(Please circulate to your Staff.) Mr. L. C. Pocock. N.S.

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Volume XV JULY, 1936 Number 1

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PLANT OF LE MATÉRIEL TÉLÉPHONIQUE,
PARIS, FRANCE, FOR THE MANUFACTURE OF
COMMUNICATION APPARATUS AND EQUIPMENT

Extension of Sottens Broadcasting Station to 100 KW

By E. METZLER, Dipl. Ing.,
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WHEN the Swiss T.T. Administration took in hand the task of providing a comprehensive broadcasting scheme to cover the whole country, plans were based on a regional scheme involving among others a high power station at Sottens to serve the French-speaking zone. This station was opened in 1931 with an initial power of 25 kW., and provision was made for a future increase in power should circumstances make this desirable.

In 1935 the decision was taken to raise the power to 100 kW. and, at the same time, to incorporate the latest methods in broadcasting technique. An order for this conversion was placed in January, 1935 with the Bell Telephone Manufacturing Company of Berne.

Ten months later, in November 1935, cutover of the entire extension was effected, the work of installation, adjustment, and testing having been completed without interruption to the broadcasting service.

The changes necessitated by the fourfold increase in power, accompanied by modernisation throughout, are such that, for descriptive purposes, it is preferable to consider the equipment as entirely new rather than as an extended installation.

A general idea of the layout can be obtained from Fig. 1. It shows a plan view of the ground floor on which is installed the transmitter proper and all power supplies except the high voltage rectifier which, together with the smoothing system and the valve water cooling plant, is accommodated in the basement of the station.

The main features which characterise the design of the equipment may be summarised as follows:

(*A*) The equipment is systematically section-

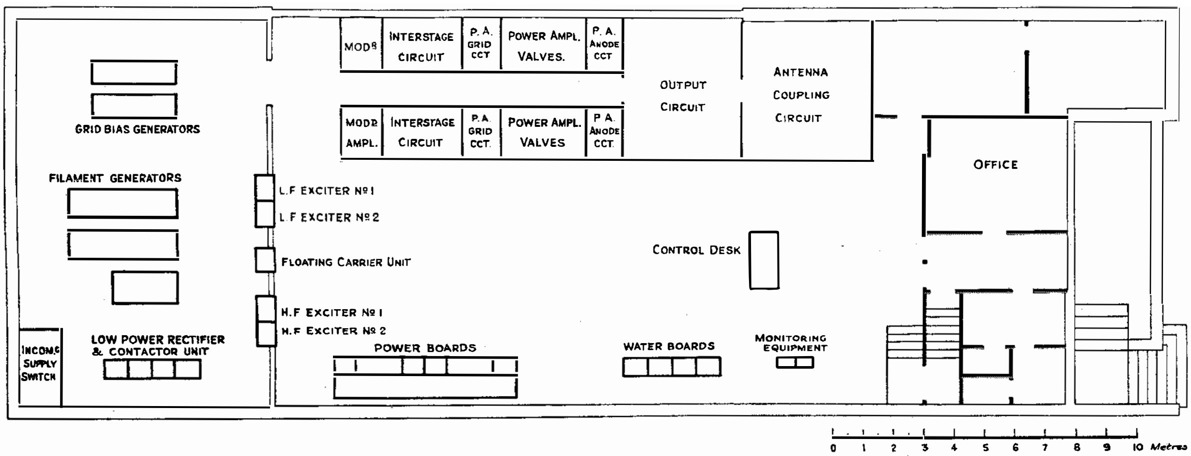


Fig. 1—Plan of Ground Floor Layout of Sottens Extension, Showing Transmitter Proper, Power Control Board, Water Control Board, Control Desk, Monitoring (Testing) Rack, and Machines. In the Basement are Installed the 18,000 Volt Rectifier, H.T. Smoothing Systems, and Water Cooling Systems.

Fig. 2—Transmitter Hall.

alised according to the functions of the component parts.

(*B*) The low power "exciter" stages, both high frequency and low frequency, are in the form of self-contained units, supplied in duplicate, with means for quick changeover. With the exception of filament heating, all power supplies for these units are obtained from metal rectifiers.

(*C*) The high power stages, including the modulator, modulated amplifier, power amplifier, and output circuits are built in the cubicle type of construction which gives exceptional freedom of access.

(*D*) Spare water cooled valves are mounted in each position, and mechanism is provided for quickly changing over the electrical supplies and the water.

(*E*) Screen grid valves are used in all low power radio frequency stages, resulting in simplification of circuit adjustment.

(*F*) All voice frequency amplifiers are in push-pull, giving improved transmission quality.

(*G*) Extremely high R.F. harmonic suppression is obtained by means of special filter circuits in the output stages.

(*H*) The system can be converted from "stable carrier" to "floating carrier" whenever desired, even during a programme item, by means of a floating carrier input equipment.

(*I*) No line amplifier is required, as the L.F. exciters can be fully driven with a very low input.

(*J*) Rotating machines are used only for filament and grid bias supplies and water cooling pumps and fans.

(*K*) Complete water flow, temperature, and pressure measuring equipment is provided, concentrated on a "water control board."

(*L*) Use of perishable materials such as rubber and wood has been avoided.

(*M*) The protective system is mechanical with additional protection by an electrical interlock system.

(*N*) Provision is made for monitoring and measuring noise level and distortion at a number of points in the equipment, and a fully equipped test position is provided whereby all the transmission characteristics—frequency response, harmonic content, etc.—can be measured in a few minutes as a daily routine operation. This new scheme has proved to be very useful and will soon be adopted in all the Swiss Broadcasting Stations.

(*O*) All rotating machinery is provided in duplicate with means for quick changeover.

The transmitter proper, manufactured by Standard Telephones and Cables, Limited, London, is installed in the main hall of the station (Fig. 2). It comprises the following principal assemblies:

(*a*) Radio frequency exciter unit (Fig. 3), crystal controlled, and delivering an output of 500 watts to the modulated amplifier. This exciter is of cabinet construction

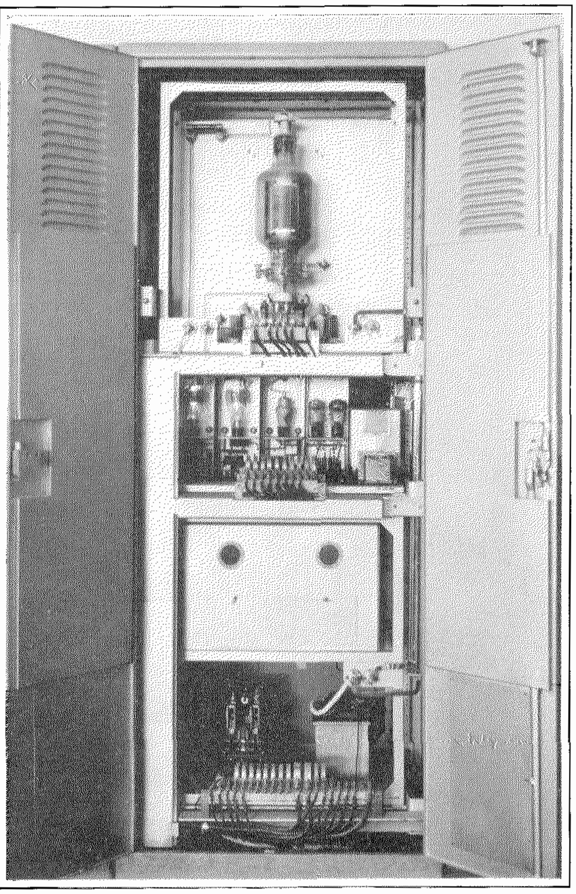


Fig. 3—H.F. Exciter, Rear View with Doors Open.

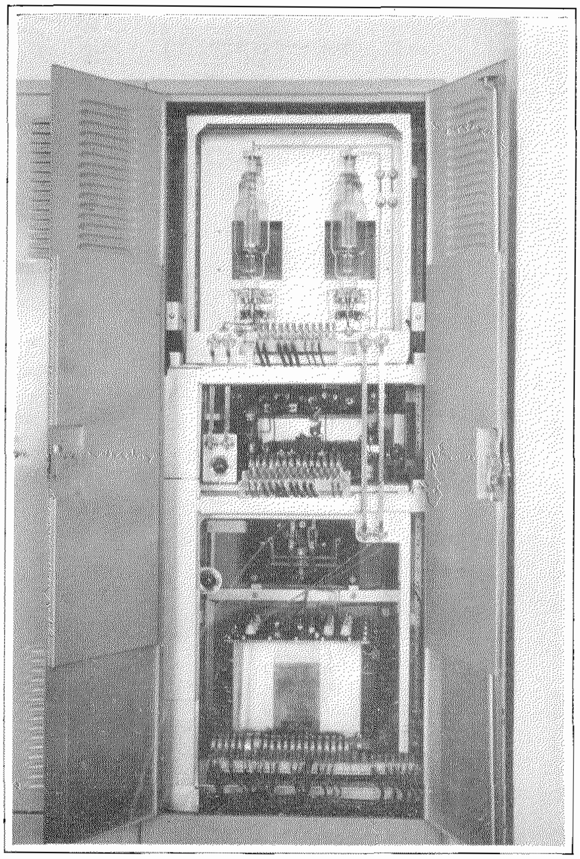


Fig. 4—L.F. Exciter, Rear View with Doors Open.

with dimensions approximately 2.2 m. $\times$0.82 m. $\times$0.57 m. All apparatus and valves are completely enclosed but easy access can be obtained through a door in the back of the cabinet opened by means of a key which forms part of the interlock system. The crystal is contained in a double-chamber oven, each chamber having its own temperature control system consisting of a mercury in glass thermometer acting on the grid of a mercury vapour relay, the plate circuit of which includes the chamber heating element. By means of a small variable condenser it is possible to vary the frequency of the crystal controlled system over a range of $\pm$20 parts in one million. If, under special circumstances, it is necessary to make a large change in the frequency, the first stage of the exciter may be used as a self oscillator. The unit includes in all a total of four R.F. stages, each stage con-

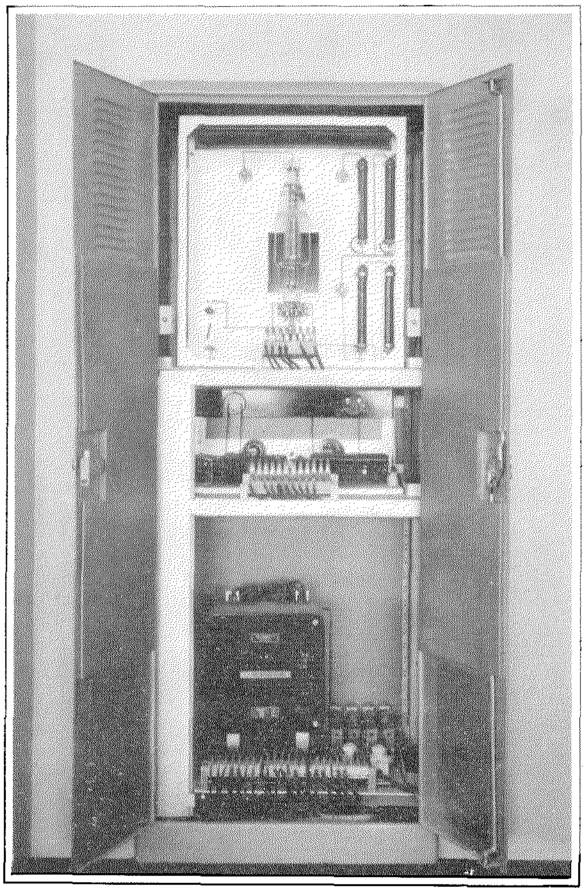


Fig. 5—Floating Carrier Unit, Rear View with Doors Open.

sisting of screen-grid valves with tuned output circuit.

(*b*) Spare R.F. exciter unit, a complete duplicate of (*a*).

(*c*) Audio frequency exciter unit (Fig. 4), consisting of a cabinet of the same dimensions as the radio frequency exciter, and including four stages of Class "A" push-pull amplification. The input and output impedances are approximately 600 ohms and 20,000 ohms, respectively. An input of −14 db. below six milliwatts is sufficient for full modulation. With such a low input level no line amplifier is required in the station, the studios at Lausanne being only twelve miles distant. As in the case of the radio frequency unit, all apparatus and valves are normally enclosed, and access to the interior is possible only when all voltages have been removed.

(*d*) Spare audio frequency exciter unit, a complete duplicate of (*c*). In the case of both the audio frequency and radio frequency exciter units, it is only necessary to operate one switch to effect a complete changeover from the working unit to the spare unit, the input and output circuits, etc. being changed over by a group of contactors.

(*e*) Floating carrier unit (Fig. 5), consisting of another cabinet of the same dimensions as those used for the exciters. It includes a dry metal rectifier energised from the audio frequency exciter to give unidirectional voltage fluctuating at syllabic frequency. This is then amplified by a two stage d-c. amplifier system, of suitable time constant, to give a reverse grid bias to the modulator. Since the latter is negatively biased towards the cut-off point when the floating carrier

Fig. 6—Corridor of Cubicle Assembly.

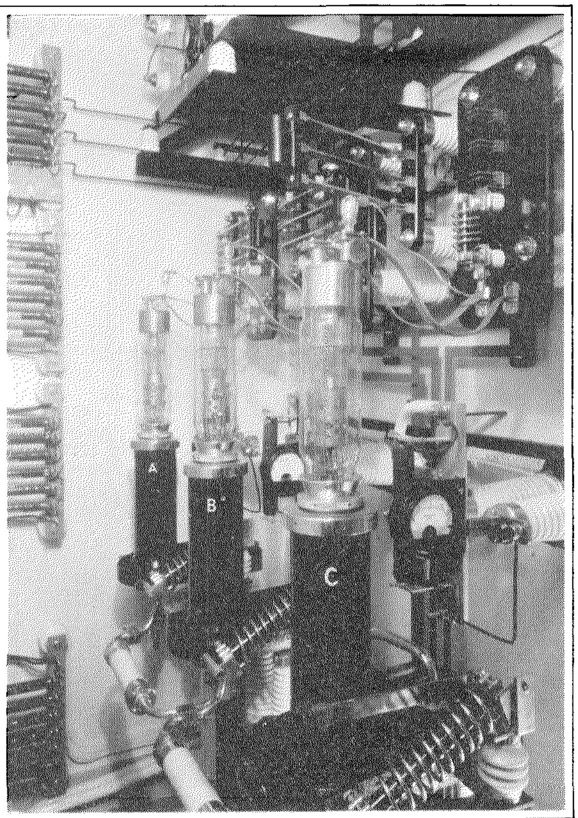


Fig. 7—Modulator Valve Cubicle.

system is in use, with no audio input the plate current in the series modulation system is very small, and the radio frequency output is correspondingly reduced, while for full audio input the reverse bias from the floating carrier unit reduces the bias on the modulator to its normal or steady carrier value, with corresponding increase in mean plate current and hence in carrier output from the modulated amplifier.

(*f*) Cubicle assembly, in which are mounted all the water cooled valves and associated equipment including the modulator and modulated amplifier, interstage circuit, power amplifier, main output circuit, and aerial tuning circuits. Of the seven cubicles comprising the line, the first five are traversed by a central corridor (Fig. 6) from which access is obtained to the individual half cubicles by sliding doors interlocked with the protective system. At the end of the corridor another sliding door gives access to the sixth cubicle, from which the seventh may be reached. The following gives an indication of the distribution of the equipment in the cubicles:

Cubicle No.	*Front*	*Rear*
1	Modulated Amplifier Valves	Modulator Valves
2	Modulated Amplifier Output	Modulated Amplifier Output
3	Power Amplifier Grid Circuit	Power Amplifier Grid Circuit
4	Power Amplifier Valves	Power Amplifier Valves
5	Power Amplifier Plate Circuit	Power Amplifier Plate Circuit
6	Power Amplifier Output Circuit	
7	Aerial Coupling and Tuning Circuits	

The efficiency of harmonic reduction from amplifier valves to aerial is such that the intensity of harmonic field strength at a distance of 5 km. from the station is only 180 microvolts/meter, representing a suppression of 71 db. on the fundamental field strength.

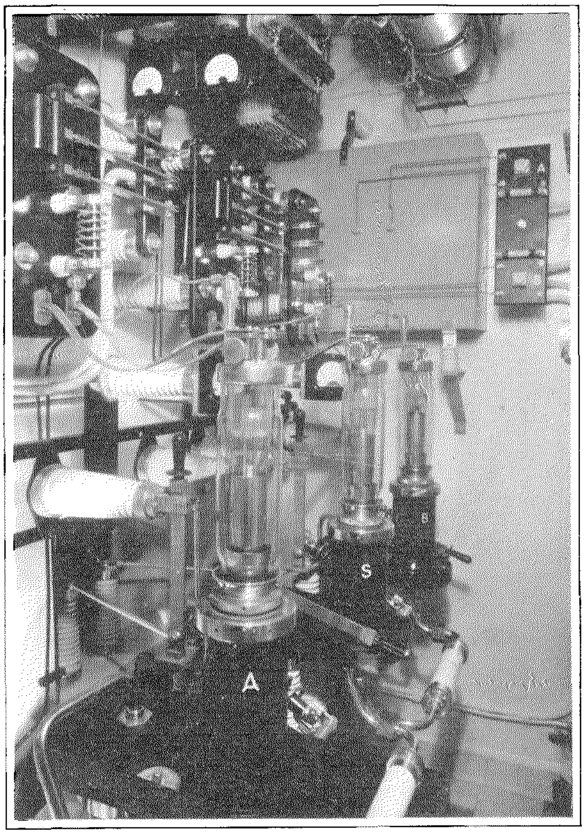


Fig. 8—Modulated Amplifier Valve Cubicle.

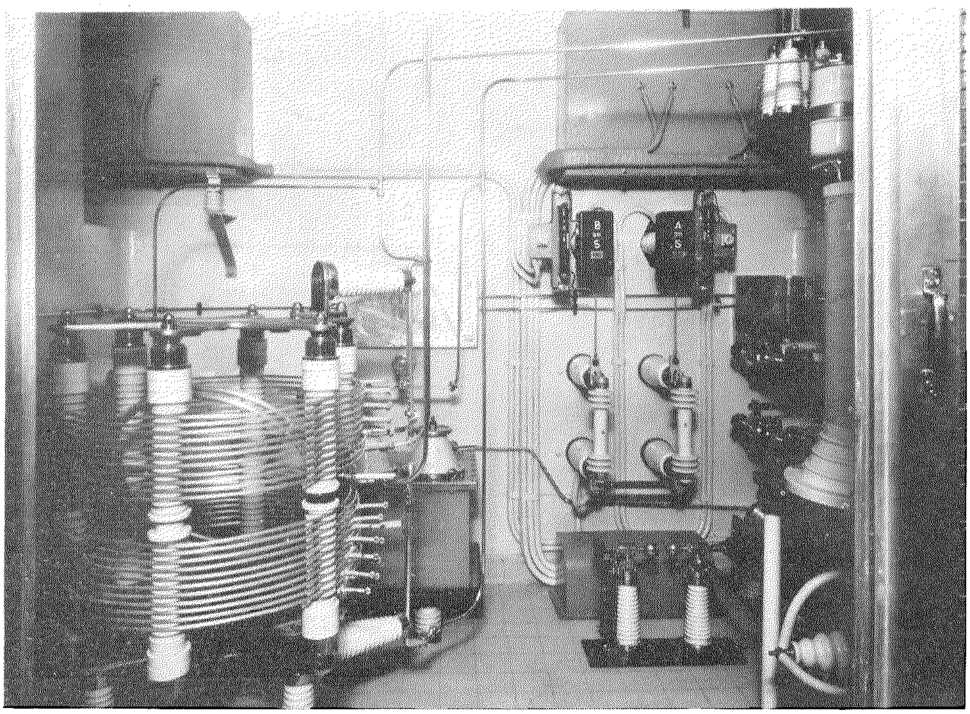


Fig. 9—Modulated Amplifier Interstage Circuit, Front Cubicle.

The circuit of the transmitter will be understood from the block schematic diagram given in Fig. 13.

The transmitter is modulated on the plates of the penultimate radio frequency amplifier. The modulator and modulated amplifier valves are operated in series from the main 18,000 volt supply for the final power amplifier. The modulator valves are on the low potential side, being interposed between the filaments of the modulated amplifier, which are insulated for high voltage, and ground. The filaments of the modulated amplifier, being at high potential to ground, are energised with a-c. from the highly insulated secondaries of transformers whose primaries are fed from the automatically regulated 380 volt, 3-phase supply. These transformers are designed for very low capacity from the secondary windings to ground, as this capacity is in shunt to the output of the modulators and consequently affects the frequency response. The transformers are Scott connected, so reducing hum arising from the a-c. heating of the filaments.

The power supply system of the transmitter is shown schematically in Fig. 14.

The main power supply for the station is derived from 8,000 volt, 3-phase, 50 cycle mains. Two sources of supply are available from separate power stations, and are brought to the station by separate feeders. The main incoming power supply is branched, one part being taken direct to the transformer for the 18,000 volt Brown-Boveri mercury arc rectifier, and the other part being stepped down to give a 380 volt supply for the motor generators, pumps, fans, and the rectifiers feeding the exciter and floating carrier units.

The general construction of the cubicles and method of mounting valves and apparatus will be gathered from the illustrations. All valves are water cooled, the water supply being taken through porcelain hose coils situated in the basement directly underneath the cubicles.

The modulator cubicle (Fig. 7) is equipped with three No. 4053-A low impedance valves. Two of these are normally connected in parallel, the third being a spare.

The modulated amplifier cubicle (Fig. 8) is equipped with two No. 4009-A valves, operating in push-pull, and with an additional spare valve which can be switched to either side of the push-pull circuit as required. Figs. 9 and 10 show the modulated amplifier interstage circuit cubicles.

There are two power amplifier valve cubicles (Fig. 11), one on each side of the corridor, each containing a pair of No. 3030-A valves in parallel, together with a spare pair of valves. The two cubicles form the two sides of a push-pull system, and in either cubicle any two of the four valves can be used together. The switching system governing these valves includes not only the electrical but also the water circuits.

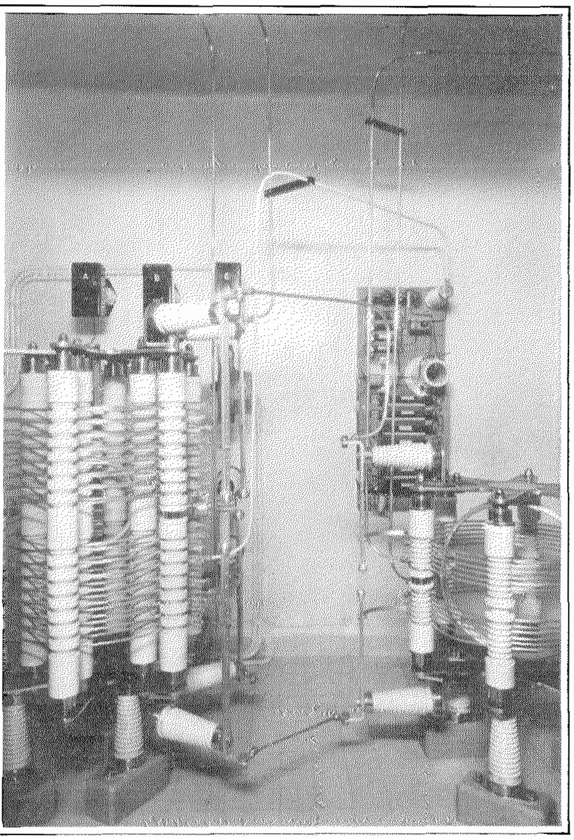


Fig. 10—Modulated Amplifier Interstage Circuit, Rear Cubicle.

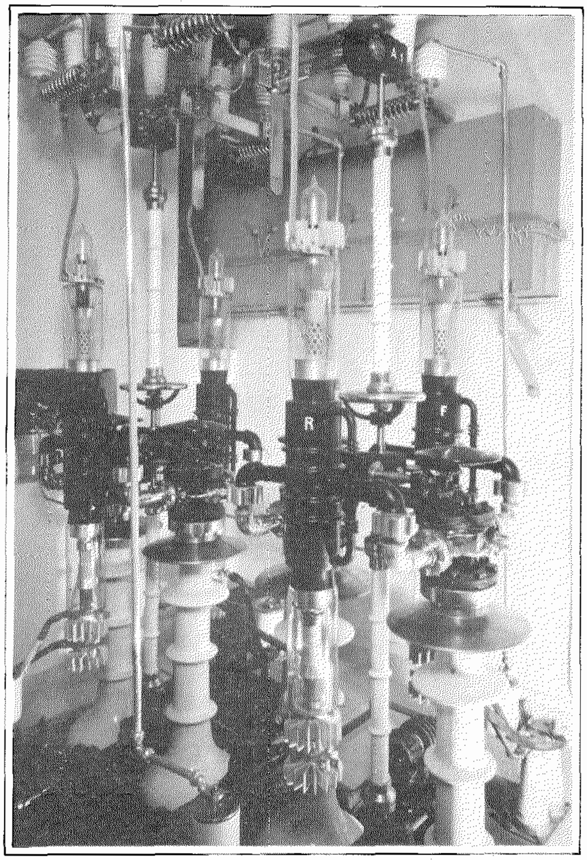


Fig. 11—Power Amplifier Valve Cubicle.

Cubicle No. 6 (Fig. 12) contains two tuned output circuits inductively coupled, working into a filter circuit of 600 ohms impedance, situated in cubicle No. 7. This value of impedance was adopted so that if the aerial system should later be changed to one requiring transmission line feed, it will be possible to connect the feeder directly to the filter output terminals.

Cubicle No. 7 contains the harmonic filter and the antenna tuning and coupling circuit. The filter includes series and shunt elements, and the antenna coupling circuit is a closed tuned circuit inductively coupled to the aerial. The aerial is tuned by a tapped coil and a shortening condenser. The high frequency transformers providing the inductive coupling between the two tuned output circuits and between the antenna coupling circuit and the antenna are fitted with earthed electrostatic shields.

To accommodate the equipment for the switching, fusing, and metering of these supplies, a

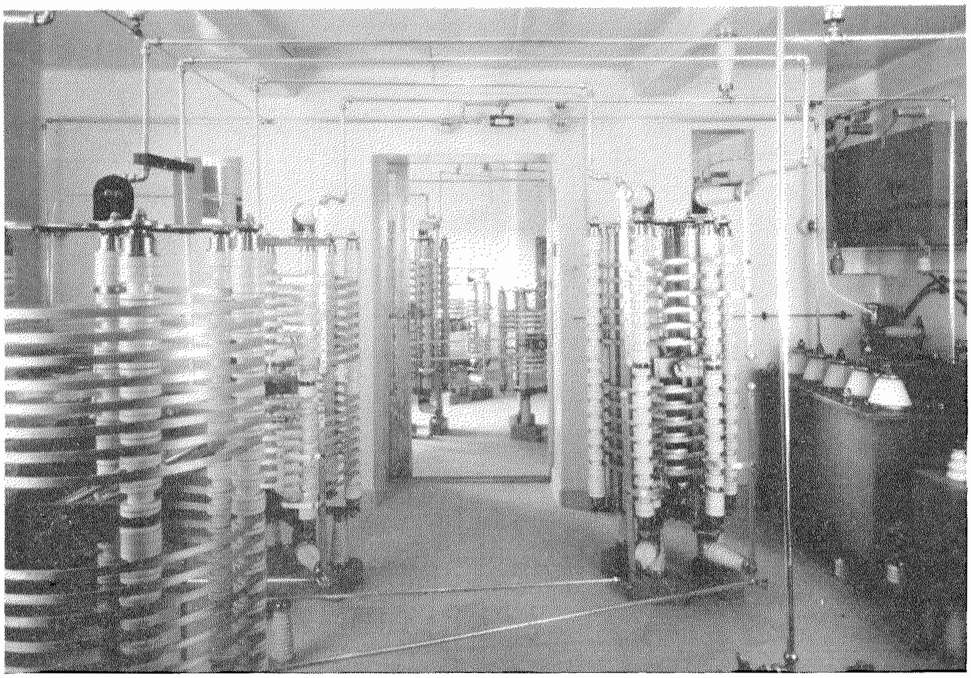


Fig. 12—Power Amplifier Output and Aerial Circuit Cubicles.

power board (Fig. 15) is provided in the Transmitter Hall. This board is of dead front panel construction, approximately 6 m. long×2.2 m. high×1.4 m. deep, and is divided into six main sections with controls for the following:

(1) Incoming 8,000 volt, a-c. supply;
(2) 380 volt, a-c. supply, non regulated, to motors, and 380 volt, a-c. supply stabilised by automatic induction regulator, to the low power supply unit rectifiers;
(3) 28 volt d-c. and 10–12 volt d-c. filament supplies from generators;
(4) 550 volt d-c. and 1,200/2,500 volt d-c. grid bias supply from generators;
(5) 28 volt generator changeover switching;
(6) 2,500 volt generator changeover switching.

Provision is made on the board for automatic control of the time taken for building up the excitation of the 28 volt generator to its normal value, in order to ensure that the power valve filaments are not brought up to full brilliancy too quickly. The external finish of the board is grey, to line up with the finish on the exciter units and control desk which are in the same room.

High tension supply for the modulation and power amplifier systems is derived from a 400 kW. 18,000 volt Brown-Boveri rectifier of the grid controlled mercury arc type. This is mounted, together with its auxiliary oil and molecular vacuum pumps and cooling system, in the basement of the station, together with the 18,000 volt smoothing system and the rectifier H.F. protective filter (Fig. 16). The full transformer voltage is always applied to the rectifier, and adjustment of the d-c. voltage is obtained by phase control of the grid voltage. The grids are also interconnected with the protective system to switch off the rectifier momentarily in the event of a back fire in the rectifier or a flash arc discharge in the transmitter valves.

The high tension filter system is divided into five branches feeding separately the modulating stage and each of the four power amplifier valves. The division of the filter gives increased protection against short circuits and reduces intermodulation between stages.

Grid bias, screen, and anode voltage supplies for both the high frequency and audio frequency exciter units, and also the anode supply for the floating carrier unit are obtained from a "Low Power Supply Unit" (Fig. 17) consisting of a group of metal rectifiers for the voltages of 2,500, 850, 425 and −150.

These rectifiers are all operated from the 380 volt supply taken through the automatic induction regulator. Each rectifier has its own working and spare transformer, arranged for changeover by a manually operated switch, also a spare rectifier element. The unit includes the necessary

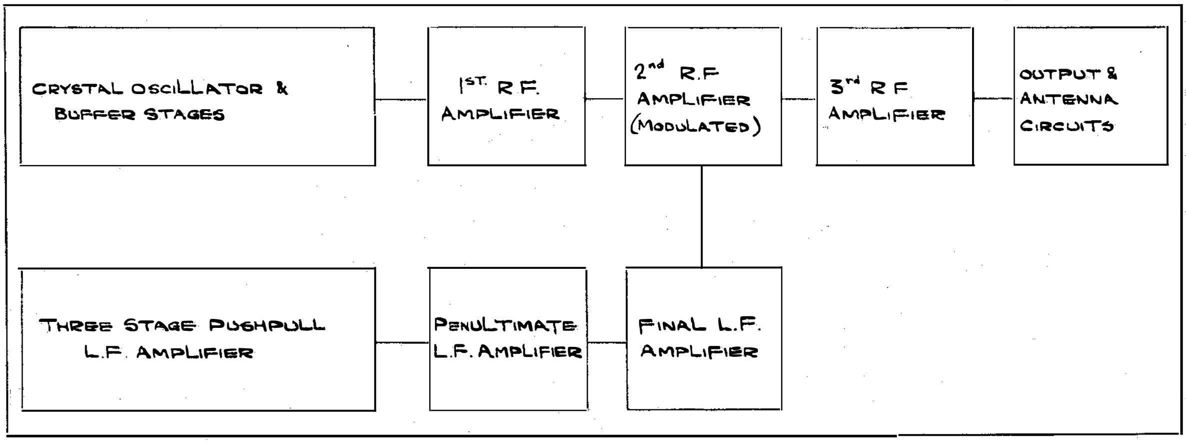


Fig. 13—Transmitter Circuit, Block Schematic.

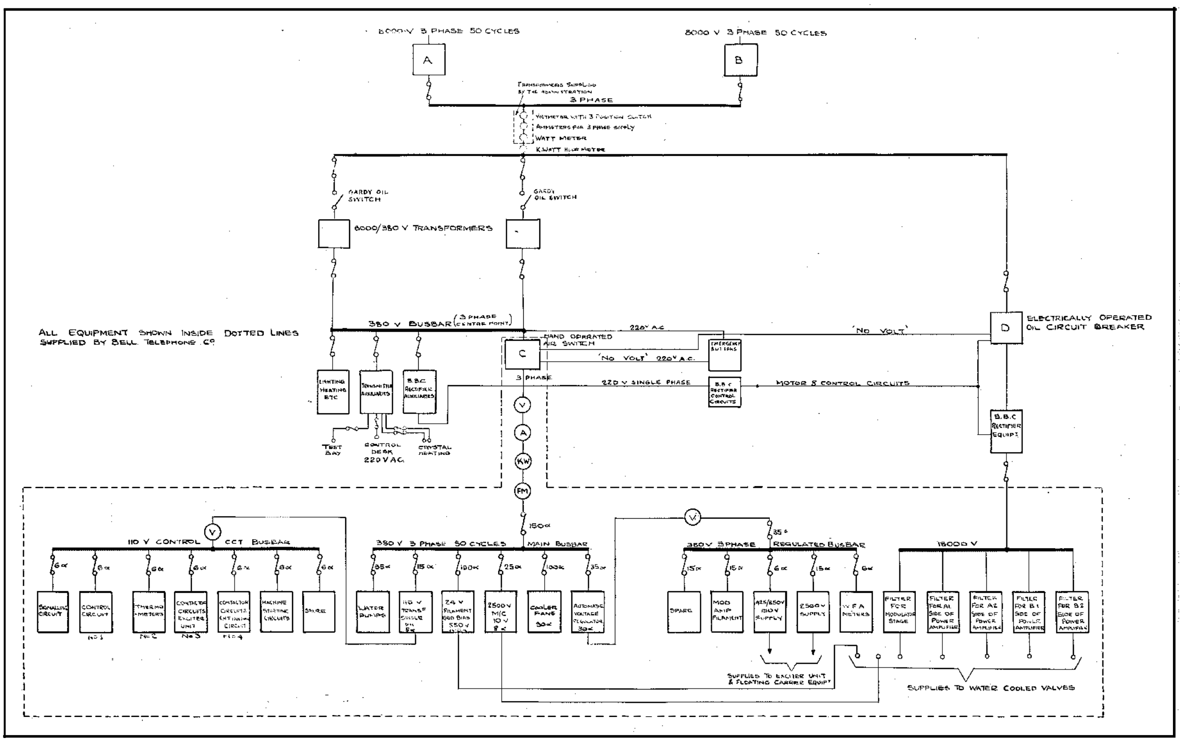


Fig. 14—Power Supply Schematic.

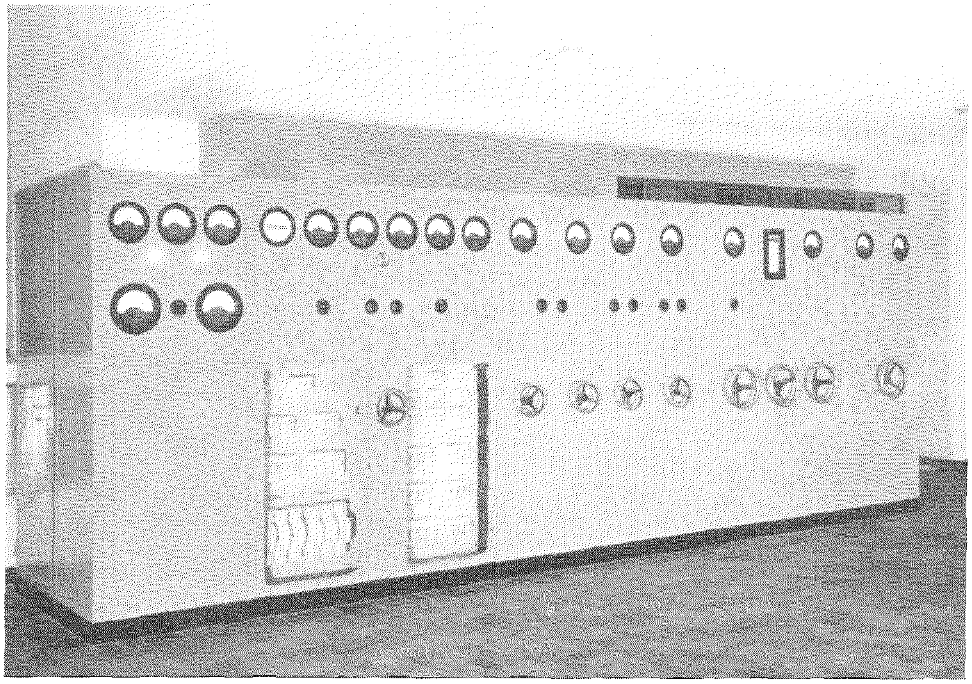


Fig. 15—Machine Power Board.

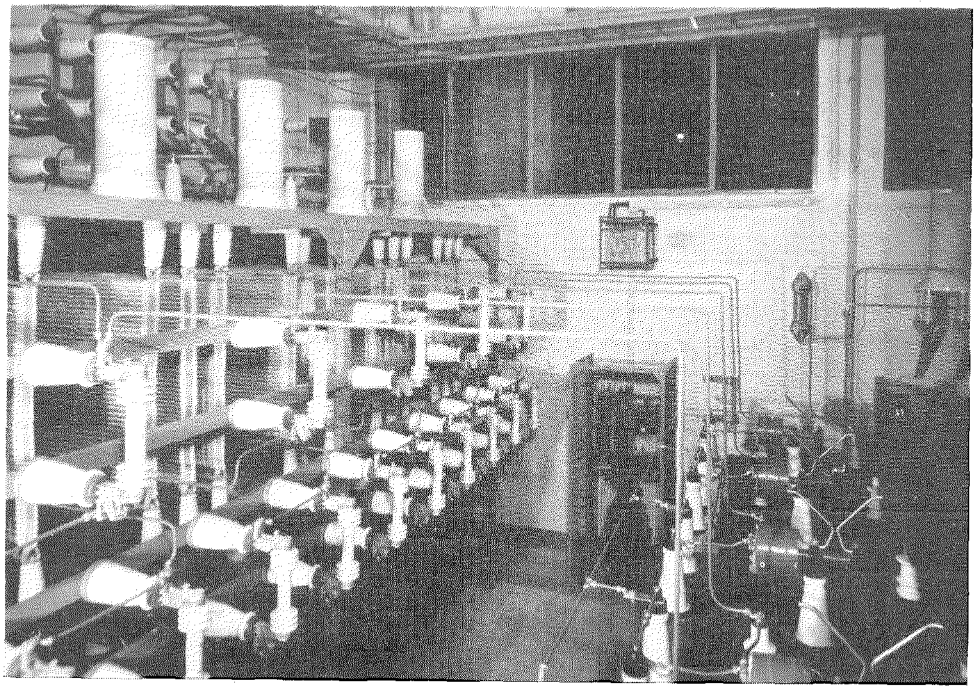


Fig. 16—18,000 Volt Rectifier Protective Filter, and Isolator System.

filter circuits for the various outputs. As in the case of the exciter units, all apparatus is completely enclosed but is accessible by opening the doors which are interlocked with the protective system to remove all dangerous voltages. Handwheels on the front of the unit operate changeover switchgear isolating the exciter units not in service.

The complete low power supply unit, including the rectifier elements, transformers, smoothing equipment, and an associated contactor rack, is installed in the machine room behind the exciter units.

The valve water cooling system is of the closed circuit type using distilled water cooled by air blast radiators. Piping, pumps, etc., are all of non-ferreous material. Where the water channel changes from an electrically conducting medium to a non-conducting medium, renewable thin lead sleeves are provided to take up the electrolytic action which inevitably occurs at such points. The system dissipates a power of the order of 300 kW.

Control and metering of the water supply to the various valve units is carried out at the water control board located in the Transmitter Hall. This control board is of the panel type, 3.2 m. $\times$ 2.2 m., and is divided into four sections. On it are mounted actuating handles for the cocks controlling the total flow and the separate flow to each valve cubicle, also water flow meters and outlet temperature thermometers for each branch circuit.

The flow meter circuits are interconnected with the electrical protective system in a manner such that the voltages cannot be switched on until normal water circulation has been established.

As already mentioned, the porcelain water coils (Fig. 18) which provide the high resistance path between the valve jackets and ground are installed in the basement, directly beneath the valves they serve. They are surrounded by strong glass partitions so that in the event of an accidental breakage while the transmitter is

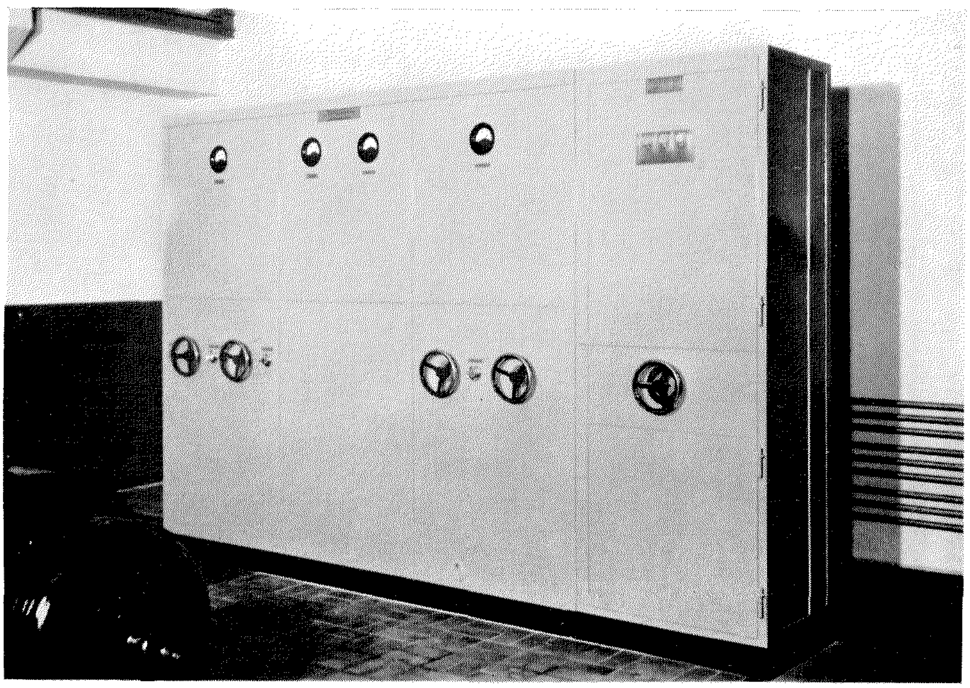


Fig. 17—Low Power Supply Unit.

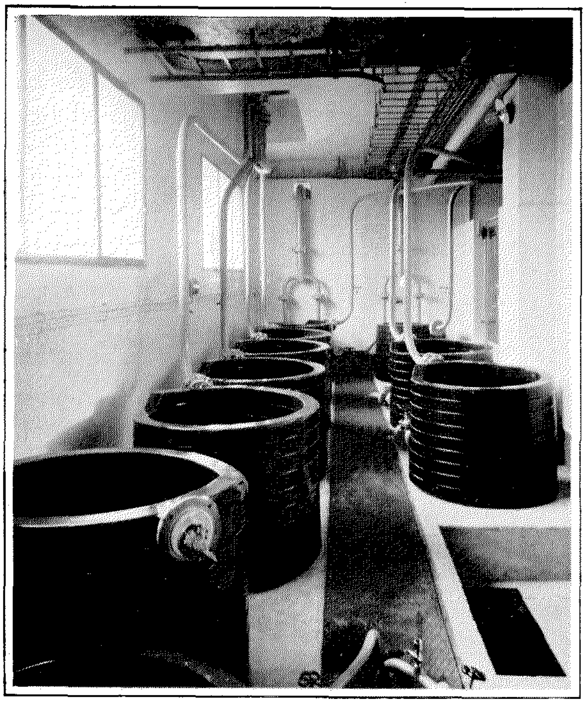


Fig. 18—Water Coils Installed in Basement.

working there can be no danger to personnel from jets of water at high potential.

The operations for bringing the transmitter into service are performed at the power board in the transmitter room, except the application of the main high voltage. The latter is applied and regulated from a control desk which is fitted also with meters and facilities for general supervision of the equipment while in operation.

The control desk (Fig. 19) is of metal construction, its dimensions being approximately 1.9 m. long × 1 m. wide by 1.13 m. high. It is finished in grey cellulose to line up with the exciter units and power board. The equipment on the desk includes the following:

(1) Meters for reading all the important valve voltages for both the exciter units and the power amplifier;

(2) Switches for the control and regulation of the 18,000 volt mercury arc rectifier;

(3) An "emergency stop" button enabling the whole station to be shut down instantaneously;

Fig. 19—Control Desk.

(4) Signal lamps to indicate any failure in the protective systems;
(5) Programme level indicator;
(6) Modulation meter indicating depth of modulation at the output of the transmitter;
(7) A signal lamp giving warning of over-modulation;
(8) A monitoring loud speaker which can be connected to any one of the monitoring points at the outputs, respectively, of the audio frequency exciters, the modulated amplifier, and the power amplifier;
(9) An hour meter indicating the operating time of the power amplifier valves.

In order to facilitate the maintenance of a high standard of transmission quality, a bay of monitoring and testing apparatus (Fig. 20) is mounted in the transmitting room available for routine measurements of performance. The equipment is permanently connected to enable measurements to be made quickly and easily at a number of points in the transmitter. The following are some of the observations which can be made at the test rack, as a routine operation:

(1) Percentage modulation on both positive and negative peaks;
(2) Programme monitoring with high speed volume indicator;
(3) Carrier noise level;
(4) Amplitude distortion in low frequency and high frequency amplifiers (harmonic content);
(5) Noise and hum level of audio amplifiers;
(6) Audio frequency response curves;
(7) Modulation curves in conjunction with the modulation meter mounted on the transmitter;
(8) Gain of low frequency amplifiers;
(9) Examination for symmetry of wave form by cathode ray oscillograph;
(10) Depth of modulation by cathode ray oscillograph;
(11) Low frequency wave form examination by cathode ray oscillograph.

The modulation indicator can be left in continuous operation and, associated with it, there is a device to indicate over-modulation by flashing of a lamp.

The aerial is of the high T type, slung between two insulated, self-supporting steel towers 125 meters high and spaced 200 meters apart. The earth system consists of a buried copper wire network covering an area of 200 meters $\times$ 260 meters.

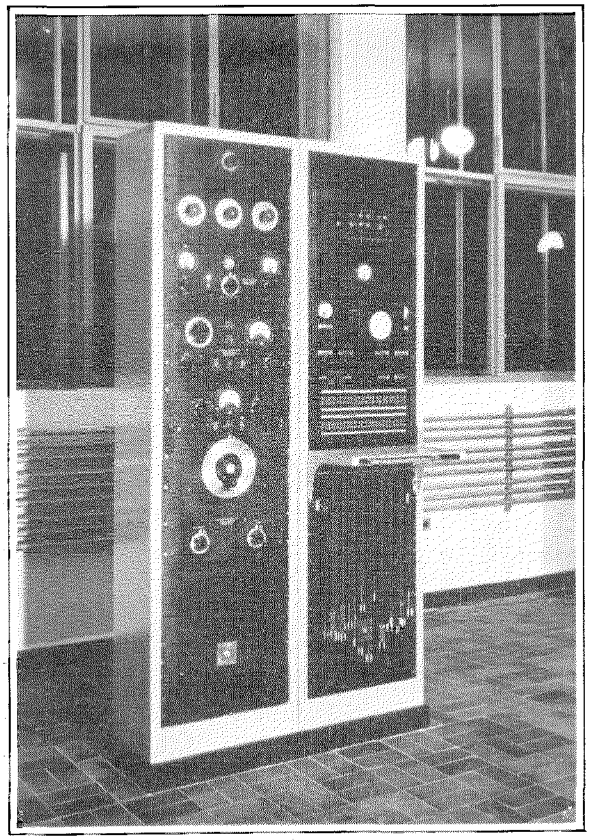


Fig. 20—Test Rack for Routine Testing.

The overall performance of the transmitter, both in regard to transmission quality and reliability, meets fully the high standards required by the Swiss Broadcasting Service. The frequency response curve lies between ± 2 db. between 30 and 10,000 cycles per second, and the audio frequency harmonic content due to amplitude distortion is of the order of 4% R.M.S. at 85% modulation.

The accomplishment of the work of extension and modernisation in the short period of ten months without any interruption to the transmissions from the station entailed the closest cooperation between the Administration and the contractors, and was secured through the assistance of the station superintendent, Mr. R. Piece, and his staff.

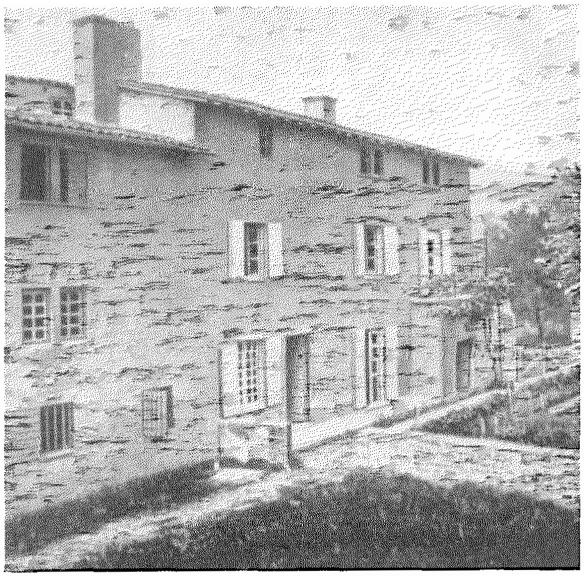
Centennials of T

André Marie Ampère

ANDRÉ MARIE AMPÈRE, one of the greatest scientists of all time, "sought the truth, elevated ideas, general principles, and he preferred them if they could be directly applied." He contributed to the idea of the electric telegraph, and his memoirs show that his investigations related to "transcendental mathematics, applications to mechanics, electricity and magnetism, optics, the theory of gases, molecular physics, animal physiology, the theory of the earth, metaphysics and psychology."[1]

"He discovered the mechanical action between electric currents, and he established mathematically and by physical demonstration the law of that action. This Maxwell declared to be one of the most brilliant achievements in science; for the whole, theory and experiment, had 'leaped full grown and fully armed from the brain of the Newton of electricity,' perfect in shape, unassailable in accuracy, and summed up in a formula from which all the phenomena could be deduced—the cardinal formula in electrodynamics."

"Thanks chiefly to the efforts of Mascart, the name of Ampère has been adopted universally as the designation of the unit of electric current, and thanks largely to Joubert his memoirs have been reproduced for posterity. Yet, if there is ever to be a temple of scientific research in Paris, devoted in the noblest sense, to the welfare of mankind, France may appropriately write across its portal the name of Ampère, for his gifts to humanity can be repaid only in contributions that further the purpose for which he lived."



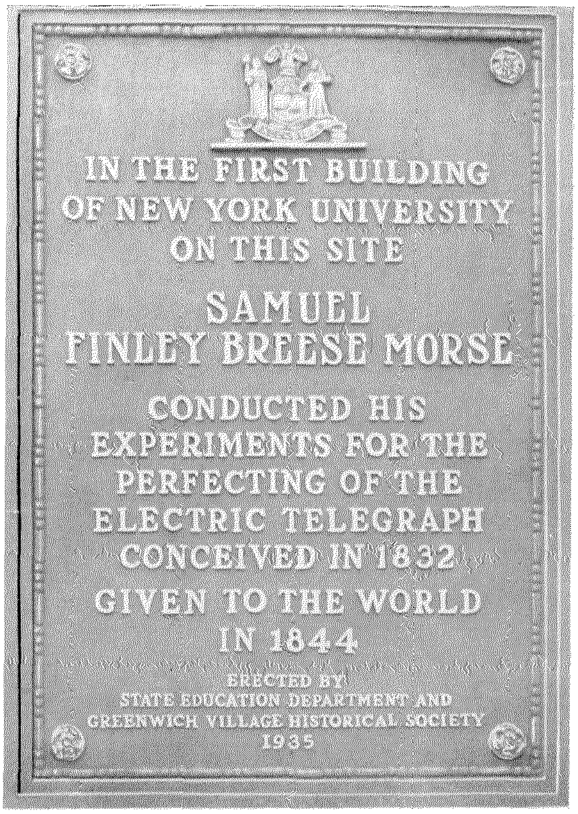
Ampère's Home at Polémieux Donated in 1928 by Colonel Sosthenes Behn and the Late Mr. Hernand Behn to the Société Française des Electriciens as a Symbol of Universal Tribute to this Great French Genius

[1] Quotations are from "Pioneers of Electrical Communication—André Marie Ampère—II," by Rollo Appleyard, *Electrical Communication*, January, 1927.

ommunication Pioneers

Samuel Finley Breese Morse

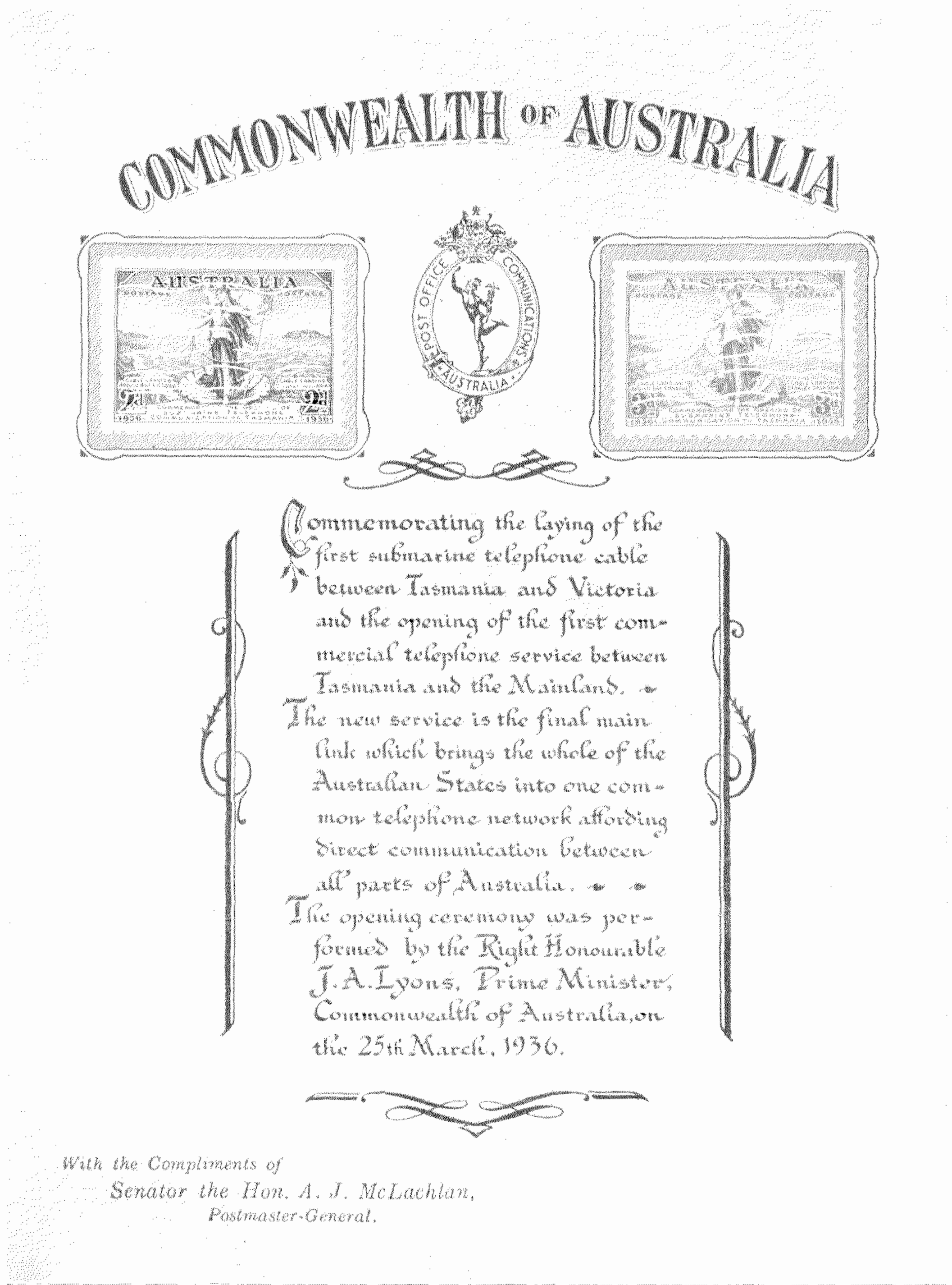
SAMUEL FINLEY BREESE MORSE, founder of the National Academy of Design, the first in America to occupy a chair of fine arts, and a distinguished portrait painter, carried on his original experiments with the telegraph at New York University in Washington Square, New York City, a century ago. He moved into the University building in 1835 before it was finished and, the stairways not being completed, his sitters, for a time, were discouraged from coming to his studio. The enforced leisure gave him an opportunity to experiment with the idea of the telegraph which he had conceived in 1832. He improvised a telegraph instrument, now in the Smithsonian Institution in Washington, and demonstrated it to friends early in 1836. The inventor continued his experiments and, at a select gathering in the Geological Cabinet, a museum of the University, on January 24, 1838, publicly demonstrated a perfected machine. When Morse asked for a message to transmit, one of the guests suggested the now famous words constituting a facetious command: "Attention, the Universe: By Kingdoms, Right Wheel!" This message was traced by four inked styluses on a paper tape and constituted a perfect quadruplicate record.



Courtesy of New York University

Bronze Memorial Tablet, Erected May 28, 1935, to Mark the Site of the Original New York University Building in New York City where Morse Sent the First Message by Electric Telegraph

Morse viewed the telegraph realistically, felt certain of its practicability and experimented extensively with batteries, overhead lines and cables. Due largely to his efforts, the system developed by his company, the Magnetic Telegraph Company, was adopted throughout the world and is today being used in rural areas virtually unchanged.



COMMONWEALTH OF AUSTRALIA

POST OFFICE COMMUNICATIONS AUSTRALIA

Commemorating the laying of the first submarine telephone cable between Tasmania and Victoria and the opening of the first commercial telephone service between Tasmania and the Mainland.

The new service is the final main link which brings the whole of the Australian States into one common telephone network affording direct communication between all parts of Australia.

The opening ceremony was performed by the Right Honourable J. A. Lyons, Prime Minister, Commonwealth of Australia, on the 25th March, 1936.

With the Compliments of
Senator the Hon. A. J. McLachlan,
Postmaster-General.

Commemoration Card issued by the Commonwealth of Australia. (On the Card Itself, the Postage Stamps are Red and Blue, respectively.)

Australia-Tasmania Cable

"TASMANIA'S separation is ended," quotes *The Mercury*, one of the leading newspapers of Tasmania, following the inauguration of telephone service over the new Australia–Tasmania cable on Wednesday, March 25, 1936. The service was opened officially by the Prime Minister, whose voice was transmitted with perfect clarity through the cable from Albury to the gathering at Hobarts Hotel, Tasmania, assembled to take part in the inauguration ceremony.

"The opening of this service tonight marks the ultimate achievement of an Australian telephone service which is truly national," said the Prime Minister, "and it is, therefore, with feelings of pride and deep gratification that I declare the line between Tasmania and the mainland open for regular business."

The communication channel requirements for which the cable is designed are five telephone circuits, seven duplex telegraph circuits, and a channel for the transmission of broadcasting programmes.

The methods employed to provide the required number of circuits may be briefly described as follows:

A specially designed carrier telephone system, having its terminal equipment at Apollo Bay and Stanley and a repeater station at King Island, providing five carrier telephone channels and a physical or voice frequency channel, the latter being brought out at the King Island Repeater Station so as to provide communication with Currie in addition to carrying through traffic. Three of the channels are extended to Melbourne on the Victorian side and to Launceston on the Tasmanian side. This extension is made by means of two further carrier telephone systems, one system providing three channels between Melbourne and Apollo Bay and a second providing three channels between Stanley and Launceston, with one channel permanently extended to Hobart. These systems are 3-channel open-wire systems of the type already in extensive use in Australia. Each of the three carrier telephone systems is of the single sideband, suppressed carrier type.

The remaining two telephone channels in the cable will, for the present, remain as spares. A broadcast programme circuit is obtained by means of a separate carrier telephone system. This operates in a frequency range above that of the carrier channels, and is thus operated simultaneously over the same open-wire lines and cable. It has its terminal equipments at Melbourne and Hobart, with repeaters at all intermediate stations. Seven duplex telegraph circuits will be obtained by applying a voice frequency telegraph system to one of the carrier telephone channels. Further channels up to a total of sixteen can be added later if desired. The voice frequency telegraph equipment will be located at Melbourne and Launceston, certain of the telegraph channels being extended to Hobart by means of composite equipment.

The submarine cable section of the system represents an advance in several respects on previous achievements in the art of telecommunication, and is the first submarine cable of this type to be equipped with a repeater station at its mid-point. The repeater equipment compensates for a cable attenuation of about 70 db. in each cable section at 42.5 kc., and amplifies the telephone channels simultaneously by means of one of the first commercial applications of the Black "negative feedback" type of amplifier. The cable is also the first submarine cable of comparable length to be operated with balanced two-wire carrier channels, and an important problem was that of designing and constructing balancing networks which would take full advantage of the uniformity of cable characteristics obtained by extremely careful manufacture of the cable, and thus enable the possibility of balanced channels to be fully exploited.

The system was designed and the equipment manufactured by Standard Telephones and Cables, Limited. The cable was manufactured and laid by Messrs. Siemens Bros. & Co., Ltd.

Ten Years' Experience In The Maintenance of Rotary Automatic Equipment in Spain

By G. N. SAURWEIN,
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BEFORE entering into a discussion of the maintenance of the Rotary Automatic equipment in Spain, a general impression of the telephone situation as it existed in this country when the Compañia Telefónica Nacional de España was granted its concession will be of interest. Only with a realization of what this situation was, can the reader form an idea as to the size of the task which was faced in the training of a maintenance organization.

The first telephone communication in Spain took place in Barcelona on December 16, 1877, one year after the invention of the telephone, but notwithstanding this auspicious beginning, the development of the service was extremely slow. The difficulties were the lack of any definite national policy in coordinating the many independent and municipal enterprises which were attempting to operate a telephone service, and the terms under which the former were licensed to do business—terms which effectively stifled any tendency to build for the future. The Spanish Government, on August 25th, 1924, entered into a contract with the Compañia Telefónica Nacional de España for the construction and operation of a unified national telephone system. The following paragraph taken from the Decree authorizing the execution of the contract gives an idea of the conditions at the time:

"The causes that have brought about the present telephone situation in our country must be looked for in the heterogeneous character of the system as a whole; in the voluminous, varied and even contradictory and antiquated special legislation; in the veritable mosaic of administrative contracts which, inspired by said legislation, regulate the numerous concessions operating to-day; and finally, in the fundamental error, so far as this service is concerned, of conceding the construction to an entity, and, in consideration therefore, granting to it the rights of operation, conditional upon the gratuitous reversion (of the plant) to the State in a period of greater or less length."

One of the outstanding characteristics of the contract was the requirement that within five years from the date on which it took effect automatic service should be established in the seventeen principal cities of the country, and that high grade long distance facilities should be extended throughout the peninsula to all of the provincial capitals and to all county seat towns of more than 8,000 inhabitants. This, in addition to presenting a construction problem of major importance, emphasized the need of developing a maintenance force capable of keeping the new plant operating at maximum efficiency. The formation of an organization for the maintenance of automatic exchange equipment was no easy task, since the experience of the personnel available had been gained in working with a large diversity of antiquated apparatus and markedly different methods of operation. These employees had been accustomed to doing their work according to their own ideas, and any system of definite and unified method of procedure was completely unfamiliar to them.

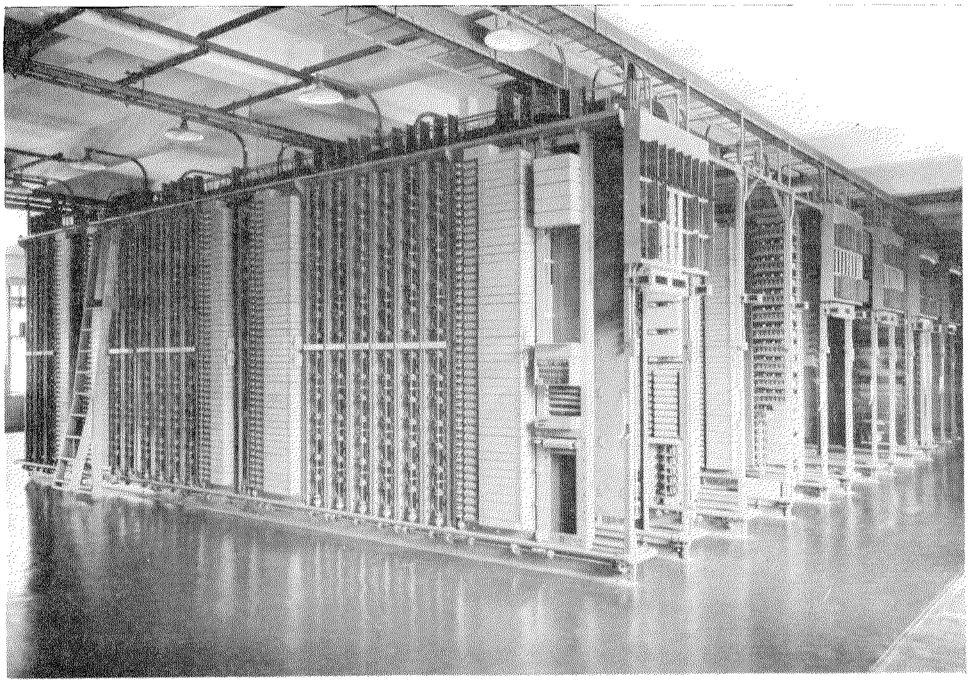
To give a concrete idea of the amount of work accomplished in the early years of the Company, the following figures are shown:

	August 1924	December 1935	Increase
Number of Rotary Automatic Exchanges, Type 7-A	—	26	**26**
Number of Rotary Automatic Exchanges, Type 7-B	—	22	**22**
Number of Telephone Exchanges	627	3,110	**2,483**
Number of Telephones Connected to Automatic Exchanges	—	217,702	**217,702**
Total Number of Telephones	78,525	329,130	**250,605**
Kilometers of Long Distance Circuits	40,000	336,991	**296,991**

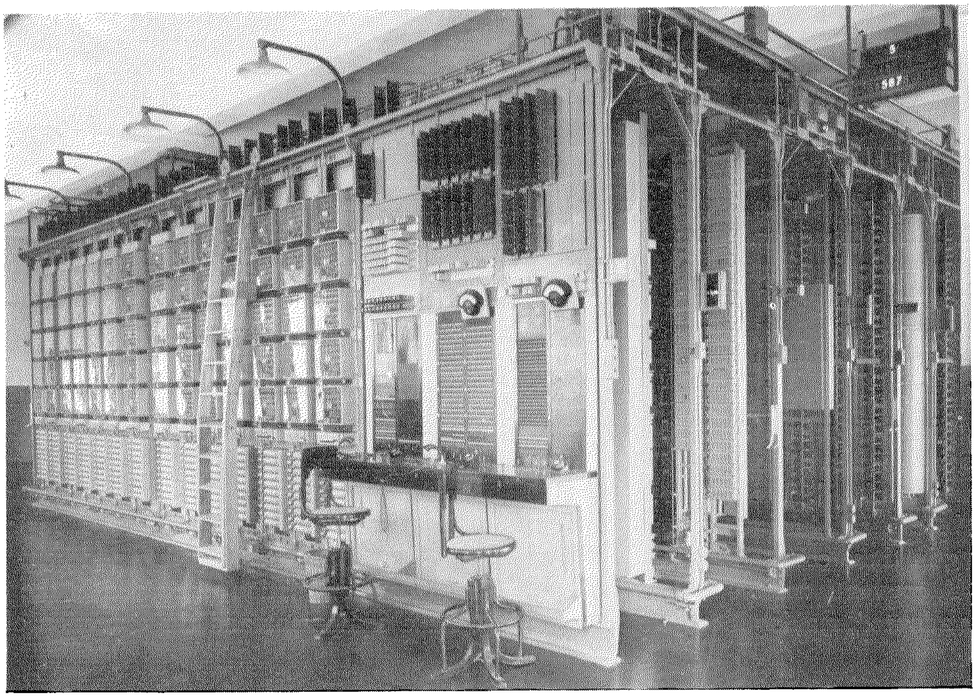
In addition to the development indicated above, there was also involved the installation of repeater stations, of underground distribution systems, of submarine cables, and of radiotelephone stations connecting the network of the peninsula with cities in North Africa, the Balearic and Canary Islands, and South America.

Coincident with the undertaking of this construction program, the company established a school for the training of personnel for all branches of its activities, and an important section of this school was that occupied with instruction in the theory and practice of the 7-A Rotary Automatic Equipment, where men were trained to take charge of maintenance in the automatic exchanges being built in the important cities throughout the country. For the theoretical instruction incomplete schematic circuits were used in which the relays and other pieces of apparatus were indicated but the electrical connections were omitted. The students traced the progress of the establishment of a communication by drawing in these connections in the order of their use. A conventional system of circuit diagrams was adopted, making it easy to see, at any step during the progress of a selection, which relays and magnets were in an operated, and which were in a normal condition. These preliminary studies of the theory of operation of component parts of the equipment were followed by further studies of the Rotary system as a whole, as well as of special features of the system not utilized in the establishment of a normal connection.

To provide for practical instruction a shop was set up where the students were trained to mount and dismount apparatus, to use the tools and measuring instruments necessary for the adjustment of switches, relays, etc., and at the same time to become acquainted with the adjustment constants and limits specified by the manufacturer. Finally, with a model of the 7-A system built specially for demonstration and study, incorporating line finders, registers, link circuits, 2nd and 3rd group and final selectors, practical instruction was given in the operation of the equipment and the detection of troubles



7-A Rotary Automatic Equipment, Madrid—Gran Via Exchange



7-A Rotary Automatic Equipment, Madrid—Gran Vía Exchange

previously introduced by the instructors.

In the instruction of the student mechanics, special care was taken to instill in them the idea that the maintenance of automatic equipment consists in keeping its component parts within the limits of adjustment necessary for their proper functioning. In general, this result may be accomplished in two ways, the corresponding methods being known respectively as preventive maintenance and corrective maintenance.

Preventive maintenance is based upon the use of appropriate systematic or routine tests of the equipment under conditions more severe than those of normal operation, in order that the weak points which show up may be corrected before they have had a chance to cause interruptions in the service. This same procedure also, of course, results in the detection of those actual faults which may not have been located as a result of investigation of service complaints.

Under corrective maintenance the weak points are not detected until they have actually caused service interruptions, after which the necessary repairs are made.

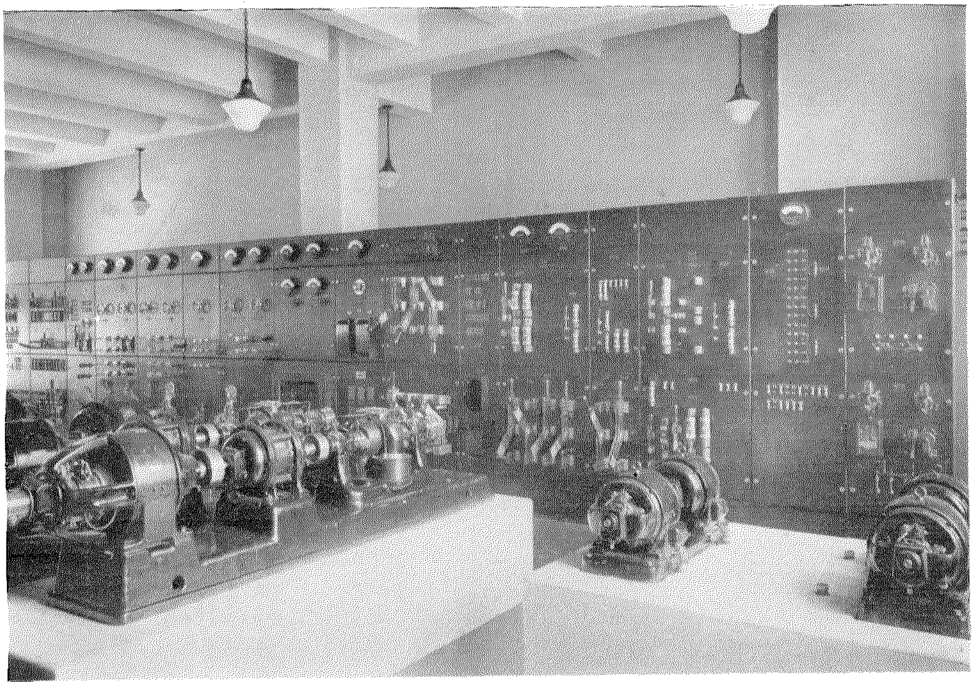
Both systems have been used extensively in telephone operations, and although the adherents to the second system often maintain that for a given class of service the corrective method is more economical, a sufficiently comprehensive study shows that the weak points, or latent imperfections, if allowed to develop, are apt to produce epidemics of troubles and failures which must be immediately attended to, with a resulting unequal load on the personnel. This inefficient use of labor inevitably increases the cost of maintenance, and since the system also involves repairs or replacements which under preventive maintenance might have been corrected by a simple adjustment, the material cost of maintenance increases as well as the labor cost, well illustrating the old adage that "a stitch in time saves nine." While the above comparison is made on the assumption of a given class of service, the highest class of service possible under corrective maintenance cannot approach the quality of service possible with preventive maintenance. The corrective method was the only one used by any of the many telephone companies and administrations in Spain before 1924. The C.T.N.E. adopted from the very beginning the principle of preventive maintenance in all phases of its operations, and especially in the automatic plant, taking full advantage of the routine test circuits with which the 7-A Rotary System is equipped.

The detection of weak points apt to cause failures as well as that of actual troubles, was effected by the joint use of the following five procedures:

(1) Routine tests and systematic inspections;
(2) Concentration tests;
(3) Spot calls;
(4) Investigation of "holdovers";
(5) Service observations.

With the automatic equipment in Spain the routine tests, as has been mentioned, consist in checking the operation of each unit by submitting it to conditions more severe than those of normal service. By this means, the poorly adjusted relays and machines are easily located, as well as poor contacts in the various circuit elements, such as the springs of relays, jacks, and keys, the brushes of selectors, finders, and interruptors, etc., and also any other abnormal circuit conditions which interfere with the satisfactory establishment of a connection. Furthermore, there are certain parts of the equipment which are used infrequently and which therefore would accumulate dirt and dust on their contact surfaces if they were not subjected to the routine tests.

Routine test circuits are installed in all of the different groups of equipment in such a way that each machine in the group may be tested. The test proceeds automatically until a fault is encountered, when the progress of the test stops and an alarm is given. The employee carrying



7-A Rotary Power Equipment, Madrid—Gran Via Exchange out the test, records on an appropriate form the number of the routine and the number of the machine affected and then, after having made the defective machine permanently busy, causes the test to proceed to the next machine. With this procedure it is apparent that routine testing can be carried out with unskilled help, the trained maintenance man being required only for the diagnosis of the trouble and the corresponding repair in the machines reported by the routine test man. The usual arrangement is for the night shift to consist of apprentices for making the routine tests when there is little traffic, while the morning shift contains the trained men able to clear rapidly the faults recorded during the night tests.

The systematic inspections include the adjustment of relays, lubrication and cleaning, and the search for weak connections, loosely mounted apparatus, defective parts, and other mechanical defects which might not be located by routine tests. These inspections, in the larger exchanges, are carried out by mechanics especially trained for this work.

The concentration tests are primarily tests of junctions and are carried out during periods of light traffic. A call is put through over a junction in a certain group, then a second call is placed over the same group without releasing the first call, and this is continued until every junction in the group is occupied and has given indication that it is in a satisfactory condition. Then the calls are released one by one, and care is taken to verify that each release operation is complete.

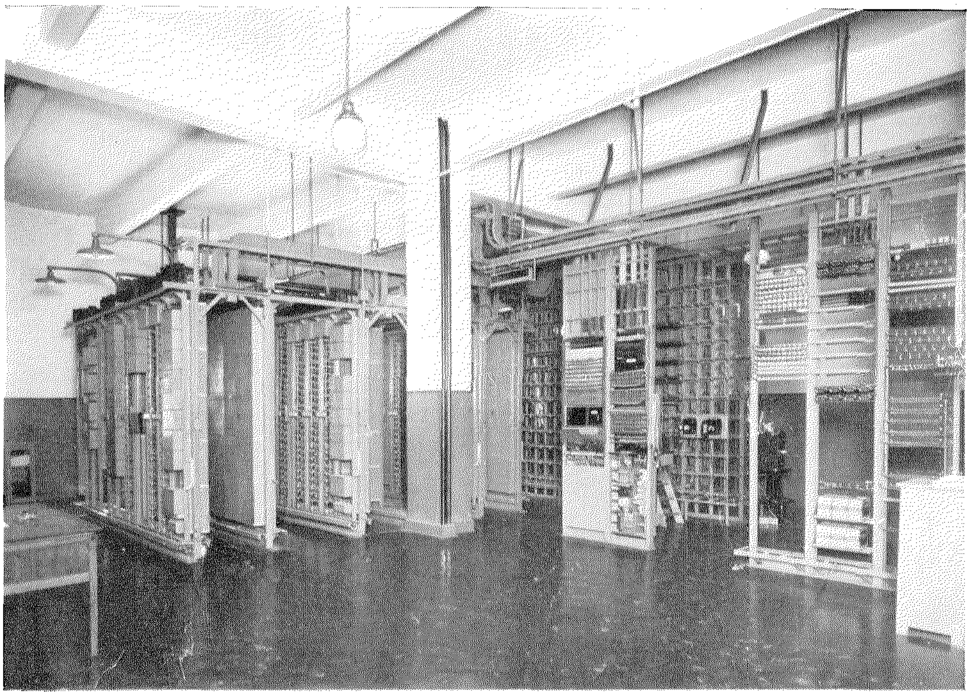
Spot calls are trial communications set up between different subscribers' lines. The test is performed with two telephones, each telephone being plugged into a subscriber's line circuit at the main frame. The number corresponding to one line is dialed from the telephone connected to the other line, and the employee conducting the trials notes whether or not the connection is properly established, and makes his corresponding record of the number of successful calls and the number of failures.

The 7-A automatic equipments installed in Spain have their registers equipped with a so-called "holdover" circuit, which indicates by a lamp signal the fact that a call has failed through some trouble in the process of selection and, while releasing the calling subscriber, holds the engaged machines until the maintenance man can locate and correct the condition which blocked the call. This feature is valuable in locating faults which develop between routine tests. Faults discovered in this way are definitely located and repaired after having involved the loss of only one call, and that with a minimum of delay to the subscriber.

Service observations are made by connecting a listening circuit and also an impulse recorder, to subscribers' line circuits or to first line finders. The observer is advised by a lamp signal when a call appears on any one of the circuits connected to the observation desk, and, after throwing a key to connect the listening circuit and impulse recorder to the corresponding circuit, makes a record of the time required for the reception of dial tone, the number dialed, the time required for the reception of the busy or ringing tone, the time taken by the called subscriber in answering, and the length of the conversation. If the selection is not completed, if the line is busy, or if the called subscriber does not answer, the observer gives a mechanic the called number, the circuit or junction number under observation, and the reason for the non-completion of the call, and proceeds to observe another call. The circuits connected to the test desk for observation are, of course, changed periodically. Service observation, besides bringing to light any faults which prevent an observed call from being completed, is the best method of obtaining a picture of the quality of service being rendered.

With these foundations, namely, a trained personnel and the five test procedures which make up a system of preventive maintenance, the Company took over the care and maintenance of its newly installed automatic exchanges, and made plans to carry out the following program:

(a) A daily routine test of each and every apparatus unit in all of its cycles of operation (two for first line finders, second and third group selectors and finals, four for connecting circuits, and eleven for registers);
(b) Continuous attention to all register holdovers;
(c) Checking of interoffice junctions every two hours;
(d) 100 spot calls daily in each exchange;



7-B Rotary Automatic Equipment—Palma de Mallorca

(e) Daily service observation of 200 calls;

(f) Systematic inspection organized to insure the cleaning of each unit every two months, and the checking of adjustment of each unit against the manufacturer's specifications every three months or every six months depending upon the apparatus.

All faults encountered were recorded on specially prepared forms which were later analyzed, and a study of these analyses over a certain period of time led to the conclusion that it was neither necessary nor advisable to carry out the routine tests daily for each machine in each of its phases of operation. Likewise an analysis of the results of the systematic inspections showed that it was not necessary to carry out the checking of the apparatus with the frequency previously established, and that the cleaning of the machines need not be effected as often as specified. In view of these conclusions, corroborated by service observations and an analysis of that part of complaints due to equipment failures, the maintenance program of the automatic exchanges was revised to allow a greater length of time between successive cleanings, routine tests, and systematic inspections.

The analyses of the troubles found in routine tests and register holdovers brought out the necessity for two important measures, viz.,

(a) To keep after the mechanics in an effort to combat their tendency to attribute the majority of faults to a few favored causes.

(b) To catalog those particular types of trouble which occurred with too great frequency in order to make a special study of them and get at the root of the trouble.

In connection with the first of these, it is interesting to note that from a certain exchange in Barcelona, where a suspiciously large proportion of the faults was attributed to certain specific elements of apparatus, the entire staff of mechanics was transferred to another exchange and the reports from this exchange began to show a preponderance of faults of the type which previously appeared in the reports from the first exchange. In order to cure the mechanics of a propensity to assign faults erroneously, a few machines of each type in some of the Madrid exchanges were very carefully adjusted, equipped with traffic meters, and then sealed. The maintenance personnel was instructed upon encountering a fault in one of these sealed machines to notify the maintenance supervisor without making any attempt to correct the fault. The results of this experiment appear in the following table:

Troubles Occurring in the Sealed Apparatus in The Delicias Exchange During the Thirteen Months from November, 1928 to December, 1929

Circuit	Number of Machines Sealed	Communications Handled	Number of Faults
Register	2	660,971	13
First Selectors	2	126,473	1
2nd Selectors (local)	2	262,929	1
2nd Selectors (incoming)	2	111,679	1
3rd Selectors	2	159,583	2
Final Selectors	2	61,167	1

These tests produced three excellent effects:

(a) They emphasized the value of preventive maintenance by showing the excellent results that can be obtained by carefully and skilfully made adjustments.

(b) They demonstrated to the mechanics the high quality and efficiency of the equipment.

(c) They consequently dispelled in the mechanics a tendency toward laxity and indifference, a phenomenon which might be called "maintenance sickness"; in other words, a slow and steady decay of morale caused by repeated faults which, because they are not conscientiously and permanently corrected, gradually come to be considered as inevitable and inherent in the system.

Continuing along these lines, and in view of the results obtained, there was prepared in 1930, with the aid of engineers from the International Telephone and Telegraph Corporation, a tentative frequency schedule for routine tests with longer intervals between successive tests on the same equipment. This schedule, with a careful distribution of the work through the month, was used for a trial period of six months in six representative exchanges, two chosen from areas containing four central offices, two from those containing two offices, and two from single office cities. In making these choices as representative as possible, the condition of the equipment, the capacity of the exchange and the geographical location were kept in mind. The importance of the latter is due to the fact that in Spain there is much more dust in the southern towns than in those of the north, and the humidity is greater in the northern towns than in those of the south. The exchanges chosen and the capacities at that time were: the Gran Vía office in Madrid (10,000 lines) and Arenas in Barcelona (6,000 lines), both four-office areas; Valencia (5,000 lines) and Bilbao (7,000 lines) from two-office areas; and Córdoba (2,000 lines) and Vigo (2,000 lines) from single-office areas.

Included in the instructions to the maintenance staff was an order to record, along with the results of each test, the number of machines tested and the total time required for the test. Also with each fault recorded was to be noted the time required in locating the trouble and the time used in correcting it. Every month the reports from the above mentioned six exchanges were examined and analyzed, and compared with reports from similar exchanges operating under the old frequency schedules.

During the first month spot calls and service observations showed that in the six exchanges where the new schedules were in effect, the quality of the service had not decreased but had continued at the same level as in the previous months, and an analysis of the faults encountered in routine tests did not show any increase, nor was any increase noted in the number of register holdovers. Thus it was immediately demonstrated that the frequency of the tests could be diminished without increasing the number of latent troubles. In the following months, as the analyses were continued, they brought out and consistently confirmed the important fact that the total number of faults in a given period of time was actually less when the frequencies of routine tests and systematic inspections were decreased. Part of this phenomenon may be explained by the fact that the repairs were perhaps being made with more care and precision in the six exchanges under experiment, but the important conclusion was that, in making adjustments, checking conditions, and carrying out tests, the mechanics were actually producing faults or maladjustments in the same or other parts of the equipment, and that, therefore, the less often the equipment was touched, within the limits of maintaining satisfactory service, the fewer the faults encountered. After the analyses of the results in these six exchanges had continued for six months, consistently confirming in each of them the above conclusion, the decision was made to economize on labor and material costs by radically reducing the frequency of tests and inspections.

In order to arrive at the extent to which this reduction could be carried, standards or bogeys were established fixing:

(a) The trouble expectancy for each type of circuit or machine per routine test;

(b) The number of register holdovers per day permissible in each class of exchange.

In keeping with these standards, new frequency schedules for the routine tests and systematic inspections were worked out for each class of central office, and after these were introduced the effect on the service was checked by means of service observations and spot calls. The application of the new frequencies to the six exchanges mentioned above resulted in the following reductions in time spent on routine tests:

Exchange	Hours per Month Spent on Routine Tests, Before and After the Change in Schedules									
	Daily Routine		Weekly Routine		Semi-monthly Routine		Monthly Routine		Total for Month	
	Before	After	Before	After	Before	After	Before	After	Before	After
Madrid, Gran Vía	740	15	—	80	—	5	—	25	740	125
Barcelona, Arenas	438	7	—	26	—	2	—	15	438	50
Valencia	350	6	—	16	—	2	—	13	350	37
Bilbao	531	9	—	32	—	3	—	19	531	63
Córdoba	81	2	—	6	—	0.6	—	3	81	11.6
Vigo	96	3	—	7	—	0.7	—	3	96	13.7

During the six month period of trial for the new schedules, inspectors from Madrid visited the exchanges and studied the time necessary for carrying out each phase or cycle of each test, and the time required in locating troubles and in correcting them. The time figures reported for these operations in the six offices were averaged and the resulting figures were used as unit or standard values, some of which are indicated below:

Machines	Simple Test		Complete Test	
	Number of Operations	Unit Time	Number of Operations	Unit Time
First Line Finders	63,744	6″	31,872	12″
Connecting Circuits	200,376	7″	50,049	28″
Registers	99,900	12″	13,320	100″
Local 2nd Selectors	32,640	4″	8,160	10″
Incoming 2nd Selectors	32,520	10″	8,130	23″
Third Selectors	79,920	4″	19,980	10″
Final Selectors	105,600	10″	26,400	23″

In collaboration with engineers from the International Telephone and Telegraph Corporation, these unit time values, together with proper allowances for miscellaneous maintenance duties, sick leave, vacation leave, etc., were applied to the new frequency schedules in order to calculate the personnel required to carry out the new maintenance procedure. The result in reduction of personnel in the six offices under special observation is indicated below:

Exchange	Old Organization	New Organization	Reduction
	Number of Employees	Number of Employees	
Madrid, Gran Vía	23	11	12
Barcelona, Arenas	13	7	6
Valencia	15	8	7
Bilbao	17	9	8
Córdoba	3	2	1
Vigo	3	2	1

The new organization was then extended to all the remaining 7-A Rotary Automatic exchanges in Spain with a corresponding economy in personnel and a notable improvement in the quality and uniformity of the service in all offices.

With this practical demonstration of the efficiency of the new maintenance plan, the engineers of the International Telephone and telegraph Corporation proceeded to incorporate it into a system instruction published as "Rotary Automatic Central Office Maintenance Practices."

As a measure of the efficiency of the work of the central office equipment maintenance personnel and to provide a just basis of comparison of efficiency between the various central offices, there was adopted by the International System a method of evaluating in 10-hour work units the normal time required to maintain any given central office. A figure or coefficient was established for each type of equipment representing the time required (expressed as a fraction of 10 hours) to maintain one unit of that equipment over a period of three months. Thus the total time, expressed in 10-hour units, required to maintain any given central office for three months is the sum of the products obtained by multiplying the equivalent time values or coefficients for each type of equipment by the respective number of machines or elements of that type in the office. The number of employee hours actually expended in the maintenance of a central office for three months, divided by the normal time required, as measured in 10-hour work units, gives an index of efficiency which is expressed as the number of employee hours expended in accomplishing maintenance work which should normally require 10 hours. As this system of measuring maintenance effort takes into consideration the actual equipment installed in each central office, it is evident that, as a basis of comparison, it is much more accurate and satisfactory than those based on "men per thousand lines" or "man-hours per line per year," as neither of these latter plans takes into consideration or makes allowance for the "traffic size" of an office, or whether it includes automatic toll switching apparatus, interoffice trunk circuits, message registers, or other miscellaneous equipment.

The efficiency of the central office maintenance forces in typical offices and for the C.T.N.E. as a whole for the first quarter of 1936 is given below, both as measured by the 10-hour work unit plan and by the number of employees per thousand lines.

Exchange	Average Time Employed in Carrying out the 10-hour Work Unit	Number of Employees per 1,000 Lines
Madrid, Gran Vía	6.97	0.91
Barcelona, Arenas	7.55	0.93
Valencia	8.29	0.88
Bilbao	7.80	1.03
Córdoba	7.54	0.61
Vigo	9.38	0.90
Spain (all 7-A offices)	8.22	0.93
Spain (all 7-B offices)	8.08	0.67
Spain (all Rotary Automatic offices)	8.20	0.90

Early in 1930, coincident with the adoption of the revised maintenance procedure in the 7-A Rotary equipment, the C.T.N.E. adopted, for small single office areas, the 7-B Rotary equipment. In fixing the maintenance practices for these offices, the same procedure as used in the 7-A offices was followed; and, due to the small size and low calling rate of these exchanges, together with the more simple circuit and apparatus units involved, it immediately became apparent that attendance of trained equipment personnel would not be required during the entire 24 hours of the day. Experience in these offices over a 6 year period and with a present total of twenty-two such offices, averaging 1,500 lines capacity each, has shown that one trained maintenance man cannot only take care of the central office equipment, including toll boards, power plant, etc., but also can maintain all associated private branch exchange installations in the exchange area. During the hours when the maintenance man is absent from the central office, all alarm signals are transferred to the toll board, and the toll operating personnel is instructed to call the maintenance man in case of an equipment alarm. In practice it has been found that the maintenance man is called to the office to attend to these alarms on the average of three times per year per office.

The end of 1935 marked for the C.T.N.E. the completion of ten years' experience in the maintenance of Rotary Automatic central office equipment. As has been shown, this experience was divided into three periods: first, the theoretical and practical training of inexperienced personnel for the maintenance of a rapidly increasing number of Rotary Automatic offices; second, the careful and systematic development of exact data on results both as to service and costs, and the development from this data of exact and adequate procedures; and third, the carefully supervised application of these procedures in a constantly increasing number of central offices, which reached a total of forty-eight at the end of 1935. The results have been satisfactory not only to the Company as regards cost, but also to the telephone using public as regards service, as indicated by the fact that less than 0.5% of all calls placed in these exchanges are unsuccessful due to failure in the equipment.

"Micro-Ray Communication," by Messrs. W. L. McPherson and E. H. Ullrich, the paper published in abstract form in the April, 1936 issue of *Electrical Communication*, has been awarded the Institution Premium—the highest award a paper can receive from The Institution of Electrical Engineers. This paper was read before the Institution on January 30, 1936 and has been published in full in the June, 1936 issue of The Journal of the Institution of Electrical Engineers.

The 7-A.2 Private Automatic Branch Exchange in a Government Building at The Hague

By IR. A. J. EHNLE, E.I., and IR. M. J. M. VAN GASTEL, E.I.
Municipal Telephone Administration, The Hague, Holland

General

THE building, situated 30, Bezuidenhout, The Hague, to-day lodges three ministerial departments: the Ministry of Agriculture and Fishery, the Ministry of Commerce, Industries and Navigation, and the Ministry of Social Affairs. It is important that a community of such a size should have a reliable telephone installation capable of carrying a heavy load and giving to its extensions as many facilities as are consistent with simple attendant's service and easy maintenance. This is the reason why, for handling incoming and toll calls, choice was made of the "old fashioned" plug and jack type of switchboard with a multiple field containing jacks which are individually connected to all subscribers by fixed wires.

The automatic P.B.X. was developed by the Bell Telephone Manufacturing Company, Antwerp, at the request of The Hague Municipality, on the basis of the 7-B junction diagram but equipped with 7-A.2 group selectors and final selectors (300 points) and 200 point finders. This system was chosen because it combines the advantages of simple, straight-on connections which are in the highest degree independent of bypaths, and of normal gear driven apparatus, well known by the maintenance people.

Call-back facility by means of a push button, earthing one of the two wires of the telephone set, is introduced. Automatic transfer by means of this push button is not accepted, but transfer of incoming and outgoing city connections is possible, in an easy way, with the help of the attendant, as described later.

The P.A.B.X. has an attendants' board consisting of two positions. The new automatic installation replaces four separate manual boards with a total of six attendants' positions. These latter boards were so loaded with city calls that satisfactory local service was practically impossible. As a consequence the automatisation caused a very considerable increase of local traffic.

The installation of the P.A.B.X. was carried out by the installation department of The Hague Municipal Telephone Administration. The cutover took place on March 14, 1936 and the service, since rendered by the P.A.B.X., has been very satisfactory.

Facilities and Method of Operation

Local calls are obtained by dialing a 3-digit number (a 4-digit number in the future, see level numbering scheme) after receipt of the local dialing tone (quickly interrupted tone). The standard busy and ringing tones are given. The connection, when completed, is under the control of the calling party but, if desired, delayed back-release can be introduced.

Calls to the attendants' board are made by dialing the single digit "1" or "9," which gives access to two separate groups of attendants' lines. The instructions for the attendants are such that calls, for which "9" has been dialed, have preference in being answered. Only a restricted number of subscribers is authorized to dial "9," whereas digit "1" is intended for general use.

False calls and wrong number calls are directed to the attendants' board. For signaling false calls, a delay of approximately 25 seconds is introduced.

The city service is arranged on the basis of "automatic out" and "attended in."

An outgoing city call is originated by dialing "0" after receipt of local dialing tone. When the city dialing tone is received, the number of the wanted city subscriber is dialed. Should all the outgoing city lines be busy at the moment "0" is dialed, continuous hunting takes place until a line becomes free or the local party gives up the call. Any local station may be debarred from originating outgoing city connections. If on such a station "0" is dialed, the local dialing tone is immediately reconnected to the line, indicating that no city connections can be made.

Incoming city and toll calls are signaled on the attendants' board and are extended to the wanted local party by means of a cord plugged into the local subscriber's multiple jack. Means are provided for offering a city call on an existing connection and breaking down this connection if it is a local one. City connections cannot be broken down.

On all city and toll connections call-back facilities are provided. For calling back, the P.A.B.X. subscriber depresses the push button on his set and, on receipt of the local dialing tone, dials the number of the wanted local party, after which the connection is established in the usual manner. Meanwhile the city line is held busy. In order to return to the city connection, the P.A.B.X. subscriber again depresses the push button.

The attendant may be called in on any city or toll connection by calling back in the usual way and dialing "1" or "9." According to the requirements, the local party may, after having been answered by the attendant, return to the city connection by depressing the push button, or have the connection transferred by the attendant.

Outgoing calls can be prepared by the attendant and extended to the local subscribers in the same way as is done for incoming calls.

Night service is obtained by switching in-

Government Building, 30, Bezuidenhout, The Hague coming city lines directly to selected extension lines.

Junction Diagram

The junction diagram is shown in Fig. 1. The amount of apparatus shown on the diagram refers to the present (initial) capacity. By suitable changes, the diagram may be maintained during all stages including the final stage for a capacity of 1,200 local subscribers.

The calculation of the number of switches is based on the following assumptions:

Calling rate in busy hour	1.5
Subdivision of calls:	
Local calls	65%
Outgoing city calls	30%
Calls to attendants' board	5%
Average holding time:	
Local calls and calls to attendants' board	100 seconds
Outgoing city calls	150 seconds

Traffic handled via the attendants' board is twice the automatic outgoing traffic.

10% of the total time for city connections is used for calling back.

On the line finder side, the subscriber lines (call-back lines included) are divided in groups of maximum 200 in accordance with the use of 200 point line finders. On the final selector side, the subscriber lines are divided into groups of maximum 300 in accordance with the capacity and the numbering scheme of the final selector.

The subscriber lines are multipled to the attendants' board and equipped with multiple jacks.

One common group of registers is provided.

In the present stage, two (incomplete) line finder groups and one final selector group are used.

Local calls are handled via a group selector level and a final selector.

Two other group selector levels are used for calls to the attendants' board (single digits "1" and "9"), and one level is used for false calls and wrong number calls. These lines are jack-ended and are provided with calling lamps.

Provision has been made for using one group selector level for tie line service to other P.A.B.X.'s in case it should be required in the future.

The city traffic is handled via two separate

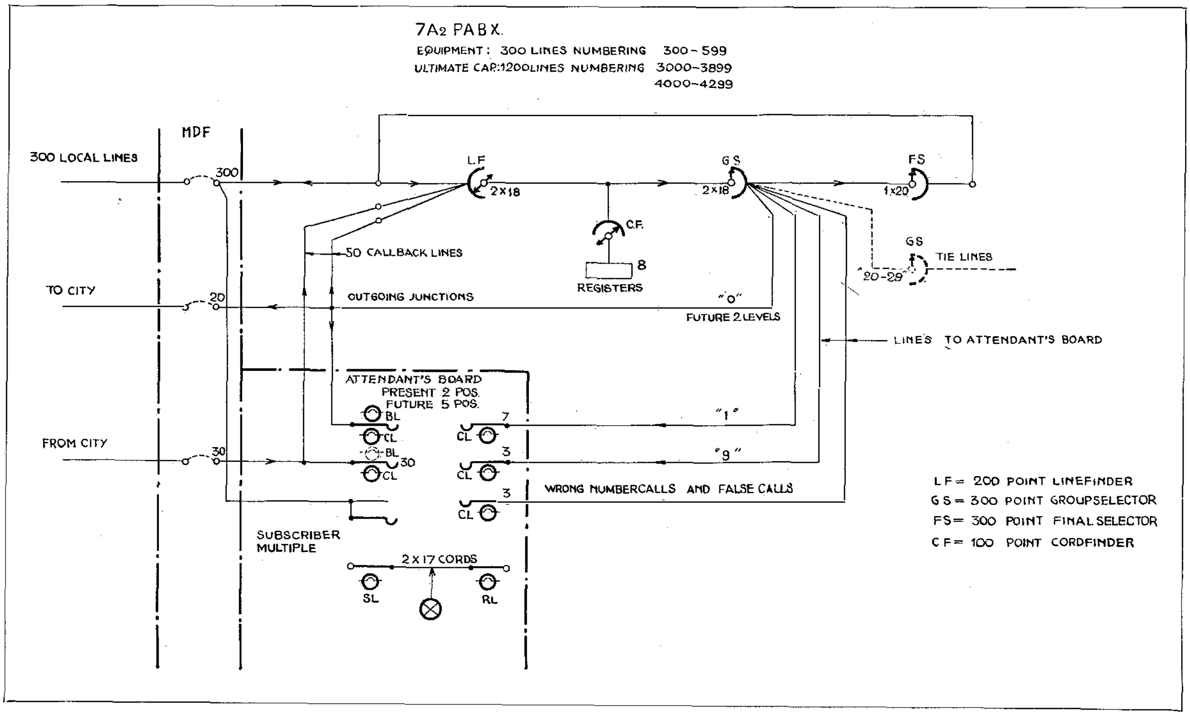


Fig. 1—Junction Diagram for 7-A.2 P.A.B.X.

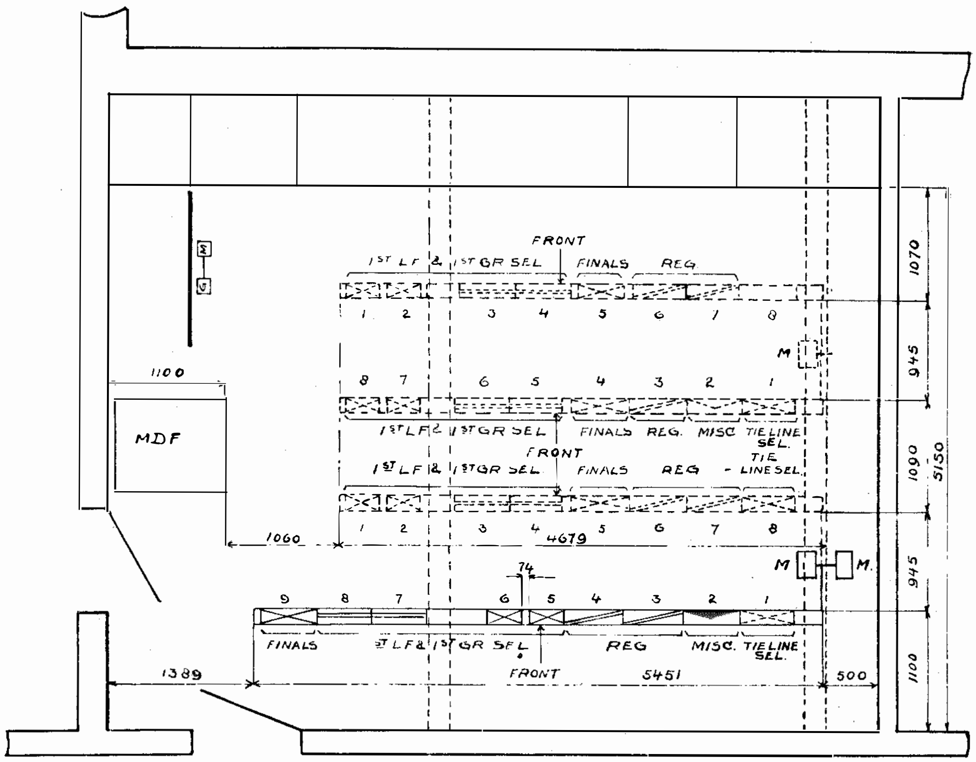


Fig. 2—Floor Plan of Switching Room

groups of lines, one group for outgoing, and the second group for incoming calls.

Outgoing lines are reached automatically (dialing "0") via a level of the group selector or manually via jacks on the attendants' board. Provision is made for double level hunting, a feature which will be used when the number of outgoing lines exceeds the capacity of one group selector level.

Incoming lines terminate on the attendants' board and are each equipped with a jack, a calling and a busy lamp.

For extending city calls and for answering purposes, use is made of one standard type of attendants' cord provided with a three position key (normal, answering, and ringing) and two supervisory lamps.

For both kinds of city lines, Fig. 2 shows the call-back lines to the line finder arcs over which call-back connections are set up. A call-back to a P.A.B.X. party is completed in the same way as a regular call. On a call-back to the attendant, the call-back line transmits an indication from the register back to the city line, with the result that a signal is given to the attendant to enter the connection.

In the case of a call-back signal on an incoming city connection, the operator enters the connection by depressing the key associated with the corresponding cord.

In the case of an automatic outgoing city connection, the call-back signal is given by means of the calling lamp of the outgoing line, and the operator enters the connection by plugging a cord in the corresponding jack. By means of the cord, the connection may be transferred from the originating to a second party.

Numbering Scheme

As previously mentioned, six group selector levels are intended for special purposes and four levels may be used for connecting 300-point

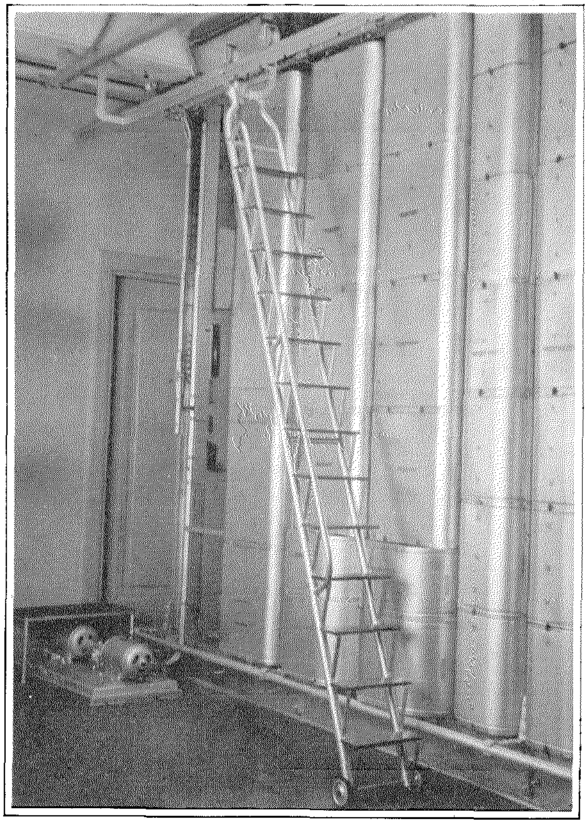


Fig. 3—Part of the Switchrack, Cabling Side

final selectors, giving an ultimate capacity of 1,200 local lines.

For special services single digits 0, 1, and 9 are used (outgoing city connections, normal and preference calls to the attendant, respectively); for tie line calls two digit numbers 20–29 have been reserved.

The local line numbering is as follows:

300 line capacity: 300–599
600 line capacity: 300–899

Beyond this capacity 4-digit numbers will be used:

900 line capacity: 3000–3899
1,200 line capacity: 3000–3899, 4000–4299.

The numbering in the final selector arc is similar to the usual arc numbering except that three instead of two 100-line groups are used.

Automatic Equipment

The automatic equipment for the present 300 line capacity is mounted on seven bays in a single row. The standard switch rack height of 4 meters is used. The length of the rack is 5.45 meters, providing sufficient free space for mounting additional equipment for tie lines, for extension of outgoing city lines, etc.

Two line finder bays are used, each bay comprising the complete equipment for 150 subscriber lines and 25 call-back lines (individual line and cut-off relays, capacity 200 lines) and 18 link circuits (capacity 20), each consisting of a 200 point line finder and two relays, completely wired, but without group selectors.

The two groups of 18 group selectors are mounted on two separate bays.

One final selector bay is used, fully equipped with 20 300-point final selectors, sequence switches, and relay sets.

The registers and cord finders are mounted on two bays, one fully equipped with 5 registers, the second equipped with 3 registers. The cord finders are 100-point 12-brush finders.

Each register comprises a set of relays, a sequence switch, and three step-by-step switches for number registering.

One miscellaneous bay is used, accommodating 20 outgoing city line circuits, the attendant's line circuits, the false call and wrong number circuits, the starting circuits for the switch rack motor, and two sets of slow-speed interruptors with changeover keys and additional apparatus. Space is available for small extensions of the above mentioned circuits.

All outside connections terminate on terminal blocks mounted on the top of the bays and all cabling between the various bays, the main frame, and the attendants' board is soldered to these blocks. For installation purposes, no soldering is required on arcs of machines, a feature which is of particular interest where it is expected that gradually extensions will have to be made.

On the rear side, the bays are provided with the normal 7-A.2 Rotary Automatic System shielding.

The switch rack is driven by a 1/8 hp. duplex motor. Two such motors have been installed, coupled in such a way that only one motor is running. In case of a failure in the a-c. mains supply the driving motor is automatically changed over to d-c. supply.

Four wires per subscriber line are run between the automatic equipment and the main frame, where they terminate on blocks on the horizontal side. On this side each subscriber line is, therefore, represented by four terminals. Three are multipled to the a, b, and c wires, leading to the attendants' board. The fourth terminal corresponds to the "e" terminal of the line finder arc and is grounded for subscribers who are not entitled to originate outgoing city calls.

The floor plan for the present and the future equipment is shown in Fig. 2. The future equipment is shown in dotted lines.

Fig. 3 shows a part of the switch rack (rear side) with the bays for the group selectors, the registers, and cord finders, the miscellaneous bay and the duplex motors.

Fig. 4 gives an idea of the front side of the 100-point cord finders, mounted in the lower part of the register bays.

Attendants' Board

The equipment for the attendants' board consists of the two desk-type attendants' positions (Fig. 5) and two relay racks.

On the upright panel of the desk are located the lamps and jacks for the incoming and outgoing city lines and attendants' lines, the subscribers' multiple jacks, and the general control lamp. Multipling is done in such a way that the complete number of city lines and local lines appears on each pair of adjacent positions.

The left position is further equipped with the night switching keys and lamps. By means of a night switching key, a city line is connected to the local line of a night subscriber, thereby disconnecting this local line from the automatic equipment. The lamp associated with the key lights when the night subscriber's line is in use.

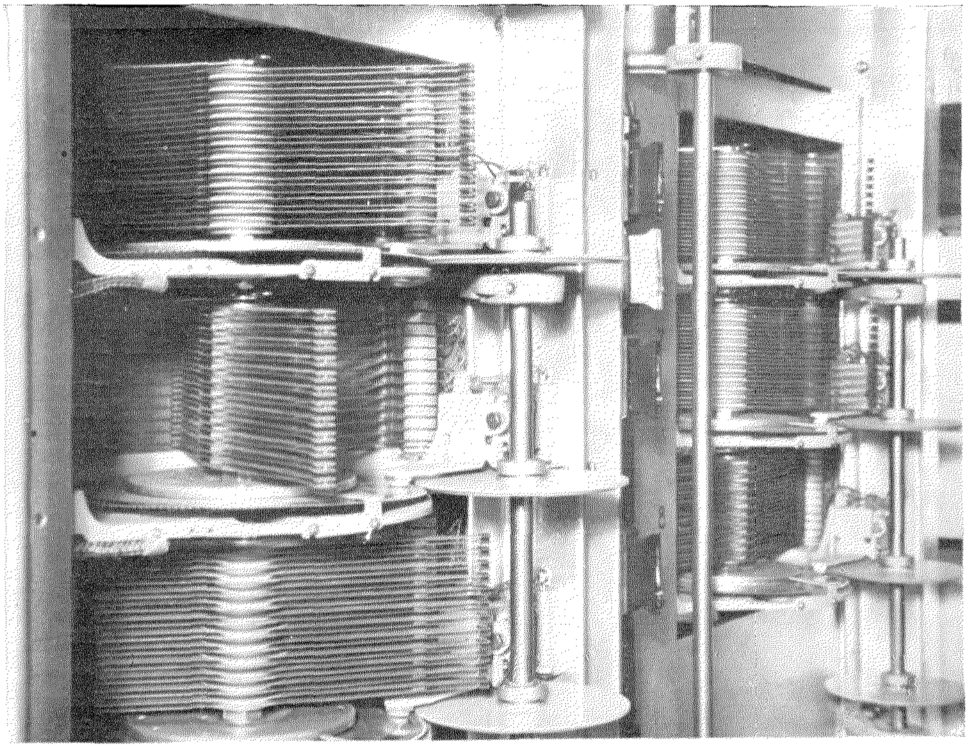


Fig. 4—100-Point Cord Finders

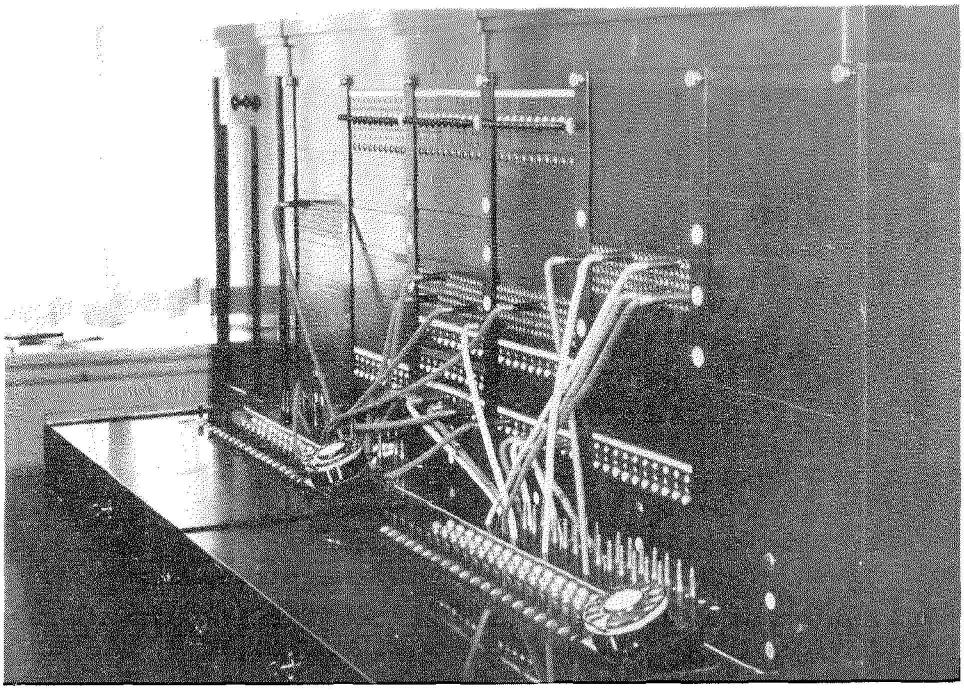


Fig. 5—Two-Position Attendants' Board

The horizontal shelf of the desk comprises keys and lamps for 17 cords. Each cord is provided with two plugs, a combined answering and ringing key, and one green and one white supervisory lamp. The green lamp lights from the time a plug is inserted into a local jack until the called subscriber answers; the white lamp lights at the end of the conversation and flickers when the operator enters into the connection. The answering keys (and the ringing keys) have only one make-contact. Contact faults on the keys are thus reduced to a minimum.

The desk shelf comprises further the position splitting key, the listening key with a listening cord, the buzzer cut-off key and a dial for originating outgoing city connections. The listening cord is provided with a special type of plug, which enables the attendant to offer a call to an existing connection without breaking down the latter.

All other apparatus used in connection with the attendants' board, such as relays, resistances, and condensers, are mounted on the relay racks.

Traffic Observation

In the registers, provision is made for centralized traffic metering, by means of which the number of automatic outgoing calls, calls to the attendants' board, and tie line calls (subdivided in accordance with the tie line numbering), which have been controlled by the registers, are metered separately.

The total number of calls is also registered. Separate registering of local calls can be obtained from the final selectors. Moreover, the usual facilities are provided for the connection of recording ammeters and overflow signaling devices.

Traffic observation has shown that the local traffic increased considerably following the installation of the P.A.B.X. This indicates not only that there was a demand for telephone communication which could not be satisfied with the old equipment, but also that the quick and reliable service, rendered at any time and to any extent by the automatic installation, improves methods of working and results in a saving of time.

In order to give an idea of the traffic handled by the new installation, some traffic data may be of interest. The following data refer to an observation period of one week (39 service hours); but, in addition, the average hour traffic and the busy-hour traffic are given. The busy-hour traffic is based on the experience that one-fifth of the local day traffic is handled in the busy hour.

	Traffic Originated by P.A.B.X. Subscribers		Traffic Handled by Operators	
	Local Calls and Calls to Attendant (call-back included)	Outgoing City Calls	Prepared City Connections and Calls to Toll Recording	Incoming City and Toll Connections
Total of a week	11,500	4,600	1,250	5,070
Average hour	295	118	32	130
Busy hour	414	165	45	182

Call-back connections, which are classed as local connections in the above table, are estimated as occurring on 10% of the total number of city and toll connections, *i.e.*, in the busy hour, 35 call-back connections are made.

Eliminating these connections, the total number of busy-hour calls originated by subscribers is 544, resulting in 1.8 busy-hour calls per subscriber.

Power Plant

The power plant is composed of a 180 ampere hour storage battery, a 2.6 kW three-phase motor generator and the necessary controlling and regulating equipment mounted on a panel which is shown in Fig. 6.

The power plant is operated on the "floating" scheme. By means of the charging machine with regulating device, the battery voltage is maintained at a fixed value, sufficiently above the normal voltage to prevent discharge.

During service hours the charging machine operates continuously and the total load of the installation is carried by the machine except for short current peaks, which are taken care of by the battery. The machine is stopped during the night and, if energy is still required, it is supplied by the battery. This energy loss and also the losses due to the above mentioned current peaks, are gradually replaced during day service.

For voltage regulation use is made of a Brown Boveri automatic quick-acting regulating device, which also includes the necessary automatic apparatus for establishing the connection between the generator and the battery at the proper voltage and for disconnecting the machine in case of reversed current. The device is mounted in a box visible at the centre of the panel.

In addition to the automatic regulating device, the panel comprises some switches and a rheostat by means of which the automatic device can be switched off and replaced by manual charging control.

Dialing tone, busy tone, and ringing current are taken from a small ringing and tone machine. In case of a failure, the tone circuit is automatically changed over to a special buzzer arrangement, whereas ringing current is supplied from the central exchange by means of a cable pair.

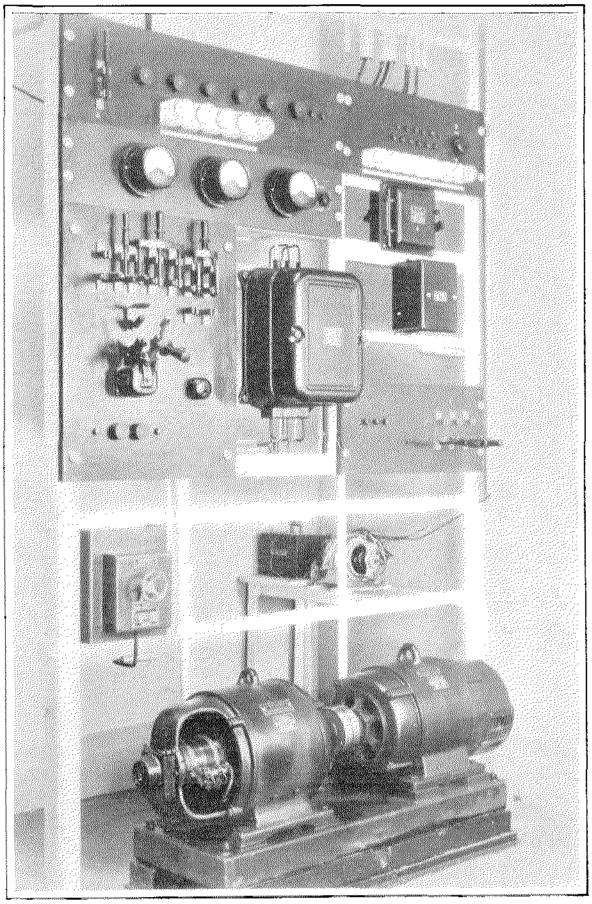


Fig. 6—Powerboard

Permalloys and Related Ferromagnetic Alloys—A Review

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IN recent years, the demands of communication and electrical engineers for ferromagnetic materials have brought into existence a branch of metallurgy concerned with the production of metals and alloys with rigidly controlled magnetic characteristics. The mechanical properties, in these cases, are of relatively minor importance.

Two classes of these ferromagnetic materials may be distinguished. On the one hand there are the permanent magnet alloys, a group of magnetically hard substances, the range of which has lately been extended considerably by the development of the aluminium-nickel-iron alloys. It is not proposed to deal with them in the present paper. Attention will be confined to the second group, consisting of the easily magnetised, magnetically soft materials including the permalloys, perminvars, and related alloys. These are employed whenever it is desired to provide an easy path for the magnetic flux, as in magnetic shields of all kinds, or to increase the inductance of a feebly energised coil or transformer by the use of a ferromagnetic, highly permeable core in which a high magnetic flux density is readily built up. The use of nickel alloys for this purpose dates from G. W. Elmen's discovery of the nickel-iron alloy called permalloy, the first patent for which was filed in the United States of America in 1916. This event had a profound influence on the study of ferromagnetism, and led the way to the development and intensive study of a numerous series of related alloys. This work has been carried out in America in the Bell Telephone, the General Electric, and the Westinghouse Laboratories; in Germany in the laboratories of the Siemens and Halske and Allgemeine Elektricitaets-Gesellschaft; as well as elsewhere.

The essential characteristics of this group of alloys are the very high values of magnetic permeability at low values of magnetising fields (H) and the almost negligible magnetic hysteresis which they exhibit when they are properly heat treated. To illustrate these features, typical magnetisation and hysteresis curves for silicon steel and a modern nickel-iron alloy, permalloy *C*, are given in Figs. 1 and 2, and the derived permeability curves for the same materials, in Fig. 3. The remarkable degree to which the permalloy is magnetised at the low values of H is clearly shown, as well as the manner in which it responds with very little hysteresis lag to small changes in magnetising field. The two properties are largely interconnected, and it is generally safe to assume (though there are some well recognised exceptions) that the higher the permeability at low fields, the lower is the hysteresis loss.

It may be advisable, incidentally, to make it clear at this stage that these materials do not retain their magnetic superiority when placed in strong magnetic fields. Under these conditions, when magnetic saturation is approached, they will not carry so high a density of magnetic flux as pure iron. They make less powerful electromagnets and find no application in the manufacture of armatures and pole-pieces of heavy current electric motors, generators, and similar equipment.

The distinction between the behaviour of magnetic materials at high and low flux densities is important. At low flux densities, where high values of permeability are a measure of the readiness of the material to respond to feeble magnetic impulses, the behaviour of all materials is very considerably modified by mechanical stressing, by the presence of small amounts of impurities, and by previous heat treatment. These external factors, however, only affect the early speed of response of the material, and have little or no effect at all on the final value of flux which it can carry at saturation. This is a function of the chemical composition alone; and values for some representative materials are given below:

	Intensity of Magnetisation at Saturation: $(B-H)$ at $H \to \infty$
50 : 50 Iron-cobalt alloy	24,000 gausses
Iron	22,000 "
45 : 55 Nickel-iron alloy	16,000 "
78.5 : 21.5 Nickel-iron alloy	10,700 "
3.8 : 78.5 : 17.7 Molybdenum-nickel-iron alloy	8,500 "
Nickel	6,150 "

The curves shown in Figs. 1 and 2 present most of the purely magnetic characteristics of the materials. In utilising these alloys it is generally only necessary to concentrate attention on a few special features of these curves, but such additional factors as the electrical resistivity of the alloys and the dimensions, particularly the thickness, of the magnetic structure, must also on occasions be taken into account. The most important of these characteristics are set forth below:

Important Characteristics of High Permeability Alloys

A. Purely magnetic characteristics	*B*. Complex characteristics, involving electrical resistivity and specimen dimensions, in addition to magnetic properties.
Initial Permeability	Effective a-c. initial permeability at specified frequencies.
Maximum Permeability	Effective a-c. initial permeability with superimposed steady field.
Hysteresis loss	Total energy loss at specified frequencies.

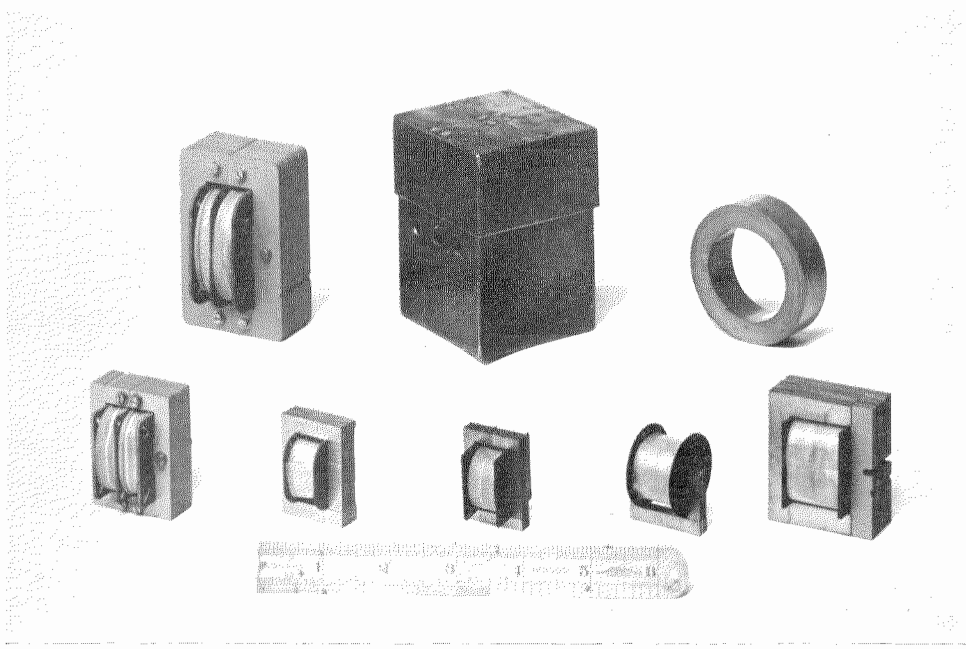
Determinations of the purely magnetic characteristics are usually carried out by ballistic measurements on a core built up from a number of annular ring stampings or else wound from narrow tape in the form of an annular coil. In some instances, annular rings machined from the solid metal have been used, and yield comparable results provided that the heat treatment applied does not involve such rapid rates of cooling as to introduce a mass effect.

In preparing ring stampings, the width of the ring should be as small as possible, in order to avoid errors due to a non-uniform distribution of flux, but otherwise the dimensions are without influence on the observed results. It should, however, be noted that if the alloys have directional properties—imparted as a result of the rolling operations or otherwise—these can only be detected by tests on tape cores.

Since, in service, the alloys usually are subjected to alternating magnetic fields, direct measurements of effective permeability under operating conditions are very desirable. If the alternating field is of small magnitude with the frequency not above 100 to 200 cycles per second, and the sample is made from sheet not thicker than about 0.015 inch, the effective permeability is very nearly identical with the ballistically-determined initial permeability. Measurement of a-c. permeability, using suitable bridge circuits, is, indeed, the simplest method of measuring initial permeability and is usually the most accurate since, even with the most sensitive galvanometers, the ballistic method is difficult to apply at very low fields. At higher frequencies when thicker specimens are under test, or when the amplitude of the alternating field is considerable, a form of "skin effect" is set up through the action of eddy currents and hysteresis effects in the material, and the value of effective permeability may be much lower than the true permeability obtained by ballistic methods.

The losses under these conditions are reduced by any factor which increases the resistance of the material. The use of very thin stampings, insulated from one another, thus often enables higher effective permeabilities to be obtained. For the same reason, it is desirable that the alloys should have as high a resistivity as possible. The effect of these factors can, of course, be calculated by the recognised formulæ with a very fair degree of precision.

One further factor which needs to be considered in certain cases cannot, however, be calculated, and it is necessary to make tests on each type of material to determine its influence. This is the action on the a-c. permeability of a superimposed steady field, such as may be produced by a direct current flowing in the windings of a transformer. The result is broadly to reduce the a-c. permeability very considerably, but the effect is complicated and the previous history of the sample needs to be considered (due to hysteresis effects).



Typical Applications of Permalloy for the Cores of Audio Frequency and Instrument Transformers and also as a Magnetic Shield

In making measurements of high precision during laboratory investigations on these high permeability alloys, the greatest difficulty which is encountered is that of making sure that the specimen is entirely free from stress. The alloys differ to some extent in their sensitivity to applied stresses; and, of their magnetic characteristics, it is the initial permeability which is most susceptible to the effects of small stresses. If, therefore, accurately reproducible results are to be obtained, every precaution must be taken to avoid stresses of any kind in the material. An obvious precaution against stressing while testing is to place the sample in a wooden, bakelite, or hard rubber thin walled container, over which the coil winding is applied. It is equally important, however, to avoid stresses being set up by adjacent layers of a coil or adjacent stampings in a pile sticking to one another during heat treatment. If this occurs, it is impossible to obtain reliable results. Several methods of prevention are available. Stampings may be interleaved with oxidised silicon steel stampings, or the surface of the alloy may be coated with some such substance as graphite, oil, paper, or a suspension of kieselguhr in water or carbon tetrachloride. It is always advisable to avoid surface oxidation during heat treatment, since it may give rise to contraction stresses; also, with stampings, to take steps to ensure that they will be as flat as possible after heat treatment.

Trend of Recent Developments

The original permalloys invented by Elmen were binary alloys of nickel and iron which develop high values of initial permeability only after suitable heat treatments.[1] The preferred heat treatment for the binary alloys consists in first annealing at 900° C. in a closed pot, in which the alloy is allowed to cool slowly in the furnace, and then reheating to 600° C. and cooling at a critical rate, usually rather faster than is provided by free suspension in

[1] For all numbered references, see list at end of paper.

still air. The superiority of this "air quenching" treatment over a simple anneal in developing high values of initial permeability in the range of compositions between about 50 and 85% nickel is illustrated in Fig. 4.[2] On the other hand, it is interesting to note that if the alloys in this region, instead of being cooled rapidly, are given a prolonged "baking" at about 400° C., the initial permeabilities are reduced to very low values.

The air quenching treatment, however, is costly and difficult to carry out with certainty as an industrial process. Furthermore, if the parts to be treated are at all massive, it may become impossible to cool every portion throughout the mass at the same rate, and thus to develop in them the best magnetic properties. Another disadvantage of the original alloys is that their electrical resistivity is somewhat low. As a result, the eddy currents which are induced when the alloys are used in fluctuating magnetic fields may appreciably reduce the effective permeability. Finally, it was not to be expected that the binary alloys should possess ideal characteristics for all applications, and it appeared desirable that alloys having special

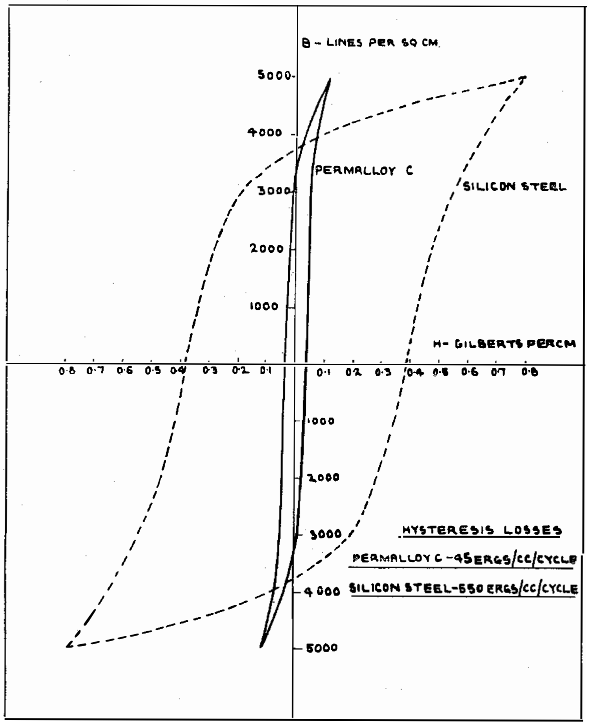


Fig. 2—Hysteresis Curves for Permalloy C and Silicon Steel

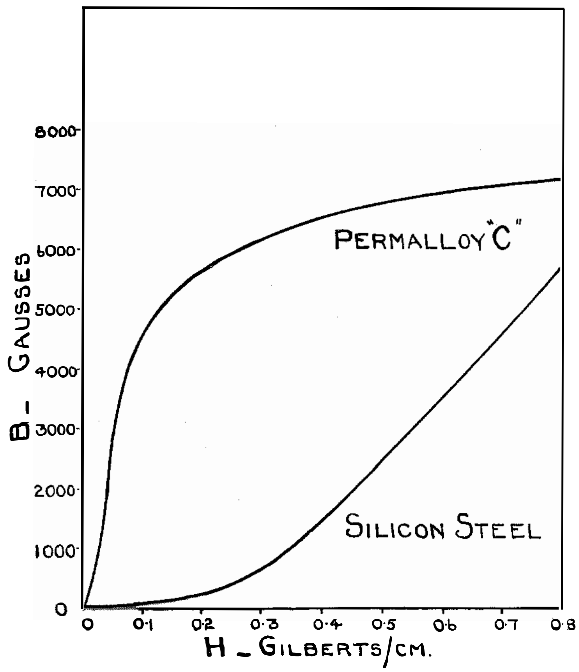


Fig. 1—Magnetisation Curves for Permalloy C and Silicon Steel

magnetic properties for specific uses should be developed if at all possible.

The main lines of attack in an endeavour to overcome these difficulties have been along the following directions:

(1) Addition of further alloying elements to the nickel-iron alloys;
(2) Control of crystal (and domain) orientation by magnetic restraint during heat treatment and by cold-working;
(3) Control of purity of the alloys.

Development of Complex Alloys

By far the greater part of the experimental work carried out during the last 15 years has been in the nature of a search for new alloys showing improved or specific characteristics; if possible, after a simple heat treatment. It will be convenient to consider these alloys in two groups:

(1) Alloys having high values of permeability and resistivity, usually after a simple heat treatment;

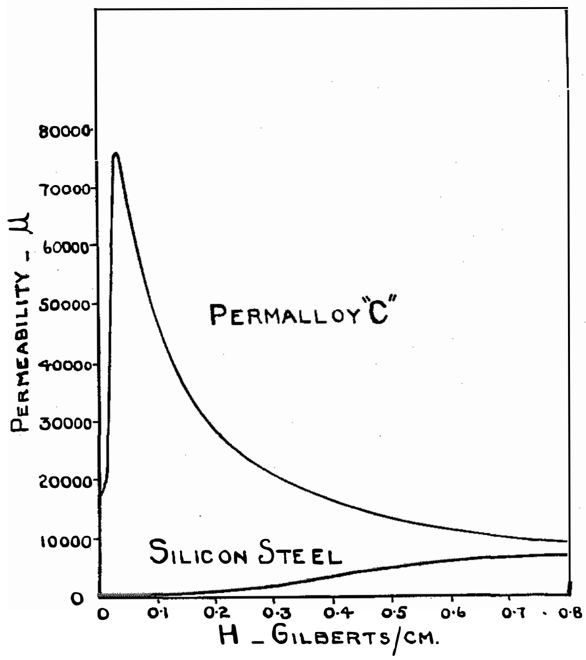


Fig. 3—Permeability Curves for Permalloy C and Silicon Steel

(2) Alloys in which the permeability remains constant from very small up to appreciable values of field strength.

High Permeability Alloys

The most important of the high permeability alloys are those in which a third element (usually molybdenum, chromium, or copper), and sometimes a fourth element is added to a nickel-iron binary alloy. These additions invariably increase the resistivity and often enable very high values of initial permeability to be obtained with a simple heat treatment.

Ternary Alloys of Ni-Fe-Cu, Ni-Fe-Mo, and Ni-Fe-Cr

The only ternary alloy system in this group which has been completely investigated is the nickel-iron-copper series, and unfortunately this is not one which in itself exhibits magnetic properties sufficiently striking to warrant its general commercial use. The exploration of this system has been conducted by Otto von Auwers and Hans Neumann,[4] in the course of which ring stampings 2.36 inches outside diameter, 1.77 inches inside diameter, and 0.014 inch thick were tested by ballistic methods. The values for initial permeability after annealing at 1100° C. in hydrogen, and after a "permalloy" double heat treatment (employing a first anneal at 900° C.) similar to that described above, are shown in Figs. 5 and 6. It will be noticed that the narrow zone of composition in which high values of initial permeability are obtained occupies much the same position, whichever heat treatment is used, and it has been contended that the differences are due more to the different temperatures used for annealing than to the difference in the cooling rates. Thus these alloys represent an advance over the binary nickel-iron alloys in being far less sensitive to heat treatment conditions. With the air quenching treatment, the greatest value observed for initial permeability was 13,500 for a composition of 70% nickel, 13% copper, 17% iron. After annealing at 1100° C., an initial permeability of 12,100 was found for

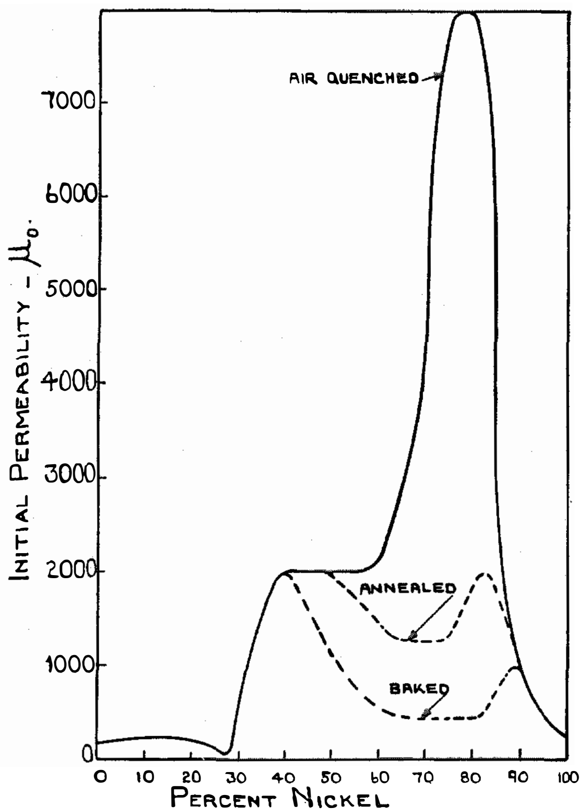


Fig. 4—Effect of Heat Treatment on the Initial Permeability of Iron-Nickel Alloys

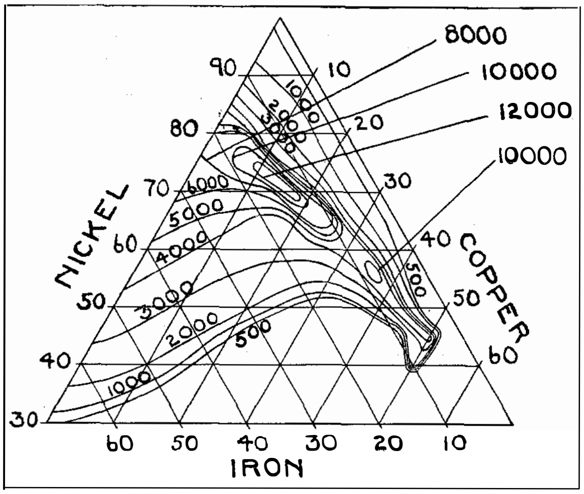


Fig. 5—Values of the Initial Permeability of Alloys in the Nickel-Iron-Copper Series after Air Quenching the Annealed Alloy from 600° C.

a composition of 60% nickel, 28% copper, 12% iron.

Certain of the ternary nickel-iron-molybdenum and nickel-iron-chromium alloys have been used widely in England and America, but for neither of these systems are complete diagrams of their magnetic properties available. It is generally believed that the best magnetic properties are obtained if the nickel content is maintained at about 78.5%, and Figs. 7 and 8 show values of initial permeability with alloys containing this amount of nickel and having up to 10% of iron replaced by molybdenum or chromium.[2, 3] The action of these added elements, which themselves are non-magnetic, in modifying the response of the alloys to heat treatment is very striking.

Small additions increase the permeability obtained after double heat treatment (air quenching) but slightly larger additions enormously increase the permeability found after a simple heat treatment; so much so that, with 3.8% molybdenum, the highest initial permeability (20,000) obtainable by any heat treatment with any of this series of alloys is obtainable. The alloy with 3.8% chromium also has a very high initial permeability (12,000) after annealing and, in addition, has a slightly higher resistivity (Fig. 9).

The curves shown for initial permeability are based on the average results obtained from a large number of tests. It may be advisable here to point out that they should be taken only as indicating the general trend of the relation between initial permeability and composition, and that the values found for any particular sample are liable to vary quite appreciably from the average. Some of the causes for the rather large "scatter" invariably observed in the study of these magnetic materials are discussed later.

Both the 3.8 chromium and 3.8 molybdenum permalloys have found a considerable application on account of the ease with which high initial permeabilities, coupled with high resistivity, are obtained after an annealing treatment at about 1000° C. followed by slow cooling. It should be noted that the magnetic saturation of both of these alloys is low, and that the maximum permeabilities are usually lower than are obtained with the original 78.5% nickel permalloy. Typical values are as follows:

	Intensity of Magnetisation at Saturation: $(B-H)$ max.	Maximum Permeability
3.8 Chromium 78.5 Nickel Permalloy............	8,000 gausses	62,000
3.8 Molybdenum 78.5 Nickel Permalloy......	8,500 "	75,000
78.5 Nickel Permalloy, air quenched............	10,700 "	105,000

More Complex Alloys

In recent years, a number of alloys having four or more constituents have been chosen, more or

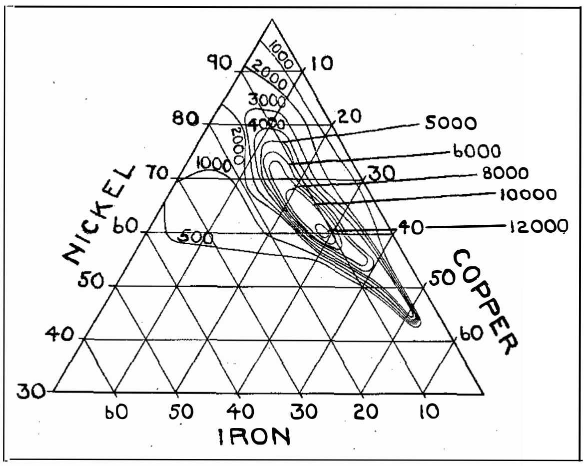


Fig. 6—Values of the Initial Permeability of Alloys in the Nickel-Iron-Copper Series after Slow Cooling from 1100° C.

less arbitrarily, and in some instances exploited commercially. Very high values of initial permeability have been recorded for some of them; as an instance, an initial permeability of 51,000 has been claimed for an alloy of 72% nickel, 11% iron, 14% copper and 3% molybdenum.[4, 5] Whether such a high value is obtainable regularly in production appears doubtful.

Constant Permeability Alloys

For some purposes it is most desirable that the permeability, instead of rising steeply as the field strength is increased, should remain—at least over a limited range—constant in value. Alloys with such characteristics were first deliberately sought in connection with the continuous loading of submarine telephone cables; and when, a few years ago, the project of a transatlantic telephone cable was receiving a large amount of attention, considerable impetus was given to their investigation.

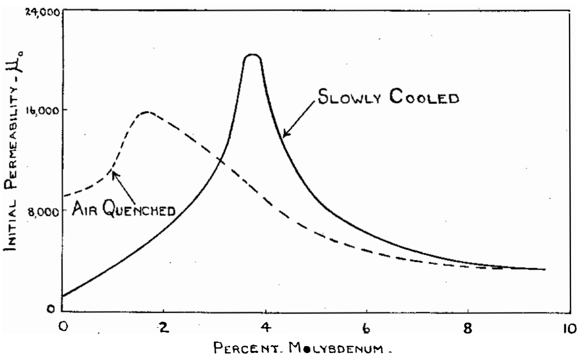


Fig. 7—Effect of Molybdenum Additions on the Initial Permeability of Permalloy Containing 78.5% Nickel

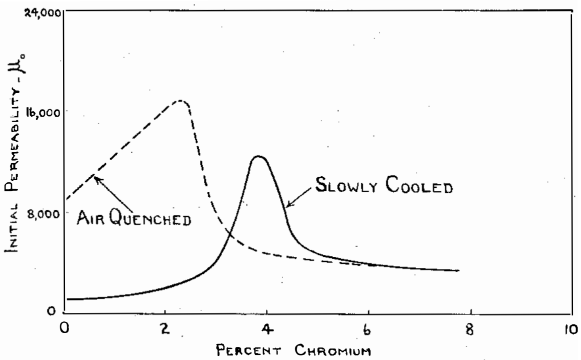


Fig. 8—Effect of Chromium Additions on the Initial Permeability of Permalloy Containing 78.5% Nickel

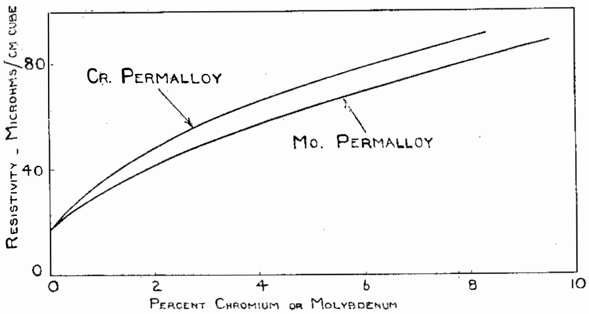


Fig. 9—Effect of Chromium and Molybdenum Additions on the Resistivity of Permalloy Containing 78.5% Nickel

These properties were first observed in the binary nickel-iron alloys containing between 64 and 76% of nickel after the annealed material had been "baked" or given a low-temperature heat treatment at a temperature between 400° and 500° C. for 24 hours or more. It was later found that the effect was very much more pronounced if cobalt were added; and an extensive investigation of the nickel-iron-cobalt series brought to light a range of such alloys, as indicated in Fig. 10, to which the name "Perminvars" was given.[3, 6, 7] All alloys in this range respond to a "baking" treatment by developing the perminvar characteristic of remaining constant in permeability as the field strength is increased from zero up to an appreciable value. A typical alloy, showing these characteristics to a marked degree, is that containing 45% nickel, 25% cobalt, and 30% iron; in Fig. 11, permeability curves for this material after air quenching and baking are given. The baking treatment reduces the initial permeability, but appreciably extends the range over which it remains unaltered. The air quenched alloy has an initial permeability of just over 600, which commences to rise at once when the field is increased, whereas for the baked alloy the initial permeability of 300 remains constant up to a field of over 3 gilberts/cm.

One disadvantage of these alloys is their low resistivity, which is only 18 microhms/cm³ for the composition quoted, but by replacing about 7% of iron by molybdenum the resistivity is increased to 80 microhms/cm³. The 7% molybdenum perminvar normally has a rather higher initial permeability than the 45–25–30 perminvar, but it does not remain constant in permeability over so wide a range. The range of constancy can be extended, however, by prolonging the baking period.

In seeking for an explanation for the behaviour of these alloys, it is tempting to suggest that precipitation of a magnetically hard constituent may occur during the baking treatment, the action being similar to the precipitation of a mechanically hard disperse phase in precipitation-hardening alloys such as duralumin. Developing this idea, it has more recently been suggested that the precipitated phase may consist of what is known as a "superlattice."[9, 10, 11, 12] If the alloy is cooled rapidly, the atoms of nickel, iron, and cobalt are arranged at random in the crystal lattice, and in this condition the material is most susceptible to weak magnetic fields. It is suggested that baking may cause the atoms, in some areas of the alloy at least, to arrange themselves in superlattices, in which the atoms of nickel and iron each occupy certain definite fixed positions. The precipitated constituent, whether a disperse phase or a superlattice, is considered to be less easily magnetised than the solid solution formed by more rapid cooling.

It has not thus far been possible to verify either by X-ray or microscopical examination the existence of two phases in the baked alloys. In a recent investigation,[12] no evidence of the existence of a superlattice was, on the contrary,

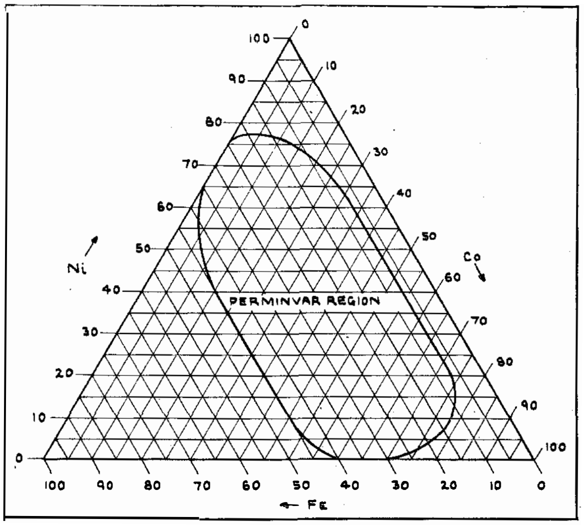


Fig. 10—Diagram Showing the Range of Composition in the Nickel-Iron-Cobalt Series in which the Alloys Show Perminvar Characteristics after a "Baking" Treatment.

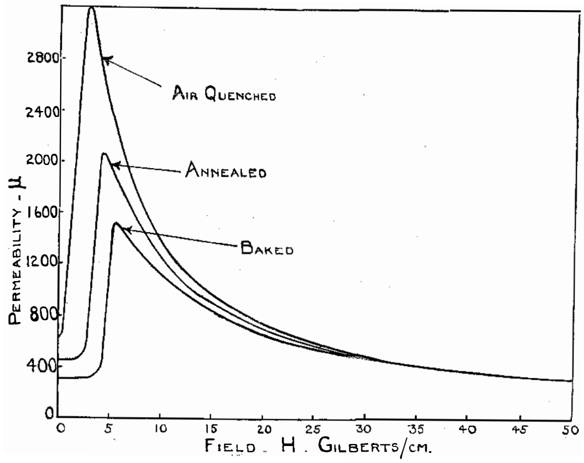
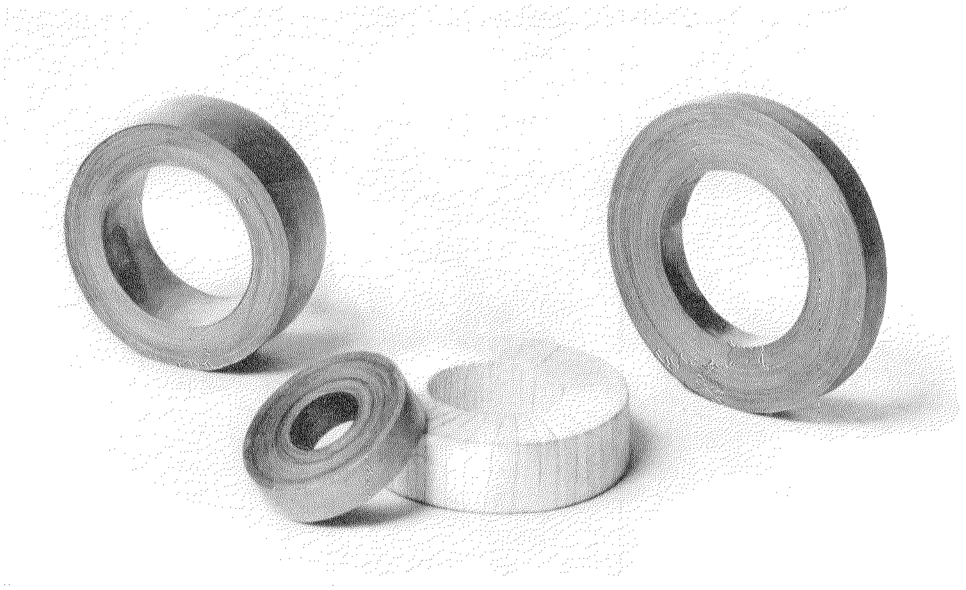


Fig. 11—Effect of Heat Treatment on the Permeability of 45 : 25 : 30 Perminvar

found by X-ray methods in the alloy containing 69% nickel, even after annealing at 447° C. for 1560 hours, and no compounds were detected in the whole range of the nickel-iron alloys. Bimetallic samples having a magnetically hard core of piano wire encased by 78.5% nickel permalloy have, however, been found to approximate very closely to perminvar in their behaviour, which has thus been held to give some support to these ideas.[2]

Furthermore, if precipitation of a disperse phase brings about these effects, it might be expected that other metals besides cobalt would form phases which could be precipitated and, in doing so, impart constant permeability characteristics to the nickel-iron alloys. According to the claims of some recent patents,[13] such properties, in fact, are possessed by a number of elements. It is stated that if one of the metals—silver, beryllium, antimony, magnesium, or calcium—is added in amounts up to 3%, it forms solid solutions with the nickel-iron alloy at high temperatures but that on cooling the solubility falls rapidly. By quenching such a ternary alloy from 900° C. or over, there is formed a supersaturated solid solution which on baking at 250–500° C. will precipitate a disperse phase. After this treatment, all these alloys are claimed to exhibit constancy of permeability over an appreciable range. Copper in large amounts will also act as a precipitable element, provided that the nickel content is not over about 80%. In-



Spiral Cores of Permalloy Strip for Instrument Transformers

creased amounts of nickel increase the solubility of copper.

By adding additional elements which are soluble in nickel-iron alloys, it is possible to increase the resistivity. Suitable resistance elements are said to include chromium (soluble up to 15%), molybdenum (up to 12%), manganese (12%), tungsten (10%), aluminium (5%), silicon (5%), vanadium (5%), and cobalt (15%). A typical alloy made according to these principles contains 78.5 parts nickel, 18 parts iron, with 3 parts molybdenum, 2 parts silicon and 1 part manganese as soluble resistance elements, and 1.2 parts beryllium as a precipitable element. After baking a supersaturated solid solution of this alloy for 36 hours at 375° C., precipitation occurs and there is obtainable a permeability of 850, which remains constant up to a field of 0.1 gilbert/cm. The resistivity is 51 microhms/cm^3.

Control of Crystal (and Domain) Orientation

Apart from varying the composition and heat treatment, it is natural that the possibility of influencing magnetic characteristics by control of the microstructure and crystal orientation of these alloys should have been explored. The effect of the most easily controlled variable, crystal size, on the permeability and—more particularly—the hysteresis losses in pure iron and silicon iron sheet has been the subject of much discussion and investigation; [14] and it has been claimed that the losses are reduced as the crystal size increases. The view put forward by Yensen [15] is that the improvement is due to the more regular spacing of the atoms which follows the reduction of boundary area, near which the atomic arrangement is inevitably distorted. On the other hand, the suggestion has been made that material with a large crystal size is often better annealed, possesses less internal stress, and contains fewer inclusions and other impurities than fine grained material; and that it is to these causes that the magnetic improvement which has sometimes been recorded must be attributed. In the light of recent investigations, it seems probable that the mere size of the crystals which make up the alloy has not in itself any appreciable influence on magnetic characteristics. Most of the observations on the effect of crystal size have ignored the important fact that the crystals of many of these materials are themselves anisotropic; that is, that they are more easily magnetised along certain crystal directions than along others. Iron (which has a body-centred cubic lattice at room temperatures) is, for example, magnetised nearly to saturation by a field of 10 gilberts/cm. applied along the direction of a cube edge—the (100) direction—whereas it requires a field of about 420 gilberts/cm. to magnetise it to the same degree along a cube diagonal (111), and over 500 gilberts/cm. along a face diagonal (110).

Nickel crystals also possess similar marked directional magnetic properties in high fields, though in this material the cube diagonal is the direction of easy magnetisation. In the binary nickel-iron alloys, the directional properties are generally less strongly marked, depending on the composition, and in the alloy containing 66% nickel no directional properties at all can be detected.[16, 17]

Although these directional properties are of very great theoretical interest, it must be pointed out that they are only really pronounced at field strengths above about 5 gilberts/cm., when the material is more than half saturated. At lower field strengths, there appears to be little difference between the values of permeability of single crystals of iron measured in various crystal directions and, though precise measurements are difficult to carry out, the same is probably true of other ferromagnetic materials. However, some observers have considered that such materials as silicon steel and some of the complex nickel-iron alloys do show directional properties even under these conditions;[18] and it is thus of some interest to consider briefly how it is possible to take practical advantage of this characteristic.

In a normal sample of polycrystalline annealed nickel-iron alloy containing about 50×10^6 crystals to the cubic inch, each oriented at random, directional properties are naturally absent. It is obvious, though, that if all or a majority of these crystals could be arranged with their crystal axes parallel, the sample should show the directional magnetic characteristics of a single crystal. Such an effect can be produced by suitable cold-rolling or drawing operations, which are well known to have a tendency to orient the crystals in preferred positions relative to the direction of working. The first effect of cold rolling is merely to distort the crystal lattices, but after greater reductions, above about 35% in the nickel-iron alloys,[19] the crystals proceed to "line themselves up." Such preferred orientation, once produced, is not easily destroyed and is largely retained even after prolonged annealing at high temperatures. By careful rolling technique,[20] it has been found possible to utilise these principles commercially to produce silicon iron sheet in which most of the crystals are arranged [21] with a cubic axis within a few degrees of the direction of rolling. In strong fields (of about 4 gilberts/cm.), this material has a permeability of about 4,000 in the direction of rolling, whereas measured at right angles the permeability in only about one-tenth of this value.

For materials which are to be operated at low fields, it is doubtful, however, whether any very great improvements are to be expected from sheet with preferred crystal orientation. Slight improvements in the initial and maximum permeabilities of certain nickel-iron-chromium-copper alloys by the choice of optimum rolling conditions have been claimed,[18] but the general experience is that such improvements, if real, are very small.

This conclusion is, further, in good accord with modern theories concerning the nature of ferromagnetism. Detailed discussion of this point would be out of place here but, for a brilliant and extremely lucid account in English of the present status of ferromagnetic theory and of its relation to such phenomena as crystal anisotropy, reference should be made to a recent paper by Dr. R. M. Bozorth.[22]

For the present purposes, it must be sufficient to explain that the crystals of a ferromagnetic substance are conceived as being built up of small elements, each having the volume of a cube about 0.001 inch on an edge, and known as domains. The exact shape of a domain is unknown, and it is not certain whether the boundaries between these domains have any relation with the imperfections which have been postulated as existing in all metal crystals. At room temperatures these domains, in iron and nickel-iron alloys, are believed to be always magnetised to saturation in the direction of one of the six cubic axes of the crystals; and the magnetisation of the material as a whole is believed to depend on the extent to which all the domains are aligned. In an unmagnetised material, equal numbers of the domains in each crystal are arranged with their magnetic axis along each of the six possible cubic directions.

It is suggested that the first effect of applying a weak magnetic field is to enlarge those domains which are magnetised in the directions of the field, the domains magnetised in other directions growing shorter. The ease with which this boundary movement can take place depends on the extent to which the material is stressed either internally or by applied forces. Thus the extreme susceptibility of high-permeability alloys to external strain is explained. On the other hand, the ease of boundary movement is only very slightly dependent on the orientation of the magnetic axes of the domains, and thus of the crystal axes, with respect to these weak applied fields.

With rather stronger applied fields, the direction of magnetisation of some of the domains can be caused to change suddenly by 90 or 180 degrees so as to be more closely aligned with the external field. The net result of these changes on the magnetisation of the alloy as a whole will obviously depend largely on the relation between the direction of the applied field and the crystal axes—and in these stronger fields single crystals will obviously show directional properties.

Normally, according to this theory, the six directions along which a domain may be magnetised are related to the crystal axes of the alloy. It would seem, however, from some recent experiments that, if certain alloys are cooled slowly in a magnetic field from a temperature above the Curie point, it is possible to align the domains parallel to the applied field.[23, 24] It is suggested that when the domains cool below the Curie temperature and thus first develop their magnetism, stresses are set up. If, therefore, they are aligned in any given direction by an external field, and cooled very slowly, there will be an opportunity for stress relief to occur, during which the domains will actually change their shape. Subsequently, it will be very much easier to magnetise the material in the direction of the field which was applied during cooling than in any other direction. So far, the observations on which this theory has been built appear to have been confined to tests on polycrystalline material, but the results are very impressive. Of the alloys in the nickel-iron series, that containing 65% nickel has been found to be most susceptible to the influence of a magnetic field applied during cooling. With this composition the maximum permeability can be increased from 5,000 to 250,000 by cooling slowly from 700° C. in a field of 15 gilberts/cm. The reason why the alloy of this particular composition is most susceptible to heat treatment in a magnetic field has been explained on the grounds that the temperature of its Curie point is a maximum for all the alloys in the nickel-iron series. This means that the temperature at which the domains first become magnetised is a maximum and that there is thus a maximum opportunity for plastic flow. This explanation is supported by the observation that in the nickel-iron-cobalt series of alloys, high values of maximum permeability are, in general, obtainable only in the region where the Curie point is above 500° C. In the other alloys, the material is too cold and is insufficiently plastic to yield at the temperature at which the domains are first magnetised. On the other hand, it may be significant that the alloy of 65% nickel, 35% iron is remarkable as showing no directional magnetic properties, and that this characteristic also possibly influences its behaviour when heat treated in the manner under discussion.[17]

Reference has already been made to the effect of cold rolling in producing a preferred crystal orientation which persists even after annealing, and to the manufacture by this process of silicon-iron sheet having directional magnetic characteristics. Cold rolling operations also produce in some nickel-iron alloys certain magnetic characteristics which are not commonly encountered in sheet material. It has been found that unannealed cold rolled sheet shows very little hysteresis loss in feeble alternating magnetic fields and, in addition, has a permeability which, although low in value, remains unaltered as the field strength is increased up to quite large intensities. Furthermore, the permeability can be made to remain virtually unaffected after the material has been subjected for a short time to intense magnetic fields.

The development of such cold rolled sheet with a permeability between 50 and 100, which remains fairly constant up to field strengths of about 10 gilberts/cm., and with a stability below about 1%, has recently received considerable attention in Germany.[25, 26] This product has been called "Isoperm."

Nickel-iron alloys with from 40 to 60% of iron were first studied but it was found that, in cold rolling, reductions which yielded the minimum values of stability did not result in the lowest hysteresis loss. Additions of aluminium up to about 4% gave improved results but increased the hardness of the alloy and made rolling difficult. Alloys containing 36% or 40% of nickel with up to 15% of copper, however, proved more satisfactory, the precise characteristics obtained depending both on the degree of reduction by cold rolling and the heat treatment applied previously. Using a 50–50 nickel-iron alloy, it has also been found possible to increase the permeability by a low temperature heat treatment at 400° C. which leaves stability and hysteresis losses unchanged.[27]

Laüe X-ray photographs show that in the heavily rolled 50% nickel-iron strip annealed at 400° C., the crystals are oriented (with a dispersion of only 5–10%) with one of the cube sides on the rolling surface and one of the edges in the direction of rolling. Magnetic tests on this tape show, as might be expected, that it possesses directional properties. The special characteristics of low hysteresis loss in the cold rolled tape cannot, however, be explained on the grounds of favourable crystal orientation alone; and it has therefore been suggested [27] that the residual stresses play their part also by causing most of the domains to be magnetised in either of the two directions at right angles to the length of the tape. When such tape is made into a core, the applied alternating field tends to orient the domains so as to point alternatively along the two longitudinal directions, and it is suggested that minimum work will be expended if the domains are originally in the mean position at right angles to the run of the tape. This theory, incidentally, requires that the effect of the small magnetising fields produced in a loading coil should be to move the magnetic axes of the domains through a small angle; whereas the usual conception is that the directions of magnetisation change only through 90 or 180 degrees under such moderate stimuli. Thus, the effect of cold rolling on these alloys may be considerably more complex than this hypothesis suggests. One possibility is that the cold working causes precipitation of a disperse phase,[28] similar to that produced in other constant permeability alloys; but all explanations must in the present state of knowledge be extremely speculative.

Impurities

Thus far, this review has dealt with the characteristics of alloys made by high frequency melting from commercially pure materials such as electrolytic or Mond nickel, Swedish iron, and so forth. Small amounts of a number of impurities are inevitably present, and undoubtedly exert a harmful effect on the magnetic properties obtainable.

It has been explained that all high-permeability alloys are extremely sensitive to the effects of internal or applied stresses. It appears likely, also, that if elements are present in the alloys which tend to strain the crystal lattice, magnetic softness will be impaired. The elements carbon, oxygen, nitrogen, and sulphur are of this type, for instead of replacing atoms in the nickel-iron lattice, they crowd into interstitial positions.[29] These elements are, in fact, found to be most injurious to the permeability characteristics; and it seems most likely that their presence in varying small amounts is one of the main causes of the quite wide differences which are frequently found between the magnetic properties of successive melts of the same alloy. Varying amounts of dissolved gases such as carbon monoxide or methane, as well as the presence of slag inclusions, are also possible sources of non-uniformity.

On account of the experimental difficulties in making accurate determinations of small quantities of carbon, oxygen, and nitrogen, the extent of their influence on the nickel-iron alloys must remain largely a matter of inference. For iron, considerably more data are available,[30] and it is clear from the most recent work that both carbon and, particularly, oxygen exert an especially damaging effect on maximum permeabilities, even when present in minute quantities, well below 0.01%, but are not additive. The improvements which can be brought about by the removal of impurities from iron are very strikingly shown by the following figures:[31, 36]

Date	Authority	Material	Maximum Permeability	Hysteresis Loss
1885	Ewing	Wrought Iron	2,600	5,000
1900	Hadfield	Swedish Charcoal Iron	2,600	2,700
1913	Breslauer	Annealed electrolytic iron	11,500	1,440
1915	Yensen	Vacuum fused electrolytic iron—probably contained hydrogen	25,800	660
1928	Yensen	Vacuum fused electrolytic iron—probably contained hydrogen	61,000	300
1935	Adcock & Bristow	Vacuum fused iron, purest made at National Physical Laboratory. Total impurities, 0.0113%	14,360	—

It is interesting to speculate on the magnetic properties which might be expected from absolutely pure iron, if ever it is found possible to produce such material, and Yensen has recently ventured the prediction [30] that a single crystal of pure iron containing no oxygen and 0.001% carbon would have a maximum permeability of 500,000 and a hysteresis loss of 20 ergs per cc. per cycle. It will be noticed that these properties are rather superior to those of the best nickel-iron alloys known, and it is natural to enquire further whether the action of the nickel and other alloying elements may not be to neutralize in some way the deleterious effects which the interstitial impurities have on iron. One suggestion [32] is that the nickel-iron alloys, when fairly rapidly cooled, retain the impurities in solution and only precipitate them on slow cooling. It seems doubtful, however, whether the behaviour of the permalloys can be explained on so simple a basis.

Apart from the effect of the interstitial elements, greatest interest probably centres around the part played by hydrogen absorbed or combined in these alloys. The facts are that treatment of iron and—to a less extent—of some alloys in hydrogen very greatly improves their magnetic properties. By heating Armco iron in hydrogen (for 18 hours at 1480° C., followed by 18 hours at 880° C.), for instance, Cioffi [33, 7] has produced samples in which the initial permeability has been increased from about 250 to 20,000, and the maximum permeability from 7,000 to 340,000. Similarly, by heating 3.8–78.5–17.7 molybdenum-nickel-iron alloy to 1400° C. in hydrogen, the value of initial permeability has been increased from the normal value of about 20,000 to 34,000, and the maximum permeability from 75,000 to 140,000. The 50–50 nickel-iron alloy is particularly susceptible to improvement by this treatment, and for some years hydrogen-annealed sheet, made from alloy which has been melted under hydrogen, has been available commercially in America.[34, 35]

Views concerning the nature of the action exerted by hydrogen have fluctuated between two extremes in recent years. When this phenomenon was first recorded, it was considered that the hydrogen, by entering into solution or combination with the metal, itself exerted some influence on the magnetic behaviour. Later, there grew up a belief that the effect of hydrogen was entirely one of purification, and that its beneficial action was due to its power of removing oxygen, carbon, and sulphur from the metal. At the present time, while it is recognised that hydrogen can effect considerable purification by prolonged action at high temperatures, nevertheless it is not considered that its beneficial action can be explained as being wholly one of purification. Recent researches at the National Physical Laboratory in England as well as elsewhere on the production and study of very pure iron have strengthened the belief that hydrogen must be classed as an alloying element which, when present in small quantities, modifies the characteristics of iron and many of the high permeability alloys to a very considerable extent.

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The Cape Town–Johannesburg Carrier Telephone And Associated Voice Frequency Telegraph System

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General

IT is felt that this project merits a general description since it is comprehensive in its features and of proved reliability in service under difficult conditions.

The facilities at present afforded by the system are fifteen voice-frequency full-duplex telegraph circuits and two carrier telephone channels in addition to the usual audio telephone outlets. The telegraph channels can be increased to eighteen when the need arises.

The telephone circuits are brought out on the long distance boards at Cape Town and Johannesburg and used for South African and overseas traffic. Creed Page Teleprinters are used almost exclusively for the telegraph traffic although Creed Morse equipment is worked on one or two channels. In addition to the usual direct facilities between the telegraph offices of Johannesburg and Cape Town, two outlets are available for leased part-time private wire teleprinter service between Johannesburg and Cape Town Telex subscribers. Overseas telegraph traffic is also routed over the equipment.

It will be apparent from the foregoing that reliability of service is of prime importance since the system carries high grade traffic. From an equipment aspect, complete satisfaction has been attained. Line maintenance is difficult through sparsely populated country and a standby pair is available over the whole route. Faulty sections can thus be speedily replaced. Criticism of the policy of deriving so many and important facilities from one pair of wires has been expressed. This disadvantage must be admitted but the argument, to be complete, should consider the state of affairs presented when the whole pole line is in trouble following violent storms or accident. The breakdown party concentrates all its activities on restoring one pair (drop wire being used if necessary) and the system is routed over this circuit. The entire facilities of the system are thus available and the accumulation of traffic can be attacked without handicap. In South Africa, where alternative pole routes are not always available, this feature is worthy of merit and the Cape Town-Johannesburg system has several times proved its capabilities in this connection.

Installation of the equipment was commenced in April, 1934 and the circuits were opened to traffic on November 1st of that year. The equipment was made in the London factories of Standard Telephones and Cables, Limited, and installed by the Union Post Office in conjunction with an engineer of the manufacturers.

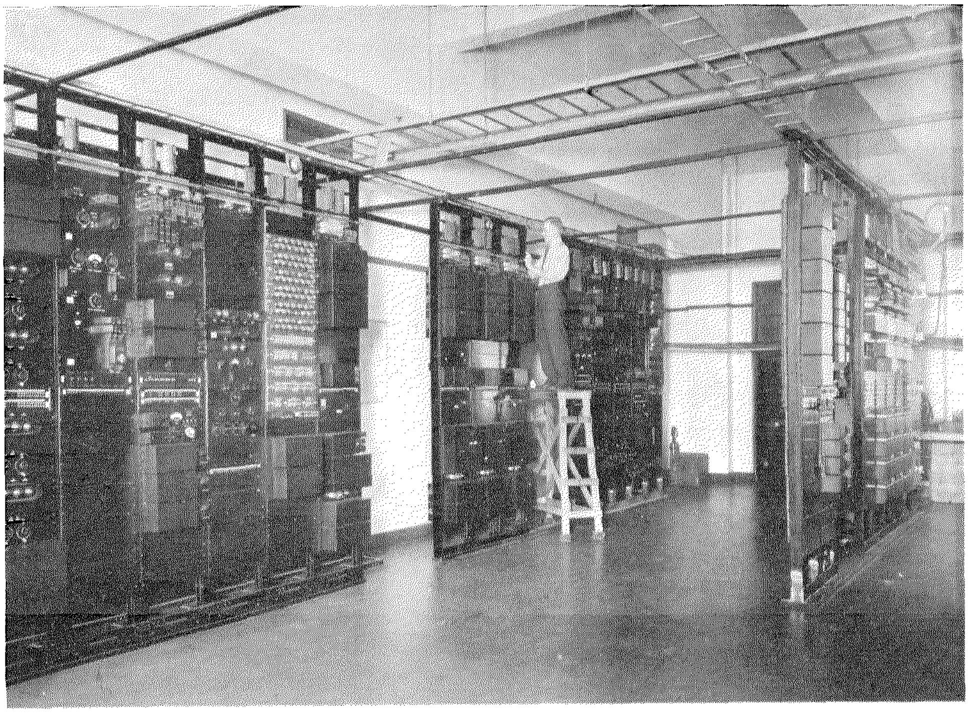
The System Layout

The Cape Town-Johannesburg route is 922 miles in length, running roughly north-east from Cape Town and passing through the mountainous scenery of Cape Province before reaching the high central plateau—Johannesburg being some 5,700 feet above sea level. The stormy seasons of the northern and southern halves of the route do not coincide and one end or the other is always liable to bad weather. The northern section, in particular, is exposed to very bad lightning and static conditions during the months between November and March.

The map (Fig. 1) indicates the location and spacing of the carrier repeater stations. Klerksdorp, Bloemhof, and Kimberley are of the "low gain" type (a maximum gain of 30 db. is afforded by the amplifiers) whilst the remaining three are "high gain" (a maximum amplifier gain of 45 db.).

With the exception of short carrier-loaded entrance cables at Cape Town and Johannesburg, the route is 150 lbs. per mile copper throughout. The configuration of the open wires changes several times due to the individualism of the early telegraph engineers of the once separate provinces which today comprise the Union of South Africa. For this reason also, the sections from Cape Town to Worcester and Fourteen Streams to Johannesburg are revolved, the remainder of the route having "point" transpositions on the telephone pairs. Preliminary line tests showed the existence of severe absorption peaks in the attenuation-frequency curves of the transposed sections, and extra transpositions were necessary in order to remove this trouble. It should be borne in mind that complete coordination of the circuits on the pole lead had not been obtained prior to the introduction of the carrier system. In fact, as indicated above, the route conditions existing were the result of miscellaneous additions spread over many years and, owing to diversified control, these additions were not coordinated in the most effective manner. In view of the consideration that the complete pole route is due for rebuilding shortly, the line work just prior to the introduction of the system was limited to that strictly necessary for its successful operation. A main line and a standby are available over the whole distance and are reasonably similar in electrical characteristics. In general, complete line sections are interchanged between the relevant repeaters in times of trouble.

The carrier loaded entrance cables at Johannesburg and Cape Town are similar—each approximately 1,000 yards in length, of 40 lb. multiple twin conductors and loaded with intermediate 3.5 mH coils at 250 yard intervals. With terminal compensating units the effective transmission of frequencies up to 43 kc./sec. is possible, and this range has been chosen in order to accommodate proposed broadcast channel systems. At present only two pairs are loaded.



Part of Johannesburg Toll Line Equipment

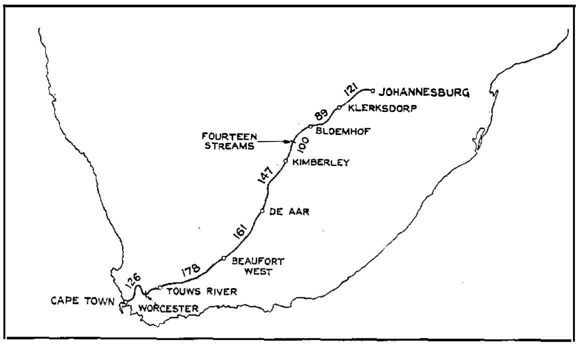


Fig. 1—Location and Spacing of Carrier Repeater Stations

The 3-Channel Carrier Telephone Equipment

The 3-channel carrier telephone equipment[1] is of the single side-band suppressed carrier type using the C.S. 3 frequency allocation (Fig. 2). Special carrier line filters enable an upper limit of 5,000 p : s to be obtained from the physical circuit in order to render it more suitable for the transmission of broadcast programmes. In its broad outline the carrier telephone system is similar to the systems described in previous articles. Two additions are, however, novel.

The lines upon which the system operate have a total overall loss during fine weather of approximately 150 db. at 30 kc./sec. The telephone channels are operated with a net loss of 6 db. between the long distance positions at the two terminals. The need for a precise and rapid control to offset the constantly varying line losses is very evident. Manual operation of repeater amplification would be cumbersome and would lead to loss of traffic time whilst the system levels were being adjusted.

Automatic gain control associated with the automatic pilot channel equipment was therefore introduced. Its main function is to change the repeater amplification in order to compensate for slow changes in line loss due to weather conditions. A steady pilot current is sent out by each terminal—these currents having selected frequencies within the relevant carrier ranges. At each repeater a loosely-coupled tuned circuit, bridged across the amplifier output, accepts only currents of the pilot frequency and the resulting voltage is fed to the grid of a rectifier valve. The anode current of the latter will thus vary with the line loss preceding the amplifier, and a meter in the anode circuit can be directly calibrated in decibels "up" or "down" with reference to a normal value. The anode current controls a marginal relay having limits of plus or minus 0.5 db. and operation of this starts a sequence of events leading to the stepping of a rotary switch. The bank contacts of the switch are connected to an attenuator inserted ahead of the amplifier and, as the switch rotates, attenuation is removed or inserted until the appropriate correction is obtained.

[1] For all numbered references see list at end of paper.

In the repeater stations the above equipment is in duplicate—one set maintaining the levels in the Johannesburg-Cape Town and the other in the opposite direction. In order to ensure that the necessary correction is always made by the requisite amplifier, a time delay is introduced between the operation of the marginal relay and the stepping of the switch. This delay increases progressively from repeater to repeater (see Fig. 3).

The pilot equipment also gives visible and audible alarms if the level drops more than 6 db. below its normal value. The complete equipment for a repeater station can be mounted on a 8′6″ bay.

In practice, the pilot channel has proved successful—fully justifying its installation. The stepping of the rotary switches passes unnoticed by the telephone subscribers and merely causes a small transient increase in the distortion on the telegraph channels.

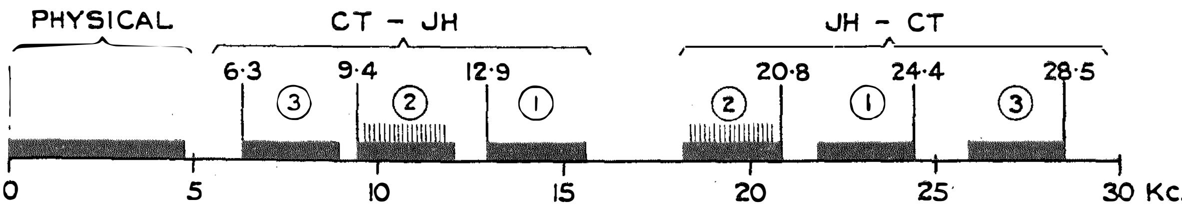
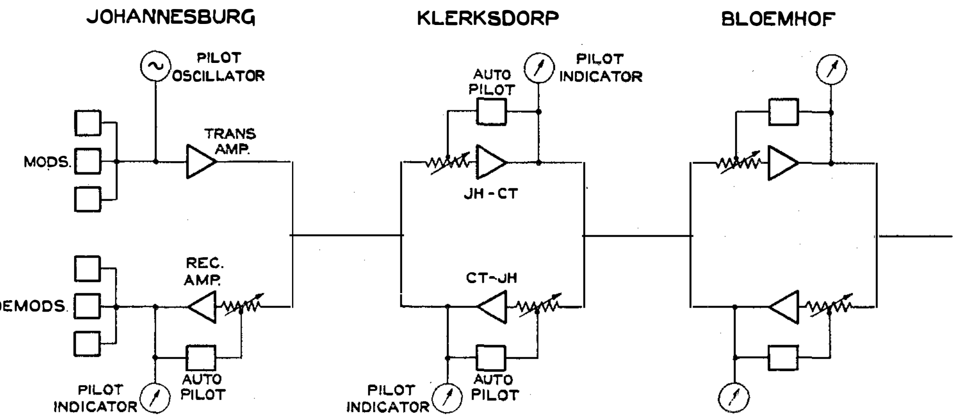


Fig. 2—Frequency Allocations



PILOT DELAY SECONDS		REPEATER STATION
CT - JH DIRECTION	JH - CT DIRECTION	
52·2	–	JOHANNESBURG
37·6	5·5	KLERKSDORP
26·8	8·6	BLOEMHOF
18·9	12·9	KIMBERLEY
12·9	18·9	DE AAR
8·6	26·8	BEAUFORT WEST
5·5	37·6	TOUWS RIVER
–	52·2	CAPE TOWN

Fig. 3—Schematic of Automatic Gain Control

As shown in Fig. 4, the output from the V. F. Telegraph system is fed into the modulator of channel 2. The terminal and repeater amplifiers, therefore, handle the products of telephone modulation from channels 1 and 3, and the telegraph modulation from channel 2. Speech transients of high level could thus produce cross modulation in these amplifiers, leading to interference with the telegraph signals. As a preventive measure, voltage limiters are inserted between the hybrid coils and modulators of the two telephone channels. A simple, but very effective, device is used for the purpose, consisting of a selected neon lamp across the secondary of a step-up transformer. The primary is shunted across the modulator input. Undue voltage across the primary winding causes the lamp to "blink." The impedance across the modulator input is then quite low, and the transient voltage effectively reduced to a safe value.

The V.F. Telegraph Equipment and Its Application to the Telephone System

The telegraph equipment has previously been described in detail.[2] The equipment in use is so similar that a further description is not warranted.

The present facilities of fifteen full duplex channels are capable of easy extension to eighteen, when required. All circuits, with the exception of an engineering order wire, are extended to the telegraph offices at Cape Town and Johannesburg. Operating practices are standard.

The transmitting side of the telegraph system feeds into the modulator and the demodulator output is connected directly into the receiving telegraph equipment. In effect four-wire working is obtained.

The maximum power level on the line due to a telegraph channel marking is approximately 3.5 milliwatts. This results partly from the transmitting gain of the carrier telephone system,

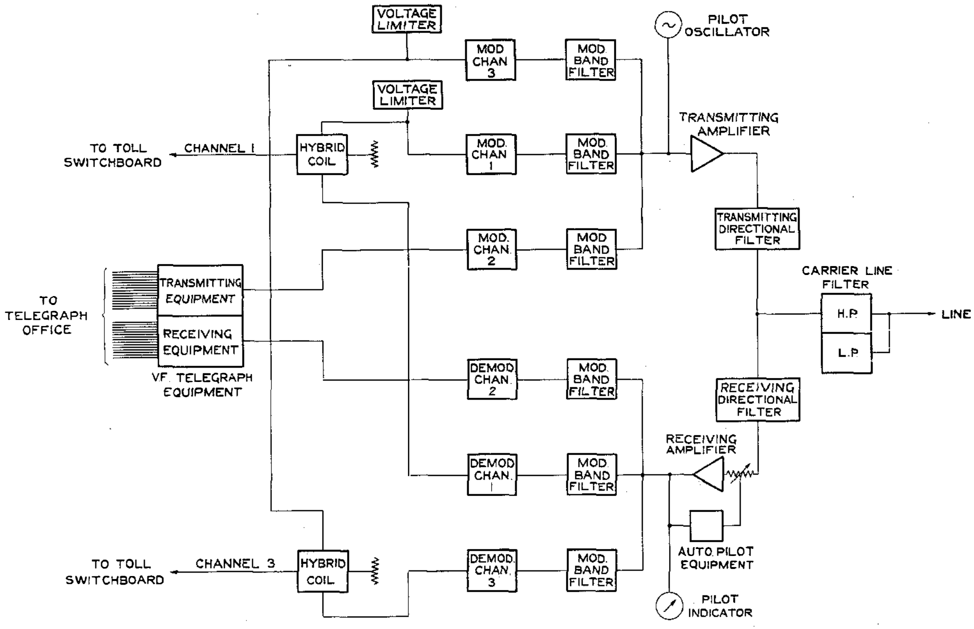


Fig. 4—Schematic of Carrier Terminal Equipment

i.e., 20 db. from modulator input to the line itself. The average power for a physical telegraph circuit working on an open wire line may be of the order of 3.5 watts (120 volts 30 milliamps).

The circuit between modulator input at the transmitting terminal and the demodulator output at the receiving terminal is operated at a gain of 8 db. This is in rough agreement with V.F. telegraph systems operated on a four-wire cable circuit and has been adopted on the Cape Town-Johannesburg system for general convenience.

Performance of the System

The operation of a carrier telephone system over 1,000 miles of open wire line has been effected elsewhere and no difficulties were experienced in securing high grade speech circuits in this instance. The automatic pilot channel is of material assistance in maintaining a 24 hour service substantially free from trouble. Care has to be taken to maintain line levels and a test line-up is carried out each week in order to check pilot channel operation.

Minor line faults, in general, leave the carrier telephone channels unaffected although the physicals may be unworkable. In times of severe static and thunderstorms slight noise becomes apparent on the channel using the lowest frequency band (channel 3 from Cape Town to Johannesburg) but the circuit is fully commercial. Broadcast programmes are frequently routed via a telephone channel between the two terminals. The frequency range is naturally limited but the absence of noise is appreciated.

Before describing the performance of the V.F. telegraph circuits, a short résumé of atmospheric conditions will be of interest. The route from De Aar to Johannesburg is liable to severe atmospheric electrical conditions from November to March—the intensity of these storms from a lightning point of view probably ranking with any experienced elsewhere.

High winds, driving dust against the lines, cause electrostatic voltages of the order of 300. The humidity in general is very low and high insulation conditions prevail. Rainfall is scanty. Two associated problems arise—protecting the equipment from injury and minimising the interference with the telegraph circuits.

It is believed that the first difficulty has been overcome by carbon-block lightning arrestors situated on the first and fifth poles outside an office. The gaps of these protectors are graduated, as shown in Fig. 5. Choke coils, consisting of 16 turns with an average diameter of 3″, are constructed of 7/22 V.I.R. cable and inserted in the lines between the office and the terminal outside protector.

Earth connections to all protectors are tested frequently. Difficulty is experienced in securing low earth resistances in some districts but, in general, values less than 3 ohms can be obtained. Inside the offices the usual line fuses and mica gap protectors are used.

The second problem is more difficult. The mutilations shown by the teleprinters originally covered, on the average, three or four letters. This time interval depends on the performance of the protectors and equipment under violent transient conditions. In this connection the vital points are, perhaps, grid-blocking of the amplifiers and the characteristics of the V.F. detector panels.[2] Grid-blocking of amplifiers has been reduced by the introduction on the line of a device shown in Fig. 5. The close coupling M between the two inductances L_1 and L_2 ensures that both protectors operate almost simultaneously. A discharge surge from a highly charged wire via the equipment and to earth through the operating protector is thereby avoided. Precise information is difficult to obtain but it is believed that the mutilations on the teleprinters have been reduced to a one letter interval by fitting these devices at all relevant points. The characteristics of the V.F. detector panels are such that the effect of a transient is greatly minimised and, in many cases, the receiving relays are not operated.

To prevent the accumulation of static charges on the lines, special repeating coils have been inserted on each side of each repeater station. The centre point of the line side of these coils is earthed. The complete protection is thus as illustrated in Fig. 5.

Mutilations have now been reduced to a low figure except in cases of severe storms near the route. Further investigation is being carried out. An automatic device in Johannesburg records all "flicks" and the information thus obtained is used to determine the efficacy of modifications.

With the above exception the telegraph circuits are capable of reliable, consistent service.

The measured distortion of the telegraph signals is of the same order as that obtaining on V.F. Telegraph systems operating over loaded cable circuits. Routine measurements of distortion are carried out by means of telegraph distortion measuring sets.[3]

The authors' thanks are due to the Chief Engineer of the Posts & Telegraphs Department of the Union of South Africa for permission to publish the information and photographs contained herein.

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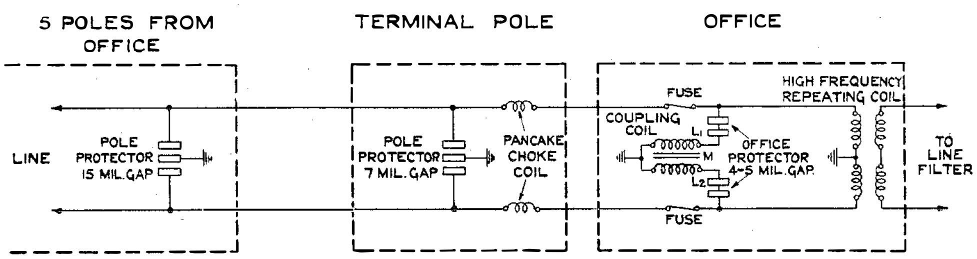

Fig. 5—Schematic of Line Protection

Telephonic Communications in China

By W. H. TAN

Secretary and Director, China Electric Company,
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DURING the past years, a serious effort has been made by those in authority in China for the establishment within the country of a good telephone communication system, both by the installation of new plant and by making improvements to the existing lines and equipment. This work has been carried out despite handicaps, including shortage of funds available for this type of work—it being considered more important to expend the money available on railroads and highways. Additional factors involved have been political disturbances, which in a number of cases have necessitated complete changes of plans; and the difficulties introduced by the existence in certain districts of bandits who have frequently completely removed the telephone wires. This latter difficulty is, however, not as serious as formerly, since the building of highways, in many cases, has provided the authorities with means for quickly reaching places where the presence of bandits is indicated. A country as vast as China is not easy to control, and it is only by close cooperation between the Ministry of Communications and the various operating Administrations that long distance telephony is becoming practicable.

Nearly every large city in China and also a great number of the smaller towns have telephone exchanges of one type or another, but facilities enabling subscribers in one town to talk to those in another have until recently been practically non-existent. Improvements and new projects recently undertaken have aimed at overcoming this deficiency.

There are approximately 164,000 telephone subscribers in the whole of China, of which approximately one-third are in the Shanghai area, which includes seven exchanges with over 52,000 subscribers in the system operated by the Shanghai Telephone Company, an associate company of the International Telephone and Telegraph Corporation. This company's system has been described in *Electrical Communication*.[1]

The Greater Shanghai area contains ten automatic exchanges with approximately 52,000 lines of automatic equipment. Automatic exchanges have also been installed in the cities indicated in the accompanying table.

AUTOMATIC EQUIPMENT INSTALLED IN CHINA

	No. of Lines
Canton	10,000
Changshu	1,000
Foochow	1,500
Hangchow	3,000
Hankow	8,500
Nanking	6,000
Shanghai Area	52,000
Swatow	1,000
Tientsin	9,000
Tsingtao	4,000

Automatic equipment installed in China totals 96,000 lines—65% Rotary and 35% Step-by-Step.

It is interesting to note that Peiping, with 16,400 subscribers, is still operating on the common battery manual system. Tientsin, in addition to three automatic offices with 9,000 lines, has two common battery manual offices with 6,000 lines. Other common battery manual exchanges of any size are: Soochow (2,000 lines), Tsinan (3,000 lines), Amoy (2,200 lines), and Wusih (1,400 lines). Ningpo has 2,100 magneto lines. Doubtless, when more important projects are completed, these common battery manual exchanges will gradually be converted to automatic.

With the exception of a cable installed underground between Canton and Hongkong, all toll lines are carried overhead. In the past, iron wire was mostly used, but recently an endeavor has been made to substitute copper wire on routes which are important from a traffic point

[1] "The Reconstruction of the Shanghai Telephone System," by J. Haynes Wilson, *Electrical Communication*, July, 1932.

of view. For some years, a few toll circuits have existed between Shanghai and Nanking, but up to two or three years ago the chance of getting a good connection over these circuits was very remote, chiefly on account of noise and poor transmission. However, about two years ago, a new pole route with copper wires was constructed following the new highway and this constituted a great improvement. Other long distance circuits which at present exist are those between Tientsin and Peiping, and Shanghai and Hangchow (Chekiang Province), as well as a comprehensive toll network in the latter Province. At present Hankow, with a population of approximately 1,500,000, is unable to communicate by telephone with any of the other larger cities in China.

In Canton, there is an exchange of the Rotary type having a capacity of 10,000 lines; and the cable between Canton and Hongkong provides efficient and stable toll circuits, but no means exist at present for communication between this system in the South and the cities in Central and Northern China.

The Hongkong-Canton cable was manufactured and installed in 1931 by Standard Telephones and Cables, London, and has been fully described in *Electrical Communication*.[2]

It is apparent from the above that the present state of telephone communications in China is poor, but the work now being undertaken by the authorities is such that this situation will, within the course of the next year or so, be considerably changed. The Government has been able to make arrangements with the British Boxer Indemnity Fund for the supply of a considerable amount of up-to-date equipment for making improvements in its long distance telephone system. The money which has been obtained from this source has been devoted to the establishment of two main systems, both of which will be described in the future in *Electrical Communication.* The first, which was nearing completion while the present article was being written, comprises several high power, short wave radio equipments which will provide telephonic communications between Shanghai, Hankow, and Canton. The second comprises equipment and line plant which will provide a long distance communications system by wire between important points in a number of provinces.

The planning of this system was carried out by the Chinese Telephone Administration in cooperation with Standard Telephones and Cables, London, which is supplying the toll boards, repeater equipment, and the cables for river crossings. The lines themselves have been designed in accordance with the most modern practices so that, at a future date, additional circuits can be obtained by the installation of carrier telephone equipment. Where the route crosses the large rivers of China, cables of special design and suitable for carrier telephony operation have been installed. The repeater equipment, located at a number of points along the route, is of the latest design and manufacture, and is of the type described in an article entitled: "The New Standard Repeater Equipment,"[3] by J. S. Lyall. Facilities provided on the toll boards which are being installed, will enable the speedy establishment of connections in the most efficient manner. It is expected that communication over the new system will be established between Shanghai and Hankow before the end of the present year.

An interesting means of providing telephone communication is being adopted in South China in the district around Canton, where the country is so cut up by rivers and creeks that the erection of pole line routes would be a difficult proposition. The authorities have decided in this case to employ 7–10 meter ultra-short wave radio facilities whereby a number of towns, which thus far have been isolated telephonically, will be brought in contact with the Canton telephone system.

The Ministry of Communications, in planning its telephone communication system, has not overlooked connections to other countries and has already established, by means of short wave radio, a circuit between Shanghai and Japan. For the past year or more, it has been carrying on tests with both England and America and it will not be long before China will be connected by radio to the large international telephone networks of the world.

[2] "Hongkong-Canton Toll Telephone Cable," by P. T. Carey and R. E. Burnett, *Electrical Communication*, April, 1932.

[3] "The New Standard Repeater Equipment," by J. S. Lyall, *Electrical Communication*, April, 1935.

Universal Telephone Set

THE wide variety of telephone sets which it has been necessary to manufacture and stock has presented a difficult problem to telephone manufacturers and operating telephone companies. Three different methods of operation, namely, local battery, common battery manual, and automatic, together with the need for sets for both table and wall mounting, are the causes for so many varieties.

The Bell Telephone Manufacturing Company,

Fig. 1—Universal Telephone Set Arranged for Local Battery Table Mounting.

Fig. 3—Universal Telephone Set Arranged for Automatic Table Mounting.

Fig. 2—Universal Telephone Set Arranged for Local Battery Wall Mounting.

Fig. 4—Universal Telephone Set Arranged for Automatic Wall Mounting.

Antwerp, Belgium, has taken a notable step towards the alleviation of this condition by the production of a new convertible bakelite set. The four illustrations show the appearance of what is fundamentally the same set:

Fig. 1 shows the set arranged for local battery table mounting;
Fig. 2, for local battery wall mounting;
Fig. 3, for automatic table mounting;
Fig. 4, for automatic wall mounting.

Common battery manual sets arranged for table and wall mounting would look the same as Figs. 1 and 2, respectively, except that the generator crank would be omitted and the crank hole covered.

It will be evident that a table set may be converted into a wall set, or vice versa, by simply rotating the microphone cradle 180°. This flexibility is achieved by inclining the plane of the cradle mounting surface at an angle of 45° with the plane of the set mounting surface.

In case the set is required for automatic operation, a dial adapter is placed under the dial when wall mounted and omitted when table mounted (Figs. 3 and 4). Thus the correct dial angle can be readily obtained regardless of the position in which the set will be mounted.

Magneto sets may be converted to manual common battery sets by changing the induction coil and omitting the generator crank. The addition of a dial and dial adapter, when necessary, converts the common battery manual into an automatic set.

The great flexibility of the new set will be appreciated from the preceding brief description, and it will be apparent that this set comes very close to being universal in its application.

The New Steel Tone Tape Machine*

AS A result of recent successful trials of the Steel Tone Tape machine by the Reichsrundfunk-Gesellschaft, problems involving electromagnetic tone recording are being given increased attention. As compared with film and disk methods, electromagnetic recording was neglected for a considerable period. The viewpoint was that its application would be limited to telephone signaling and control circuits and to the dictation of letters, messages, etc. Electromagnetic recording, however, as compared with the other two methods, has definite inherent advantages: before recording is completed, its quality can be tested; frequent reproduction does not cause deterioration; and, furthermore, erasure is a simple process and the tape can be reused indefinitely. In addition, electromagnetic recording and reproduction are not affected by external vibration, and relatively long uninterrupted use of records is practical. These characteristics are especially useful in the broadcasting field where it may frequently be desirable to record lengthy reports or speeches, and where facilities are required for making records while on a moving vehicle, such as a train or motor car. That the Steel Tone Tape machine is peculiarly fitted to meet these requirements has been shown by the experience of the Reichsrundfunk-Gesellschaft.

In the present article, the general technical considerations involved in the development and construction of the Steel Tone Tape machine will be discussed.

Mechanical Construction of the Steel Tone Tape Machine

Fig. 1 shows a view of the commercial machine which for purposes of transportation was designed in trunk form. Two large drums, "*a*" and "*b*," carry the steel recording tape which is 3 mm. wide and .08 mm. thick. Between these drums the steel tape travels through the erasing and recording mechanism "*c*," and the two reproducing mechanisms "*d*," as well as over the four guide rollers "*e*," and the main driving wheel "*f*." The arrangement is depicted schematically in Fig. 2.

Briefly, the mechanical considerations involved in the development of the Steel Tone Tape machine were the following:

(1) The steel tape, during recording and reproduction, must always travel at the same speed at a given stage of its progress through the electromagnetic mechanisms or "heads." For practical reasons, therefore, a constant tape velocity is desirable. Velocity restrictions obviously are imposed by the necessity of adhering to a definite frequency band.

(2) Both drums "*a*" and "*b*" must be arranged for winding up the steel tape. After each recording, the tape must be returned to the initial recording position.

(3) To achieve flexibility, the drums "*a*" and "*b*" must be readily interchangeable. After a tape has been used for recording purposes, it must be possible to readily substitute an unused tape for a subsequent recording.

It might be thought desirable to arrange either drum "*a*" or "*b*" for driving purposes according to need. This would be impracticable, however, due to the requirement that the tape be arranged to travel at a constant velocity; for, during winding and unwinding, the effective cross-sections of the drums with the tape partially wound thereon, change continuously. The tape is, therefore, driven by the drum "*f*" (Figs. 1 and 2). This drum, by means of a reducing gear, is mechanically connected to a motor and maintains a practically uniform speed, so that the tape is transported at constant velocity. In order to prevent slippage, a seamless textile belt, which is kept under tension, travels over "*f*," "*e*," "*l*," and "*e*," as indicated in Fig. 2 and maintains the steel tape tightly pressed against the main driving drum "*f*."

To meet requirement (2) above, the following construction was adopted:

(1) A driven drum on which the unrecorded tape is placed;

* Translated and republished in slightly abbreviated form from "Die neue Stahlton-Bandmaschine," ***Lorenz Berichte*** (No. 1, January, 1936), Technische Nachrichten der C. Lorenz Aktiengesellschaft, Berlin-Tempelhof.

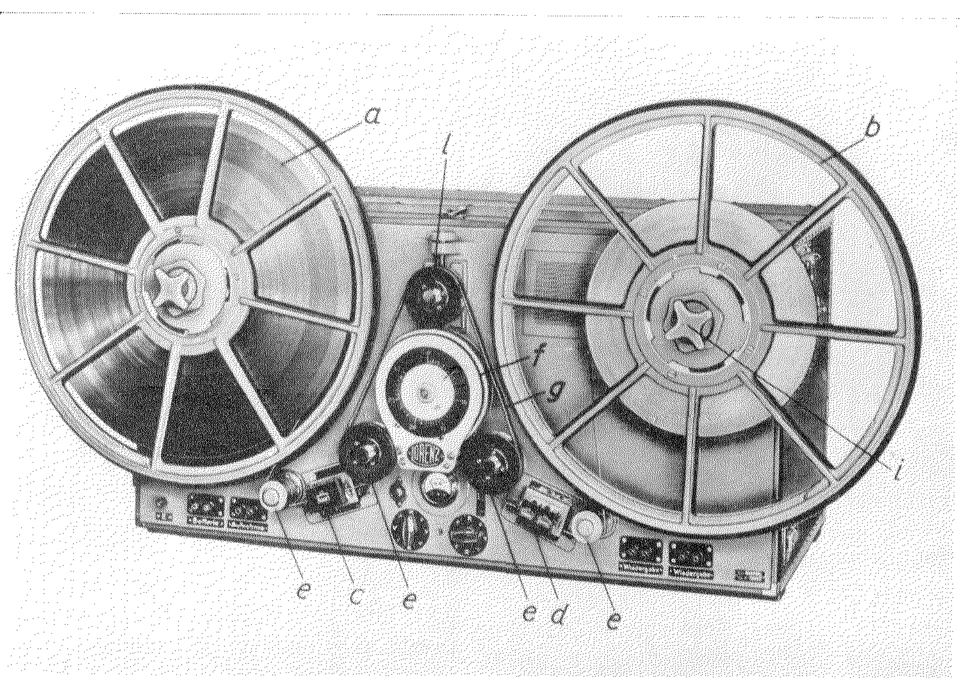


Fig. 1—Lorenz Steel Tone Tape Machine.

(2) A main driving drum "*f*"; and

(3) A driving drum on which the recorded tape is wound.

The design of the machine is such that the velocity of the tape on the three drums is identical. The driving tape drum must tend to accelerate in order to exert tension on the tape. It is, therefore, frictionally coupled to a driving mechanism which rotates at a velocity somewhat higher than is required for winding up the tape. The tendency of the driving drum to step ahead is counteracted by slippage at the frictional coupling. In the case of the driven drum, it is sufficient to provide braking to prevent undue acceleration.

Fig. 3 illustrates schematically the design of the driving drum. To wind up the steel tape "*a*" the drum "*b*" must rotate in the direction indicated by the arrow. The drum is driven by means of the belt "*d*" and the pulley "*c*" through the agency of the reversible coupling "*e*" and the frictional coupling "*f*." To convert the driving drum into the driven drum, when it is necessary to unwind the tape, "*e*" is held against the body of the machine "*h*." The axle "*g*" is thus held in a fixed position and the coupling "*f*" then operates as a brake on the drum.

To meet the third or interchangeability requirement, each tape drum has a large center hole which fits on to a cylinder on the axle "*k*" in a manner such that any drum can be assembled on either machine axle as required. The manipulation involved in interchanging drums is simple and can be accomplished in a single minute by means of a simple tool.

The problems involved in starting and stopping the machine merit attention. Under these conditions, a relatively great mass must be respectively accelerated and decelerated rather rapidly for satisfactory operation. The possibility, for example, of failure of the motor current supply must be considered. In this event, difficulty would hardly be experienced with the driving tape drum, inasmuch as it is connected by a belt with the main driving drum. The driven drum, however, must be braked in the event of failure of the power supply in order to prevent continued revolutions which might cause the steel tape to become entangled with subsequent breakage on restarting the machine.

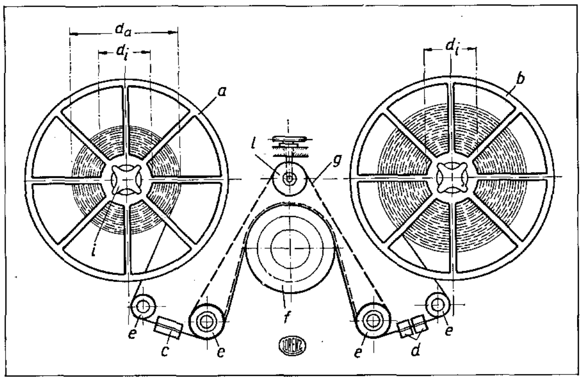


Fig. 2—Schematic Illustrating the Travel of the Steel Tone Tape.

The problem is simplified when stoppage occurs after a considerable period of operation, inasmuch as most of the tape is then unwound from the driven drum and its effective mass is smaller. In Fig. 4, the total drum weight is designated as *G;* the drum cross-section, d_a (the drum without the steel tape has a maximum diameter of $d_i = 20$ cm.); and the drum moment of inertia, *J.* Fig. 5 shows the relation of the length of operation versus the braking time for different braking moments. The weight of the drum without tape is taken as 4.6 kg. and its moment of inertia as 1.6 kg. cm.sec.^{2}, these figures being average for running periods between 20 and 40 minutes. In plotting the curves, the tape speed necessary for the required frequency band has been assumed to be 1.5 m./sec. The aim has been to provide the longest practicable recording period. From these curves, the relation of the elapsed recording to braking time will be evident. For the Steel Tone Tape machine, a compromise operating period of one-half hour has been chosen.

Constant braking on the driven drum and slippage of the driving tape drum obviously influence the size of the motor required. The power loss due to braking and slippage is:

$$N_v = \frac{736}{75} M_b(\omega_g + \omega_k - \omega_z) \text{ watts.} \qquad (1)$$

M_b is the braking moment which, because of the design, is alike for both the driving and the driven side, and is constant for a given total operating period; ω_k is the angular velocity of the constantly revolving half of the frictional coupling on the driving side; ω_z is the changing angular velocity of the driving drum; and ω_g is the changing angular velocity of the driven drum. ω_k is so chosen that it is always greater than ω_z. From equation (1), if $\frac{75}{736 M_b} = \alpha$:

$$\alpha \cdot N_v = \omega_g + \omega_k - \omega_z. \qquad (1a)$$

The relation between ω_g and ω_z, as will readily be apparent, is:

$$\omega_z = \frac{2\omega_g \cdot v}{\sqrt{\omega_g{}^2 k - 4v^2}}; \qquad (2)$$

and, therefore,

$$\alpha \cdot N_v = \omega_g + \omega_k - \frac{2\omega_g \cdot v}{\sqrt{\omega_g{}^2 k - 4v^2}}. \qquad (3)$$

v is the velocity of the steel tape, and k is a constant depending upon the operating period, and d_a^2 max.$+d_i^2$. $\alpha N_v = \omega_g + \omega_k - \omega_z$ has been plotted in Fig. 6 as a function of the elapsed recording time for a total recording period of 30 minutes. It follows that the power loss towards the end of the recording period is a maximum. The driving motor must, of course, be of sufficient capacity to take care of this maximum loss. Since, however, independent of the total recording period but towards its end, ω_g remains constant for a given cross-section d_i and a tape velocity of 1.5 m/sec., the maximum power loss changes only with ω_z. From the curve it will be seen, however, that the influence of ω_z

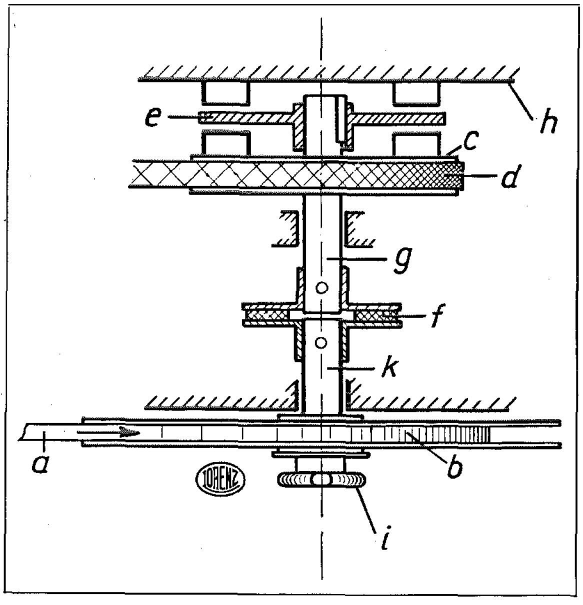


Fig. 3—Schematic of Drive of a Tape Drum.

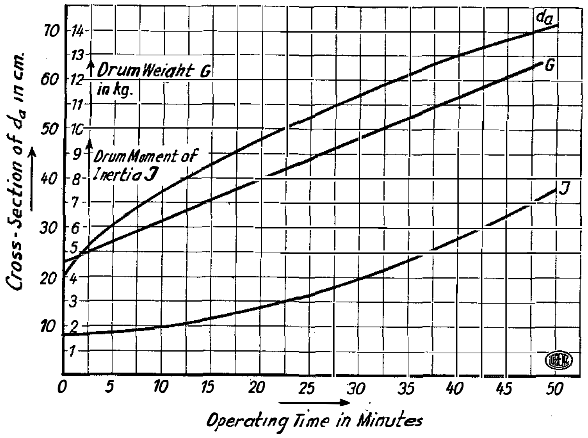


Fig. 4

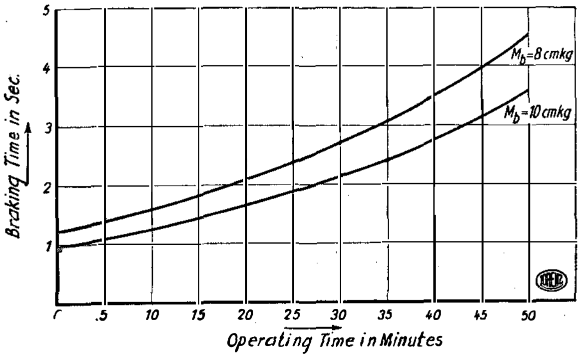


Fig. 5—Operating Time Versus Braking Time for Different Braking Moments.

with increasing time, approximately after 20 minutes, is no longer great. In fact, if the braking moment for any total running period could be held constant, the power loss would not be appreciably greater if a 45 minute instead of a 30 minute reproduction period were chosen. Since, however, with a specified braking time, the braking moment must increase with elapsed recording time (Fig. 5), α is no longer constant. The power loss, in accordance with equation (1), increases proportionally with the braking moment.

Magnetic Recording

Magnetic tone recording and reproduction, in recent years, have been the subject of a series of investigations and descriptive articles in the technical press.[1] In the development of the new tape machine for use in connection with broadcasting, experience up to date was utilized fully in order to achieve the requisite quality. Since a detailed description of the magnetic relations would be beyond the scope of this paper, only the fundamentals involved will be briefly considered. Three different operations are involved: (1) Erasure, (2) Recording, and (3) Reproduction. These three operations are performed with mechanisms which are alike in principle, viz., an erasure head, a recording head, and a reproduction head. These heads (Fig. 7) consist of cores "*a*" with spools "*b*." The cores "*a*" are movable longitudinally and are in each case offset slightly with respect to each other, and are pressed by means of springs "*c*" against the side of the tone tape "*d*." Fig. 7 illustrates the principle of the arrangement. The erasure and recording heads are arranged in a common housing and are shown in Fig. 8*a*; the reproduction heads, in Fig. 8*b*. The magnetic field in the cores and in the steel tape is illustrated by Fig. 9. The main lines of magnetic flow are indicated by *H*, and the stray flux by *St*. It will be noted that in the steel tape the flux *St* opposes *H*, and thus

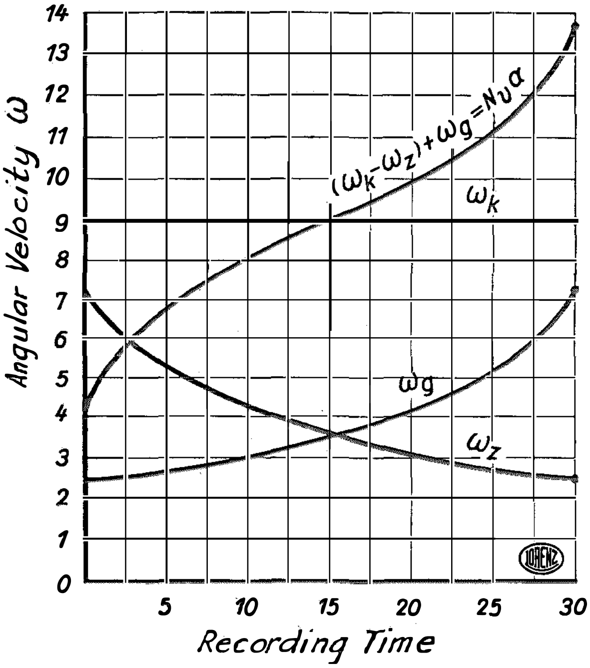


Fig. 6

[1] Hormann: "Zur Theorie der elektromagnetischen Tonaufzeichnung" *E. N. T.*, 1932, Heft 10; E. Meyer und E. Schüller: "Magnetische Schallaufzeichnungen auf Stahlbänder," *Zeitschr. f. tech. Physik*, 1932, Heft 12; S. Begun: "Beitrag zur Theorie der elektromagnetischen Tonaufzeichnung auf Stahldraht," Dissertation Sonderdruck Studentenhaus, 1933; Dr. Hans Joachim von Braunmühl: "Magnetische Schallaufzeichnung im Rundfunkbetrieb," Funk, 1934, Heft 40.

the latter is somewhat diminished. To simplify the following description, the stray flux will be neglected.

Erasure of the record from the steel tape is accomplished by magnetically saturating the tape (point S on the magnetization curve of Fig. 10) by means of the erasure head. After the tape passes beyond its field of influence, magnetization falls to the point R. The coils of the recording head are energized with a constant current I_g in a direction such that the resulting flux is opposed to that of the erasure flux and, in the vicinity of the recording heads, the magnetization of the tape reaches the point V. After passing beyond this head, the tape magnetization is represented by V'. During the process of recording, an alternating current I_w is imposed on the direct current I_g. As a result of the current I_g+I_w, the magnetization of the steel tape in passing the recording head oscillates between V_a and V_b with the point V as a mean. Beyond the sphere of influence of the recording head, the corresponding values rise to V_a' and V_b'. Since counter magnetization only very slightly distorts the magnetization curve, it may be neglected. Maximum results depend on the selection of the point V and on the slope of the useful portion of the magnetization curve.

The foregoing discussion of the recording process applies only when the zone affected by the recording head is regarded as a point or at least as very small compared with the wave-

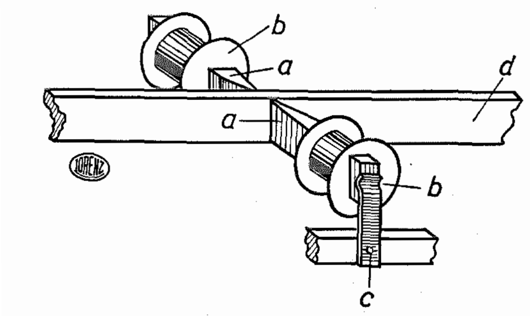


Fig. 7—Heads with Steel Tape, Illustrating Principle of Design.

length of the recording current. In the contrary case, the phenomena are extremely complex and their consideration would extend beyond the scope of this paper.

The lateral distance "a" between the off-set cores, also the effective core width "b" (Fig. 9),

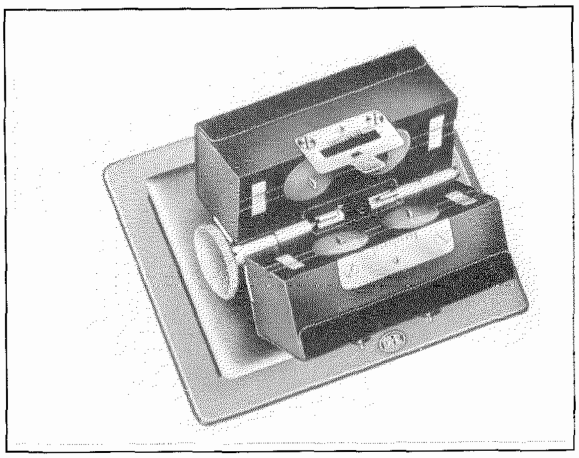


Fig. 8a—Erasing and Recording Heads.

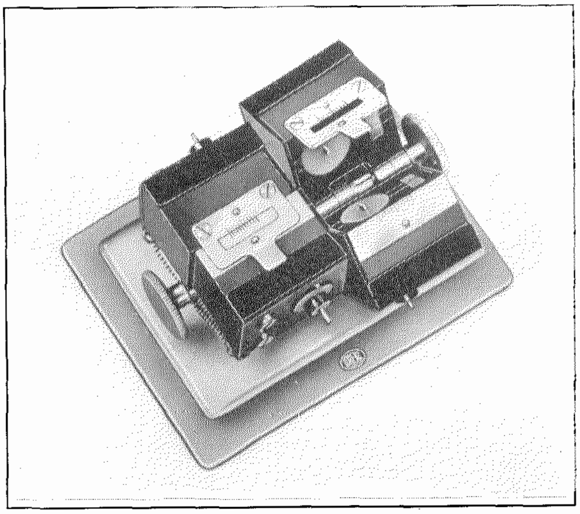


Fig. 8b—Reproduction Heads.

are of controlling importance in connection with the zone of influence of the recording head. In order that these dimensions may be kept small, the cores are pointed and the off-set between the two cores is made as small as practicable. Fig. 8 shows the micrometer screw for adjusting this off-set, which must have a specified minimum width in order that the direction of the main magnetic flux in the steel tape will be longitudinal. For practical recording purposes, the tape must be magnetized in a lengthwise direction.

Since the fundamental relations involved in recording have been described, it will be necessary to consider the influence of the stray flux. It will be desirable first to return to the phenomena involved in erasing the record from the tape. When under the influence of the erasure cores, the steel tape is magnetized to the point S on the magnetization curve (Fig. 10). After a cross-sectional element of the steel tape passes from the zone of influence of the primary flux to that of the secondary flux, magnetization falls from the point R to R_1 and finally through counter magnetization reaches R_1'. The location of the point R_1 on the magnetization curve is dependent on the erasing magnetic flux. In the most unfavorable case R_1 may fall to a very low point on the straight portion of the magnetization curve. By careful determination of the magnetizing flux of the erasing cores, however, the influence of the stray flux need not be disturbing even though a small portion of the upper branch of the magnetization curve no longer serves a useful purpose. In recording, however, the stray flux, compared to the useful flux, is of some importance because of its counter influence beyond the point at which recording takes place. For this reason the direct current magnetization of the steel tape and, similarly, the maximum amplitude of the alternating speech flux relative to the straight portion of the magnetization curve must be kept small in order to prevent an undue

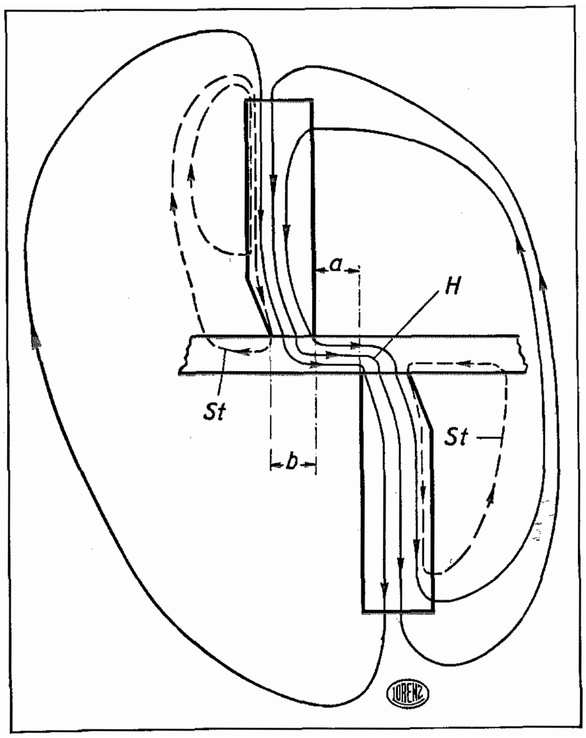


Fig. 9—Magnetic Flux in Cores and Steel Tape.

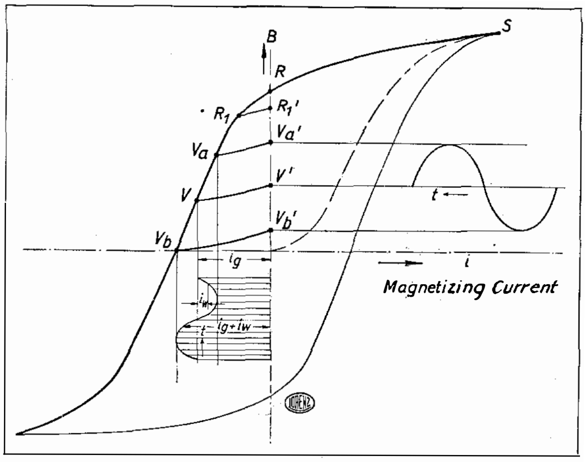


Fig. 10—Magnetization Curve Illustrating Phenomena Involved in Erasing and Recording.

increase in stray flux resulting from I_g+I_w. It follows, therefore, that the useful branch of the magnetization curve, rather than comprising the straight portion below R_1, is in reality considerably smaller. It should be noted also that, even though the recording current remains uniform in amplitude with increasing frequency, the amplitude of the flux induced in the tape decreases as a result of demagnetization phenomena, which will not be discussed herein.

Reproduction

In reproduction, the longitudinal flux emanating from the flat surface of the steel tape may be represented by

$$\Phi_a = \frac{d\Phi_i}{dl}, \qquad (4)$$

where Φ_i is the flux in a cross-section of the tape during pick-up. To simplify the description, it will be assumed that only a single magnetic core is associated with the steel tape. As soon as the core touches the steel tape the flux distribution, instead of remaining symmetrical with respect to the longitudinal axis of the tape, changes in accordance with Fig. 11, the flux density on the core side increasing. For the present purpose, however, this unsymmetrical flux distribution will be disregarded. As indicated in the illustration, the flux lines from the steel tape flow completely or partially through the core. If, however, it be assumed that all lines flow entirely through the core, the equation of flux in the core may be written:

$$\Phi_k = \tfrac{1}{2}\int_{l-\frac{b}{2}}^{l+\frac{b}{2}} \Phi_a dl = \tfrac{1}{2}\int_{l-\frac{b}{2}}^{l+\frac{b}{2}} d\Phi_i. \qquad (5)$$

When the steel tape contacts the core, the magnetizing force becomes

$$U = \alpha\frac{d\Phi_k}{dt} = \tfrac{1}{2}\alpha\frac{d}{dt}\int_{l-\frac{b}{2}}^{l+\frac{b}{2}} d\Phi_i, \qquad (6)$$

where α is a constant depending on the coil winding.

If the induced flux in the steel tape changes sinusoidally, we may write:

$$\Phi_i = \Phi_{max}\cdot\sin\omega t, \qquad (7)$$

provided the recording and reproduction tape speeds are the same. To solve equation (6), integration within limits in terms of time is necessary:

$$U = \tfrac{1}{2}\alpha\cdot\omega\cdot\Phi_{max}\cdot\frac{d}{dt}\int_{t-\frac{k_0T}{2}}^{t+\frac{k_0T}{2}} \cos\omega t dt, \qquad (8)$$

where T is the inverse of the frequency of the wavelength λ and $k_0 = b/\lambda$. In solving equation (8) we obtain the magnetizing force:

$$U_1 = \alpha\cdot\Phi_{max}\cdot\omega\cdot\sin k_0\pi\cdot\sin\omega t, \qquad (8a)$$

and the effective magnetizing force:

$$U = \frac{\alpha}{\sqrt{2}}\Phi_{max}\cdot\omega\cdot\sin k_0\pi. \qquad (9)$$

U equals zero when $\sin k_0\pi = 0$, also when $k_0 = 0$ or 1 or an integral multiple of π. That is, $k_0 = 0$ when the ratio of the core width to the wavelength becomes negligible or, in other words, when the recording flux frequency equals zero. $k_0 = 1_0$ when the width of the core equals the wavelength, that is, when the lines of flux are closed within the core. Sin $k_0\pi$ is maximum when $k_0 = \frac{1}{2}$, that is, when the width of the core equals one-half a wavelength.

With decreasing wavelengths recorded on the steel tape, the paths of the flux in the core become shorter and, correspondingly, a smaller part of the coil is enclosed by the flux (Fig. 12). The above equations, therefore, require modification to meet actual conditions. Furthermore, it has been assumed that Φ_{max} is constant for all frequencies, whereas in reality the magnetic amplitude decreases with increasing frequency. Experimental results check with this exposition.

Measurements show that the double core arrangement results in appreciable improvement. As previously mentioned, theoretical computations become much more involved for the case of the double core as compared with the single core. Certain controlling considerations are: With the double core, the reluctance of the magnetic circuit is considerably decreased and the efficiency is thus increased; furthermore, association of the two cores produces a certain addition of the magnetizing forces, depending on the phase relations, and also gives more satisfactory general results.

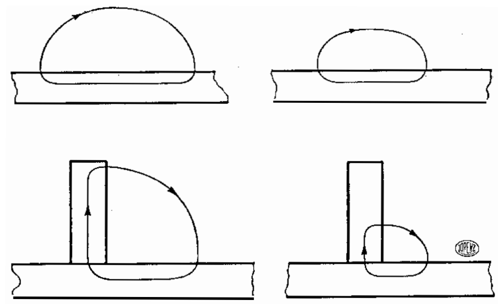


Fig. 11—Flux Distribution.

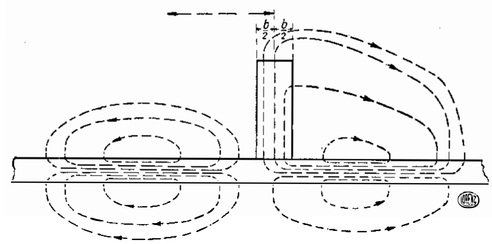


Fig. 12—Flux Distribution.

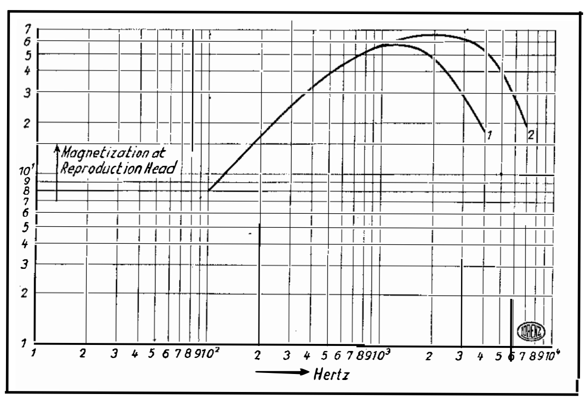


Fig. 13—Frequency Curves with Double Core Working.

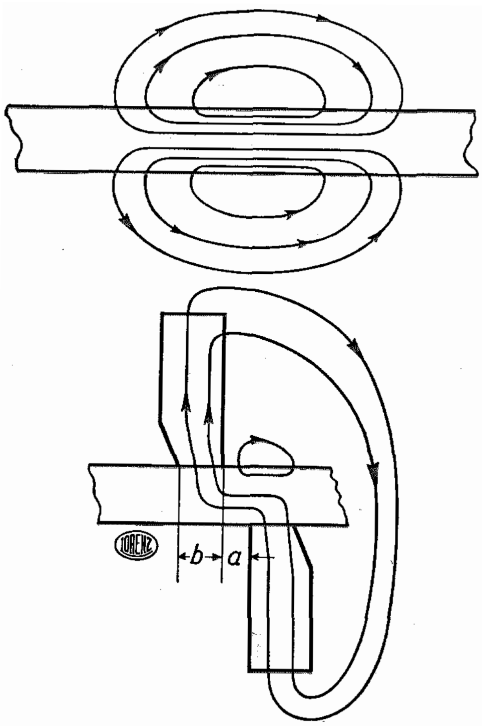


Fig. 14—Illustrating Increased Flux Obtained with Two Cores.

Fig. 13 shows the frequency curve for two core recording. Off-setting the cores is important, as already pointed out. As long as the sum of "*a*" and "*b*" (Fig. 14) is smaller than one-half the recording wavelength, the flux in both cores increases. With smaller areas of core contact and decreased lateral spacing between the cores, the high frequency characteristics of the mechanism are improved (Fig. 13). To procure a straight line frequency curve in the case of recording and reproduction, or both, simultaneous distortion corrective devices can be utilized. Practically straight line frequency curves can thus be obtained between 70–5500 Hz, which experience shows amply meet the requirements.

As in the case of disk and film reproduction, electromagnetic reproduction gives rise to inherent noise effects. Those extending over the entire frequency range are occasioned by magnetic inequalities and mechanical oscillations. The latter result from reactions between the steel tape and the cores, and are greatest at frequencies corresponding to the natural core frequencies, which may be between 4000–7000 Hz. Inasmuch as the dimensions of the parts involved cannot be identical, these frequencies result in difference and summation tones. However, in the case of electromagnetic reproduction, it is possible by suitable design to reduce the noise effects so that the ratio of the maximum to the disturbing amplitude is 85 : 1.

The new Steel Tone Tape machine has found many practical applications. For example, trials by the Reichsrundfunk-Gesellschaft, such as in trains in Hamburg, in underground tramways, and in automobiles (Fig. 15) were entirely satisfactory, and were made possible largely through technical developments of the last few years. In addition to its use in the radio and reportorial fields, electromagnetic tone recording and reproduction in the future will be applied to the solution of many problems which heretofore could not be successfully attacked because of the fact that the machine was not fully developed. Today, however, investigation of certain difficult problems can be resumed with reasonable expectation of achieving satisfactory results.

Fig. 15—Lorenz Steel Tone Tape Machine of the Reichsrundfunk-Gesellschaft.

A Discussion of Methods Employed in Calculations of Electromagnetic Fields of Radiating Conductors

By ANDREW ALFORD
Mackay Radio and Telegraph Company, New York

THERE are two procedures for caluclating the electromagnetic field in the neighborhood of a radiating conductor. One procedure is based on the use of the so-called Vector and Scalar potentials and the other, on the solution obtained by Heinrich Hertz for the field of a small dipole.

The first of these two methods has been used in a number of recent investigations on the interaction between radiating conductors. It is well adapted for calculating the electromagnetic field surrounding a linear radiator a half-wave or a number of half-wave lengths long wherein the current is assumed to be distributed in the form of a complete standing wave. Indeed, it will be shown later that this method applies to all radiating systems which are complete in themselves and in which no current either enters or leaves the radiating conductor. This requirement, that no current shall enter or leave the conductor, is tacitly assumed in the derivation of the formulae with which calculations by the first method are made, and constitutes the most serious limitation of the Vector-Scalar potential method. In fact, it is not applicable to terminated radiators now frequently made use of in high frequency transmitting as well as receiving antennae because large amounts of current must both enter and leave such radiators—a condition which violates the basic assumption made in the derivation of the method itself.

The second method, while somewhat more laborious and perhaps not quite as clean cut, is entirely free from this limitation. For this reason, despite being restricted, at least in its simplest form, to conductors with axial symmetry, it is suited for calculations of fields surrounding almost every type of radiator met with in practice.

While the second of these two methods is somewhat older than the first, it has not been applied in recent literature as much as it perhaps deserves to be. It, therefore, seems worth while to describe it in some detail, showing how it may be applied to terminated, as well as unterminated radiating conductors, and to compare the results obtained by this method with those obtained by the first, both when they should agree and when they should disagree because of the failure of the first method.

In view of the fact that the limitation of the first method referred to above is not generally mentioned in the literature, it appears advisable to include a somewhat detailed discussion of this subject.

I. The Second Method

As already mentioned, the second method is based on the solution for the field due to a small dipole. This solution, being a rigorous one, satisfies Maxwell's equations, as well as the boundary conditions, and may be made to serve as an elementary solution. Because of linearity of Maxwell's equations the sum of several solutions is also a solution. Consequently, if a radiating conductor could be broken up into a system of infinitesimal dipoles and the fields due to each of these dipoles were known, the total field could be obtained by addition or integration of the elementary fields. This very procedure with minor modifications will be employed for obtaining the field due to a radiating linear conductor.

Because of axial symmetry, it is convenient in these calculations to use cylindrical coordinates. Let Z_0 in Fig. 1 be the distance measured along the wire AB from A to some point D on the wire. Let ρ be the perpendicular distance from some point P in space to the wire or its continuation. Let Z be the distance from point A to the base of ρ, and Θ be the angle measured around the wire in counterclockwise direction from some arbitrary fixed plane through the wire. Let H_Θ, E_Z, and E_ρ be, respectively, the Θ component of

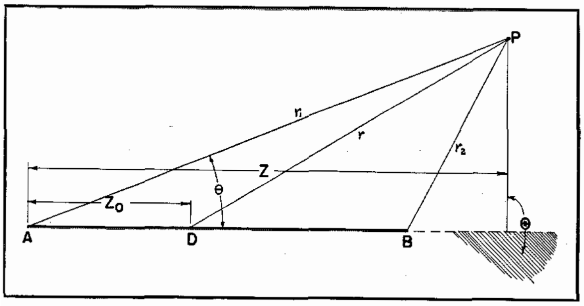


Fig. 1

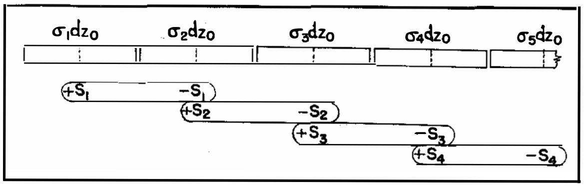


Fig. 2

the magnetic field, and the Z and the ρ components of the electric field. Then, if at some point D along the conductor AB, there is a dipole of moment $F(t)$ oriented so that its axis coincides with AB, the various components of the electric and magnetic fields produced by it at P are given by the following equations due to Hertz:

$$H_\Theta = \frac{1}{\rho}\frac{1}{C}\frac{\delta Q}{\delta t}, \tag{1}$$

$$E_Z = \frac{1}{\rho}\frac{\delta Q}{\delta \rho}, \tag{2}$$

$$E_\rho = -\frac{1}{\rho}\frac{\delta Q}{\delta Z}, \tag{3}$$

$$Q = \rho\frac{\delta}{\delta\rho}\frac{F\left(t-\frac{r}{C}\right)}{r}, \tag{4}$$

where $r = PD$, C is the velocity of light and t is the time. The Θ component of the electric field and the Z and ρ components of the magnetic field are equal to zero.

Any given charge distribution along conductor AB may be replaced by a suitable system of dipoles. Thus, for example, let $\sigma_1 dZ_0$, $\sigma_2 dZ_0, \cdots$ (Fig. 2) be the charges on the successive elements dZ_0 of the conductor. We may obviously put:

$$\sigma_1 dZ_0 = S_1,$$
$$\sigma_2 dZ_0 = S_2 - S_1,$$
$$\sigma_3 dZ_0 = S_3 - S_2, \text{ etc.}$$

Then charges S_1 and $-S_1$, S_2 and $-S_2$, etc., may be considered as charges on the opposite ends of dipoles of moments $S_1 dZ_0$, $S_2 dZ_0$, etc. We have in general

$$\sigma dZ_0 = \frac{\delta S}{\delta Z_0} dZ_0,$$

$$\sigma = \frac{\delta S}{\delta Z_0} \tag{5}$$

and hence

$$S = \int \sigma \delta Z_0 + N(t). \tag{6}$$

In this equation for S, $N(t)$ is as yet an arbitrary function of t. This arbitrary function appeared in the expression for S because it is possible to add or subtract a distribution of dipoles of equal strength along the wire without in any way disturbing the value of σ except at the ends of the wire. The value of this function may be found in each particular case from the boundary conditions of the problem.

Having replaced the given current distribution by a system of dipoles of moments SdZ_0, we may calculate the components of the electromagnetic field due to a typical dipole SdZ_0 and then obtain the total field by integration. Equations (1), (2), (3), and (4) give the components of the electromagnetic field due to a dipole of moment $F(t)$. Consequently, if in these equations, we replace $F(t)$ by SdZ_0, we shall have the components of the electromagnetic field due to SdZ_0. Thus, for example, the Θ component of the magnetic field due to SdZ_0 is

$$dH_\Theta = \frac{1}{\rho}\frac{1}{C}\frac{\delta}{\delta t}(dQ), \tag{7}$$

where

$$dQ = \rho\frac{\delta}{\delta\rho}\left(\frac{\bar{S}dZ_0}{r}\right). \tag{8}$$

In this equation $\bar{S}$ is equal to S in which t has been replaced by $\left(t-\frac{r}{C}\right)$.

The total magnetic field due to the system of dipoles is given by

$$H_\Theta = \int_A^B dH_\Theta = \int_A^B \frac{1}{\rho}\frac{1}{C}\frac{\delta}{\delta t}(dQ) = \frac{1}{\rho}\frac{1}{C}\frac{\delta}{\delta t}\int_A^B dQ;$$

that is,

$$H_\Theta = \frac{1}{\rho}\frac{1}{C}\frac{\delta Q}{\delta t}, \tag{9}$$

where

$$Q = \rho\frac{\delta}{\delta\rho}\int_A^B \frac{\bar{S}dZ_0}{r}. \tag{10}$$

The above transformations are allowable since the integration is performed with respect to Z_0 which is entirely independent of the coordinates ρ and Z of a point P in space.

What has been said with respect to H_Θ is, of course, directly applicable to the other components of the electromagnetic field. Thus we find that our system of dipoles produces the following electromagnetic field:

$$H_\Theta=\frac{1}{\rho}\frac{1}{C}\frac{\delta Q}{\delta t}, \quad (11)$$

$$E_Z=\frac{1}{\rho}\frac{\delta Q}{\delta \rho}, \quad (12)$$

$$E_\rho=-\frac{1}{\rho}\frac{\delta Q}{\delta Z} \quad (13)$$

where

$$Q=\rho\frac{\delta}{\delta\rho}\int_A^B\frac{\bar{S}dZ_0}{r}. \quad (14)$$

Here $\bar{S}$ has the same meaning as in (8).

When the distribution of charges on the wire propagates with velocity of light C and without distortion of form, the auxiliary quantity Q may be evaluated with comparative ease. Indeed, let us assume that

$$S(t, Z_0)=S\left(t-\frac{Z_0}{C}\right);$$

then

$$Q=\rho\frac{\delta}{\delta\rho}\int_A^B\frac{S\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}dZ_0.$$

If we put

$$u=t-\frac{r}{C}-\frac{Z_0}{C}$$

$$du=\frac{1}{C}\left(\frac{Z-Z_0}{r}-1\right)dZ_0,$$

we have

$$Q=\rho\frac{\delta}{\delta\rho}\int_{u_1}^{u_2}\frac{CS(u)}{Z-Z_0-r}du$$

or

$$Q=\rho\frac{\delta}{\delta\rho}\int_{u_1}^{u_2}\frac{CS(u)}{Z+(u-t)C}du.$$

In the last equation for Q, there are no quantities under the integral sign which depend on ρ. Consequently, the derivative with respect to ρ may be obtained by merely differentiating the limits; hence,

$$Q=\rho\left\{\frac{\delta u_2}{\delta\rho}\frac{CS(u_2)}{Z+(u_2-t)C}-\frac{\delta u_1}{\delta\rho}\frac{CS(u_1)}{Z+(u_1-t)C}\right\}.$$

If at A

$$Z_0=0 \quad \text{and at } B \quad Z_0=l,$$

we have

$$u_2=t-\frac{r_2}{C}-\frac{l}{C}, \qquad u_1=t-\frac{r_1}{C},$$

$$\frac{\delta u_2}{\delta\rho}=\frac{1}{C}\frac{\rho}{r_2}, \qquad \frac{\delta u_1}{\delta\rho}=\frac{1}{C}\frac{\rho}{r_1},$$

so that

$$Q=\frac{\rho^2}{r_2}\frac{S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{Z-r_2-l}-\frac{\rho^2}{r_1}\frac{S\left(t-\frac{r_1}{C}\right)}{Z-r_1}.$$

Since

$$(Z-r_1)(Z+r_1)=Z^2-r_1^2=-\rho^2,$$
$$(Z-l-r_2)(Z-l+r_2)=(Z-l)^2-r_2^2=-\rho^2,$$

it follows that

$$Q=S\left(t-\frac{r_1}{C}\right)\left(1+\frac{Z}{r_1}\right)-S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\left(1+\frac{Z-l}{r_2}\right). \quad (15)$$

From this value of Q the various components of the field may be obtained by differentiations in accordance with (11), (12), and (13). For example, the Θ component of the magnetic field is thus found to be

$$H_\Theta=\frac{S'\left(t-\frac{r_1}{C}\right)}{C\rho}\left(1+\frac{Z}{r_1}\right)-\frac{S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{C\rho}\left(1+\frac{Z-l}{r_2}\right), \quad (16)$$

where

$$S'\left(t-\frac{r_1}{C}\right)=\frac{\delta}{\delta t}S\left(t-\frac{r_1}{C}\right),$$

$$S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)=\frac{\delta}{\delta t}S\left(t-\frac{r_2}{C}-\frac{l}{C}\right).$$

As equation (16) is of some interest, we will examine it in some detail. Let us, first, convince ourselves that H_Θ as given in (16) satisfies the various boundary conditions.

When $\rho\rightarrow0$ and $Z>l$ or $Z<0$, that is, along the continuations of the wire in either direction, H_Θ should vanish. This it does. In fact for $Z<0$ and $\rho\rightarrow0$, we have

$$\left(1+\frac{Z}{r_1}\right)\rightarrow0,$$

$$\left(1+\frac{Z-l}{r_2}\right)\rightarrow0;$$

moreover as $\rho \to 0$,

$$\frac{1}{\rho}\left(1+\frac{Z}{r_1}\right)\to 0,$$

since the quantity in the parenthesis approaches zero as ρ^2. This may be made more apparent by putting

$$\rho = r_1 \sin\theta;$$

then

$$1+\frac{Z}{r_1} = 1-\cos\theta,$$

so that

$$\frac{1}{\rho}\left(1+\frac{Z}{r_1}\right) = \frac{1}{r_1}\frac{\sin^2\theta/2}{\sin\theta/2\cos\theta/2}.$$

This obviously approaches zero when $\theta \to 0$. In a similar manner, it may be shown also that

$$\frac{1}{\rho}\left(1+\frac{Z-l}{r_2}\right)\to 0$$

when $\rho \to 0$. Consequently, $H_\Theta \to 0$ when $\rho \to 0$ and $Z<0$.

When $Z>l$ and $\rho \to 0$,

$$\left(1+\frac{Z}{r_1}\right)\to 2, \qquad \left(1+\frac{Z-l}{r_2}\right)\to 2$$

and

$$\frac{r_2}{C}+\frac{l}{C}\to\frac{r_1}{C}.$$

Moreover all of the following quantities,

$$\epsilon_1 = 1+\frac{Z}{r_1}-2,$$

$$\epsilon_2 = 1+\frac{Z-l}{r_2}-2,$$

$$\epsilon_3 = \frac{r_2+l}{C}-\frac{r_1}{C},$$

are of order ρ^2. Consequently, for very small values of ρ, we may write

$$\epsilon_1 = a\rho^2, \qquad \epsilon_2 = b\rho^2, \qquad \epsilon_3 = d\rho^2,$$

where a, b and d are all finite. Introducing these quantities into (16), we find

$$H_\Theta = \frac{S'\left(t-\frac{r_1}{C}\right)}{C\rho}(2+a\rho^2) - \frac{S'\left(t-\frac{r_1}{C}-d\rho^2\right)}{C\rho}(2+b\rho^2)$$
$$= \frac{2}{C}\left[\frac{S'\left(t-\frac{r_1}{C}\right)-S'\left(t-\frac{r_1}{C}-d\rho^2\right)}{\rho}\right] + \left[a\rho S'\left(t-\frac{r_1}{C}\right)-b\rho S'\left(t-\frac{r_1}{C}-d\rho^2\right)\right].$$

Now, if the derivative of $S'\left(t-\frac{r_1}{C}\right)$ is finite, we have

$$S'\left(t-\frac{r_1}{C}\right)-S'\left(t-\frac{r_1}{C}-d\rho^2\right) = -d\frac{\delta S'}{\delta t}\rho^2,$$

so that

$$H_\Theta = \frac{2}{C}\rho d\frac{\delta S'}{\delta t}+\rho\left[aS'\left(t-\frac{r_1}{C}\right)-bS'\left(t-\frac{r_1}{C}-\rho^2 d\right)\right].$$

This expression obviously approaches zero when $\rho \to 0$.

Next we must examine the behavior of H_Θ near the wire. When $\rho \to 0$ and $0<Z<l$, H_Θ reduces to

$$H_\Theta = \frac{2S'\left(t-\frac{Z_0}{C}\right)}{C\rho}. \tag{17}$$

This would be exactly what we should expect if $S'\left(t-\frac{Z_0}{C}\right)$ were equal to the current at the particular value of Z_0. Let us show that this is the case provided we neglect the derivative of the arbitrary function which occurs in (6). From the equation of continuity which must always hold along any conductor we have

$$\text{div}\, i+\frac{\delta\sigma}{\delta t} = 0. \qquad \text{(E)*}$$

Since we are dealing with only one dimension, this reduces to

$$\frac{\delta i}{\delta Z_0}+\frac{\delta\sigma}{\delta t} = 0; \tag{18}$$

Consequently,

$$i = -\int\frac{\delta\sigma}{\delta t}dZ_0 = -\frac{\delta}{\delta t}\int\sigma dZ_0.$$

In view of (6) we may also write

$$i = -\frac{\delta S}{\delta t}+\frac{\delta N(t)}{\delta t} = -S'\left(t-\frac{Z_0}{C}\right)+\frac{\delta N(t)}{\delta t}.$$

Hence $i=-S'$ when $\delta N(t)/\delta t = 0$. The minus sign before S' has no particular significance as far as (17) is concerned because this sign merely has to do with the sense of H_Θ. From the above discussion, it may be concluded that the boundary conditions are satisfied only if $\delta N(t)/\delta t = 0$; that is, only if $N(t) =$ a constant. Then and only then does

$$H_\Theta = -\frac{2i}{C\rho}$$

near the wire, as should be the case.

* See page 84, equation (e).

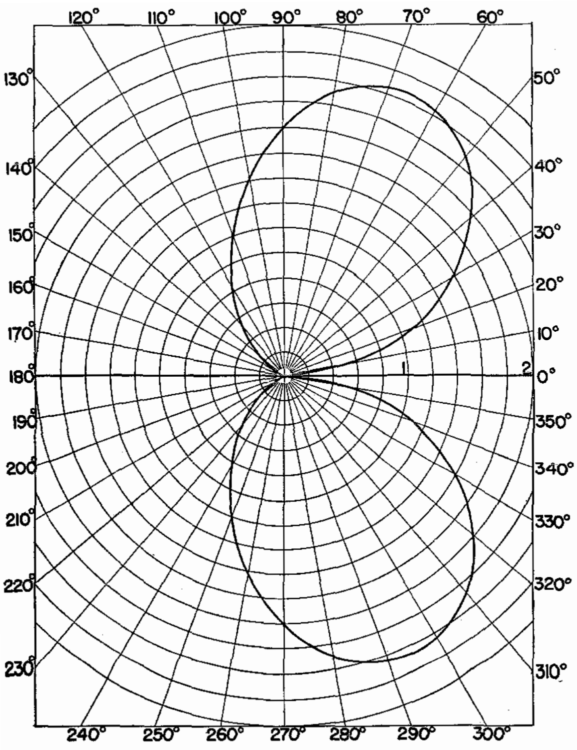


Fig. 3

So far, we have examined the behavior of H_Θ near the wire. We now wish to inquire what happens to H_Θ at a great distance from the wire. When r_1 is assumed to be very large, the following equations hold (see Fig. 1):

$$\frac{Z}{r_1}=\frac{Z-l}{r_2}=\cos\,\theta,$$

$$\rho=r_1\,\sin\,\theta,$$

$$r_1-r_2=l\,\cos\,\theta$$

and

$$H_{\Theta\infty}=\frac{1}{r_1C}\cot\frac{\theta}{2}\left\{S'\left(t-\frac{r_1}{C}\right)-S'\left[\left(t-\frac{r_1}{C}\right)-\frac{l}{C}(1-\cos\,\theta)\right]\right\}. \quad (19)$$

From this equation, it is clear that when $r_1\rightarrow\infty$, $H_{\Theta\infty}\rightarrow 0$. The same relations obtain, even when $\theta=0$ or $180°$; for, as we have already seen, $H_\Theta=0$ along the continuations of the wire for any value of r_1.

Before leaving H_Θ, it may be well to point out that equations (16) and (19) hold good regardless of the shape of the current wave as long as this wave propagates with the velocity of light and without distortion. For example, these equations should be useful in calculations of magnetic fields produced by lightning surges traveling along power transmission lines, as well as in the studies of radiation fields of terminated antennae with sinusoidal current distributions.

We shall now derive an expression for E_Z. This expression may be obtained from (15) by performing the differentiation indicated in (12). Since

$$\frac{\delta}{\delta\rho}S\left(t-\frac{r_1}{C}\right)=-S'\left(t-\frac{r_1}{C}\right)\frac{\rho}{Cr_1},$$

$$\frac{\delta}{\delta\rho}S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)=-S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\frac{\rho}{Cr_2},$$

we have

$$E_Z=-\frac{S'\left(t-\frac{r_1}{C}\right)}{Cr_1}\left(1+\frac{Z}{r_1}\right)+\frac{S'\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{Cr_2}\left(1+\frac{Z-l}{r_2}\right)-S\left(t-\frac{r_1}{C}\right)\frac{Z}{r_1^3}+S\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\frac{Z-l}{r_2^3}. \quad (20)$$

It is quite apparent from this equation that the electric field is made up of two parts: The first part is in the nature of a radiation field which varies roughly as $1/r$. The second part is a purely electrostatic field, due to charges at the ends of the wire.

Equation (20) enables us to learn a little more regarding the physical nature of $N(t)$ which first occurred in (6) and which was later shown to be a

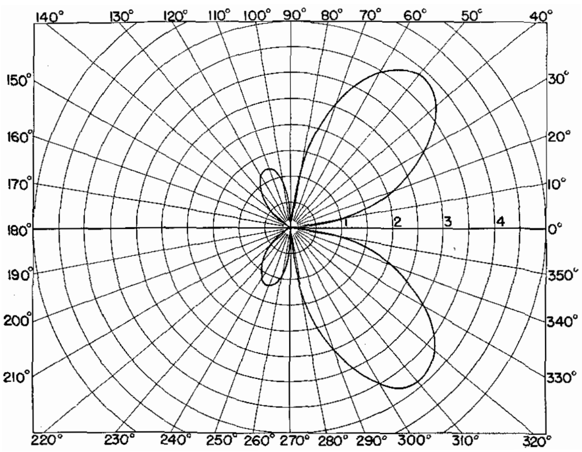


Fig. 4

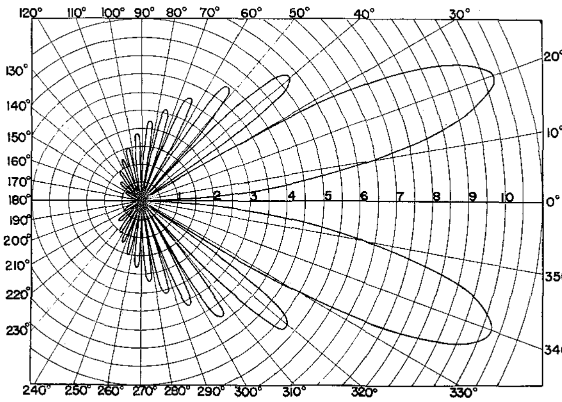


Fig. 5

constant. Indeed, by adding a constant N to S in (20), we add

$$e_Z = -N\frac{Z}{r_1^3} + N\frac{Z-l}{r_2^3}$$

to E_Z. The first term in e_Z is obviously the Z component of the $1/r^2$ field due to charge $+N$ at $Z=0$. Similarly, the second term in e_Z is due to charge $-N$ at $Z=l$. When we are dealing with a purely alternating distribution of current, we must be careful to select S in such a manner that it contains no terms which are independent of time. This may be done by adding a proper value of N. In general, the choice of N presents little difficulty as long as its physical nature and its origin are kept in mind.

A case of considerable practical interest to radio engineers is obtained by putting

$$i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right).$$

This is roughly the distribution of current actually obtained in the so-called "terminated antennae" (Rhombic antennae, Beverage antennae, etc.). In these antennae the wires are terminated into their surge impedances so that current waves are not reflected from the end. When

$$i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right),$$

we have

$$S' = i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right)$$

$$S = -\frac{i_0}{\omega}\cos \omega\left(t - \frac{Z_0}{C}\right) + c$$

$$c = 0.$$

From (16)

$$H_\Theta = \frac{i_0}{C\rho} \sin \omega\left(t - \frac{r_1}{C}\right)\left(1 + \frac{Z}{r_1}\right) - \frac{i_0}{\rho C} \sin \omega\left(t - \frac{r_2}{C} - \frac{l}{C}\right)\left(1 + \frac{Z-l}{r_2}\right). \quad (21)$$

From (19), for very large values of r,

$$H_{\Theta\infty} = \frac{2i_0}{Cr_1} \cot\frac{\theta}{2} \sin\left[\frac{\omega l}{2C}(1 - \cos\theta)\right] \cos\left[\omega\left(t - \frac{r_1}{C}\right) - \frac{\omega l}{2C}(1 - \cos\theta)\right]. \quad (22)$$

From (20)

$$E_Z = -\frac{i_0 \sin \omega\left(t - \frac{r_1}{C}\right)}{Cr_1}\left(1 + \frac{Z}{r_1}\right) + \frac{i_0 \sin\left(t - \frac{r_2}{C} - \frac{l}{C}\right)}{Cr_2}\left(1 + \frac{Z-l}{r_2}\right) + \frac{i_0}{\omega}\cos \omega\left(t - \frac{r_1}{C}\right)\frac{Z}{r_1^3} - \frac{i_0}{\omega}\cos \omega\left(t - \frac{r_2}{C} - \frac{l}{C}\right)\frac{Z-l}{r_2^3}. \quad (23)$$

The amplitude of $H_{\Theta\infty}$ has been plotted against θ in Figs. 3, 4 and 5 for $l=\lambda/2$, $l=\lambda$, $l=6\lambda$. All of these figures clearly show the assymmetrical nature of radiation from terminated wires. For the sake of completeness, the angle of maximum radiation from wires of various lengths is given in Fig. 6. From this figure, incidentally, it appears that the angle of maximum radiation from a terminated wire 1/2 λ long is not 90° but 68°. For longer wires, the angles of maximum radiation approach those for unterminated wires with standing waves.[1]

[1] See equations (28) and (29).

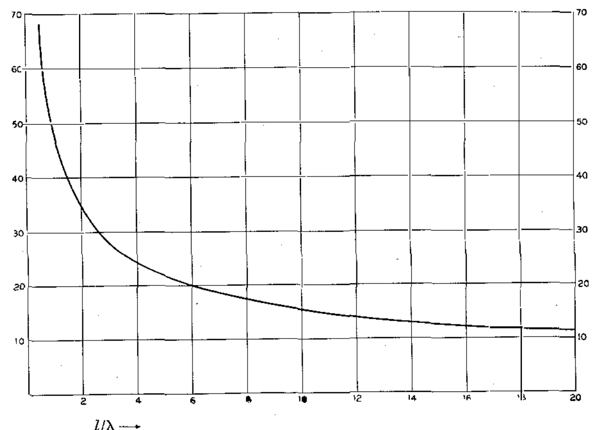


Fig. 6

The power radiated by a terminated antenna may be calculated by two methods.

First Method: This method is based on the properties of the Poynting Vector. If we surround the wire by a large imaginary sphere of radius r_1 with its center at $Z=0$, the power which passes through each surface element dS of this sphere is given by

$$dP=\frac{CH_{\theta\infty}^2}{4\pi}\,dS.$$

Since $H_{\theta\infty}$ is constant along small circles defined by $\theta=$ a constant, it is convenient to divide the whole surface into annular elements delimited by small circles which correspond to $\theta=\theta_1$ and $\theta=\theta_1+d\theta_1$. The surface of the annular region formed in this manner is

$$dS=2\pi r_1^2 \sin\theta d\theta.$$

The power radiated through the annular element is

$$dP=\frac{CH_{\theta\infty}^2}{4\pi}\,2\pi r_1^2\sin\theta d\theta.$$

Hence the total power radiated through the sphere at any given instant is given by

$$P=\int_0^\pi \frac{CH_{\theta\infty}^2}{4\pi}\,2\pi\sin\theta r_1^2 d\theta$$

$$=\frac{2i_0^2}{C}\int_0^\pi \cot^2\frac{\theta}{2}\sin^2\frac{\omega l}{2C}(1-\cos\theta)\cos^2\left[\omega t-\frac{\omega l}{2C}(1-\cos\theta)\right]d\theta.$$

The average power radiated per cycle is given by

$$\overline{P}=\frac{\omega}{2\pi}\int_0^{2\pi/\omega}Pdt;$$

that is,

$$\overline{P}=\frac{2i_0^2}{C}\int_0^\pi\frac{\omega}{2\pi}\int_0^{2\pi/\omega}\cot^2\frac{\theta}{2}\sin^2\frac{\omega l}{2C}(1-\cos\theta)\cos^2\left[\omega t-\frac{\omega l}{2C}(1-\cos\theta)\right]d\theta dt.$$

By carrying out the integration with respect to t first we get

$$\overline{P}=\frac{i_0^2}{C}\int_0^\pi\cot^2\frac{\theta}{2}\sin^2\frac{\omega l}{2C}(1-\cos\theta)d\theta.$$

If we now put $u=1-\cos\theta$ and note that

$$\cot^2\frac{\theta}{2}=\frac{1+\cos\theta}{1-\cos\theta},$$

we obtain

$$\overline{P}=\frac{i_0^2}{C}\int_0^2\left(\frac{2}{u}-1\right)\sin^2\frac{\omega l}{2C}u\,du$$

$$=\frac{i_0^2}{C}\int_0^2\frac{1-\cos\frac{\omega l}{C}u}{u}du-\frac{i_0^2}{C}\int_0^2\sin^2\frac{\omega l}{2C}u\,du,$$

$$P=\frac{i_0^2}{C}\int_0^2\frac{1-\cos\frac{\omega l}{C}u}{u}du-\frac{i_0^2}{C}\left(1-\frac{\sin\frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right). \tag{24}$$

Second Method: By putting $r_1=Z_0$, $r_2=l-Z_0$ in (23), we find that the electric field along the wire is given by

$$E_2'=-2i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}+\frac{i_0\cos\omega\left(t-\frac{Z_0}{C}\right)}{\omega Z_0^2}+i_0\frac{\cos\omega\left(t+\frac{Z_0}{C}-\frac{2l}{C}\right)}{\omega(l-Z_0)^2}.$$

The drop of potential across an element dZ_0 of the wire is $E_Z'dZ_0$. Whenever current flows against a drop of potential it does work. The rate at which this work is done, that is, power, is given by the product of the in-phase components of the current and the opposing potential drop. In this case, the current is $i=i_0\sin\omega(t-Z_0/C)$ and the drop of potential opposing the current is

$$-E_Z'dZ_0=2i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}dZ_0-i_0\frac{\cos\omega\left(t-\frac{Z_0}{C}\right)}{\omega Z_0^2}dZ_0-i_0\frac{\cos\omega\left(t-\frac{Z_0}{C}\right)\cos\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0-i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0.$$

The in-phase component of $-E_Z'dZ_0$ is

$$-E_Z''dZ_0=2i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)}{CZ_0}-i_0\frac{\sin\omega\left(t-\frac{Z_0}{C}\right)\sin\frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}dZ_0.$$

Consequently, the power dissipated in dZ_0 is

$$dP = -iE_z''dZ_0 = 2i_0^2 \frac{\sin^2 \omega\left(t-\frac{Z_0}{C}\right)}{CZ_0} dZ_0$$

$$- i_0^2 \frac{\sin^2 \omega\left(t-\frac{Z_0}{C}\right) \sin \frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2} dZ_0.$$

The average power per cycle is

$$d\bar{P} = \frac{\omega}{2\pi}\int_0^{2\pi/\omega} dP\delta t$$

$$= \frac{i_0^2}{2}\left[\frac{2}{CZ_0} - \frac{\sin \frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2}\right] dZ_0. \quad (25)$$

The power radiated by the portion of the wire included between $Z_0=\alpha$ and $Z_0=l-\alpha$ is given by

$$\bar{P} = \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \frac{2}{CZ_0} dZ_0 - \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \frac{\sin \frac{2\omega}{C}(l-Z_0)}{\omega(l-Z_0)^2} dZ_0.$$

If in the second integral we put $l-Z_0=u$, we have

$$\bar{P} = \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \frac{2}{CZ_0} dZ_0 - \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \frac{\sin \frac{2\omega u}{C}}{\omega u^2} du$$

or

$$\bar{P} = \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \frac{2}{CZ_0} dZ_0 - \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \frac{2 \cos \frac{2\omega}{C} u}{Cu} du$$

$$+ \left. \frac{\sin \frac{2\omega u}{C}}{\omega u} \right|_\alpha^{l-\alpha}.$$

If now in the first integral we let $u=Z_0$, we may write

$$\bar{P} = \frac{i_0^2}{2}\int_\alpha^{l-\alpha} \left[\frac{2}{Cu} - \frac{2 \cos \frac{2\omega}{C} u}{Cu}\right] du + \frac{i_0^2}{2} \left. \frac{\sin \frac{2\omega u}{C}}{\omega u} \right|_\alpha^{l-\alpha}.$$

When $\alpha \to 0$, this becomes

$$\bar{P} = \frac{i_0^2}{2}\int_0^{l} \left[\frac{2}{Cu} - \frac{2 \cos \frac{2\omega}{C} u}{Cu}\right] du - \frac{i_0^2}{C}\left(1 - \frac{\sin \frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right);$$

or if we put

$$u = \frac{l}{2}u',$$

$$\bar{P} = \frac{i_0^2}{C}\int_0^2 \frac{1-\cos \frac{\omega u'}{C}}{u'} du' - \frac{i_0^2}{C}\left(1 - \frac{\sin \frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right) \quad (26)$$

This is exactly the same result as the one already obtained by the previous method. Equation (26) gives the power radiated from a terminated wire in terms of the peak current i_0 and the length of the wire in wavelengths.

For convenience of discussion, we may introduce a fictitious resistance R defined as follows:

$$R\left(\frac{i_0}{\sqrt{2}}\right)^2 = \bar{P}.$$

This resistance may be called the Radiation Resistance of a terminated wire.

From (26) we have

$$R = \frac{2}{C}\int_0^2 \frac{1-\cos \frac{l\omega u}{C}}{u} du - \frac{2}{C}\left(1 - \frac{\sin \frac{2\omega l}{C}}{\frac{2\omega l}{C}}\right).$$

If we put

$$\beta = \frac{\omega l}{C} = 2\pi\frac{l}{\lambda}$$

and

$$\chi = \beta u,$$

then

$$R = \frac{2}{C}\int_0^{2\beta} \frac{1-\cos \chi}{\chi} d\chi - \frac{2}{C}\left(1 - \frac{\sin 2\beta}{2\beta}\right)$$

$$= \frac{2}{C}\left[\log_e 2\beta + \text{sil } 2\beta + \gamma - 1 + \frac{\sin 2\beta}{2\beta}\right], \quad (26A)$$

where

$$\gamma = .577 \cdots.$$

In practical units, this becomes

$$R = 60\left[\log_e 2\beta + \text{sil } 2\beta + \gamma - 1 + \frac{\sin 2\beta}{2\beta}\right] \text{ ohms.} \quad (26B)$$

Fig. 7 illustrates variation of R with l/λ.

These results enable one to make some estimates of practical interest. As an example, consider a half wave antenna fed off-center by a single feeder of length L adjusted, as usual, so that it carries only traveling waves. Suppose that the average height of the feeder is $H=50'$ and that the diameter of the feeder is 0.162 inches (No. 6 A.W.G.). The surge impedance of the feeder is

$$Z_0 = 138 \log_{10} \frac{4H}{d} = 580 \text{ ohms.}$$

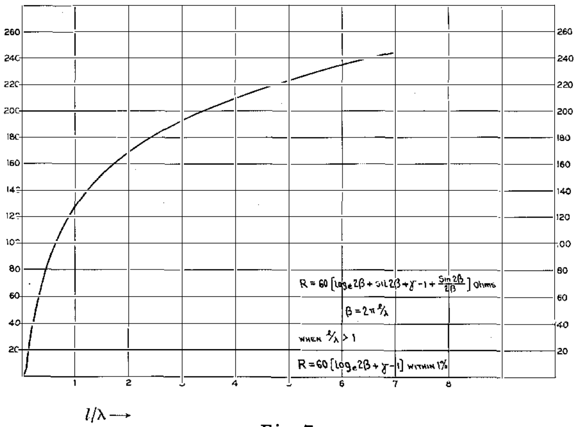


Fig. 7

Then if the R.M.S. current in the feeder is I, the power delivered to the feeder is

$$I^2 z_0 = 580 I^2 \text{ watts.}$$

On the other hand, the power radiated by the feeder is $I^2 R$, where R is the radiation resistance of the feeder given in terms of l/λ in Fig. 7. Suppose that the feeder is 1λ long, then $R = 127$ ohms. The power delivered to the half wave is

$$z_0 I^2 - R I^2 = 463 I^2,$$

that is,

$$\frac{463}{580} = .80$$

or 80% of the power delivered to the feeder. The balance of 20% is radiated by the feeder. These calculations are admittedly rough since the image of the feeder in the ground is not taken into account. When the feeder proceeds at an angle to ground so that the major portion of the feeder is a considerable fraction of a wavelength above ground, the above calculation should be approximately correct.

Before leaving this subject, we wish to call attention to equation (25) which was used in the calculation of the total radiated power. From this equation, it appears that when Z_0 is small $d\overline{P}$ is positive and when Z_0 is large, and particularly when it is nearly equal to l, $d\overline{P}$ is negative. This means that energy is thrown into space near $Z_0 = 0$ and partially reclaimed near $Z_0 = l$. Only the balance is radiated into free space. The amount of power which is circulated between the ends of the wire is very large; in fact, in accordance with our equations, it is infinite. This infinite value, however, is entirely due to the fact that in our calculations the wire was assumed to be very thin so that E_Z'' varies as $1/Z_0$ near $Z_0 = 0$ and as $1/(l - Z_0)$ near $Z_0 = l$. In any actual case E_Z'' cannot become infinite at $Z_0 = 0$ and at $Z_0 = l$ and consequently the amount of circulating power will be finite. Since our equations for E probably become correct a small distance away from the ends, we have every reason to expect that the amount of circulating power is large in reality as well as in the idealized theory.

Let us now consider a wire which is open ended at $Z_0 = l$. In this case, there will be two wave trains: the direct wave traveling forward, and the reflected wave traveling back. The current in the forward wave is given by

$$i = i_0 \sin \omega\left(t - \frac{Z_0}{C}\right);$$

the current due to the reflected wave is

$$i' = -i_0 \sin \omega\left(t + \frac{Z_0}{C} - \frac{2l}{C}\right)$$
$$= -i_0 \sin \omega\left[\left(t - \frac{l}{C}\right) - \frac{l - Z_0}{C}\right].$$

The total current at any place along the wire is

$$I = i + i' = -2i_0 \sin \omega \frac{l - Z_0}{C} \cos \omega\left(t - \frac{l}{C}\right).$$

The amplitude of the total current thus varies sinusoidally along the wire, starting with $I = 0$ at $Z_0 = l$. The loop current is $2i_0$. The electromagnetic field produced by this distribution of current may be easily calculated from our equations for traveling waves. Indeed, the total field is simply the sum of the fields—the field due to the direct wave and the field due to the reflected wave. For example, the H_Θ component produced by the direct wave according to (21) is

$$H_\Theta = \frac{i_0 \sin \omega\left(t - \frac{r_1}{C}\right)}{\rho C}\left(1 + \frac{Z}{r_1}\right)$$
$$- \frac{i_0 \sin \omega\left(t - \frac{r_2}{C} - \frac{l}{C}\right)}{\rho C}\left(1 + \frac{Z - l}{r_2}\right).$$

The H_Θ component produced by the reflected wave may be obtained from H_Θ by interchanging r_1 and r_2, also, Z and $l - Z$, and by putting

$(t-l/C)$ in place of t, and $-i_0$ in place of i_0.

After carrying out these changes, we obtain

$$H_\Theta' = -\frac{i_0 \sin \omega\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{\rho C}\left(1+\frac{l-Z}{r_2}\right) + \frac{i_0 \sin \omega\left(t-\frac{r_1}{C}-\frac{2l}{C}\right)}{\rho C}\left(1-\frac{Z}{r_1}\right).$$

The total field is $h_\Theta = H_\Theta + H_\Theta'$.

In a special case when l is equal to an integral number of half waves,

$$\frac{2\omega l}{C} = 4\pi\frac{l}{\lambda} = 2\pi N; \qquad N = 1, 2, 3, \cdots,$$

$$\sin \omega\left(t-\frac{r_1}{C}-\frac{2l}{C}\right) = \sin \omega\left(t-\frac{r_1}{C}\right)$$

and

$$h_\Theta = \frac{2i_0}{\rho C}\left[\sin \omega\left(t-\frac{r_1}{C}\right) - \sin \omega\left(t-\frac{r_2}{C}-\frac{l}{C}\right)\right]$$

$$= \frac{I_0}{\rho C}\left[\sin \omega\left(t-\frac{r_1}{C}\right) - (-1)^N \sin \omega\left(t-\frac{r_2}{C}\right)\right], \quad (27)$$

where $I_0 = 2i_0$ is the loop current. This equation is one of the equations first derived by Pistolkors[2] using the Vector Potential Method. If in (27) r_1 is assumed to be very large so that

$$r_1 - r_2 = l \cos \theta,$$
$$\rho = r_1 \sin \theta,$$

the magnetic field reduces to the well known equations for the radiation field due to wires an integral number of half waves long:[3]

$$h_{\Theta\infty} = \frac{2I_0}{Cr_1}\frac{\sin\left(\frac{\pi}{2}N\cos\theta\right)}{\sin\theta} \quad (28)$$

[2] "The Radiation Resistance of Beam Antennas," by A. A. Pistolkors, *Proceedings I. R. E.*, Vol. 17, No. 3, Mar. 1929, pp. 562–579.

[3] "Die electrischen Schwingungen um einen Stabförmigen Leiter, behandelt nach der Maxwell'schen Theorie," by Max Abraham, *Annalen der Physik und Chemie*, Vol. 66, No. 3, pp. 435–472, 1898, No. 11.

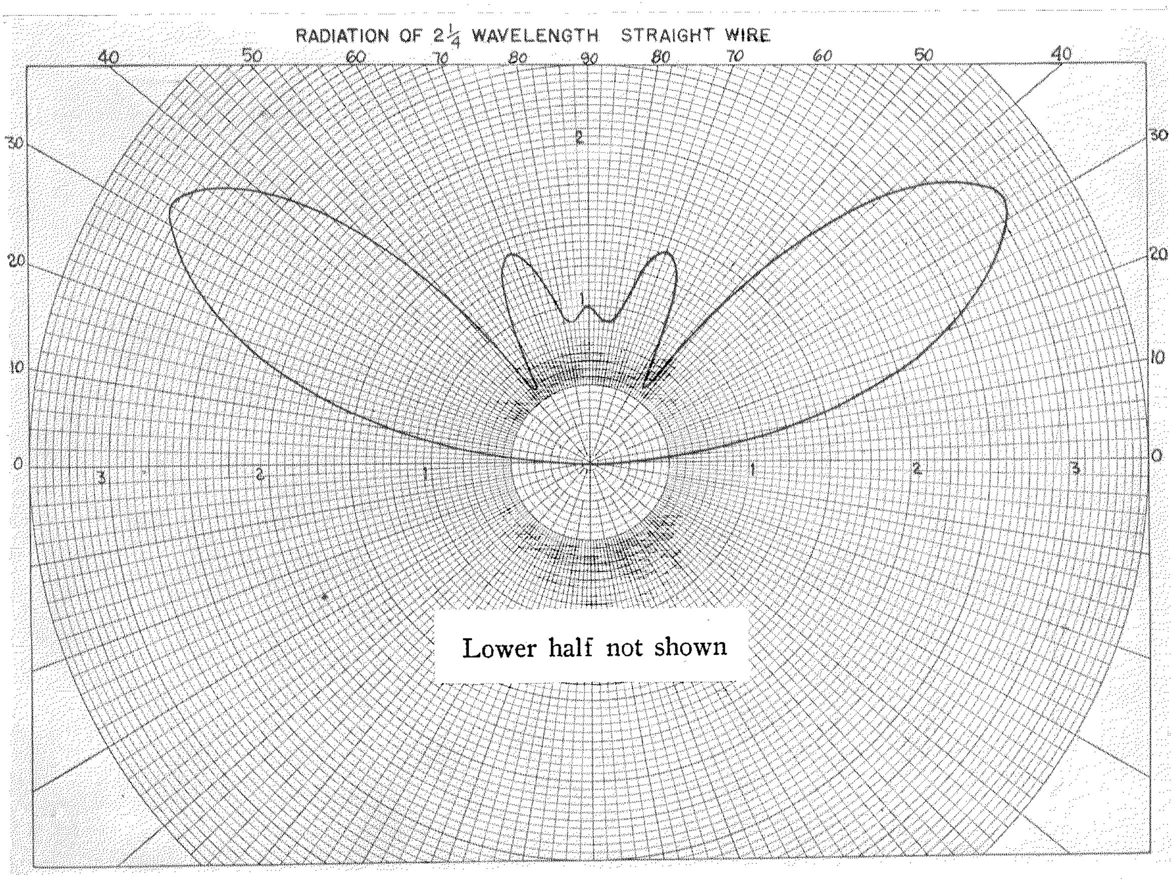


Fig. 8

where $N=2, 4, \cdots,$

$$h_{\Theta\infty}=\frac{2I_0}{Cr_1}\frac{\cos\left(\frac{\pi}{2}N\cos\theta\right)}{\sin\theta}, \qquad (29)$$

where $N=1, 3, 5, \cdots.$

Other components of the electromagnetic field due to a wire with standing waves may be obtained by exactly the same method as the one employed above to obtain H_Θ.

When l is not equal to an integral number of half wavelengths but is an arbitrary length we may still write

$$h_\Theta=H_\Theta+H_\Theta'$$

and hence also

$$h_{\Theta\infty}=H_{\Theta\infty}+H_{\Theta\infty}'.$$

In this case

$$H_{\Theta\infty}=\frac{2i_0}{r_1C}\cot\frac{\theta}{2}\sin\frac{\omega l}{2C}(1-\cos\theta)$$
$$\times\cos\left[\omega\left(t-\frac{r_1}{C}\right)-\frac{l\omega}{2C}(1-\cos\theta)\right]$$

and

$$H_{\Theta\infty}'=-\frac{2i_0}{r_1C}\tan\frac{\theta}{2}\sin\frac{\omega l}{2C}(1+\cos\theta)$$
$$\times\cos\left[\omega\left(t-\frac{r_1}{C}\right)-\frac{l\omega}{C}-\frac{l\omega}{2C}(1-\cos\theta)\right].$$

From the above values of $H_{\Theta\infty}$ and $H_{\Theta\infty}'$ it is clear that in general these vectors are not in phase but out of phase by angle

$$\left(\pi-\frac{l\omega}{C}\right).$$

Hence the total field is

$$|h_{\Theta\infty}|=\sqrt{|H_{\Theta\infty}|^2+|H_{\Theta\infty}'|^2-2H_{\Theta\infty}H_{\Theta\infty}'\cos\frac{\omega l}{C}}.$$

In Figs. 8 and 9 are shown radiation diagrams of wires $2\frac{1}{4}\lambda$ and $7\frac{3}{4}\lambda$ long. Both were calculated from the above equation for $|h_{\Theta\infty}|$. Fig. 9A, for comparison, shows the radiation diagram of a wire 8λ long.

RADIATION OF 7¾ WAVELENGTH STRAIGHT WIRE

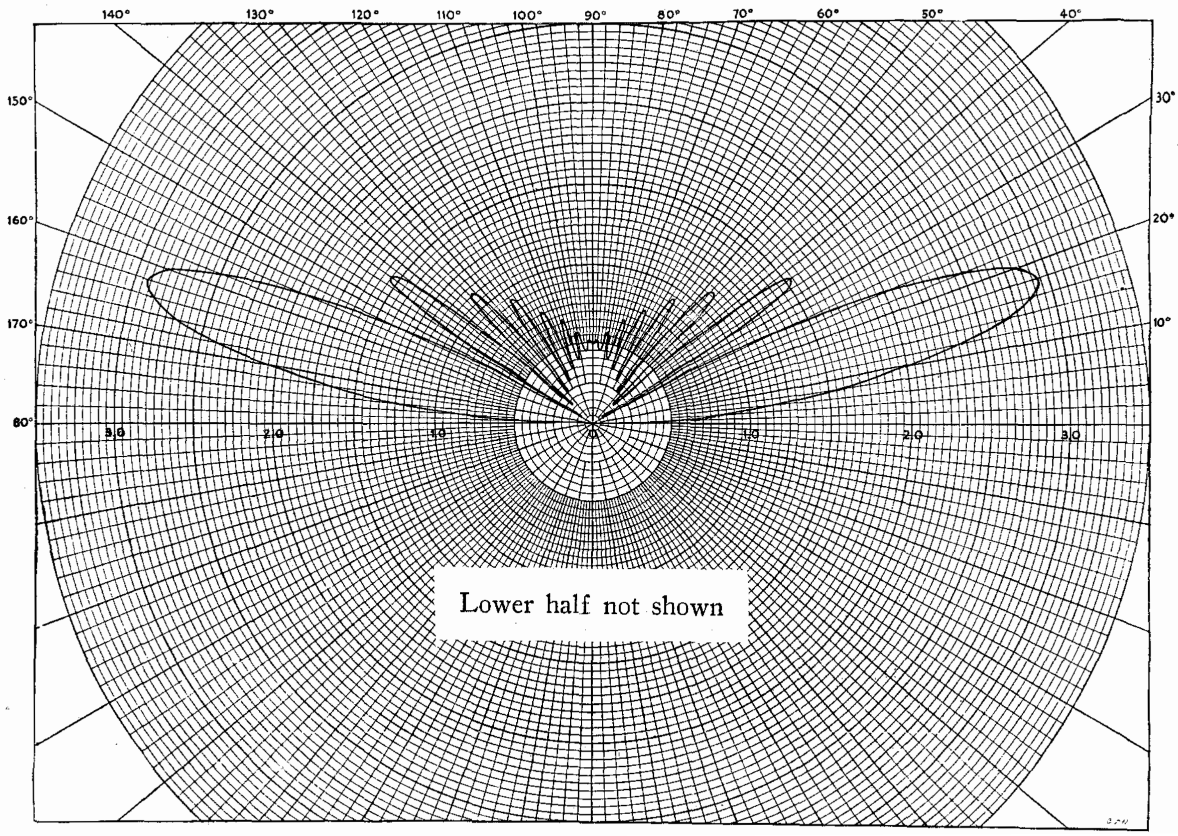


Fig. 9

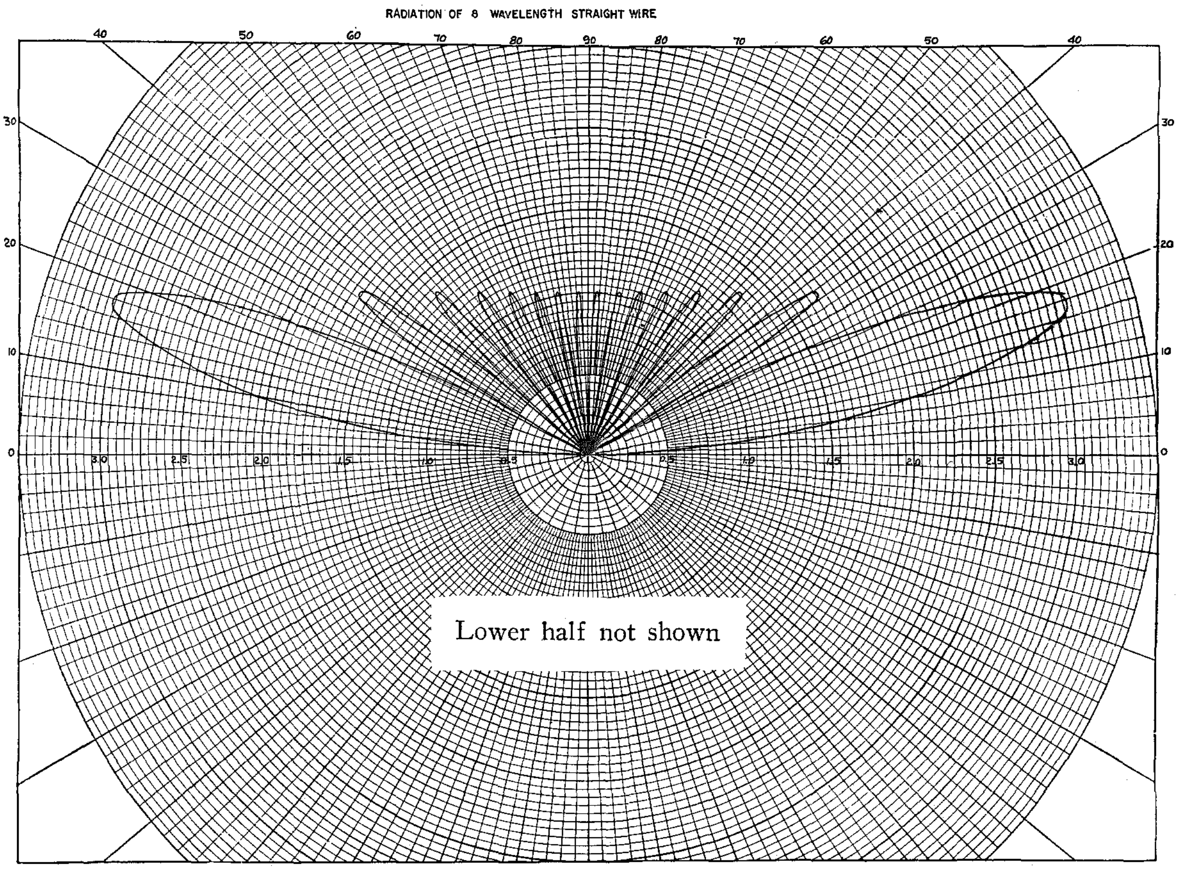


Fig. 9A

Power $\overline{P}$ radiated by a wire of length l may be obtained by the use of the Poynting theorem. This power may be represented by means of radiation resistance defined as follows:

$$\left(\frac{2i_0}{\sqrt{2}}\right)^2 R_l = \overline{P},$$

where $(2i_0/\sqrt{2})$ is the loop RMS current. After the necessary integrations are carried out it is found that

$$R_l = 30[\log_e (3.562\beta) - \sin^2 \beta + \text{sil } 2\beta] \text{ ohms},$$

where $\beta = 2\pi(l/\lambda)$. Fig. 10 shows how R_l varies with l/λ.

The following method of obtaining R_l is probably most enlightening.

Since

$$|h_{\Theta\infty}|^2 = |H_{\Theta\infty}|^2 + |H_{\Theta\infty}'|^2 - 2|H_{\Theta\infty}||H_{\Theta\infty}'| \cos \beta,$$

the average power radiated is

$$P_0 = \frac{C}{8\pi}\int_0^\pi |H_{\Theta\infty}|^2 2\pi r^2 \sin \theta d\theta$$

$$+\frac{C}{8\pi}\int_0^\pi |H_{\Theta\infty}'|^2 2\pi r^2 \sin \theta d\theta$$

$$-\frac{C}{8\pi}\int_0^\pi 2|H_{\Theta\infty}||H_{\Theta\infty}'|2\pi r^2 \sin \theta \cos \beta d\theta$$

$$= \text{I} + \text{II} - \text{III}.$$

The first term is the power radiated by the traveling wave proceeding toward the open end. This has already been calculated. (See equations (24), (26), (26A), and (26B).) The second term is the power radiated by the reflected wave. Under the present assumption that the reflected wave is equal to the direct wave this term is obviously equal to the first term. The third term is the interaction term which gives the power dissipated by the current in the forward wave flowing against the field of the reflected wave plus the power dissipated by the current in the reflected wave flowing against the field of the forward wave. This third term is the only one which we now must calculate.

We have

$$\text{III}=\frac{i_0^2}{C}\int_0^{\pi}\sin\frac{\beta}{2}(1-\cos\theta)\,\sin\frac{\beta}{2}(1+\cos\theta)\times\sin\theta d\theta\cos\beta.$$

If we put $\cos\theta=u$

then

$$\text{III}=2\frac{i_0^2}{C}\int_{-1}^{+1}\sin\frac{\beta}{2}(1-u)\,\sin\frac{\beta}{2}(1+u)\cos\beta du$$

$$=\frac{i_0^2}{C}\int_{-1}^{+1}(\cos\beta u-\cos\beta)\cos\beta du$$

$$=2\frac{i_0^2}{C}\left(\frac{\sin 2\beta}{2\beta}-\cos^2\beta\right).$$

Now from (26A)

$$\text{I}+\text{II}=2\frac{i_0^2}{C}\left(\log_e 2\beta+\text{sil }2\beta+\gamma-1+\frac{\sin 2\beta}{2\beta}\right);$$

hence

$$\text{I}+\text{II}+\text{III}=\frac{2i_0^2}{C}\left\{\log_e 2\beta+\text{sil }2\beta+\gamma-\sin^2\beta\right\};$$

$$\therefore\quad R_l=\frac{1}{C}\left\{\log_e 2\beta+\text{sil }2\beta+\gamma-\sin^2\beta\right\}.$$

The interaction resistance R_m defined by

$$R_m\left(\frac{i_0}{\sqrt{2}}\right)^2=-\text{III, is}$$

$$R_m=120\left(\cos^2\beta-\frac{\sin 2\beta}{2\beta}\right)\text{ ohms.}$$

On the loop current basis

$$r_m=\frac{1}{4}R_m.$$

When the far end of the wire is not open ended but terminated into an impedance with reflection coefficient $\rho e^{i\Psi}$, the phase angle between $H_{\Theta\infty}$ and $H_{\Theta\infty}'$ is not $(\pi-\beta)$ but $(-\beta+\Psi)$. In this case the field

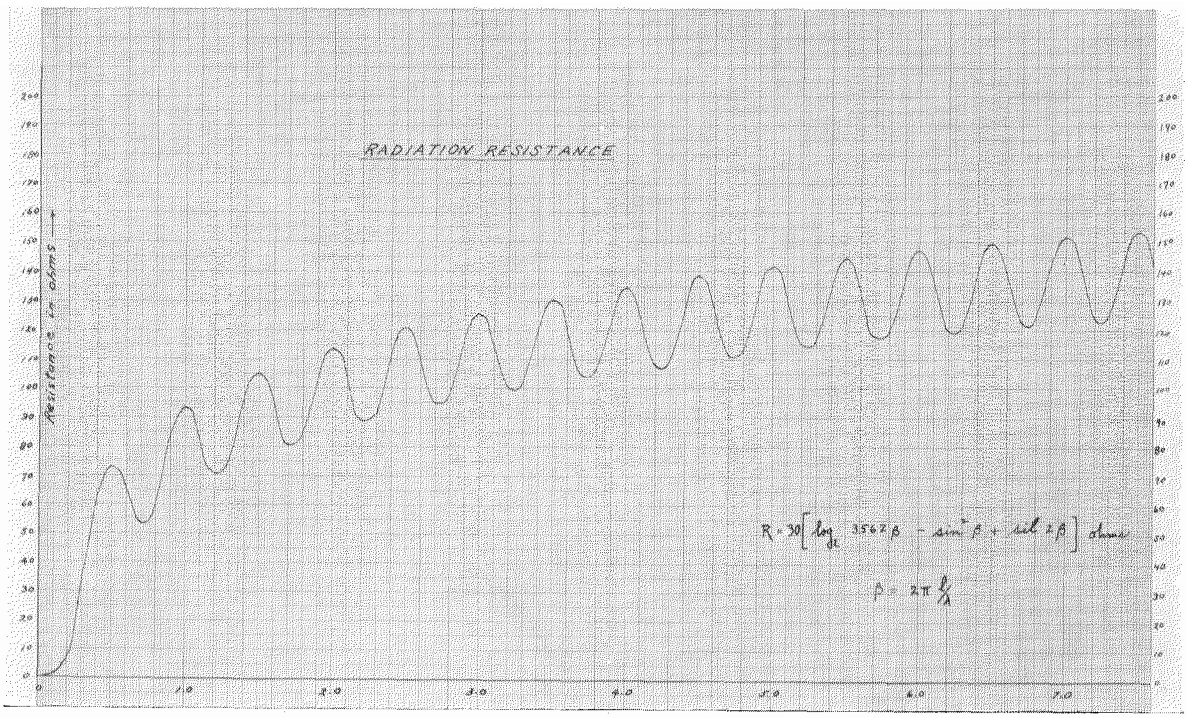
$$|h_{\Theta\infty}|=\sqrt{|H_{\Theta\infty}|^2+|H_{\Theta\infty}'|^2+2H_{\Theta\infty}H_{\Theta\infty}'\cos(\beta-\Psi)}$$

and the mutual interaction resistance (on the $i_0/\sqrt{2}$ basis) is

$$R_m=-120\left[\cos\beta-\frac{\sin\beta}{\beta}\right]\cos(\beta-\Psi)\text{ ohms.}$$

The total radiation resistance on the $(i_0/\sqrt{2})$ basis is

$$R_T=R+\rho^2R+\rho R_m,$$



Length of Antenna — l/λ ⟶

Fig. 10

where R is the radiation resistance of a terminated wire of the same length.

So far, only single wires have been considered. Let us now illustrate by a simple example some of the phenomena which may be expected when more than one terminated wire is employed. In Fig. 11 there are shown two colinear wires AB and BC connected through a phase delay device B. Assume that the system is fed at A and terminated into the surge impedance at C, also that the phase delay device is such that there is no reflection of waves at B.

Let the current along AB be

$$i_1 = i_0 \sin \omega\left(t - \frac{Z}{C}\right).$$

and the current along BC be

$$i_2 = i_0 \sin \omega\left(t - \frac{Z}{C} + \sigma\right).$$

The delay at B is then $-\sigma\omega$ radians. The total power radiated by the whole system consists of four parts:

- the power dissipated by i_1 flowing against its own field E_1;
- the power dissipated by i_2 flowing against its own field E_2;
- the power dissipated by i_1 flowing against E_2;
- the power dissipated by i_2 flowing against E_1.

The first two terms have already been discussed in some detail so that here only the third and the fourth terms need be considered. The average work done per unit time by E_1 on i_2 in element dZ is given by

$$-E_1' i_2 dZ = -\frac{1}{2}\left\{\frac{2i_0}{C}\frac{\cos\omega\sigma}{Z} + \frac{2i_0}{C}\frac{\cos\omega\sigma}{Z-l} + \frac{i_0}{\omega}\frac{\sin\omega\sigma}{Z^2} - \frac{i_0}{\omega}\frac{\sin\sigma\omega}{(Z-l)^2}\right\}dZ;$$

similarly, the average work done per unit time by E_2 on i_1 in element dZ is

$$-E_2' i_1 dZ = -\frac{1}{2}\left\{\frac{i_0}{\omega}\frac{\sin\omega\left[\frac{2(Z-l)}{C}+\sigma\right]}{(Z-l)^2} - \frac{i_0}{\omega}\frac{\sin\omega\left[\frac{2(Z-2l)}{C}+\sigma\right]}{(Z-2l)^2}\right\}.$$

E_1' and E_2' are, of course, the in-phase components of E_1 and E_2. The total power dissipated by interaction is

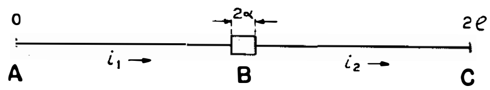


Fig. 11

$$P_i = -\int_{l+\alpha}^{2l} E_1' i_2 dZ - \int_0^{l-\alpha} E_2' i_1 dZ$$

and the total mutual interaction resistance on the $i_0/\sqrt{2}$ basis is then

$$R_m = \frac{C}{i_0^2} 60 P_i \text{ ohms.}$$

By carrying out the indicated integrations and then letting $\alpha \to 0$,

$$R_m = 60\cos\omega\sigma\left\{\log_e 2 - \frac{R_0}{60} - \left[\frac{\sin 2\beta}{2\beta} - \frac{\sin 4\beta}{4\beta} + \text{sil } 2\beta - \text{sil } 4\beta\right]\right\} + 60\sin\omega\sigma\left\{-\frac{1}{4\beta} - \frac{1-\cos\beta}{2\beta} + \int_0^{2\beta}\frac{\sin\phi}{\phi}d\phi + \left[\frac{\cos 2\beta}{2\beta} - \frac{\cos 4\beta}{4\beta} - \int_{2\beta}^{4\beta}\frac{\sin\phi}{\phi}d\phi\right]\right\}.$$

When $l > \lambda$,

$$R_m \approx 60\cos\omega\sigma\left[\log_e 2 - \frac{R_0}{60}\right] + 60\sin\omega\sigma\left[\frac{\pi}{2} - \frac{3}{4\beta}\right] \text{ ohms,}$$

where R_0 is the radiation resistance of a terminated wire of length l and

$$\beta = 2\pi\frac{l}{\lambda}.$$

Example

Suppose that $l = 2\lambda$, then $R_0 = 168$ ohms and

$$R_m = -127\cos(\omega\sigma) + 90.5\sin(\omega\sigma) = 156\cos[(\omega\sigma) - 144.5°].$$

The total radiation resistance of the system is thus

$$R_t = 2R_0 + R_m = 336 + 156\cos(\omega\sigma - 144.5°) \text{ ohms.}$$

The maximum radiation resistance of 492 ohms is obtained with phase delay of 215.5° and minimum radiation resistance of 180 ohms, with phase delay of 35.5°.

The radiation resistance of a single wire 4λ long is, of course,

$$R_4 = 336 + 156 \cos (144.5°) = 209 \text{ ohms.}$$

It may be of interest to note that the major lobes radiated by the individual wires add in phase and result in maximum directional radiation when the delay at B is 237°. This value of delay corresponds to the total radiation resistance of 479 ohms. Thus a radiating system made up of terminated wires may have maximum directivity at the very time when its total radiation resistance is nearly maximum. This result is in direct contrast with the usual conclusion that the directivity varies inversely as the total radiation resistance.

Before leaving this subject, it must be pointed out that all of the above calculations of radiation resistance are subject to correction for attenuation due to radiation. As long as the calculated values of radiation resistance on the $i_0/\sqrt{2}$ basis are small in comparison with the surge impedances of the radiating wires, this correction is quite small. When, however, the values of radiation resistance differ only slightly from the value of surge impedance, this correction may be fairly large. Indeed, the radiation resistance of a very long terminated wire should asymptotically approach some value close to the surge impedance of the wire. For this reason equation (26A) cannot be regarded as even approximately accurate when the value of R calculated from it is nearly equal to the surge impedance of the wire.

II. The First Method

In accordance with the first or Vector-Scalar Potential Method, the components of the electromagnetic field at a point P in space are calculated from the following equations:

$$H = \text{curl } A, \tag{30}$$

$$E = -\frac{1}{C}\frac{\delta A}{\delta t} - \text{grad } \phi, \tag{31}$$

$$\bar{A} = \int \frac{[i]}{r} dv, \tag{32}$$

$$\phi = \int \frac{[\sigma]}{r} dv. \tag{33}$$

In these equations H is the magnetic field, E the electric field, i the conduction current along the radiating conductor, σ the charge density in the conductor, $\bar{A}$ an auxiliary vector usually referred to as vector potential, and ϕ is an auxiliary scalar (scalar potential). r is the distance between point $P(X, Y, Z)$ in space and a point (X_0, Y_0, Z_0) on the conductor. dv is an element of volume. Symbols [ ] are used to indicate that, in the function within the brackets, time t has been replaced by $(t - r/C)$. The integrations extend over the whole volume of the conductor. When the conductor extends in more than one dimension, current i is a vector which has two or more components. Accordingly, $\bar{A}$ is also a vector.

The above fundamental equations may be derived from Maxwell's equations and some additional assumptions in the following manner: Consider Maxwell's equations

$$\text{curl } H - \frac{1}{C}\dot{E} = \frac{4\pi i}{C}, \quad (a) \qquad \text{curl } E + \frac{1}{C}\dot{H} = 0, \quad (c)$$

$$\text{div } E = 4\pi\sigma, \quad (b) \qquad \text{div } H = 0. \quad (d)$$

From (a) and (b) it follows that

$$\text{div } i + \dot{\sigma} = 0. \quad (e)$$

In these equations dots placed above various quantities indicate partial differentiations with respect to time. If we let

$$H = \text{curl } A \tag{34}$$

we have, in view of (c), curl $\left[E + \frac{\dot{A}}{C}\right] = 0$. The fact that the curl of vector $\left[E + \frac{1}{C}\dot{A}\right]$ is zero, makes it possible to put

$$E + \frac{1}{C}\dot{A} = -\text{grad } \phi$$

without limiting $\left[E + \frac{1}{C}\dot{A}\right]$ in any way whatsoever. ϕ, of course, is as yet an unknown scalar. We are now in a position to express both E and H in terms of the new quantities A and ϕ. By introducing these quantities into (a) and (b) we get

$$\text{curl curl } A + \frac{1}{C^2}\ddot{A} + \frac{1}{C}\text{grad } \dot{\phi} = 4\pi\frac{i}{C}, \tag{35}$$

$$-\text{div } \dot{A} - \nabla^2\phi = 4\pi\sigma. \tag{36}$$

Let us now *assume* that A and ϕ are such that

$$\text{div}\, A+\frac{1}{C}\dot{\phi}=0; \tag{37}$$

then (35) and (36) become

$$\nabla^2 A-\frac{\delta^2 A}{\delta t^2}\frac{1}{C^2}=-\frac{4\pi}{C}i, \tag{38}$$

$$\nabla^2\phi-\frac{\delta^2\phi}{\delta t^2}\frac{1}{C^2}=-4\pi\sigma. \tag{39}$$

These equations, as is well known, have the following solutions:

$$A=\frac{1}{C}\int\frac{[i]}{r}dv, \tag{40}$$

$$\phi=\int\frac{[\sigma]}{r}dv, \tag{41}$$

in which the indicated integrations extend over that portion of space where i and σ are different from zero.

If we retrace the steps we have taken to derive (40) and (41) in the reverse direction, starting with (40) and (41), we will have the proof of the following theorem:

If

$$A=\frac{1}{C}\int\frac{[i]}{r}dv$$

and

$$\phi=\int\frac{[\sigma]}{r}dv,$$

and if A and ϕ are such that

$$\text{div}\, A+\frac{1}{C}\dot{\phi}=0,$$

then

$$H=\text{curl}\, A,$$

$$E=-\frac{\delta A}{\delta t}-\text{grad}\,\phi$$

are solutions of Maxwell's equations and consequently the correct solutions of a given problem.

Let us now ask the following questions: Suppose we are given a certain distribution of i and σ, what guaranty is there that A and ϕ calculated from this distribution are such that

$$\text{div}\, A+\frac{1}{C}\dot{\phi}=0?$$

Or, in general, what distributions of i and σ, if any, will give us A and ϕ which do satisfy this condition?

In order to answer these questions, we must express condition (37) in terms of i and σ themselves. By replacing A and ϕ in (37) by their expressions in terms of i and σ, we obtain

$$\text{div}\frac{1}{C}\int\frac{[i]}{r}dv+\frac{\delta}{\delta t}\int\frac{[\sigma]}{Cr}dv=0.$$

Now since the integrations are to be performed with respect to coordinates X_0, Y_0, Z_0 of points on the conductor while the divergence is taken with respect to entirely independent coordinates X, Y, Z of a point P in space, we may reverse the order of these operations. Similarly the differentiation with respect to t may also be carried under the integral sign. Thus we get

$$\int\left[\text{div}_{XYZ}\frac{[i]}{r}+\frac{[\dot{\sigma}]}{r}\right]dv=0. \tag{42}$$

At this point the following observations are pertinent:

We are dealing with two entirely independent sets of coordinates: coordinates of a point P in space X, Y, Z and coordinates of a point on the conductor X_0, Y_0, Z_0. Current i is a function of $X_0Y_0Z_0$ and t;

$$i=i(t,\, X_0,\, Y_0,\, Z_0).$$

Distance r is a function of both sets of coordinates,

$$r^2=(X-X_0)^2+(Y-Y_0)^2+(Z-Z_0)^2;$$

$[i]$ is also a function of both sets of coordinates:

$$[i]=i\left[\left(t-\frac{r}{C}\right),\, X_0,\, Y_0,\, Z_0\right].$$

Divergence which occurs in (42) or in (37) is taken with respect to coordinates X, Y, Z of a point in space and will be designated by div_{XYZ}, in order to distinguish it from a divergence taken with respect to coordinates $X_0Y_0Z_0$, which will be denoted by $\text{div}_{X_0Y_0Z_0}$. Now

$$\begin{aligned}\text{div}_{XYZ}[i]&=\text{div}_{XYZ}\, i\left[\left(t-\frac{r}{C}\right),\, X_0,\, Y_0,\, Z_0\right]\\&=\frac{\delta[i]}{\delta X}+\frac{\delta[i]}{\delta Y}+\frac{\delta[i]}{\delta Z}\\&=\frac{\delta[i]}{\delta t}\left(-\frac{1}{C}\frac{\delta r}{\delta X}\right)+\frac{\delta[i]}{\delta t}\left(-\frac{1}{C}\frac{\delta r}{\delta Y}\right)\\&\qquad+\frac{\delta[i]}{\delta t}\left(-\frac{1}{C}\frac{\delta r}{\delta Z}\right)\\&=\frac{\delta[i]}{\delta t}\left(\frac{1}{C}\frac{\delta r}{\delta X_0}+\frac{1}{C}\frac{\delta r}{\delta Y_0}+\frac{1}{C}\frac{\delta r}{\delta Z_0}\right),\end{aligned} \tag{42A}$$

since

$$\frac{\delta r}{\delta X} = -\frac{\delta r}{\delta X_0}, \quad \frac{\delta r}{\delta Y} = -\frac{\delta r}{\delta Y_0}, \quad \frac{\delta r}{\delta Z} = -\frac{\delta r}{\delta Z_0}.$$

On the other hand,

$$\text{div}_{X_0Y_0Z_0}[i] = -\frac{\delta[i]}{\delta t}\left(\frac{1}{C}\frac{\delta r}{\delta X_0} + \frac{1}{C}\frac{\delta r}{\delta Y_0} + \frac{1}{C}\frac{\delta r}{\delta Z_0}\right) + [\text{div}_{X_0Y_0Z_0} i], \quad (43)$$

where by $[\text{div}_{X_0Y_0Z_0} i]$ is meant $\text{div}_{X_0Y_0Z_0} i$ in which t has been replaced by $\left(t - \frac{r}{C}\right)$ *after* the differentiations had been performed. From (42A) and (43) it follows that

$$\text{div}_{XYZ}[i] = -\text{div}_{X_0Y_0Z_0}[i] + [\text{div}_{X_0Y_0Z_0} i]. \quad (44)$$

The continuity equation (*e*) which, of course, holds along the conductor, requires that

$$\text{div}_{X_0Y_0Z_0} i + \dot{\sigma} = 0$$

for any and all values of t and, in particular, for $t' = \left(t - \frac{r}{C}\right)$; consequently also

$$[\text{div}_{X_0Y_0Z_0} i] + [\dot{\sigma}] = 0. \quad (45)$$

If B is any vector,

$$\text{div}\left(\bar{B}\frac{1}{r}\right) = \frac{\text{div}\,\bar{B}}{r} + \bar{B}\cdot\text{grad}\,\frac{1}{r},$$

in which the divergences are taken with respect to any system of coordinates. Therefore,

$$\text{div}_{XYZ}\left\{[i]\frac{1}{r}\right\} = \frac{\text{div}_{XYZ}[i]}{r} + [i]\cdot\text{grad}_{XYZ}\,\frac{1}{r},$$

$$\text{div}_{X_0Y_0Z_0}\left\{[i]\frac{1}{r}\right\} = \frac{\text{div}_{X_0Y_0Z_0}[i]}{r} + [i]\cdot\text{grad}_{X_0Y_0Z_0}\,\frac{1}{r}.$$

Now since

$$\text{grad}_{XYZ}\frac{1}{r} = -\text{grad}_{X_0Y_0Z_0}\frac{1}{r},$$

$$\text{div}_{XYZ}\frac{[i]}{r} + \text{div}_{X_0Y_0Z_0}\frac{[i]}{r} = \frac{\text{div}_{XYZ}[i] + \text{div}_{X_0Y_0Z_0}[i]}{r}$$

or, in view of (44),

$$\text{div}_{XYZ}\frac{[i]}{r} = \frac{[\text{div}_{X_0Y_0Z_0} i]}{r} - \text{div}_{X_0Y_0Z_0}\frac{[i]}{r}. \quad (46)$$

With the help of the above auxiliary equations, we may now simplify equation (42). In fact, if in (42) we replace $\text{div}_{XYZ}\frac{[i]}{r}$ by its value as given by (46), we obtain

$$\int\left\{\frac{[\text{div}_{X_0Y_0Z_0} i] + \dot{\sigma}}{r} - \text{div}_{X_0Y_0Z_0}\frac{[i]}{r}\right\}dv = 0.$$

In view of (45) this reduces to

$$\int \text{div}_{X_0Y_0Z_0}\frac{[i]}{r}dv = 0. \quad (47)$$

In accordance with the well known theorem due to Gauss the volume integral of divergence of a vector is equal to the surface integral of the normal component of the same vector; hence,

$$\int \text{div}_{X_0Y_0Z_0}\frac{[i]}{r}dv = \int_S \left[\frac{[i]}{r}\right]_n dS = \int_S \frac{[i]_n}{r}dS = 0 \quad (48)$$

and this must hold for any and all locations of point P in space.

When the conductor is entirely disconnected from all other conductors, the component of current normal to the boundary of the conductor is certainly equal to zero at all points on the surface and

$$\int_S \frac{[i]_n}{r}dS = 0.$$

But when a conductor is fed with power, the situation is quite different.

Assume, for example, that the conductor receives current through two small areas S_1 and S_2. Then $[i]_n$ is zero except at S_1 and S_2; consequently,

$$\int_S \frac{[i]_n}{r}dS = \frac{[i_1]_n}{r_1}S_1 + \frac{[i_2]_n}{r_2}S_2.$$

In this equation r_1 and r_2 are distances from S_1 and S_2 to a point P in space. Obviously in this case $\int_S \frac{[i]_n}{r}dS$ cannot be equal to zero for all possible locations of P unless both $[i_1]_n$ and $[i_2]_n$ are equal to zero.

Thus we have arrived at the following conclusion:

(1) When a conductor is disconnected from all others so that no current either enters or leaves it

$$\int_S \frac{[i]_n}{r}dS = 0$$

and hence the condition

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}=0$$

fulfilled.

(2) When a conductor is fed, this condition is in general not satisfied.

From these considerations, it follows that when the vector-scalar potential method is applied to wires which are an integral number of half wavelengths long and which are considered to be free of feeders, the results obtained will be correct. But when this method is applied to such systems as, for example, a terminated wire in which current must enter and leave, the results in general will be wrong.

As an illustration of the erroneous result which may be obtained by this method when

$$\operatorname{div} A+\frac{1}{C}\dot{\phi}\neq 0,$$

the following calculation of the electric field due to a terminated wire of length l is presented. The current is assumed to be

$$i=i_0 \sin \omega\left(t-\frac{Z_0}{C}\right);$$

hence

$$\sigma=\frac{i_0}{C}\sin \omega\left(t-\frac{Z_0}{C}\right)$$

and consequently,

$$A=\frac{1}{C}\int_0^l \frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0,$$

$$\phi=\frac{1}{C}\int_0^l \frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0,$$

$$E_Z=-\frac{1}{C}\frac{\delta A}{\delta t}-\frac{\delta\phi}{\delta Z}.$$

Since

$$\frac{\delta}{\delta Z}\left[\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\right]=\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\frac{\delta}{\delta Z}\left(\frac{1}{r}\right)+\frac{1}{r}\cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\frac{\delta}{\delta Z}\left(-\frac{r\omega}{C}\right),$$

$$\frac{\delta}{\delta Z_0}\left[\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\right]=\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\frac{\delta}{\delta Z_0}\left(\frac{1}{r}\right)+\frac{1}{r}\cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)\left[\frac{\delta}{\delta Z_0}\left(-\frac{r\omega}{C}\right)-\frac{\omega}{C}\right];$$

and since

$$\frac{\delta}{\delta Z}\left(\frac{1}{r}\right)=-\frac{\delta}{\delta Z_0}\left(\frac{1}{r}\right);\qquad \frac{\delta}{\delta Z}(r)=-\frac{\delta}{\delta Z_0}(r),$$

it follows that

$$\frac{\delta}{\delta Z}\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}=-\frac{\delta}{\delta Z_0}\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}-\frac{1}{C}\frac{\cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}.$$

Hence

$$E_Z=-\frac{1}{C}\frac{\delta A}{\delta t}+\frac{1}{C}\int_0^l \frac{\delta}{\delta Z_0}\frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0+\frac{\omega}{C^2}\int_0^l \frac{i_0 \cos \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0.$$

In this expression, the last term is equal to $\frac{1}{C}\frac{\delta A}{\delta t}$ so that

$$E_Z=\frac{1}{C}\int_0^l \frac{\delta}{\delta Z_0}\frac{i_0 \sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\,dZ_0=\frac{i_0}{C}\left.\frac{\sin \omega\left(t-\frac{r}{C}-\frac{Z_0}{C}\right)}{r}\right|_0^l=-\frac{i_0 \sin \omega\left(t-\frac{r_1}{C}\right)}{Cr_1}+\frac{i_0 \sin \omega\left(t-\frac{r_2}{C}-\frac{l}{C}\right)}{Cr_2}.$$

This result, while it is offhand apparently reasonable, is of course wrong. This may be seen by comparing it with equation (23).

Summary and Remarks

Two procedures for calculating radiation fields have been discussed in some detail. It was shown that while the first procedure is applicable only to unfed and unterminated radiators, the other is quite free from these limitations. The second was used to derive the expressions for the magnetic and the electric fields produced by traveling waves progressing along a linear conductor of length l. These expressions hold along the conductor, near the conductor, as well as at a large distance from the conductor. The energy radiated by traveling waves which progress along a conductor of length l was calculated and expressed in terms of Radiation Resistance defined in a suitable manner. It was shown that the fraction of energy lost by traveling waves, through radiation, depends on the surge impedance of the radiating conductor. The lower this surge impedance, the greater is the fraction of energy radiated by the traveling waves; hence the rate of attenuation due to radiation is also greater. Therefore, an antenna, employing terminated conductors, is made more efficient by reducing the surge impedance of these conductors. The values of Radiation Resistance calculated in the paper enable one to estimate the radiation attenuation.

By making use of the expressions for the magnetic and electric fields due to traveling waves, the fields produced by open ended conductors were calculated. These calculations were based on the assumption that the amplitude of the reflected wave is equal to the amplitude of the forward wave, in order that the results obtained from the present theory may be more readily compared with the well known results obtained by Max Abraham[4] and Pistolkors[4] for wires an integral number of half wave-lengths long. For the sake of completeness, the fields produced by wires of any length, as well as the radiation resistance of such wires, were calculated on the same assumption. The radiation resistance versus length of wire curve thus obtained (see Fig. 10) was found to be wavy and not smooth. This result is at variance with the accepted radiation resistance curves found in current literature.

[4] Loc. cit.

A method for calculating the radiation resistance, as well as the field due to wires of any length and terminated into any impedance, is included.

The effect of a phase delay device placed at the center of a wire terminated into its surge impedance was considered in some detail. These calculations show that the radiation efficiency of terminated conductors is increased by the use of phase changers. It can be shown also that the fields, produced at a distant point by wires equipped with phase changers, are greater than those produced by continuous wires of the same length.

No attempt was made in this paper to treat the subject of radiation attenuation in as much detail as it deserves. It should be pointed out, however, that in calculations of radiation fields as well as of radiation from very long radiators or from long radiators equipped with phase changers, the radiation attenuation must be taken into account if erroneous results are to be avoided. When the radiation resistances on the $i_0/\sqrt{2}$ basis are not too large in comparison with the surge impedances, first approximations may be secured by simply calculating the attenuation of the forward waves from the radiation resistance, as explained in the body of the paper, and then assuming that only the current which is left over is reflected from the end of the conductor, so that the total radiation pattern and the second approximation to the radiation resistance of the radiating conductor are calculated on the basis of two waves of unequal amplitudes traveling in opposite directions.

The author, in conclusion, gratefully acknowledges the encouragement, helpful criticisms, and suggestions received in connection with the preparation of this paper from Mr. Haraden Pratt, Vice-President and Chief Engineer, Mackay Radio and Telegraph Company.

The Radio Installation on the Cunard White Star, R.M.S. Queen Mary

By H. THORPE–WOODS
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THE R.M.S. Queen Mary of the Cunard White Star, Limited, has been provided with a radio installation entirely in keeping with the high standard of naval architecture and marine engineering represented in the design and construction of this magnificent ship. Undoubtedly, the radio installation is the largest and most complete in the history of marine radio, and has been engineered to meet all commercial telephone and telegraph traffic requirements, in addition to the usual navigational and safety services. Many recent advances in radio technique have been embodied in the design of the radio system, and several features hitherto associated only with land stations have been applied for the first time to a marine radio installation.

In planning the radio telephone installation, every consideration was given to features contributing to the convenience of the passengers or otherwise improving the value of the service. As a result, radio telephone service to or from the Queen Mary is practically on a par with long distance telephone service so familiar to the subscriber on land.

A complete voice-operated switching device, the so-called V.O.D.A.S., which forms part of the ship's radio installation, makes it possible for a passenger to talk on the radio telephone circuits from any one of the 500 telephones of the ship's two-wire telephone exchange, even under the most difficult radio conditions. Passengers' telephones are located in all cabin class staterooms and in booths conveniently located with respect to the various public salons throughout the ship.

A second feature designed to minimize service delays is the duplication of the radio telephone facilities, making it possible to maintain a circuit to Europe simultaneously and independently of a direct circuit to America. Both circuits may also be diverted to Europe or America, thereby providing two independent circuits when required to handle the traffic load.

An innovation introduced to insure complete secrecy of radio telephone conversations against the casual "eavesdropper" is the frequency "wobbler." This equipment is additional to the usual privacy devices and provides the same degree of secrecy as is obtained on high grade overseas radio telephone circuits.

During the maiden voyage, radiotelephone calls were completed from passengers' cabins to points as distant as Cape Town and Johannesburg, South Africa.

Radio Telegraphy

The radio telegraph facilities also have been engineered on an ample scale, permitting the rapid handling of passenger radiograms, navigational services, and extensive press dispatches utilized for the publication of the ship's daily newspaper.

Each of the four normal operating positions is equipped with a typewriter, a telegraph key, and a number of radio receivers, as well as with remote control for starting, stopping, and changing the wavelength of the radio transmitters.

While each position is normally manned by one operator, it is possible for two operators to work at each position for full duplex operation. The

R.M.S. "Queen Mary" Shortly Before Docking at New York.

average operating speed is between 25 and 30 words per minute for manual operation.

For higher speeds and to minimize delays during peak conditions, three auxiliary automatic positions are available. Two positions are equipped with perforators and auto-transmitters, while a third position is fitted with an undulator and typewriter for high speed reception. Telegraph speeds up to 100 words per minute have been obtained under practical conditions.

Broadcasting

The Queen Mary is provided with a complete built-in broadcasting system, rivalling the most modern land broadcasting stations in quality of performance.

The two short wave transmitters, which are also used for telegraphy and commercial telephony, have uniform frequency characteristics up to 8,000 p:s, and the harmonic content is surprisingly low.

Permanent microphone pickup points are available in the principal public salons. The ship's modern soundproof studio possesses excellent acoustical properties and is equipped with a piano.

A special high fidelity radio receiver is available for the reception of important broadcast programs from land stations. These programs can be distributed to any part of the ship through the numerous loudspeakers of the ship's sound rediffusion system.

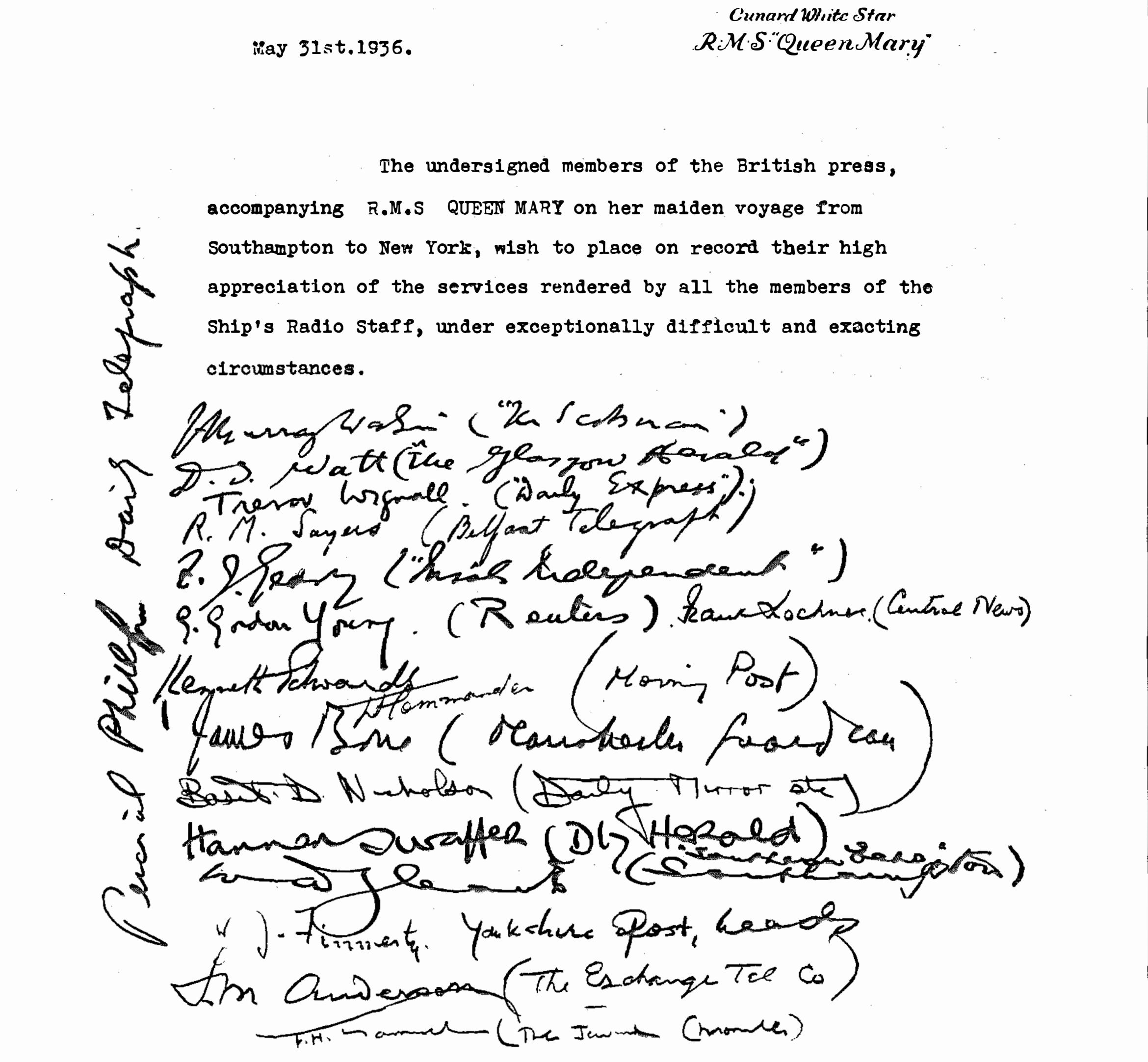
On the maiden voyage, numerous broadcast programs of various durations up to three-quarters of an hour were transmitted successfully to England, France, Denmark, and Holland, and were distributed in America over several nation-wide hookups.

Navigational and Safety Services

One of the principal duties of the radio staff at sea is to keep a permanent watch for distress signals. There are also numerous navigational instructions, weather reports, ice and obstruction warnings, etc., to be received at regular intervals. The Queen Mary, in fact, will at no time be too much occupied to work even the smallest collier or tramp on the 600–800 meter band, in addition to listening for distress signals. Reliable equipment obviously is required for these services.

These requirements are substantially met by one long and one medium wave transmitter of solid construction with approximate ranges of 2,000 and 1,000 miles, respectively. A bank of selective and stable receivers covering the same wavelength ranges ensures uninterrupted reception. These equipments are also utilized for handling commercial radiograms during the intervals when not required for the more important navigational services.

For safety purposes, an independent unit

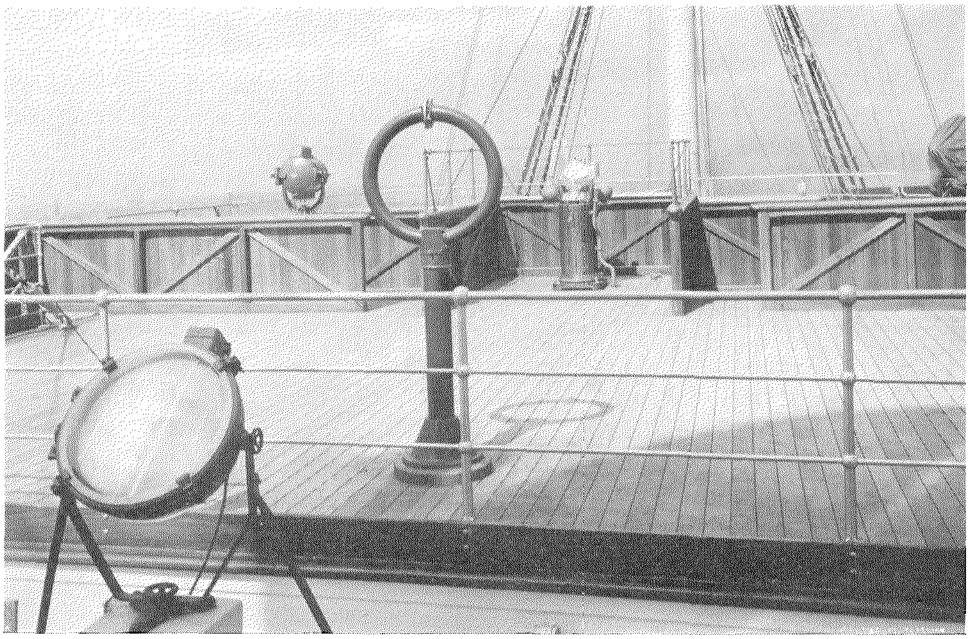


Cunard White Star
R.M.S. "Queen Mary"

May 31st.1936.

The undersigned members of the British press, accompanying R.M.S QUEEN MARY on her maiden voyage from Southampton to New York, wish to place on record their high appreciation of the services rendered by all the members of the Ship's Radio Staff, under exceptionally difficult and exacting circumstances.

Testimonial from Members of the British Press.



Rotating Loop Portion of the I.M.R.C. Radio Direction Finder Installed on the Bridge of the R.M.S. Queen Mary.

consisting of a medium wave transmitter and receiver, operated from a storage battery installation, is always kept in readiness in case of major failures or interruptions to the ship's power supply. The emergency transmitter has an approximate range of 500 miles and is of the type normally installed as the main transmitter in ships of average size. Provision has also been made for keying the main transmitters locally from the transmitting room in the event of failure of the control circuits from the operating room.

Two of the motor lifeboats are fitted with radio installations of standard Board of Trade type. In addition, these lifeboats have small radio telephone sets similar to those usually supplied to coasters and trawlers and are so simple to operate that communication can be maintained by any member of the crew in the absence of a skilled radio operator. These are the first ship's boats ever equipped with radio telephony in addition to the usual radio telegraph installation required by the Board of Trade.

The I.M.R.C. Radio Direction Finder is located in a special compartment on the bridge adjacent to the Sperry Gyro Master Compass compartment and near the ship's standard compass. One of the several "repeater" compasses controlled by the Gyro Master Compass is associated with the scale of the direction finder in a manner such that it is possible to obtain the compass bearing of a radio station without reference to a simultaneous reading of the standard compass, as is usually required. The range of the direction finder is 300 to 400 miles. On the return voyage a considerable amount of fog was experienced east of the Bishops, and the direction finder was in constant use as a check upon the position of the ship by dead reckoning. The results obtained proved to be extremely satisfactory, and as a consequence Cherbourg Harbor was made without difficulty and with complete confidence.

Automatic Wave-Change Feature

A large modern liner requires many frequencies or wavelengths—the Queen Mary uses thirty-two different frequencies—for the successful operation of its radio services. Moreover, these frequencies must be shifted frequently during the day in order to meet varying conditions depending largely on time and distance. In the past, the various coils and condensers associated with the radio transmitters were changed manually and the time required for a single wavelength change varied between 5 and 15 minutes. It was usually necessary to keep a permanent watch at the transmitters and close cooperation was essential between the radio operator and transmitter attendant. The alternative solution on small installations was for the operator to leave the circuit while making the necessary changes in the transmitter. In any case, a considerable percentage of the total time was lost and the service was subject to fairly long delays.

The problem was solved on the Queen Mary by means of the simple automatic dial familiar to telephone subscribers and associated with relays similar to those found in an automatic telephone exchange. The ten numbers on the dial correspond to ten different frequencies, and the time required for a complete wavelength change is from 3 to 5 seconds. The four main transmitters on the Queen Mary are on dial control direct from the operating positions located about 400 feet from the transmitting room. In addition to the tremendous saving in time and reduction in service delay, the transmitting room may be left unattended.

Multiplex Operation

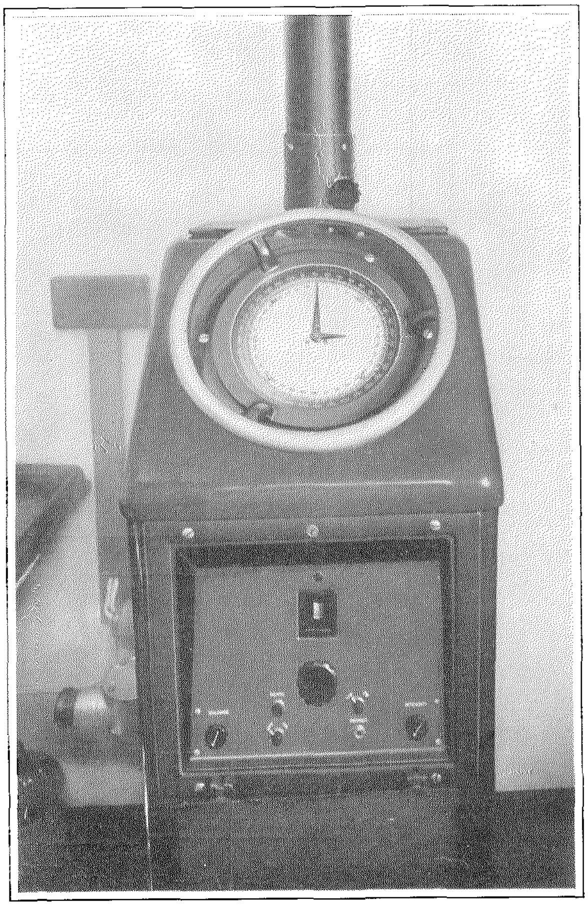
A feature contributing largely to the traffic handling capacity of the Queen Mary's radio installation is multiplex working, one of the most difficult problems that presents itself to the marine engineer. Its solution on land is comparatively simple since the transmitting and receiving aerials are usually separated by a considerable distance. On a ship, however, this separation is reduced to a few yards.

The problem has been completely solved on the Queen Mary by special attention to antenna design, lead-in arrangements, and selective receivers. It is possible to operate duplex telegraph circuits, two-way telephone circuits, and receive broadcast programs while all four transmitters are in operation on full power and on any combination of the thirty-two operating frequencies. On one occasion during the maiden voyage, the traffic volume was so heavy that three outgoing and five incoming telegraph channels were being operated simultaneously while, at the same time, a radio telephone call was in progress.

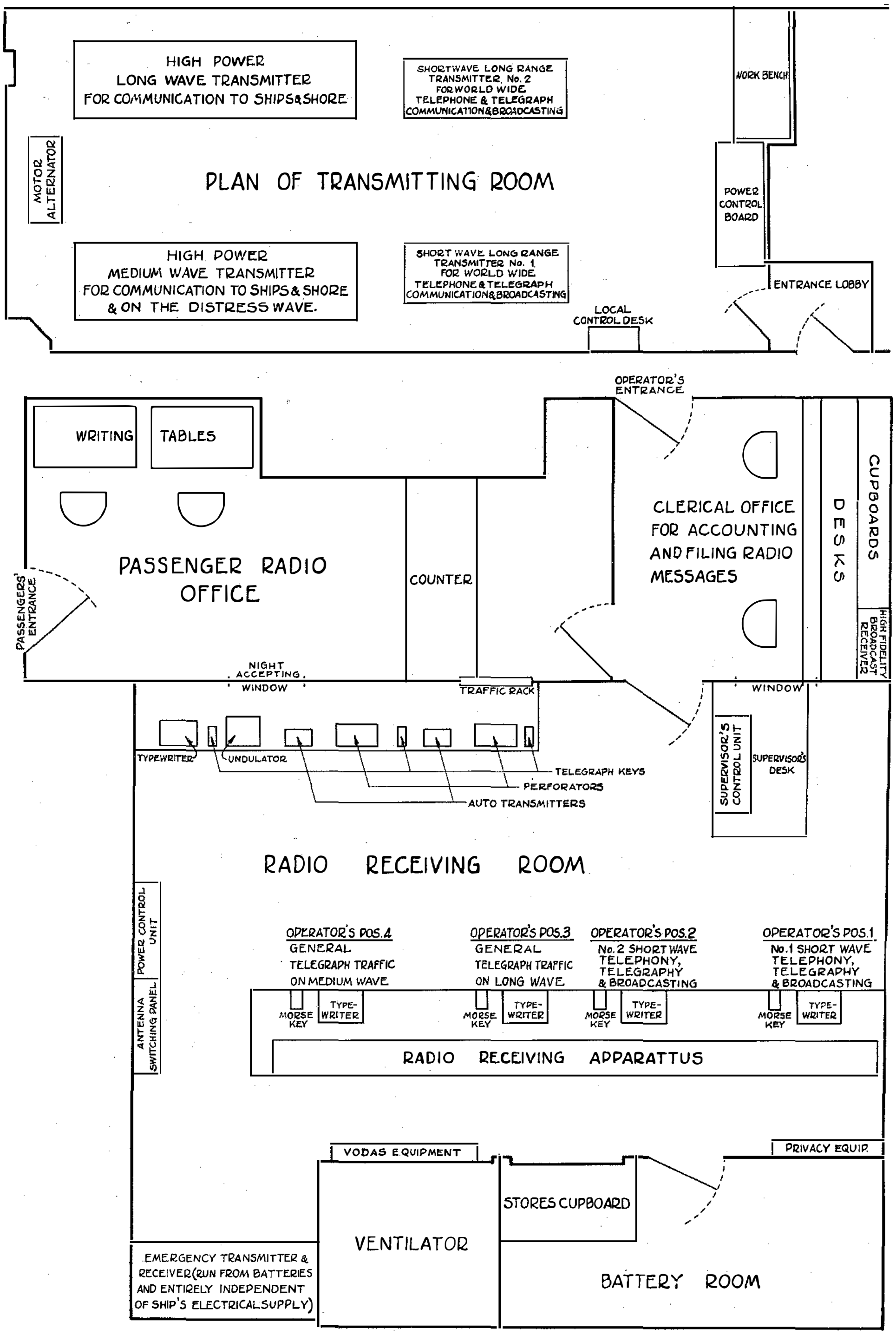
Traffic Handling Capacity

Some idea of the traffic handling capacity of the installation may be gained from the following figures of traffic completed on the maiden westbound voyage. These figures constitute a record by a very wide margin in each of the categories listed and were made possible by two features—automatic wave change and multiplex operation:

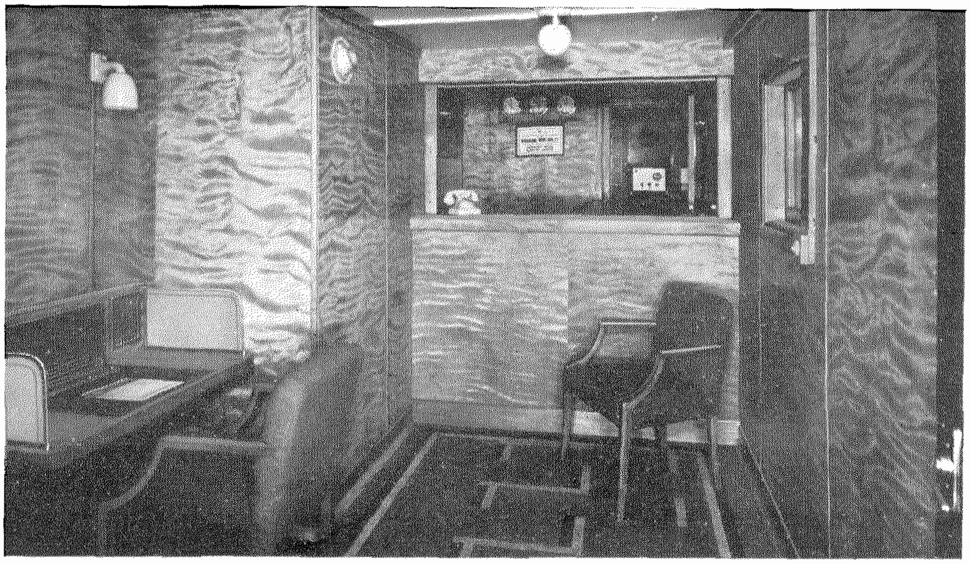
1,808 radiograms transmitted, totalling 95,744 words;



Direction Finder Apparatus Fitted in a Special Compartment Immediately below the Loop.



Floor Plan of Radio Rooms on the Queen Mary.



Radio Office on Board the Queen Mary.

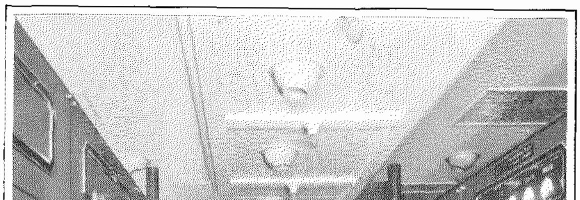
1,351 radiograms received, totalling 36,119 words;
149 commercial radio telephone calls, totalling 826 minutes;
40 different broadcast programs transmitted from the ship, totalling 647 minutes.

General Description of Radio Installation

The layout and general appearance of the radio rooms are illustrated by the floor plan and photographic views reproduced on these pages.

Passenger Radio Office

The passenger radio office is located on the port side of the sun deck immediately above the main hall, and may be reached by the staircase on either side of the main hall or by the main elevators. Here, radio officers are in constant attendance to care for passengers' requirements. Messages may be received directly across the counter or by telephone from any part of the ship. The principal duties of these officers are to accept radiograms and radio telephone calls, to supervise the delivery of incoming radiograms, to assist in locating a passenger called by a land subscriber, and to supply information regarding rates and addresses. For the latter purposes, tele-



Radio Transmitter Room, Showing the Transmitters Which Are Remotely Controlled from the Radio Operating Room 400 Feet Away.

Radio Operating Room, Showing Some of the Receiving Equipment.

phone directories and information on rates to all parts of the world are available at the counter.

In the passenger office, also, are two comfortable writing desks, suitably equipped with writing materials and message blanks, and a portable typewriter is available for the use of passengers who prefer to type their messages.

Clerical Office

A small clerical office, immediately behind the passenger accepting office, is used for accounting, billing, and filing, and is equipped with the necessary cabinets and desks. Here, incoming radiograms are also prepared for delivery.

Radio Operating Room

The radio operating room is entered through the clerical office. Four operating positions, two for short wave and broadcasting, one for medium wave telegraphy, and one for long wave telegraphy extend the length of the room. The installation comprises eleven receivers, four for short waves, four for medium waves, and three for long waves, in addition to two radio telephone terminal equipments, and the remote control equipment for starting, stopping, changing wavelengths, and adjusting the power output of the radio transmitters.

The auxiliary automatic telegraph equipment is mounted on a separate table opposite the main operating positions. A supervisor's desk and the emergency radio equipment complete this part of the installation.

Radio Transmitter Room

For convenience in antenna lead-in arrangements, the four radio transmitters are located in a separate room about 400 feet aft of the operating room and approximately in the position of the rear mast. The two short wave transmitters deliver about 500 watts to the antenna systems and ten spot wavelengths are available on each transmitter under dial selection. These transmitters are used for telephony, telegraphy, or broadcasting, as required, and insure good communication during practically the entire Atlantic crossing.

The long and the medium wave transmitters deliver approximately 3 kW. to the antenna and are primarily used for telegraphic communication. Seven wavelengths are used for long wave and five wavelengths for medium wave communication. As in the case of the short wave transmitters, automatic dial selection is employed.

The power board, seen at the end of the transmitter room, distributes a-c. power to the various transmitters and all equipment in the operating room.

Power Supply Room

The power supply room, located on a lower deck near the engine rooms, contains a duplicate machine group of 40 kW. each for converting the ship's d-c. supply to 220 volt 3-phase 50 cycle a-c. for the operation of the radio equipment. These machine groups are entirely controlled from the power board in the transmitter room.

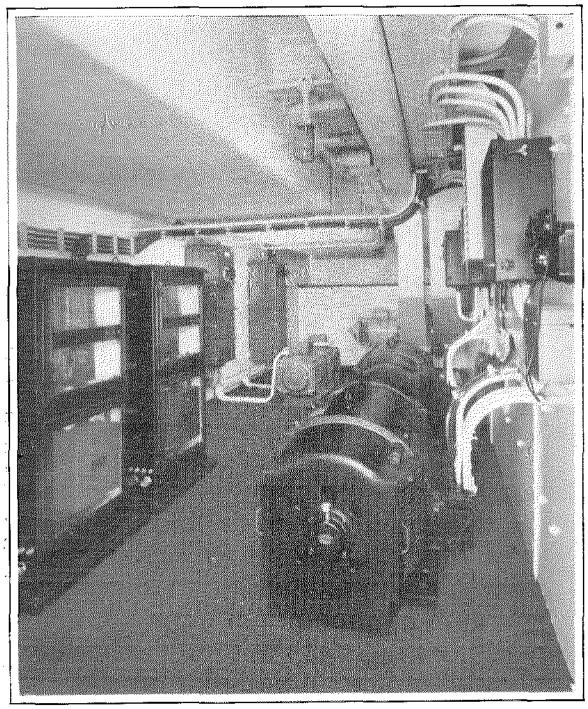
Antenna Systems

The antenna installation comprises four transmitting, five receiving, and one emergency transmitting-receiving aerial. Two features are of special interest:

For short wave transmission, the use of directive aerials is practicable due to the fact that the ship's normal bearing during the major portion of the transatlantic crossing does not vary more than thirty degrees from the bearing of the shore stations.

On the receiving side, coaxial cables similar to those now being installed for broad band transmission are used for transmission lines connecting the aerials to the various receivers. A unique coaxial switching panel permits the selection of any aerial for connection to any receiver.

Various precautions have been taken to insure quiet receiving conditions, such as the provision of filters in all power machinery and equipment throughout the ship. To eliminate the usual troublesome stay noises so familiar on ship installations, all stay wires on the mast and funnels have been securely connected to earth at both ends of the stays. All downhauls on the masts and funnels have been insulated and securely fastened to avoid any possible swinging of these cables against any metallic structures.



Electrical Generating Plant, Supplying Power for the Queen Mary Radio Installation. This Equipment is Duplicated against the Possibility of a Breakdown.

In connection with the successful completion of the Queen Mary radio installation, grateful acknowledgment is made for the assistance and cooperation of the Cunard White Star officials, the Naval Architect, and the Marine Superintendent. The British General Post Office also made special arrangements for exchanging operators on the Queen Mary with those of the Portishead Radio Station, as well as for calibrating the direction finder off the Port Patrick Radio Station.

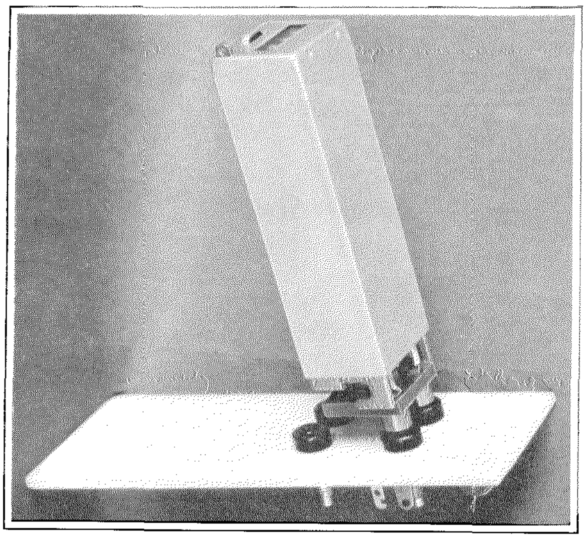
The radio equipment of the R.M.S. Queen Mary was almost entirely manufactured by companies in the International System and was supplied and installed and is operated by the International Marine Radio Company, Limited, under contractual agreement with the Cunard White Star, Limited. The I.M.R.C. has equipped eight of the ten British transatlantic liners so far furnished with facilities for subscribers' radio telephone service.

Recent Telecommunication Developments of Interest

PLUG-IN TYPE MESSAGE REGISTER. With gradual transfer from flat rate to message rate service, an economical cabling scheme has not been as practicable as in cases where message rate service has been standardized. Since, in general, provision of message registers for all lines simultaneously is not economical, the practice has been to run register cables to spare terminal strips on the M.D.F. to which the lines are jumpered as required. Objections to this procedure are that registers cannot be arranged in the sequence of the subscribers' numbers and, as message rate subscribers increase, it becomes difficult or impossible to provide accommodations for terminal strips or jumpers.

The plug-in type message register has been designed by the Bell Telephone Manufacturing Company, Antwerp, to provide for such cases. It permits a simpler layout and eliminates the costly process of jumpering, cables being run directly from the register rack to the numerical side of the M.D.F. and permanently connected to the existing terminals. When a subscriber is transferred from flat to message rate, all that is necessary is to plug in one of these message registers.

In 7-A.1 Rotary Exchanges, where the message register is connected in parallel with the cut-off relay, and where it is necessary to maintain the combined resistance of message register and cut-off relay at 600 ohms, a plug-in type resistance has been developed for use on lines without message registers. It therefore is possible to change lines from flat rate to message rate without altering the strapping of the cut-off relay.



Plug-In Type Message Register

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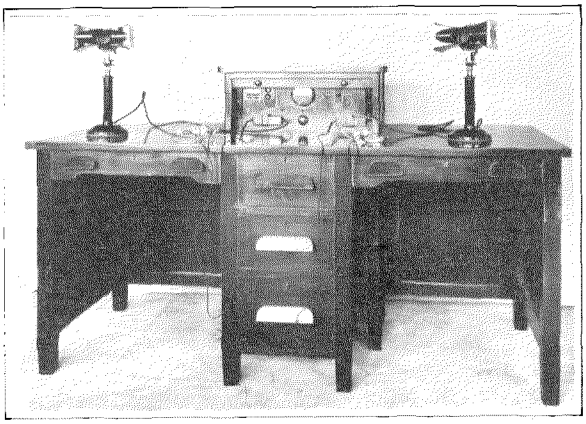
AN interesting development of the Bell Telephone Manufacturing Company, Antwerp, Belgium, is the so-called "Speech Translating System."

When meetings are held at which speakers use a language which is not understood by all the delegates present, it has generally been the custom to read a translation of the speech either immediately thereafter or at the end of the conference. Apart from the loss of time involved, this procedure has generally been regarded as unsatisfactory inasmuch as it disturbs the continuity of the meeting and is rather trying to the patience of those who have already heard and understood what has taken place.

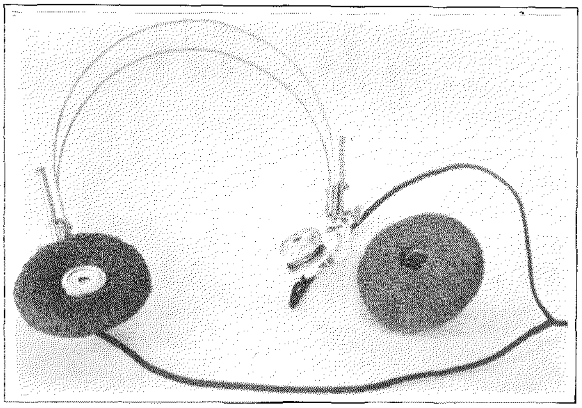
By means of the equipment shown in the accompanying illustration, a translation of the speech can be distributed by means of headphones to any of the delegates present at the time the speech is delivered. Such equipments were recently supplied by the Bell Telephone Manufacturing Company to the "Chambre des Représentants" and to the "Commission Syndicale de Belgique," both of Brussels. So far as is known, they represent the only installations of this character to date, apart from the system in use by the League of Nations at Geneva. Two positions, which can be used either simultaneously to translate into two languages for the benefit of the delegates or as relief desks, are provided at the translator's desk.

The equipment is mains operated. The microphones are of the permanent magnet, moving coil type provided with a special mouthpiece designed to eliminate room noise. The amplifier, which is mounted in the upper part of the desk, provides an amplification of approximately 70 db., the gain-frequency being constant to within 2 db. over the frequency range of 100–6,000 p : s.

A small potentiometer at each listening point provides facilities for volume adjustment. The headphones are of exceptionally light design, weighing only 130 grammes.



Speech Translating System



Lightweight Head Receivers

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1935

Countries	Number of Telephones: Government Systems	Number of Telephones: Private Companies	Number of Telephones: Total	Per Cent of Total World	Telephones Per 100 Population
NORTH AMERICA:					
United States	—	16,868,955	16,868,955	50.29%	13.36
Canada	190,602	1,003,127	1,193,729	3.56%	11.00
Central America	11,748	13,921	25,669	.08%	0.37
Mexico	1,337	107,315	108,652	.32%	0.62
West Indies:					
Cuba	500	32,494	32,994	.10%	0.79
Puerto Rico	537	11,529	12,066	.04%	0.72
Other W. I. Places	7,594	14,800	22,394	.07%	0.33
Other No. Am. Places	—	11,111	11,111	.03%	3.03
Total	212,318	18,063,252	18,275,570	54.49%	10.47
SOUTH AMERICA:					
Argentina	—	322,873	322,873	.96%	2.69
Bolivia	—	2,218	2,218	.01%	0.07
Brazil	1,924	190,742	192,666	.57%	0.41
Chile	—	50,360	50,360	.15%	1.12
Colombia	7,407	25,377	32,784	.10%	0.34
Ecuador	3,121	3,250	6,371	.02%	0.25
Paraguay	—	2,996	2,996	.01%	0.33
Peru	—	20,985	20,985	.06%	0.32
Uruguay	19,651	12,532	32,183	.09%	1.60
Venezuela	600	18,685	19,285	.06%	0.58
Other So. Am. Places	2,803	—	2,803	.01%	0.52
Total	35,506	650,018	685,524	2.04%	0.75
EUROPE:					
Austria	258,748	—	258,748	.77%	3.82
Belgium**	323,423	—	323,423	.96%	3.91
Bulgaria	20,646	—	20,646	.06%	0.34
Czechoslovakia	150,245	21,401	171,646	.51%	1.13
Denmark#	16,401	361,164	377,565	1.13%	10.31
Finland	2,369	138,698	141,067	.42%	3.75
France	1,399,869	—	1,399,869	4.17%	3.30
Germany#	3,134,103	—	3,134,103	9.34%	4.69
Great Britain and No. Ireland	2,366,311	—	2,366,311	7.06%	5.06
Greece	—	26,712	26,712	.08%	0.40
Hungary	121,067	735	121,802	.36%	1.37
Irish Free State#	34,799	—	34,799	.11%	1.16
Italy	—	516,075	516,075	1.54%	1.19
Jugo-Slavia	47,234	2,612	49,846	.15%	0.34
Latvia#	65,345	—	65,345	.20%	3.35
Netherlands	352,741	—	352,741	1.05%	4.20
Norway*	121,231	78,453	199,684	.60%	6.96
Poland	118,904	92,430	211,334	.63%	0.63
Portugal	10,833	38,633	49,466	.15%	0.70
Roumania	—	56,797	56,797	.17%	0.30
Russia¶	739,381	—	739,381	2.20%	0.43
Spain	—	312,719	312,719	.93%	1.28
Sweden	615,554	1,393	616,947	1.84%	9.90
Switzerland	383,289	—	383,289	1.14%	9.25
Other Places in Europe	85,153	13,290	98,443	.29%	1.29
Total	10,367,646	1,661,112	12,028,758	35.86%	2.13
ASIA:					
British India#	24,328	40,120	64,448	.19%	0.02
China	70,000	94,000	164,000	.49%	0.04
Japan#	1,068,244	—	1,068,244	3.19%	1.56
Other Places in Asia	141,106	66,593	207,699	.62%	0.13
Total	1,303,678	200,713	1,504,391	4.49%	0.14
AFRICA:					
Egypt	49,765	—	49,765	.15%	0.23
Union of South Africa#	140,349	—	140,349	.42%	1.64
Other Places in Africa	97,750	1,970	99,720	.30%	0.09
Total	287,864	1,970	289,834	.87%	0.20
OCEANIA:					
Australia*	501,402	—	501,402	1.49%	7.51
Dutch East Indies	37,407	3,641	41,048	.12%	0.06
Hawaii	—	23,857	23,857	.07%	6.36
New Zealand#	159,170	—	159,170	.48%	10.20
Philippine Islands	6,000	20,358	26,358	.08%	0.19
Other Places in Oceania	3,700	278	3,978	.01%	0.17
Total	707,679	48,134	755,813	2.25%	0.83
TOTAL WORLD	12,914,691	20,625,199	33,539,890§	100.00%	1.58

* June 30, 1934. ** February 28, 1935. # March 31, 1935.

¶ U.S.S.R., including Siberia and Associated Republics.

§ Includes approximately 15,560,000 automatic or "Dial" telephones, of which about 45% are in the United States.

Telephone and Telegraph Wire of the World, by Countries

January 1, 1935

Countries	Service Operated By (See Note)	Miles of Telephone Wire: Number of Miles	Per Cent of Total World	Per 100 Population	Miles of Telegraph Wire: Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	86,800,000	55.88%	68.73	2,270,000	32.40%	1.80
Canada	P.G.	5,134,000	3.30%	47.32	367,000	5.24%	3.38
Central America	P.G.	61,000	.04%	0.89	20,000	.28%	0.29
Mexico	P.	557,000	.36%	3.17	90,000	1.28%	0.51
West Indies:							
Cuba	P.	275,000	.18%	6.62	14,000	.20%	0.34
Puerto Rico	P.	33,000	.02%	1.98	2,000	.03%	0.12
Other W. I. Places	P.G.	105,000	.07%	1.54	8,500	.12%	0.12
Other No. Am. Places	P.	19,000	.01%	5.18	11,000	.16%	3.00
Total		92,984,000	59.86%	53.26	2,782,500	39.71%	1.59
SOUTH AMERICA:							
Argentina	P.	1,250,000	.80%	10.42	200,000	2.85%	1.67
Bolivia	P.	5,500	.004%	0.17	5,000	.07%	0.16
Brazil	P.	683,000	.44%	1.46	110,000	1.57%	0.24
Chile	P.	201,000	.13%	4.48	55,000	.79%	1.23
Colombia	P.	130,000	.08%	1.36	20,000	.29%	0.21
Ecuador	P.G.	9,000	.01%	0.36	4,000	.06%	0.16
Paraguay	P.	7,000	.005%	0.78	3,000	.04%	0.33
Peru	P.	60,000	.04%	0.92	12,000	.17%	0.18
Uruguay	P.G.	105,000	.07%	5.21	8,000	.11%	0.40
Venezuela	P.	78,000	.05%	2.34	7,000	.10%	0.21
Other So. Am. Places	G.	6,000	.004%	1.11	500	.01%	0.09
Total		2,534,500	1.63%	2.76	424,500	6.06%	0.46
EUROPE:							
Austria	G.	670,000	.43%	9.89	49,000	.70%	0.72
Belgium**	G.	1,831,000	1.18%	22.12	35,000	.50%	0.42
Bulgaria	G.	67,000	.04%	1.10	7,000	.10%	0.15
Czechoslovakia	P.G.	601,000	.39%	3.95	82,000	1.17%	0.54
Denmark#	P.	1,249,000	.80%	34.10	13,000	.19%	0.35
Finland	P.	350,000	.22%	9.30	18,000	.26%	0.48
France	G.	5,160,000	3.32%	12.16	521,000	7.44%	1.23
Germany#	G.	15,850,000	10.20%	23.73	130,000	1.85%	0.20
Great Britain and No. Ireland#	G.	11,670,000	7.51%	24.98	252,000	3.60%	0.54
Greece	P.	76,000	.05%	1.13	35,000	.50%	0.52
Hungary	G.	400,000	.26%	4.50	45,000	.64%	0.51
Irish Free State#	G.	125,000	.08%	4.17	22,000	.31%	0.73
Italy	P.	1,600,000	1.03%	3.69	266,000	3.80%	0.61
Jugo-Slavia	G.	145,000	.09%	0.99	58,000	.83%	0.39
Latvia#	G.	276,000	.18%	14.15	5,000	.07%	0.26
Netherlands	G.	1,150,000	.74%	13.70	16,000	.23%	0.19
Norway*	P.G.	602,000	.39%	20.98	28,000	.40%	0.98
Poland	P.G.	1,056,000	.68%	3.15	48,000	.68%	0.14
Portugal	P.G.	134,000	.09%	1.89	18,000	.26%	0.26
Roumania	P.	213,000	.14%	1.12	49,000	.70%	0.26
Russia¶	G.	1,300,000	.84%	0.75	600,000	8.56%	0.35
Spain	P.	1,220,000	.79%	4.98	92,000	1.31%	0.38
Sweden	G.	2,275,000	1.46%	36.50	27,000	.38%	0.43
Switzerland	G.	1,362,000	.88%	32.86	15,000	.21%	0.36
Other Places in Europe	P.G.	302,000	.19%	3.96	23,000	.33%	0.30
Total		49,684,000	31.98%	8.81	2,454,000	35.02%	0.44
ASIA:							
British India#	P.G.	424,000	.27%	0.12	427,000	6.09%	0.12
China	P.G.	520,000	.33%	0.04	130,000	1.86%	0.03
Japan#	G.	3,834,000	2.47%	5.58	233,000	3.33%	0.34
Other Places in Asia	P.G.	645,000	.42%	0.40	188,000	2.68%	0.12
Total		5,423,000	3.49%	0.52	978,000	13.96%	0.09
AFRICA:							
Egypt	G.	263,000	.17%	1.23	35,000	.50%	0.16
Union of South Africa#	G.	576,000	.37%	6.73	31,000	.44%	0.36
Other Places in Africa	P.G.	287,000	.19%	0.25	141,000	2.01%	0.12
Total		1,126,000	.73%	0.78	207,000	2.95%	0.14
OCEANIA:							
Australia*	G.	2,581,000	1.66%	38.66	98,000	1.40%	1.47
Dutch East Indies	G.	254,000	.16%	0.38	22,000	.31%	0.03
Hawaii	P.	89,000	.06%	23.73	0	.00%	0.00
New Zealand#	G.	588,000	.38%	37.69	26,000	.37%	1.67
Philippine Islands	P.G.	66,000	.04%	0.48	11,000	.16%	0.08
Other Places in Oceania	P.G.	8,000	.01%	0.35	4,000	.06%	0.17
Total		3,586,000	2.31%	3.94	161,000	2.30%	0.18
TOTAL WORLD		155,337,500	100.00%	7.33	7,007,000	100.00%	0.33

NOTE: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates that the telephone service is wholly or predominantly operated by private companies. G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See preceding table.

* June 30, 1934. ** February 28, 1935. # March 31, 1935.

¶ U.S.S.R. including Siberia and Associated Republics.

Telephone Development of Large and Small Communities—January 1, 1935

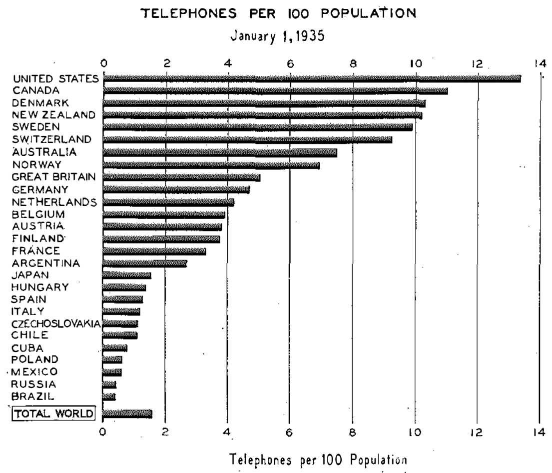
Country	Service Operated By (See Note)	Number of Telephones: In Communities of 50,000 Population and Over	Number of Telephones: In Communities of less than 50,000 Population	Telephones per 100 Population: In Communities of 50,000 Population and Over	Telephones per 100 Population: In Communities of less than 50,000 Population
Australia*	G.	293,477	207,925	9.07	6.04
Austria	G.	197,134	61,614	8.97	1.35
Belgium**	G.	227,133	96,290	6.43	2.03
Canada	P.G.	647,481	546,248	18.99	7.34
Czechoslovakia	P.G.	87,092	84,553	5.06	0.63
Denmark	P.	196,404	183,596	19.07	6.95
Finland	P.	54,141	86,926	11.00	2.66
France	G.	755,526	644,343	8.51	1.92
Germany†	G.	1,897,458	1,056,156	7.12	2.69
Great Britain and No. Ireland#	G.	1,740,600	676,000	6.59	3.33
Hungary	G.	92,679	29,123	4.53	0.43
Japan#	G.	699,811	368,433	3.51	0.76
Netherlands	G.	229,881	122,860	6.71	2.47
New Zealand#	G.	63,730	95,440	11.10	9.68
Norway*	P.G.	78,421	121,263	19.36	4.92
Poland	P.G.	122,452	88,882	2.46	0.31
Spain	P.	193,841	118,878	3.80	0.61
Sweden	G.	240,801	376,146	23.13	7.24
Switzerland	G.	173,861	209,428	19.76	6.41
Union of South Africa	G.	82,487	57,852	7.25	0.78
United States	P.	9,608,965	7,259,990	18.91	9.62

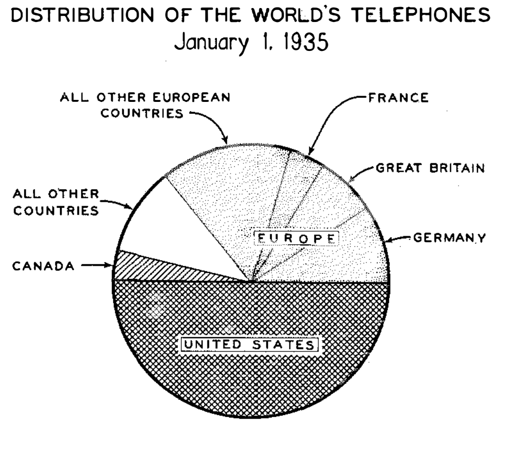
NOTE: P. indicates that the telephone service is wholly or predominantly operated by private companies, G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See first table.
* June 30, 1934. † March 31, 1934. ** February 28, 1935. # March 31, 1935.

Telephone Conversations and Telegrams—Year 1934

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent of Total Wire Communications: Telephone Conversations	Per Cent of Total Wire Communications: Telegrams	Wire Communications per Capita: Telephone Conversations	Wire Communications per Capita: Telegrams	Wire Communications per Capita: Total
Australia	428,000,000	14,051,000	442,051,000	96.8	3.2	64.3	2.1	66.4
Austria	600,000,000	1,689,000	601,689,000	99.7	0.3	88.7	0.2	88.9
Belgium	245,424,000	5,312,000	250,736,000	97.9	2.1	29.7	0.7	30.4
Canada	2,298,508,000	9,857,000	2,308,365,000	99.6	0.4	213.4	0.9	214.3
Czechoslovakia	270,000,000	3,860,000	273,860,000	98.6	1.4	17.8	0.3	18.1
Denmark	611,395,000	1,684,000	613,079,000	99.7	0.3	167.2	0.5	167.7
Finland	225,000,000	730,000	225,730,000	99.7	0.3	60.0	0.2	60.2
France	888,065,000	27,943,000	916,008,000	96.9	3.1	21.0	0.7	21.7
Germany	2,288,596,000	17,233,000	2,305,829,000	99.3	0.7	34.3	0.3	34.6
Great Britain and No. Ireland	1,720,000,000	43,926,000	1,763,926,000	97.5	2.5	36.9	0.9	37.8
Hungary	146,000,000	1,873,000	147,873,000	98.7	1.3	16.5	0.2	16.7
Japan	4,051,000,000	54,571,000	4,105,571,000	98.7	1.3	59.4	0.8	60.2
Netherlands	407,000,000	3,126,000	410,126,000	99.2	0.8	48.8	0.4	49.2
Norway	226,000,000	2,806,000	228,806,000	98.8	1.2	78.9	1.0	79.9
Poland	526,000,000	3,164,000	529,164,000	99.4	0.6	15.8	0.1	15.9
Spain	735,000,000	24,393,000	759,393,000	96.8	3.2	30.2	1.0	31.2
Sweden	900,000,000	3,592,000	903,592,000	99.6	0.4	144.6	0.6	145.2
Switzerland	278,335,000	1,857,000	280,192,000	99.3	0.7	67.3	0.5	67.8
Union of South Africa	247,000,000	5,529,000	252,529,000	97.8	2.2	29.0	0.7	29.7
United States	24,250,000,000	160,000,000	24,410,000,000	99.3	0.7	192.4	1.3	193.7

NOTE: Telephone conversations represent completed local and toll or long distance messages. Telegrams include inland and outgoing international messages.



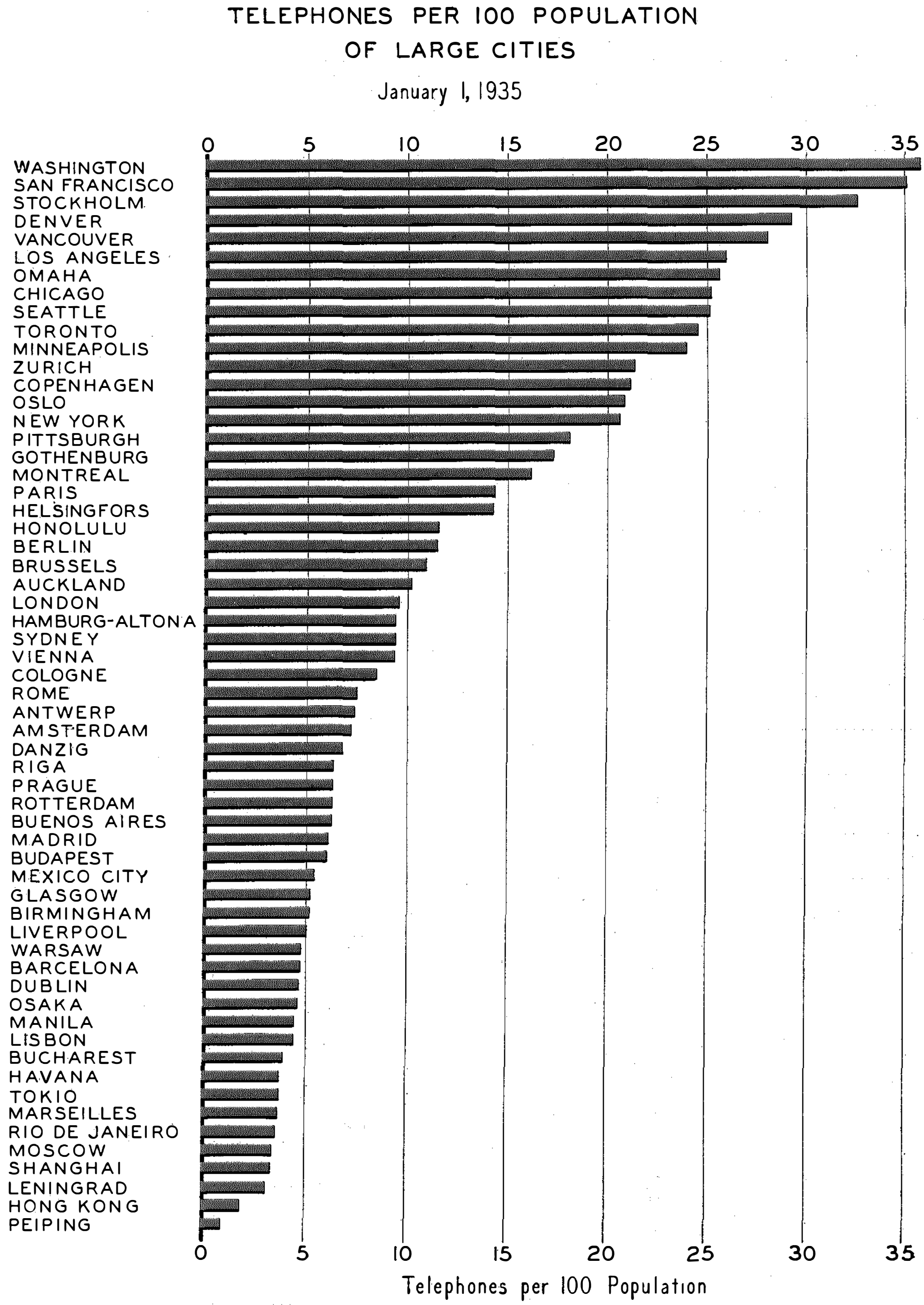


Telephone Development of Large Cities
January 1, 1935

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones Per 100 Population
ARGENTINA:			
Buenos Aires	3,000,000	188,528	6.28
AUSTRALIA:			
Adelaide	314,000	28,949	9.22
Brisbane	305,000	26,707	8.76
Melbourne	1,000,000	103,137	10.31
Sydney	1,249,000	117,759	9.43
AUSTRIA:			
Graz	153,000	10,784	7.05
Vienna	1,875,000	175,947	9.38
BELGIUM:**			
Antwerp	530,000	39,228	7.40
Brussels	965,000	105,654	10.95
Liege	424,000	23,695	5.59
BRAZIL:			
Rio de Janeiro	1,800,000	64,046	3.56
CANADA:			
Montreal	1,016,700	164,594	16.19
Ottawa	188,000	35,441	18.85
Toronto	766,300	188,287	24.57
Vancouver	187,500	52,549	28.03
CHINA:			
Canton	1,060,000	8,056	0.76
Hong Kong	850,000	14,845	1.75
Peiping	1,540,000	12,948	0.84
Shanghai††	1,650,000	54,861	3.32
CUBA:			
Havana	700,000	25,899	3.70
CZECHOSLOVAKIA:			
Prague	913,000	57,725	6.32
DANZIG:			
Free City of Danzig	265,000	17,964	6.78
DENMARK:			
Copenhagen	820,000	173,372	21.14
FINLAND:			
Helsingfors	270,000	38,653	14.32
FRANCE:			
Bordeaux	268,000	20,348	7.59
Lille	202,000	17,346	8.59
Lyons	670,000	35,317	5.27
Marseilles	930,000	34,165	3.67
Paris	2,905,000	416,870	14.35
GERMANY:#			
Berlin	4,250,000	488,244	11.49
Breslau	630,000	42,185	6.70
Cologne	765,000	64,935	8.49
Dresden	735,000	60,899	8.29
Dortmund	585,000	23,958	4.10
Essen	665,000	30,254	4.55
Frankfort-on-Main	655,000	61,968	9.46
Hamburg-Altona	1,650,000	155,826	9.44
Leipzig	775,000	65,038	8.39
Munich	745,000	79,219	10.63
GREAT BRITAIN AND NO. IRELAND:#			
Belfast	415,000	19,280	4.65
Birmingham	1,210,000	62,147	5.14
Bristol	417,000	22,711	5.45
Edinburgh	444,000	34,565	7.78
Glasgow	1,195,000	61,747	5.17
Leeds	514,000	25,922	5.04
Liverpool	1,200,000	60,131	5.01
London	9,300,000	891,725	9.59
Manchester	1,103,000	67,336	6.10
Newcastle	471,000	20,558	4.36
Sheffield	520,000	21,202	4.08
HAWAII:			
Honolulu	138,000	15,942	11.55
HUNGARY:			
Budapest	1,360,000	81,886	6.02
Szeged	138,000	2,100	1.52
IRISH FREE STATE:#			
Dublin	429,000	19,920	4.64
ITALY:			
Milan	1,065,000	88,701	8.33
Naples	880,000	27,098	3.08
Rome	1,150,000	86,393	7.51
JAPAN: #			
Kobe	854,000	34,700	4.06
Kyoto	1,053,000	42,408	4.03
Nagoya	1,018,000	34,846	3.42
Osaka	2,723,000	124,883	4.59
Tokio	5,663,000	209,605	3.70
LATVIA:#			
Riga	385,000	24,437	6.35
MEXICO:			
Mexico City	1,150,000	61,969	5.39
NETHERLANDS:			
Amsterdam	782,000	56,468	7.22
Haarlem	162,000	12,775	7.89
Rotterdam	616,000	38,808	6.30
The Hague	518,000	48,939	9.45
NEW ZEALAND:#			
Auckland	218,000	22,236	10.20
NORWAY:*			
Oslo	250,000	52,198	20.88
PHILIPPINE ISLANDS:			
Manila	394,000	17,328	4.40
POLAND:			
Lodz	900,000	14,356	1.60
Warsaw	1,260,000	59,842	4.75
PORTUGAL:			
Lisbon	651,000	28,470	4.37
ROUMANIA:			
Bucharest	640,000	24,718	3.86
RUSSIA:			
Leningrad	3,000,000	91,023	3.03
Moscow	4,000,000	134,440	3.36
SPAIN:			
Barcelona	1,080,000	51,014	4.72
Madrid	1,000,000	61,017	6.10
SWEDEN:			
Gothenburg	255,000	44,228	17.32
Malmö	139,000	21,591	15.56
Stockholm	441,000	144,011	32.64
SWITZERLAND:			
Basel	151,000	32,441	21.48
Berne	114,000	24,992	21.92
Geneva	147,000	27,235	18.53
Zurich	268,000	57,330	21.39
UNITED STATES: (See Note)			
New York	7,247,000	1,493,374	20.61
Chicago	3,270,000	824,293	25.21
Los Angeles	1,315,000	341,221	25.95
Pittsburgh	1,015,900	183,761	18.09
Total 10 cities over 1,000,000 Population	21,777,600	4,437,758	20.38
Milwaukee	763,200	135,963	17.81
San Francisco	690,000	242,026	35.08
Washington	528,000	189,017	35.80
Minneapolis	505,000	121,123	23.98
Total 10 cities with 500,000 to 1,000,000 Population	6,515,300	1,320,692	20.27
Seattle	417,200	105,087	25.19
Denver	300,000	87,755	29.25
Omaha	238,600	61,186	25.64
Hartford	237,300	53,224	22.43
Total 34 cities with 200,000 to 500,000 Population	10,191,900	1,812,160	17.78
Total 54 cities with more than 200,000 Population	38,484,800	7,570,610	19.67

NOTE: There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups, and the development of certain representative cities within each of such groups.

* June 30, 1934. ** February 28, 1935. # March 31, 1935. †† International Settlement and French Concession.


TELEPHONES PER 100 POPULATION
OF LARGE CITIES
January 1, 1935
0 5 10 15 20 25 30 35
WASHINGTON
SAN FRANCISCO
STOCKHOLM
DENVER
VANCOUVER
LOS ANGELES
OMAHA
CHICAGO
SEATTLE
TORONTO
MINNEAPOLIS
ZURICH
COPENHAGEN
OSLO
NEW YORK
PITTSBURGH
GOTHENBURG
MONTREAL
PARIS
HELSINGFORS
HONOLULU
BERLIN
BRUSSELS
AUCKLAND
LONDON
HAMBURG-ALTONA
SYDNEY
VIENNA
COLOGNE
ROME
ANTWERP
AMSTERDAM
DANZIG
RIGA
PRAGUE
ROTTERDAM
BUENOS AIRES
MADRID
BUDAPEST
MEXICO CITY
GLASGOW
BIRMINGHAM
LIVERPOOL
WARSAW
BARCELONA
DUBLIN
OSAKA
MANILA
LISBON
BUCHAREST
HAVANA
TOKIO
MARSEILLES
RIO DE JANEIRO
MOSCOW
SHANGHAI
LENINGRAD
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