tape instead of paper rolls in this connection since, although it is not as strong electrically, it will tend to minimise the risk of air occlusion. Comparative tests, however, have not yet been made.

The increase in cable diameter effected in this way may normally be anything up to 50 per cent. and should not be more than 75 per cent., otherwise difficulties in handling will be experienced with the rolls, but no very rigid rules can be given. Each case must be considered on its own merits. The reduction of stress obtained in this way may be deduced from Table II.

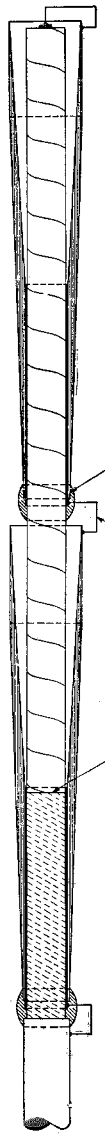


Fig. 2—Two Cones in Series on a Cable End. As the Upper Cone absorbs half the Voltage Drop, the Stress in the Filling Compound of this Cone is proportionately less than in that of the Lower Cone.

In the case of old, dry or gassy cables or lengths which have been subjected to bending tests, especial difficulty is often experienced with the ends. This is due to the films of gas ionising under the action of the radial stress, and so forming a longitudinal conducting path from the end of the cable core to the lead sheath. It should be borne in mind that a longitudinal stress must always exist at a cable termination; the condenser cone simply gives a uniform gradient to the stress. When failure occurs in such an end, dendritic markings are often found between paper tapes on the cable several layers down. The only satisfactory way of dealing with these cases is to remove the lead sheaths for more than the normal distance, unwind several layers of the cable paper without tearing them, and re-smear each with oil on rewinding. In this way the strength of the end may be greatly improved without affecting the cable characteristics. Prevention, however, is better than cure; therefore in making bending tests, the ends should be handled as little as possible, and precautions taken to prevent movement of paper relative to copper at the extremities.

TABLE III

Length of Cone Inches.	Total Length of Added Roll Inches.	Length of Chamfer Inches.
16.5	6	1.5
25	9	2
50	12	2.5

Since the stress on the oil used for filling is a function of its permittivity, it is to be supposed that raising the value of this constant would have a beneficial effect; and, provided it can be done without causing other factors to obtrude, it has been found to be the case within the limits of materials available. Certain substances, notwithstanding, such as Aroclor, which appear to have everything in their favour, have proved curiously disappointing.

There is, however, another method which has been found to effect a very substantial improvement; it consists in purposely giving the filling compound a high power factor. As the underlying principle may not be obvious, the following explanation may help to make it clear.

Referring to Fig. 5, C_1 and C_2 are two capacities in series, and an alternating voltage E is applied to both. This voltage will divide into two parts e_1 and e_2 depending on the ratio of the admittances of C_1 and C_2. Now if a conductance G_1 is placed across C_1 it is evident that as this conductance becomes infinite, it will short circuit C_1 and hence the voltage e_1 will vanish, while the whole of E will be thrown across C_2. For intermediate values of G_1 it can be shown that

$$\frac{e_1}{E} = \frac{1}{\sqrt{\frac{C_1^2}{C_2^2} \, Cosec^2 \, \Phi + 2\frac{C_1}{C_2} + 1}} \quad (1)$$

$$\text{where } \cot \Phi = \frac{G_1}{wC_1} \quad (2)$$

$$w = 2\pi \times \text{frequency.}$$

For the particular case in which $C_1 \gg C_2$ the current is practically constant for all values of G_1 and

$$\frac{e_1}{e_2} = \frac{C_2}{C_1} \sin \Phi \quad (3)$$

In the case of the condenser cone, C_1 represents the capacity of the filling compound, and C_2 that of the cable dielectric in series with it, as illustrated in Fig. 6. The stresses S_1 and S_2 at the surface of discontinuity between these two are proportional to e_1 and e_2, respectively, while C_1 and C_2 are proportional to the permittivities k_1 and k_2. Thus:

$$\frac{S_1}{S_2} = \frac{k_2}{k_1} \sin \Phi \quad (4)$$

If the filling compound has substantially zero power factor then $\sin \Phi = 1$ and equation (4) reduces to the well-known form:

$$\frac{S_1}{S_2} = \frac{k_2}{k_1} \quad (5)$$

Fig. 3—Withdrawing a 25-inch Cone from its Packing Tin in which it is immersed in Compound. Note how the Cone is attached to the Lid of the Tin.

As the power factor (*cos* Φ) of the compound increases, however, *sin* Φ decreases, and so the stress is transferred from the latter to the cable dielectric which is better able to withstand it. In the limit, if all the stress were thus thrown back on the cable it would still be no greater than in the main body of the cable under the lead sheath. *Sin* Φ is thus the reduction factor which gives a measure of the stress transferred. Its well-known variation with *cos* Φ is illustrated in Fig. 7.

Fortunately enough, compounds of high power factor are usually allied with those of high permittivity; and, moreover, desirable values may be obtained without any appreciable sacrifice of dielectric strength or *B.D.V.*

As a single example, nitrobenzene has a permittivity of 34 and a power factor (*cos* Φ) of over 0.98 at room temperatures. Despite these extreme values, however, its breakdown value is of the same order as cable oil.

It is not suggested that nitrobenzene would be a suitable compound for filling cones. There are two main objections: the first is

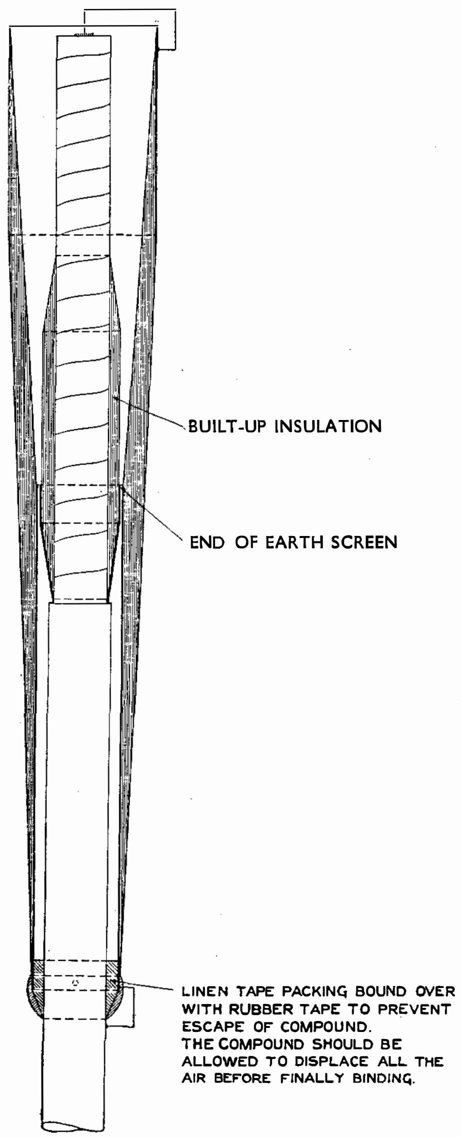


Fig. 4—Built-up Insulation on Cable End combined with Cone. This strengthens the End, and may be used in conjunction with Ordinary Cable Compound or with Special Compound to attain the Highest Voltages.

that it has an inconveniently low viscosity, so that there would be considerable risk of its penetrating the cable where its characteristics would then be objectionable ; and the second is that its power factor is so high that the longitudinal stress which must always exist at a cable end would cause undue heating. It also has a rather objectionable smell and is slightly toxic.

If a thin compound can be tolerated, Halowax Oil has been found to give good results. This material has a permittivity of 4.91, a *B.D.V.*[4] of 25 kV, and a power factor of 0.67 at 20° C. rising to 0.93 at 60° C. Its viscosity, however, is only 3.99 centipoises at 20° C.

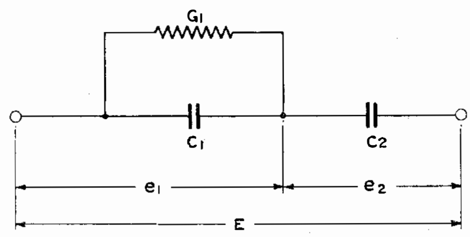


Fig. 5

It might be thought that the losses generated in all compounds of high power factor would give rise to a condition of thermal instability, but in practice this has not been found to occur if the limits are correctly chosen. As the temperature of the compound rises, the consequent elevation in power factor so redistributes the stress that a condition of equilibrium is attained while the compound is still only slightly warm. Occasionally excessive heating occurs at the end, usually when testing old and gassy cable, but it is due to the heat generated in the ionised gas films between the paper tapes.

The main difficulty in producing an altogether satisfactory compound has been to combine a suitably high power factor with high viscosity. Since the former is due to the presence of polar molecules, any attempt at raising the viscosity usually results in a sharp decrease in power factor, and considerable research has been involved in balancing effectively these two opposing factors.

Two compounds have, however, been evolved which appear to be satisfactory. The first (coded as "C.C.8") has the consistency of cable compound and is odourless, non-toxic and clean to handle. It is used for making short time breakdown tests on cable samples where the applied voltage may be anything over three times the working voltage.

[4] The break down value (B.D.V.) of compounds referred to in this paper is in accordance with the B.E.S.A. specification (4 mm. gap).

Electrical and physical characteristics are given in Table IV. The permittivity is 5.82 and the *B.D.V.* is 38 kV. Moreover it will only mix with cable mineral oil to the extent of 1 per cent. at 20° C. and 3 per cent. at 60° C.

TABLE IV

C.C.8 (Liquid Compound)

Temp. °C.	Power Factor Cos Φ at 50 p : s.	Viscosity Centipoises.
20	0.32	550
30	0.47	220
40	0.63	114
50	0.79	68
60	0.90	45

so that there is little risk of its penetrating the cable, or influencing in any way the characteristics of the latter in the course of even a fairly prolonged test.

The second compound is coded as "C.C.11." At room temperatures it is a thick, clear and plastic material. On heating to a temperature of about 150° C., it becomes sufficiently fluid to enable it to be poured into the cone; on cooling a glossy film forms on the surface from which dust may easily be brushed. The electrical characteristics are given in Table V.

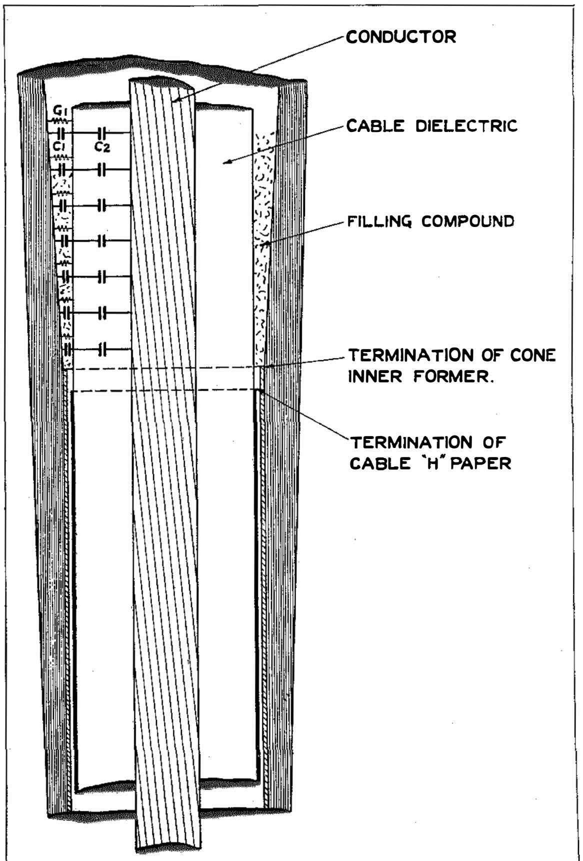


Fig. 6—Section of Base Cone on Cable End showing Capacity Interlinkages between Filling Compound and Cable Dielectric. By controlling the Value of C_1 and G_1 the Stress may be transferred to C_2.

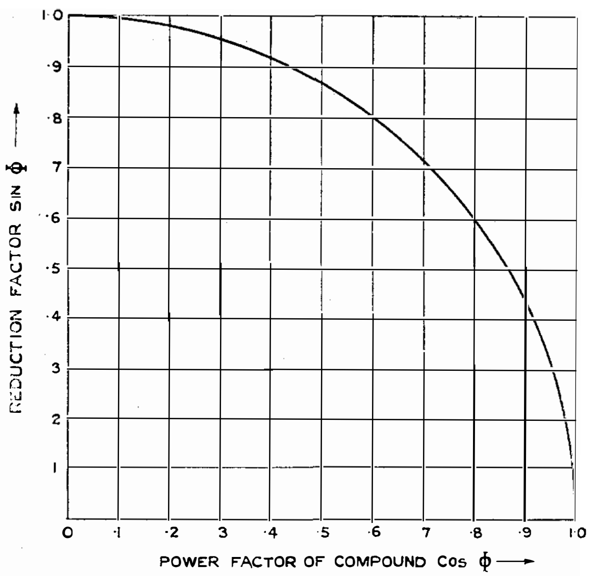


Fig. 7—Graph showing how by increasing the Power Factor of the Filling Compound, the Radial Stress thereon is reduced.

TABLE V

C.C.11 (Plastic Compound)

Temp. °C.	Power Factor Cos Φ at 50 p : s.
20	0.63
30	0.78
40	0.87
50	0.92
60	0.95

The permittivity is 3.8 and the *B.D.V.* is 45 kV. This compound will adhere tenaciously to oil impregnated paper, and is very effective in sealing the end of a cable on test from outside sources of contamination. To complete the seal, the inner tin tube of the cone may be soldered to the lead sheath, provided the cone is fitted over the "*H*" paper. Alternatively, it may be slipped over the lead sheath so that the compound attaches itself to the latter. These two methods are illustrated in Fig. 8.

Cones may conveniently be used as guard-rings, an application which is valuable when taking Schering-bridge readings. Ordinary guard-rings used in the open do not altogether guard against the effect of the vigorous sparking which occurs at higher voltages unless the cable is effectively screened, but cones do not suffer from this defect. The technique of adapting cones as guards is as follows:

The lead should first be trimmed from the end for a distance equivalent to the total length of the cone, and the "*H*" paper removed for a distance corresponding to the length of the inner cone. A ring of "*H*" paper about $\frac{1}{8}$ inch wide should then be removed approximately $\frac{1}{2}$ inch from the lead sheath. This ring should first be covered with an oil impregnated paper about 1 inch wide, and then with lead foil which makes contact only with the "*H*" paper above the cut. Some binding wire round this lead foil will serve the double purpose of making contact with the cone and in preventing the latter from contacting with the lead sheath. This binding wire also serves as an earth connection, while the lead sheath is connected to the bridge circuit. Rubber tape may be used for binding round the bottom of the cone and thus preventing the escape of oil but, on completion of power factor tests, if it be desired to take a long voltage run, the earth connection from the cone should be cut short and bound over with rubber tape; otherwise oil tends to leak out where it projects.

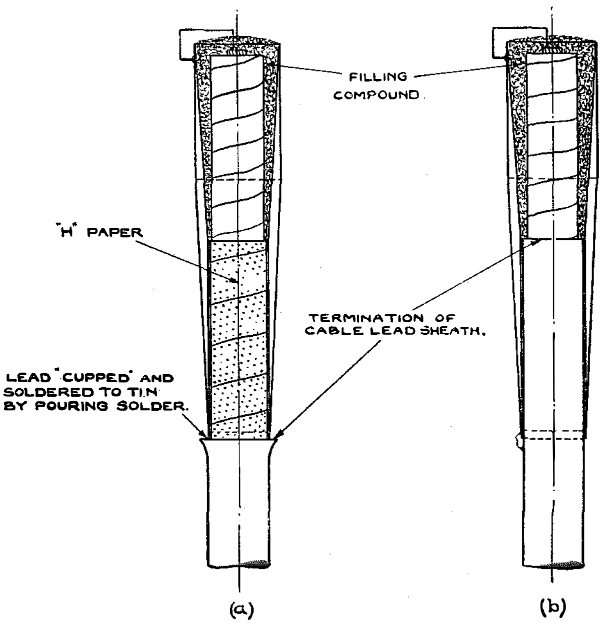


Fig. 8—Cones filled with Plastic Compound to seal off Cable End. Oil-impregnated Cones so filled, as in (b), have been working satisfactorily on Accelerated Ageing Tests in Air continuously for Eleven Months.

The special compounds described herein may be used for cases in which the minimum cable stress does not exceed about 11 kV/mm. Referring again to Table II, this value will be seen to correspond to voltages 6 to 8 times working voltage, depending on the type of cable. If still higher voltages are contemplated, then the cable insulation may be built up so that the calculated stress at the outer surface of the added insulation will not exceed 11 kV/mm. In this way the highest possible voltages may be achieved.

It should be noted in particular that increasing the size of the conductor has the effect of augmenting the minimum cable stress. This is clearly indicated in Table II. Thus the tests on large conductor cables are relatively more severe than on those having small conductors as far as the ends are concerned.

Voltage tests may be divided into two main categories:

(*a*) Acceptance tests.
(*b*) Breakdown tests.

Considering the two cables given in Table II, the acceptance tests as specified in various countries would be as listed in Table VI.

In the case of the British and German tests, ordinary cable oil might be used to fill the cones. There would be no necessity to build up the insulation since it will be noted that the minimum cable stress lies below the limit of 5.5 kV/mm at the test pressure. Americans, however, would either have to build up the insulation or use special compound.

Voltage tests to breakdown are not covered by British specification. The German *V.D.E.* specification calls for a 5 minute test of 6 times working voltage on 5 metre samples. This corresponds to 114 kV for 33 kV cables and 228 kV for 66 kV cables. American practice specifies tests on selected samples as given in Table VII, corresponding to voltages of 130 kV

TABLE VI

Rated Voltage kV. 3 Phase (British Rating).	British (Customary Test).		German (V.D.E. Spec.).		American (A.E.I.C. Spec.).	
	Test Voltage 1 Phase to Earth kV.	Period Minutes.	Test Voltage 1 Phase to Earth kV.	Period Minutes.	Test Voltage 1 Phase to Earth kV.	Period Minutes.
33	53	15	49	30	72	15
					86[5]	15
66	106	15	97	30	150	15
					179[5]	15

on 33 kV cables and 260 kV on 66 kV cables.

TABLE VII

As specified in normal high-voltage test	6 hours
300 volts/mil of specified insulation ..	3 hours
350 ,, ,, ,, ,, ..	3 hours
400 ,, ,, ,, ,, ..	until failure occurs.

Manufacturers for their own information might wish to make short time breakdown tests on samples of cable on even higher voltages. In all such cases, the minimum cable stress at the voltage considered should first be calculated. If this does not exceed 11 kV/mm a cone fitting directly over the cable dielectric may be used if filled with special compound. For stresses exceeding 11 kV/mm the insulation should be built up as already indicated.

Standard cones increase in diameter by increments of 0.2 inch, providing a tolerance which is permissible with respect to any cable. If it be desired to use a cone which is normally too big for a particular cable, the insulation of the latter may always be built up to suit. It has not been found necessary to centre the cable accurately in the cone.

[5] On 15 per cent. of lengths.

Recent Telecommunication Developments of Interest

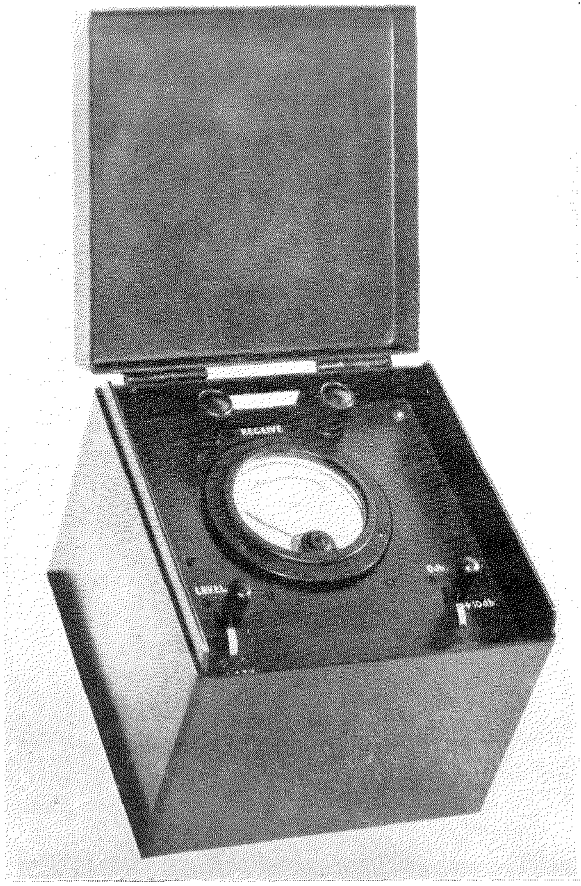
DIRECT READING TRANSMISSION MEASURING SETS of compact and simple design, giving reasonably accurate results, are recent developments of Standard Telephones and Cables, Limited, London. The sets meet the requirements for simple and lightweight testing apparatus, and are intended as auxiliaries to more precise and expensive transmission measuring sets. They should prove useful in the general maintenance of telephone systems.

Recent advances in meters and metal rectifiers are embodied in their design, and no battery or calibrating oscillator is required. Due to the high input impedance, lower levels can be measured than is usual with these types of instruments.

The 74105-A set covers the voice frequency range of 35 to 5000 p : s. The measuring range of this set is + 20 db to − 15 db (or alternatively, +2 to −1.75 nepers) with an accuracy of $\pm$ 0.5 db.

The 74105-B set covers the 50–50 000 p : s range and is suitable for measuring levels of −10 db to + 20 db (− 1.0 to + 2 nepers) referred to 1 mW in 600 ohms. The accuracy is $\pm$ 0.5 db up to 10 kc and $\pm$ 1.0 db up to 50 kc.

The Sets are mounted in robust metal boxes. The 74105-A set measures $6 \times 6 \times 5$ in. ($152 \times 152 \times 127$ mm) and weighs 9 lb. (4 kg). The 74105-B set is somewhat smaller; it measures $6 \times 3\frac{3}{4} \times 3\frac{1}{4}$ in. ($152 \times 95 \times 83$ mm) and weighs $2\frac{1}{2}$ lb.



Transmission Measuring Set.

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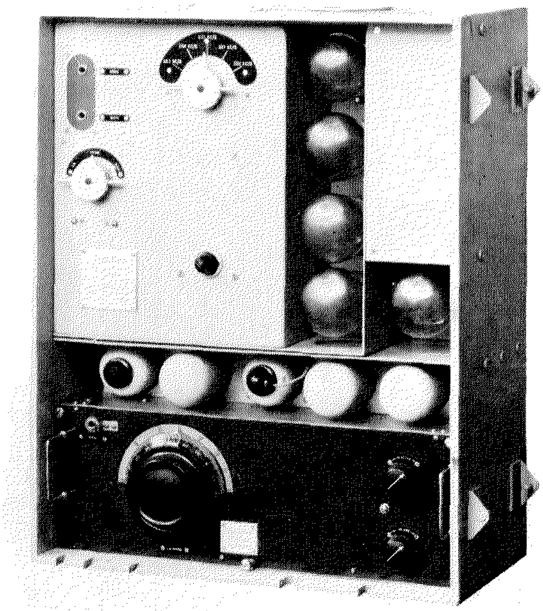
AIRCRAFT RADIO EQUIPMENT (Type R.9). The rapid growth of civil aviation during the last few years has resulted in a European network of daily scheduled air routes. It has become necessary to allocate internationally specified wavelengths to handle the increasing volume of aviation radio traffic and to confine their use to well defined zones controlled and served by established aerodrome and other radio ground stations. It is, therefore, increasingly important for the aircraft transmitter to have these international wavelengths preset, and for the pilot to be able to switch instantaneously from one wavelength to another—each change being registered by well-defined "clicks" and suitable dial indication.

The R.9 Aircraft Radio Equipment, developed by Standard Telephones and Cables, Limited, to meet these requirements, provides for radio telephone or telegraph transmission on six fixed medium wavelengths, namely: 600—827—862—900—918 and 932 metres (500—363—348—333—327 and 322 kc respectively) and for reception on wavelengths between 550 and 1150 metres (545 and 261 kc respectively).

The inclusion of 600 metres permits aircraft



Aircraft Radio Equipment.

engaged on overseas flying to communicate with any ship or shore station operating on 600 metres.

The R.9 equipment allows full advantage to be taken of navigational assistance from medium wave direction finding stations as well as of two-way communication with ground stations.

The method of installation varies according to the type of aircraft and whether the equipment is to be operated by direct or remote control. When the equipment is to be operated by the pilot only, remote control is usually used.

Where space permits, the transmitter and receiver units are mounted in a single box, as illustrated. If necessary, however, the two units can be supplied in separate cases and mounted apart, provided the receiver is kept reasonably near to the transmitter. In all cases, shock absorbing slings are provided.

The control box, being relatively small, may be located to suit the convenience of the operator. The fairlead should be installed as near as possible to the aerial winch, while the latter must be accessible to the operator.

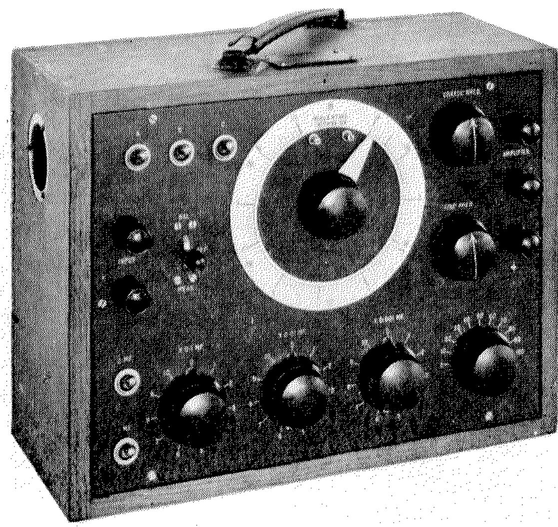
The equipment can be operated either from a wind-driven generator mounted in the leading edge of the wing or under the fuselage, or from the 12-volt plane battery. The power supply is suitably filtered.

The method of construction permits much latitude in the installation of the equipment, which can be fitted in aircraft ranging from the small Moth variety to the largest multi-engined machines.

• • •

A DISTORTION FACTOR METER, No. 74300-A, has been developed by Standard Telephones and Cables, Limited, London, to provide a simple method of harmonic content determination without the complexities which are inherent in high precision wave form analysis. In conjunction with a suitable amplifier, it can be employed for measuring the harmonic content of any voice frequency wave form.

This meter is intended as a general purpose harmonic measuring set for the quantitative determination of the quality of the output from oscillators or amplifiers over the voice frequency range. Fundamental frequencies from 20 to 3000 p : s and the total harmonic content (i.e., ratio of total harmonics to fundamental plus harmonics) up to 10 per cent. can be measured. The associated amplifier must have a flat frequency response over the range 20 p : s to 10,000 p : s, and the No. 74302-B amplifier is specially recommended for this purpose.



Distortion Factor Meter.

The overall dimensions of the set are $12 \times 9 \times 5\frac{1}{2}$ in. ($305 \times 229 \times 140$ mm), and the weight is 20 lb. (9 kg).

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