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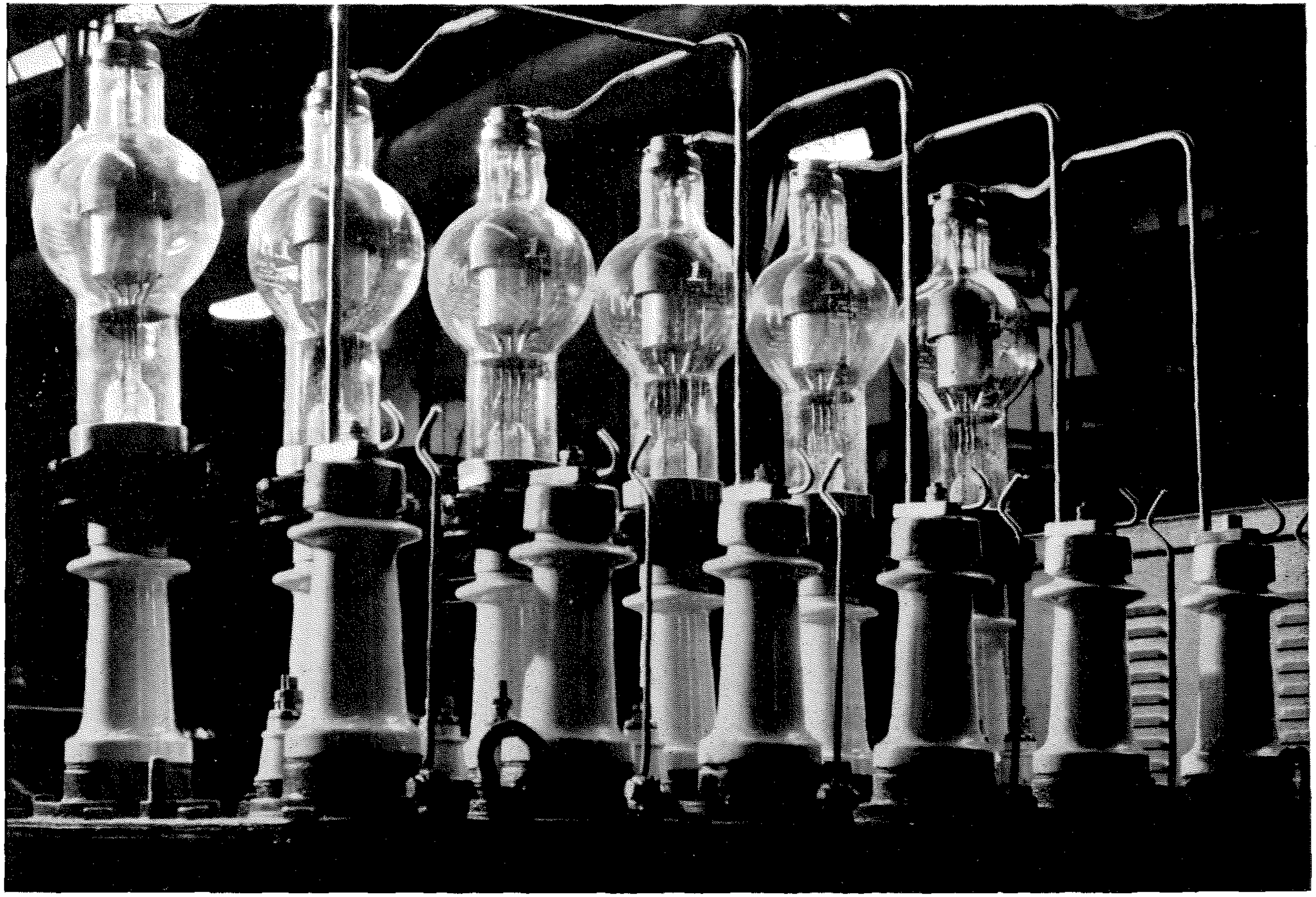

A bank of high power grid-controlled mercury vapour rectifiers (Le Matériel Téléphonique, Paris, France).

Electrical Communication in 1939

SOMEWHAT paradoxically, the extent to which electrical communication contributes to the world of 1939 is reflected in the attenuated nature of this attempt to review communications progress during the past year.

The record of a year which at the outset promised such great applications of new and developing techniques has been temporarily obscured, so far as Europe is concerned, by the drop curtain of war, which has entirely blotted out many important telecommunication developments, and has drawn the discreetest of veils over others which have a special bearing on the war effort.

Electrical communication played a valuable rôle in peace, and, by providing means for the interchange of views, did much towards preserving it; but its importance in war is even greater. The various wire and radio communication facilities are vitally necessary to all arms, forming the eyes and ears of navies and of air and land forces. Thus, whilst war conditions impose silence about much of what has been done in Europe in 1939, research, development, and manufacture are proceeding at a greatly accelerated rate, and will so continue throughout the duration of hostilities.

It may be noted that telecommunications and their allied applications are playing a much bigger relative part than they did in the 1914–1918 war, when long-distance telephony and the radio transmission of speech were novelties. Even at the end of that war, international telephone communication in Europe was restricted by the lack of any organization to achieve it. The war of 1939 started with a wealth of telecommunication facilities practically undreamed of 21 years ago, but the extent and precise nature of their employment depend on circumstances which cannot at present be foreseen.

WIRE TRANSMISSION SYSTEMS

In 1939, many countries made additions to their toll cable networks, and among these, 12-channel carrier-on-cable systems were particularly prominent. In Great Britain, 900 km of 12-channel cable were installed during the year, whilst a further 1 100 km is under construction or on order. The coaxial cable between London and Newcastle has now been completed, and in addition to the carrier cable, a total of approximately 4 000 km of loaded trunk cables were completed or under construction.

Initial 12-channel carrier-on-cable systems have been completed or are under construction in a number of countries. In Belgium, the Antwerp—Roosendaal cable (which will eventually be extended to Brussels, linking up the Belgian and Dutch toll networks) was completed. Work is proceeding in Sweden on the Göteborg—Malmö system (278 km), whilst in Finland some progress had been made with the Helsinki—Turku system (169 km). The intention was to connect the Helsinki—Turku system to the recently-laid Stockholm — Turku submarine cable, which is also designed for 12-channel operation. A combined 12-channel and loaded cable is under construction in Denmark, between Aalborg and Aarhus (111 km), and this will eventually be extended to Copenhagen. In Rumania, the Bucharest—Ploesti combined 12-channel and loaded cable system[1] has been extended to Brasov, making a total distance of 170 km.

The Norwegian and Swedish cable systems were linked up with the installation of the Halden—Kornsjo cable (70 km). This is a loaded cable designed for voice frequency and single-channel carrier operation.

[1] See references at the end of this article.

A number of additional 12-channel carrier systems (both open-wire and cable) were placed in service in various parts of the United States of America. Tests on the New York—Philadelphia coaxial cable were continued with the frequency increased to 3 megacycles, and the first coaxial cable installation in the U.S.A. definitely intended for commercial telephone service is being made between Stevens Point, Wisconsin, and Minneapolis, Minnesota, a distance of slightly under 320 km.

In Australia, a 12-channel open-wire carrier system was placed in service between Sydney and Melbourne. This equipment, the first of its type to be installed outside the U.S.A., was manufactured by the Western Electric Company.

Following the opening of the Japan—Manchukuo non-loaded cable telephone circuit, a similar telephone circuit was completed in China between Tientsin and Peking. By connecting calls from or for China at Hoten (Mukden), Manchukuo, to the above-mentioned Japan—Manchukuo circuit, a Japan—Manchukuo—China circuit was established.

SUBSCRIBERS' APPARATUS

Changes in subscribers' apparatus must necessarily be slow on account of the large plant investment, but development of components and provision of increased facilities can be made more readily. 1939 witnessed no exceptional change in telephone sets as a whole.

Development work on transmitters continued, with the aim of reducing non-linear distortion and securing a good frequency characteristic.

Considerable interest has been shown in the magnetic (or battery-less) telephone, a reversion to the earliest type of telephone, made possible in efficient form by the great improvement in magnetic materials in recent years.

AUTOMATIC TELEPHONY

Automatic Ticketing

An outstanding event in the history of automatic telephony was the successful installation of automatic ticketing equipment in all the exchanges of the city of Brussels. Equipment has been added to each local exchange which automatically identifies and determines the number of the calling subscriber and passes this information to the central toll exchange, where it is printed on a ticket which is produced on outgoing multi-fee connections. The ticket also records the number of the called subscriber, the toll prefix of the called town, the date and time of day and the basic tariff. The introduction of automatic ticketing, together with means for the automatic identification of the calling subscriber on outgoing multi-fee connections, has been made without any interruption to regular service and without serious modification or addition to the existing local exchange equipment, some of which is of a very early type.

For the time being, the Brussels subscribers can call automatically subscribers in the surrounding rural zone, but in 1940 it is planned to extend full automatic operation to distant towns, commencing with Antwerp, Mons, Namur and Malines. All calls will be automatically recorded on tickets. The installation of automatic ticketing equipment in the local exchanges of Antwerp is now in hand, and in the near future full automatic toll service between Antwerp and Brussels will be in operation in both directions.

A second notable achievement was the cut-over of a new Rotary exchange in Malines, equipped for automatic ticketing. Subscribers of the Malines exchange have full automatic service to the neighbouring towns, Brussels and Antwerp, each toll connection being recorded on a ticket.[2]

In April, 1939, another new exchange equipped with automatic ticketing was put into service at Huy. The subscribers of this exchange have facilities for automatically calling subscribers of Liége and Namur.

This work is part of the general plan to provide full automatic long-distance service over the whole of Belgium, and all outgoing multi-fee connections will be recorded on tickets. In Belgium alone there were, at the end of 1939, twenty-five Rotary exchanges to which were connected 135 000 lines operating with automatic ticketing facilities. Twenty-nine new Rotary exchanges are on order and the total number of lines and exchanges, in service and on order, equipped for automatic ticketing, is 150 000 lines in 54 exchanges.

Number Indicating

During the year, an order was received by Standard Telephones and Cables for the provision of two new trunk exchanges for Dublin, Eire. The initial order comprises 43 positions which, it is planned, will subsequently be extended to 120 positions. Each of these positions will carry a number indicator ("Numbercator") mounted on the plug shelf to notify the operator of the identity of a subscriber calling for a toll connection.

National Dialling

In Holland, the automatization of The Hague zone or district was continued with the cut-over on July 4th, 1939, of the Leiden exchange, equipped with 7 000 lines of the 7-D Rotary system. In addition, equipment for an automatic toll and rural main exchange, constituting the switching centre or pivotal point of The Hague district, is now being manufactured; it comprises 568 outgoing and incoming toll lines to and from other districts, 774 rural lines to and from the different automatic exchanges in The Hague district, such as Leiden, and 990 junctions to and from the urban exchanges of The Hague city. When this automatic toll exchange is cut over, Leiden, Delft and other towns of The Hague district will have the facility of full automatic national dialling.

Orders have also been placed for two more exchanges in The Hague district totalling 5 000 lines of 7-D Rotary equipment.

The Danish Telephone and Telegraph Administration is also actively engaged in studying the introduction of automatic long-distance service. A national fundamental plan has been compiled and all telephone equipment, whether owned by the State or by private Companies, must fulfil its requirements. The fundamental plan includes provision for automatic ticketing of toll calls.

The interworking of the existing automatic equipment in Denmark with the national toll network is being studied and a model is being erected.

In Geneva, Switzerland, a new full automatic toll exchange is now in course of installation, which will enable the subscribers of the Geneva city and rural networks to obtain communication automatically with similar networks in Lausanne and Berne. The equipment permits full national dialling on the basis of the fundamental toll plan adopted by the Swiss Telephone Administration. Full automatic service will be established progressively on other Swiss networks.

Voice Frequency Signalling and Dialling

The first stage of an automatic national toll dialling and signalling system for Eire has been completed and placed in service. The systems installed provide for operator to subscriber dialling between Cork, Limerick and Dublin by two-voice frequency signalling, chiefly over open-wire carrier circuits. Additional systems are in process of installation at Waterford, Wexford, Galway, Sligo and Claremorris. The system installed uses a prefix composed of the two frequencies transmitted simultaneously, and is suitable for use in conjunction with both Rotary and step-by-step systems. A system of this type was recommended for International use by the C.C.I.F. at the Meeting in Oslo in 1938.[3]

Rotary Automatic System

The year 1939 showed no diminution of the steady growth of the Rotary system and while, owing to the war, it has not been possible to compile exact figures, a substantial increase can be foreseen over the total of 2 250 000 lines installed and on order recorded at the end of 1938.

New exchanges of the 7-A2 and 7-D Rotary types are being manufactured for installation in many different countries, including Belgium, Brazil, Denmark, Holland, Norway, New Zealand, Peru, Rumania and Switzerland.

Laboratory engineers are continually engaged in the evolution of new refinements in the art, with the object of maintaining the world-wide application of the Rotary system and its ability to fulfil the complex requirements of large metropolitan exchanges or the simple requirements of isolated single offices.

The Rotary system has been equally successful in the private automatic branch exchange field, and during 1939 over 1 500 P.A.B.X.'s were manufactured.

RADIO BROADCASTING

Following the Cairo Conference (1938), broadcasting wavelengths were discussed at Montreux in the Spring of 1939, and a new plan for the European zone was worked out. Considerable attention was given to the use of synchronizing systems, anti-sky wave and directive aerials to utilize to the best advantage the limited number of channels available. The plan, which was to come into force in 1940, envisaged an extensive use of these methods, coupled with an increasing number of high power stations, and involved 61 groups of synchronized networks and 48 cases of directive aerials.

The tendency to increase the power of medium wave broadcast transmitters was again apparent. Table I shows the distribution of existing stations in 1939 compared with the proposed stations under the Montreux plan for 1940.

The increase in number and average power in the high power group is most marked, but it may be noted that the upper limit of power remains at 120 kW.

Broadcasting in Asia

There has been further expansion of broadcasting in Asia. Of great interest is the network of stations being erected in Iran. This scheme is particularly applicable to tropical territories which have a number of population centres separated by wild and sparsely populated districts. It envisages small medium-wave local transmitters which radiate a programme supplied by powerful central short-wave transmitters. In Iran, the capital, Teheran, will be equipped with a 1.5-kW and a 20-kW short-wave transmitter, while Teheran and 12 other towns will have local medium-wave transmitters of suitable power. It may also be noted that such a system permits a cheap type of medium-wave receiver which is within the purchasing power of the population.

Several of the Indian States are considering development of their local medium-wave service, and a 5-kW and several smaller stations are being supplied to Travancore State.

The Thailand P.T.T. have a 100-kW medium-wave station under construction for Bangkok. This will be of the Standard Telephones and Cables Class B final stage modulation type as used by the B.B.C. It will also be equipped with a Standard-Blaw-Knox vertical radiator and with extensive new studios.

The Rome short-wave station of two 100-kW and one 50-kW transmitters was completed and is in service, and a 100-kW transmitter was planned for Finland.

British Stations

In England the British Broadcasting Corporation brought into service the new high-power transmitting station at Start Point, in South Devon, and the medium-power transmitting station at Clevedon, near Bristol. These transmitters replaced the transmitter which had been carrying the West of England Regional service, and the low-power relay transmitters at Plymouth and Bournemouth.

The 100-kW Standard Telephones and Cables transmitter at Start Point[4] employed a directional radiator system phased on the allotted wavelength of 285.7 metres to give increased radiation roughly to the East and West, and a correspondingly reduced radiation to the South over the sea.

The medium-power station at Clevedon, also equipped with a S.T. & C. transmitter, which came into service at the same time as Start Point, covered the Bristol area and parts of North Devon and Somerset which are not within the service area of Start Point.

TABLE I

Power Group	No. of Stations 1939	No. of Stations 1940	Total Power 1939	Total Power 1940	Average Power/Station 1939	Average Power/Station 1940
0.2– 2 kW ..	69	76	75.7	85.5	1.1	1.1
2.5–10 kW ..	46	65	371	497.5	8.1	7.6
15 –50 kW ..	42	43	1 175	1 230	28	28.5
60 –120 kW ..	33	64	2 720	6 650	82	104
TOTAL ..	190	248	4 341.7	8 463	22.8	34

Independent Crystal Drives

Developments in quartz crystal technique applied to crystal oscillators of extreme accuracy led to the installation in 1938 of independent crystal drives at broadcasting stations sharing a common wavelength, and resulted in greatly improved synchronization between the stations concerned. In 1939, this system of crystal drive was extended to the remaining British Regional stations working on exclusive wavelengths. Orders were placed for two new Regional transmitters, each of 120 kW (the maximum power admissible by the new Broadcasting Convention of Montreux). These transmitters were intended for service at Brookmans Park (London Regional) and Moorside Edge (North Regional).

The importance of long distance broadcasting on short waves has again been prominent and the B.B.C. is adding further 100-kW transmitters to its station at Daventry for Empire broadcasting.

Use of Ultra-short Waves

The use of ultra-short waves for local broadcasting continues to receive attention, particularly in view of the possibilities it offers for improving quality by taking advantage of the large amount of available channel space to increase the range of modulation frequency and to provide a wide frequency separation between adjacent channels. There is a further advantage in that the noise level in the ultra-short waveband is lower than in the medium waveband. Application of the ultra-short waveband to broadcasting has so far been confined in Europe to the sound channels associated with television, notably in connection with the London and Paris television services.

Developments in the U.S.A.

A line of development which has attracted a good deal of attention in the United States has been the use of frequency modulation for U.S.W. sound broadcasting. This development is conditional on the availability of wide channel frequency space, since its advantages are obtained at the expense of using a bandwidth of the order of 200-kc, even on a sound channel. The advantages claimed include a decrease in the noise level over and above that already observed with amplitude modulation when operating in the same waveband, and the possibility of working neighbouring stations on the same wavelength with a big reduction in the area of poor reception due to over-lapping of the two fields. In the U.S.A. several experimental stations were placed in operation at frequencies in the neighbourhood of 40 megacycles. Some of the leading manufacturers are in commercial production of both transmitters and receivers. The system also appears to have possibilities for mobile station communication.

Recording Broadcast Programmes

A great deal of attention has been paid to the recording of broadcast programmes for re-radiation on short-wave services at more convenient listening times. Many systems, including steel tape, celluloid film and the acetate disc types, have been given extensive service trials. The acetate disc, as used by the B.B.C., will be adopted in Iran, Thailand and other countries.

The most interesting development in the microphone field is the introduction of the directional or "cardioid" microphone.

During the year the B.B.C., the British Post Office, and the British Standards Institution carried out further co-operative work on the subject of electrical interference with radio reception, and a number of agreed standard specifications were issued.

Attention was also directed to the problem of interference caused by electro-medical equipment on short and ultra-short wavelengths.

AVIATION RADIO

The most outstanding event in the application of radio to the problems of air navigation has been the acceptance and standardization by the U.S. Civil Aeronautics Authority of an instrument landing system developed by the International Telephone Development Company Inc. to the specifications of the Civil Aeronautics Authority. It is anticipated that some 25 airports in the U.S.A. will be equipped with this system in the next two years.

The U.S. system differs in two points from the European systems exemplified by the Lorenz equipment. Firstly, the wavelengths chosen are between 3 and 4 metres, whilst the European systems utilize longer wavelengths (approximately 9 metres). Secondly, the U.S. system employs fixed beams, the path being defined by the equality of two modulations, whilst the European systems rely on interlaced beams keyed on a dot-dash rhythm. A similarity between the present standardized system for the U.S. and the system developed by Le Matériel Téléphonique in 1938 is that the equipment for runway horizontal localizer and glidepath has been separated in both cases.

An important event in the history of aviation radio was the constitution in 1939 of an International Advisory Committee under the title of "Comité International Radio-aéronautique" (C.I.R.A.). First projected in 1938, this body was formally constituted on July 1st, 1939, with headquarters in Brussels.

Crystal-Controlled Transmitters

The continued expansion of civil aviation, and hence the need for radio channels for communication purposes, has resulted in wider adoption of crystal control for transmitters. The increased certainty of rapid contact ensured by crystal control is of vital importance as aircraft speed and traffic increase, and modern transmitters for civil aircraft are now equipped with up to ten crystal-controlled spot frequencies. The use of long waves and the corresponding ether congestion in Europe has strengthened the tendency towards the employment of telegraphy as the normal mode for operating services.

Work in the U.S. is being carried out to include the use of facsimile transmission with an equivalent keying speed of from 200 to 300 words per minute. The Paris C.M.E.R.A. Conference recognized the increasing demand for radio communication for private aircraft in Europe and allocated wavelengths in the ultra-short waveband for this service.

Considerable attention has been paid to the problem of acoustic interference in aircraft telephone transmissions due to cross modulation in the microphone between speech and air-borne engine noise. Microphones with a linear pressure response have been developed to overcome this trouble; the 4027-A magnetic microphone of Standard Telephones and Cables, Limited, is a typical example.

Radio Compass in Navigation

An interesting application of the radio compass to aerial navigation is the combination of the radio compass indication with that of the gyro or magnetic compass. The navigator requires to know at any moment the bearing of a radio station with regard to true North, and this involves simultaneous reading of two instruments (the gyro compass and the radio compass), a procedure which becomes difficult and inaccurate if the airplane is swinging badly. The combination of these two indications permits of greater rapidity and precision of radio navigation.

Research on Landing Systems

The necessity of standardization for landing systems and their immediate installation has not prevented further research. The Massachusetts Institute of Technology, with the official backing of the U.S. Civil Aeronautics Authority, has been actively engaged on the development of a system for glidepath indicators, working on 45 cm and employing an equi-modulation path; all previous work done in Europe and America has been based on equifield strength paths.

MARINE RADIO

To meet the need for an up-to-date medium-powered telegraph marine transmitter suitable for all the larger classes of compulsorily-fitted ships from cargo vessels to passenger liners, the International Marine Radio Company Ltd. (an associate of the I.T. & T. Corporation) introduced the first commercial transmitter providing high-quality service on all marine telegraph frequency bands. Design features of the new transmitter include variable tuning, master-oscillator control over the whole frequency range (16.9–55, 583–820, and 1 875–2 800 metres), with optional crystal control on a number of spot high frequencies.

Another interesting I.M.R.C. development was that of a 135-watt marine radio beacon equipment satisfying the widely varying requirements of a number of countries.

Ship-to-Shore Telephony

A further advance in ship-to-shore telephony was made during the year, when successful experiments in "duplex" working (more correctly described as two-way communication without the use of carrier suppression arrangements) were carried out by the I.M.R.C. between vessels of the British and Irish Steam Navigation Company, operating between Liverpool and Dublin, and the land telephone networks in Great Britain and Eire, through a British Post Office shore station.

Such short-distance radiotelephony is carried out on the maritime frequencies around 2 megacycles, and until quite recently was more or less confined to the exchange of telegrams by radiotelephony between ship and shore, the service being mainly for the convenience of coasters and trawlers which did not carry radio officers. An increasing demand existed, however, for direct radio telephone communication with such ships through the land telephone systems, and once this was introduced, the demand for a public ship-to-shore radiotelephone service for the use of passengers in small ships rapidly followed.

COMMERCIAL RADIO

Shortly after the outbreak of war in Europe, the International Telephone and Telegraph Corporation through its radio subsidiary at Buenos Aires established radio-telephone circuits connecting the telephones of most of South America directly with Belgium and Holland to augment existing services. Other direct circuits between South America and neutral countries in Europe will probably be opened.

Two important radiotelephone circuits were opened in 1939 in South America. One is the connection between the radio stations of the I.T. & T. subsidiary at Buenos Aires and the station recently acquired and improved by an I.T. & T. company at La Paz, Bolivia. This circuit opened world telephone service to Bolivia for the first time. The other circuit is a direct radiotelephone connection between Buenos Aires and Caracas, Venezuela.

Coastal harbour radiotelephone service has been opened by the I.T. & T. radio company in Puerto Rico.

The radiotelephone service between South America and Japan via the station of the I.T. & T. radio company at Santiago, Chile, has been extended to Colombia and Peru through the radiotelephone stations of All America Cables & Radio, Inc., which is also an associated company of the I.T. & T. System.

Service was opened between England and the new trans-oceanic receiving station of the American Telephone and Telegraph Company at Manahawkin, New Jersey. This installation was equipped with the newly-developed multiple unit steerable antenna.

The use of single sideband on short wave transoceanic telephone circuits continues to increase. The direct circuit between the U.S.A. and Switzerland will be equipped with single sideband apparatus which is being manufactured by the Western Electric Company. Further circuits are planned between the U.S.A. and South America.

REMOTE CONTROL

In the field of supervisory remote control and switchgear, many important orders for large scale equipments were secured by Standard Telephones and Cables Ltd., London, including installations for London Transport, the London and North Eastern Railway, Manchester Corporation, and Wellington City Council, New Zealand. In all cases, the orders have included large central control rooms.

It is interesting to record that Standard systems are now being employed for the control and indication of 3 196 switches, 524 meters and 90 transformers in many countries of the world.

The Standard multi-service system for the control of street lighting and other municipal services[5] was largely installed during the year in many new areas. Altogether thirty-three undertakings in the British Isles now employ this system, whilst a notable order was received from Wellington for the control of 3 000 water heaters by means of this system.

FACSIMILE TRANSMISSION

The Western Union Telegraph Company has developed facsimile transmission systems for use by subscribers[6]. In the first system, the subscriber is provided with an apparatus which is used either for transmitting or for receiving; it contains a rotating cylinder suitable either for wrapping the message to be transmitted, or for a sensitive paper when receiving, and means are included for putting into action a photocell when transmitting, or a printing stylus when receiving. Printing is done on a special dry paper by the action of the current passing through a semi-conductive layer covering a paper containing a suitable conductive material such as lamp black or aluminium powder.

Another apparatus, which can be installed at any public place, resembles a letter box. The message, written on a standard form, is inserted into a slot and a mechanism automatically performs all operations.

At the central office, reception is also made on special dry sensitized paper, elaborate machines being used which are automatically fed with sensitive paper.

TELEGRAPH

In a number of European countries, the year was characterized by widespread demands for written communication facilities.

These demands, which involved a wide range of printing telegraph apparatus, were of such magnitude and urgency that they taxed to the utmost the facilities of the Telegraph Administrations concerned, and also the production capacity and technical resources of the manufacturers.

During the earlier part of the year, progress was made in several Balkan countries, including Turkey, towards the reorganization of their national telegraph services, and initial Creed Teleprinter installations were made in Burma and Newfoundland.

The demand for Creed high speed morse apparatus for both radio and submarine cable services was well maintained throughout the year.

TELEVISION

In the U.S.A., the National Broadcasting Company made a start with experimental television broadcasts using a transmitting antenna at the top of the Empire State Building in New York City.

The stoppage of television transmission in Britain and France on the outbreak of war has delayed the full application of much of the technical development of the earlier months of the year. In Britain progress was made in increasing the number of outside television broadcasts, successful transmission over ordinary telephone lines up to distances of four miles enabling many additional programme sources to be linked to the special balanced-pair television cable which runs around central London.

For outside broadcasts passed by radio link using one of the two mobile units (consisting of scanning and ultra-short wave transmitting vans), the receiving station established at Highgate, London, in 1938 as an alternative to reception at Alexandra Palace was taken into general use. The received signals were conveyed thence to Alexandra Palace at vision frequency by the neighbouring balanced-pair television cable. The receiving aerial was a two-element array half-way up a 76-m mast, but experiments were begun with the use of a rotatable receiving array for horizontally polarized waves, with which a gain of about 10 db. was anticipated.

POWER CABLE

The battle for supremacy among the three types of supertension cable mentioned last year (oil-filled, gas-filled and gas-pressure) was continued in 1939. The oil-filled type continues to meet the requirements of supply engineers who prefer a type with an established operating reputation. The gas-pressure type, however, has increased its number of installations in virtue of contracts placed in Germany and England. Some interest is also being shown in this type in the U.S.A. For various reasons, including economics, the cable drawn into a steel pipe has been preferred to the self-contained type (in which the gas-containing pipe is a reinforced lead sheath).

While continuing to enhance its operating record, the gas-filled type has been the centre of a fierce academic argument. In the U.S.A., a paper by Shanklin produced an interesting discussion, and at the C.I.G.R.E. in Paris in July, the debate between gas-filled and gas-pressure was particularly lively. The argument centres round the necessity of excluding the gaseous pressure medium from the insulation proper. It is probable that during 1940 further research work will tend to clarify the position.

For voltages of the order of 60 kV, there have been signs of renewed interest in solid-type cables.

The problem of emergency repairs under air raid conditions has led to development work on joints and terminations made without the application of heat. Particular interest has been shown in the possibilities of cold-setting compounds.

I.T. & T. OPERATING TELEPHONE COMPANIES

Telephone operating subsidiaries of the International Telephone and Telegraph Corporation had a highly successful year during 1939, with a net increase of more than 71 000 telephones, a figure only exceeded in the System's history by the record year of 1938.

The United River Plate Telephone Company in Argentina contributed a gain of approximately 26 500 telephones. The Shanghai Telephone Company continued its remarkable recovery from the effect of unsettled conditions in the Far East and gained about 15 600 telephones, and in Rumania the Telephone Company reported an increase of approximately 8 000 telephones.

In Chile a severe earthquake destroyed several cities in the early part of the year, but the Telephone Company quickly restored service in the stricken areas, and went on to finish the year with an additional 6 000 telephones in service. The Mexican Telephone and Telegraph Company gained approximately 7 000 telephones, and the systems in Peru, Cuba, Puerto Rico, as well as Southern Brazil, likewise reported noticeable increases.

The programme of conversion to automatic service continued throughout the year, particularly in the Argentine, Rumania, and Chile, and approximately 76 per cent. of the total number of telephones operated by the International Telephone and Telegraph Corporation's companies are now automatic.

Demand for Long-distance Service

A continued demand for long-distance service in the various countries served by I.T. & T. telephone systems resulted in increases of about 9 per cent. in toll and international calls in 1939, and thus continued the series of record years enjoyed by the I.T. & T. companies in this phase of operations. Typical of this demand may be mentioned the provision of additional long-distance circuits, by the use of carrier equipment, between Mexico and the U.S.A., the establishing of regional toll centres and additional carrier equipment in Argentina further to promote rapid handling of toll service, and the extension of the long-distance underground cable system in Rumania.

Services Extended

The telephone service of I.T. & T. companies has furthermore been amplified and extended by the following projects carried out during the year. In Argentina more than 25 000 lines of automatic equipment were installed and international telephone service was opened with Bolivia and Venezuela and further extended to Uruguay. In Chile, about 3 500 lines of automatic equipment were added to the Company's network, and toll facilities extended to distant points including the opening of radiotelephone service to Magallanes, southernmost city of South America. Brasov, an industrial city in Rumania, was converted to dial operation with a new exchange of 3 000 lines of Rotary equipment. The Shanghai Telephone Company added approximately 8 000 lines to its automatic plant; and the other companies continued a well balanced development programme to meet the telephone service requirements of their respective areas.

IN MEMORIAM

With the passing on June 18th of Doctor A. E. Kennelly, the electrical engineering profession lost one of its most famous scientists. Born in Bombay, India, 77 years ago, he was educated in private schools in France and England, and at University College School, London. Almost his entire life was devoted to electrical work, first as chief electrician of a cable repairing steamer and senior ship's electrician for the Eastern Telegraph Cable Company. He was principal electrical assistant to Thomas Alva Edison from 1887 to 1894. From 1894 to 1902 he served as consulting electrical engineer, and from 1902 until 1930 he was Professor of Electrical Engineering at Harvard University.

He was also Professor of Electrical Engineering at the Massachusetts Institute of Technology between 1913 and 1924.

Apart from his purely scientific work, Dr. Kennelly's outstanding contribution to electrical engineering lay in his adaptation of the use of hyperbolic functions and the complex quantity to the regular solution of alternating current transmission problems.[7] This method, which was later put forward by him in a series of lectures before the University of London in 1911, and was published (in 1912) under the title "The Application of Hyperbolic Functions to Electrical Engineering Problems," has now received universal acceptance, and is of particular value in all fields of communication engineering.

To Dr. Kennelly belongs the credit of predicting, in 1902, that there would be found an ionized reflecting layer at a considerable height above the surface of the earth. This prediction was made almost simultaneously with, but quite independently of, a similar prediction by the English mathematician, Oliver Heaviside, and for this reason both scientists are commemorated in the name "Kennelly-Heaviside Layer" now popularly given to the "E" region of the ionosphere. Dr. Kennelly served as President of the American Institute of Electrical Engineers, the Society for the Promotion of the Metric System of Weights and Measures, the American Illuminating Engineering Society, and the Institute of Radio Engineers. He was also a corresponding member of the British Association for the Advancement of Science, member of the National Academy of Sciences, and a Vice-President of the American Academy of Arts and Sciences.

Among numerous honours awarded to Doctor Kennelly may be mentioned the French Cross of the Legion of Honour in 1922, the Edison Gold Medal in 1933, and the gold medal from the Franklin Institute of Philadelphia.

The career of J. L. McQuarrie, formerly General Technical Director of the International Telephone and Telegraph Corporation, was outlined briefly in the April, 1939 issue of this journal. Mr. McQuarrie had the affection and respect of telephone leaders in practically all parts of the world, and his passing is deeply mourned by a wide circle of friends.

On July 26th, 1939, John Joseph Gilbert, Vice-President of the International Standard Electric Company, died in New York. Mr. Gilbert was born in 1872, and at the age of 18 entered the employ of the Western Electric Company. In 1918 he was appointed Export Sales Manager of the International Western Electric Company, and joined the International System in 1925 as Export Manager of the International Standard Electric Corporation. In 1929 he was elected Vice-President and later also a director of that company. During nearly 50 years of service in the telephone industry, Mr. Gilbert travelled extensively in Europe and South America, where he made many warm friendships.

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(3) "Development Aspects of International Voice Frequency Signalling and Dialling Under Consideration by the C.C.I.F.," by E. P. G. WRIGHT, *Electrical Communication*, July, 1939, p. 3.

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A. H. GRISWOLD (1879-1940)

COLONEL A. H. GRISWOLD, Vice-President and Director of the International Telephone and Telegraph Corporation, died on February 24th in New York after a brief illness. Colonel Griswold was in charge of telephone and radio operating companies of the I. T. & T., and assisted materially in shaping the development of I. T. & T. properties throughout the world during the past twelve years.

He was born at Milo, Illinois, U.S.A., on September 29th, 1879, graduated from the University of Illinois in Electrical Engineering in 1901, and entered the Chicago factory of the Western Electric Company. He went to the Pacific Telephone and Telegraph Company in 1905, became Plant Engineer and took part in building the first coast to coast telephone line across the United States.

Entering the United States Army in 1917, he was first Director of Long Lines and then Director of all telephone and telegraph services of the American Expeditionary Force in Europe. He was promoted Lieutenant Colonel, decorated by the French Government (Legion of Honour), cited by General Pershing and decorated by the American Government. In 1919 he was Chairman of the Engineering Commission which assisted the French Government in restoring communication services in the devastated areas.

In 1920 he remained in Europe as Assistant Chief Engineer of the International Western Electric Co., and worked on the engineering and installation of the first modern long-distance telephone and telegraph cable in Europe, that between Stockholm and Gothenburg. He returned to the United States as Assistant Vice-President of the American Telephone and Telegraph Company in 1921 and was assigned to the Pacific Coast in 1924, first as head of the Southern California Telephone Company, then as Vice-President and operating head of the Pacific Telephone and Telegraph Company.

He joined the International Telephone and Telegraph Corporation as Vice-President in 1928. At the same time he became Executive Vice-President of the Postal Telegraph and Cable Corporation, which position he held until 1938, when he was placed in charge of all telephone and radio operating properties of the I. T. & T.

His experience had been very varied, his outlook was broad, and his manner of working with others was sympathetic. To all who knew him his death is a sad loss.

ALEXANDER DAVIDSON (1870-1940)

ALEXANDER DAVIDSON, M.I.E.E., European Communications Representative of the International Telephone and Telegraph Corporation, and a director of Creed & Co., Ltd., and the International Marine Radio Co., Ltd., died on January 3rd, in his 70th year.

Mr. Davidson was born at Mauchline, Ayrshire, and started his life-long career in electrical communication as a Post Office employee at Mauchline, Greenock and Glasgow. Continuing his technical education at the Glasgow Technical College, where he was one of the most distinguished students of his time, he left in 1892 to become assistant electrician in the c.s. *Minia* on service in the Atlantic; then came service in the c.s. *Mackay Bennett* as chief electrician, and later in c.s. *Relay* and c.s. *Guardian* with the Central and South American Telegraph Company (now All-America Cables & Radio, Inc.).

After this extensive sea-going experience, he was appointed Divisional Superintendent of All-America Cables at Lima, Peru, became General Manager in New York in 1917, and, a year later, Vice-President in charge of operations. Returning to England in 1923 as Vice-President of All-America Cables, he was appointed European Communications Representative of the I.T. and T. Corporation in 1936, and held this position until his death.

He was prominently connected with the early stages of development of automatic cable working over many successive links, embodying relay working, automatic perforator operation, and steps which later developed into regenerator operation.

Mr. Davidson's cheery disposition endeared him to a large circle of friends, and his sound, balanced and far-sighted judgment will be remembered by all with whom he came in contact. He is survived by his widow, one son and one daughter.

Automatic Ticketing of Long-Distance Telephone Connections

By WILLIAM HATTON,

Technical Administrator, Bell Telephone Manufacturing Company, Antwerp, Belgium

INTRODUCTION

FULL automatic service for toll or long-distance telephone connections, as they are variously termed, has been in operation in a number of European countries for some years. In countries which have not yet adopted this service, the Administrations and Operating Companies, anxious to improve the quality of their service and reduce annual charges, are giving it their serious consideration.

When converting telephone networks of national dimensions from manual to automatic operation, certain problems arise which can be dealt with in a purely technical manner, while others cannot be solved without due regard to the reaction of the telephone subscriber.

Signalling over long-distance circuits by voice frequency currents, automatic regulation of the transmission level and other technical features of automatic long-distance service do not directly concern the subscriber, provided that the final result is satisfactory. The manner in which charges for long-distance service are established and the form in which the monthly or quarterly account is presented are, however, matters which have both technical and administrative aspects, and in which the subscriber is greatly interested.

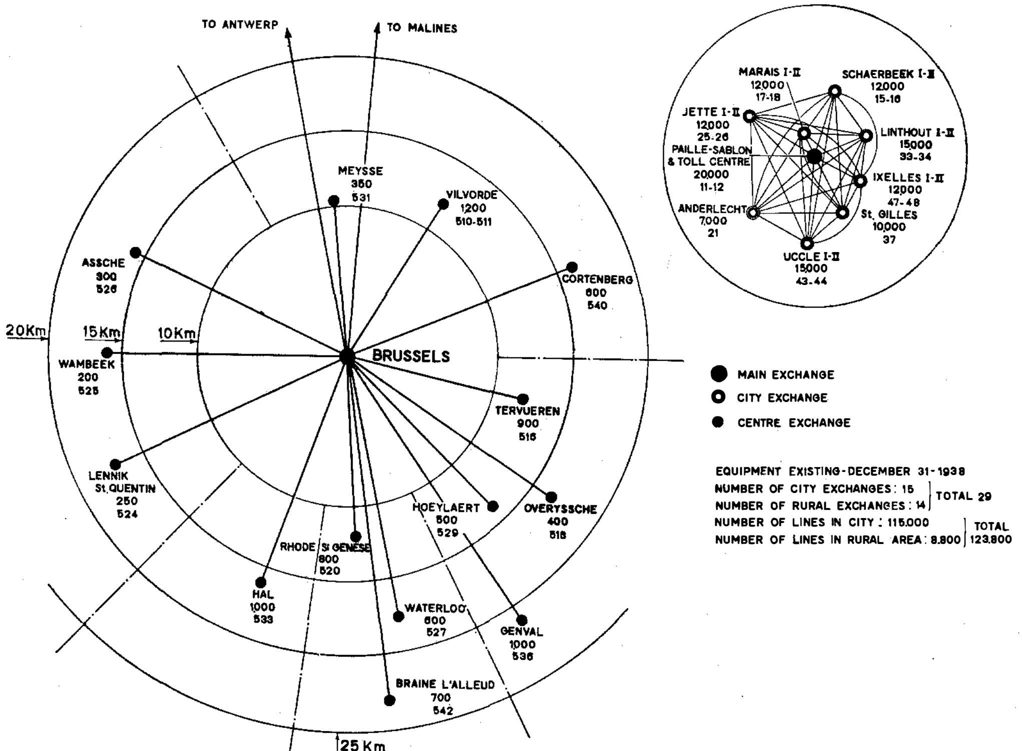


Fig. 1—*Brussels network.*

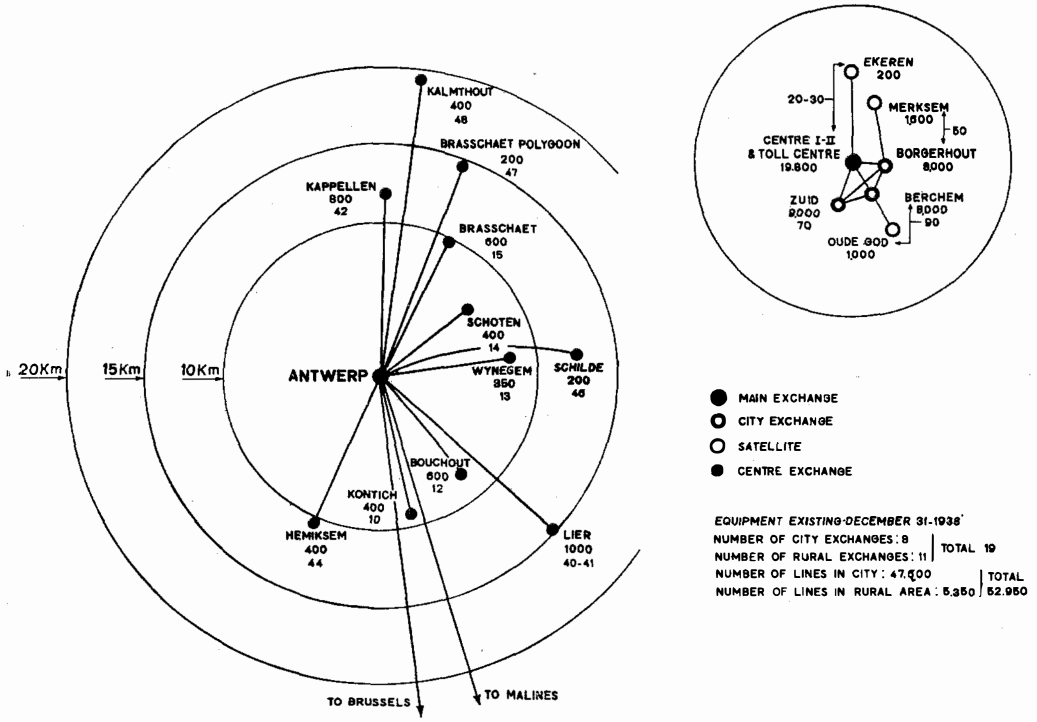


Fig. 2—Antwerp network.

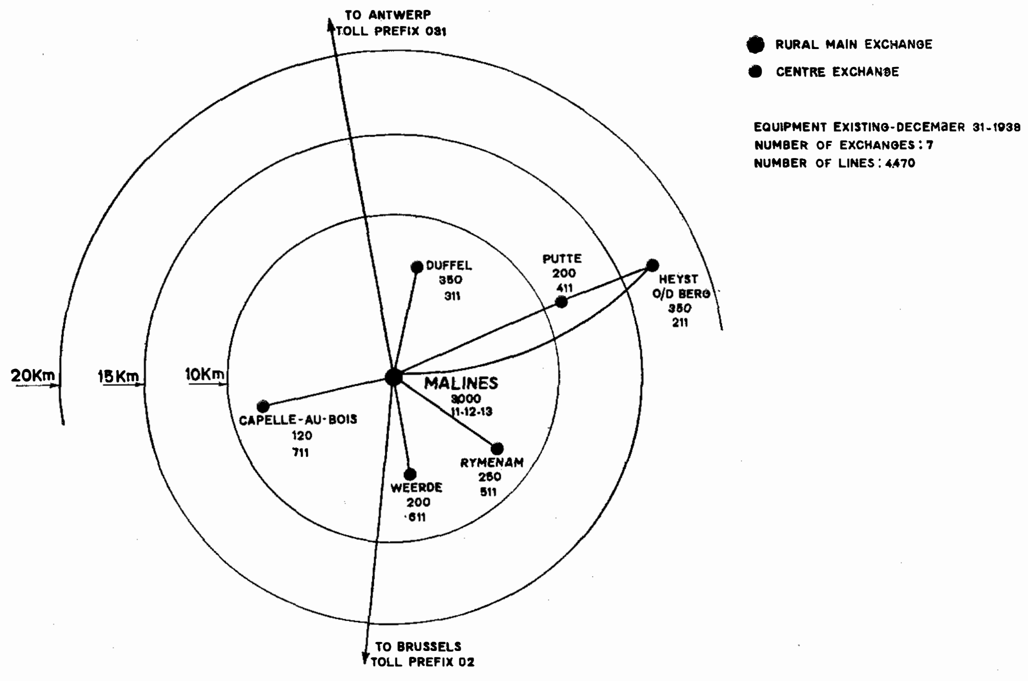


Fig. 3—Malines network.

To operate long-distance service on an automatic basis, calls must be charged automatically, and the method adopted for this must give complete satisfaction to the subscriber.

Prior to the introduction of a system of automatic ticketing, first applied in Belgium, there appeared to be no method of automatically charging subscribers for their long-distance connections except by means of the well-known message register.

This "message register" method, known to the telephone world as "time and zone" or "multiple metering" has its disadvantages, and a brief review of these will show why automatic ticketing was developed.

(*a*) The message register can only furnish an aggregate record of units consumed, being a simple electromagnetic counter, each operation or step recording one unit.

(*b*) The long-distance tariff structure must be based on the same unit charge as local service since the message register must record both classes of calls.

(*c*) The local call fee is usually too small to use as a unit for long-distance charges. In small networks this disadvantage may not be serious providing that readings of the message registers can be taken at frequent intervals.

(*d*) Many of the message registers in service to-day are unable to respond to a succession of impulses during a single call. This technical difficulty can only be removed by modification or complete replacement of existing registers, which is a costly undertaking.

(*e*) It is common practice to offer a local service tariff which includes a sliding scale reduction of the unit charge as the number of connections increases. This reduction of the unit charge is generally not applicable to long-distance connections, and therefore the local service tariff must be changed or a second message register, arranged to function only on long-distance connections, must be provided for each line.

(*f*) Another form of local service tariff gives the subscriber the right to a certain number of local calls free of charge, and above this figure the

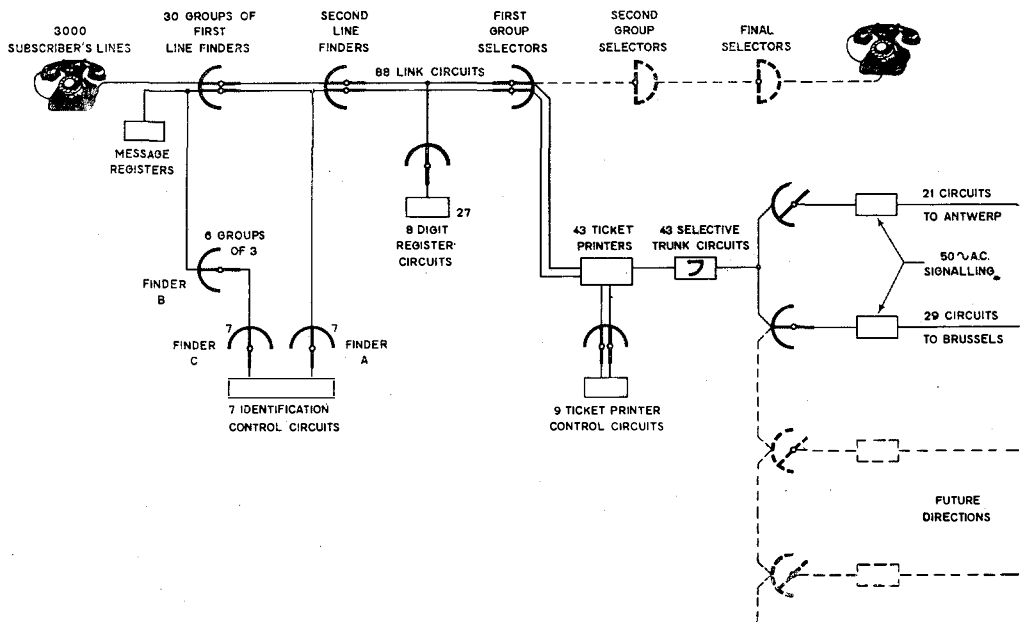


Fig. 4—Junction diagram, Malines.

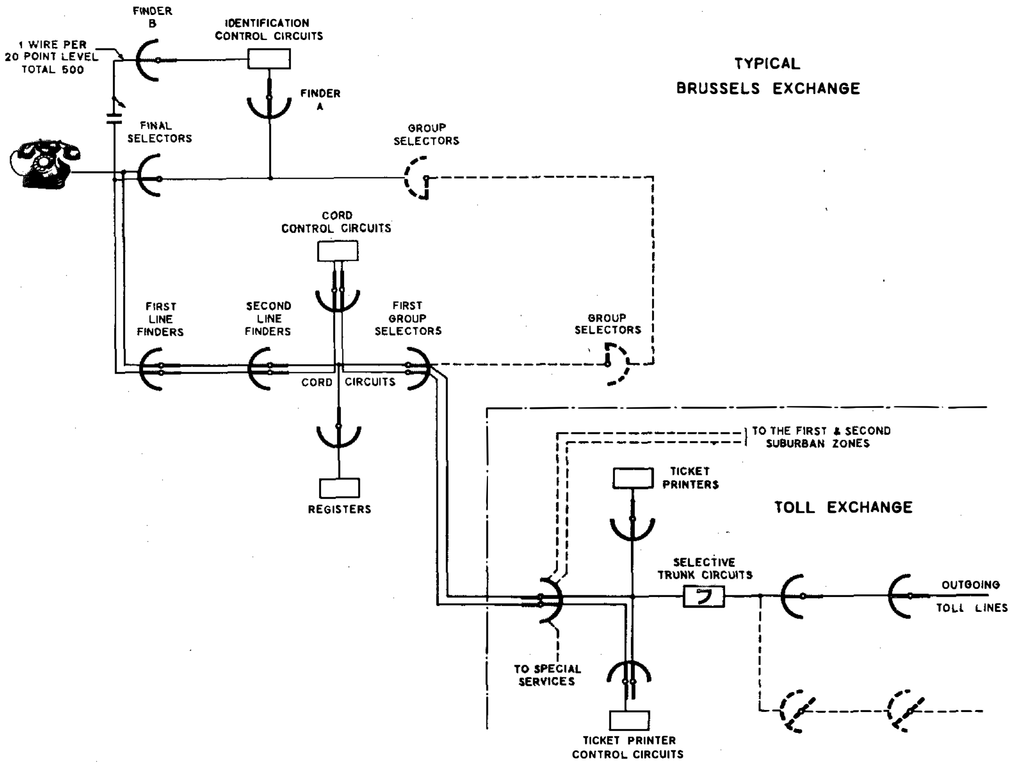


Fig. 5—Junction diagram, Brussels.

unit fee is charged per call. Here again, this privilege does not usually apply to long-distance connections, and the local tariff must be changed or a second message register provided. Further, there are Administrations which operate local service on a flat rate basis for residential subscribers and on a measured rate for business lines. This case requires similar treatment.

(*g*) Perhaps the most serious objection to the use of the message register is the absence of a separate record of each connection.

Business organizations are reluctant to accept a monthly or quarterly bill without particulars of their long-distance connections, and in the case of hotels, these particulars must be furnished immediately on demand. The installation of a device known as a "tax indicator" at the subscribers' premises, partially meets the requirement. This device is nothing more than a second message register operated from the exchange, and provided with means for resetting after each connection. The cost of this equipment is passed on to the subscriber by a rental charge, usually about $8 per indicator per annum. This scheme is not completely satisfactory as it fails to provide a permanent record.

With authority to change existing tariff structures and credits to modify exchange equipment, time and zone metering can be operated in small networks, but it is at best a compromise. It does not completely satisfy the requirements of the public and it results in a rigid long-distance tariff structure tied to the local call fee.

The development of full automatic long-distance service should not deprive the subscriber of any existing facility but, on the contrary, should offer even greater efficiency.

The real solution appears to be one which maintains the present separation between local and long-distance tariffs (allowing each to be developed to suit their separate requirements) and which, at the same time, provides a printed record, giving particulars of each long-distance connection.

Automatic ticketing of long-distance connections is now in operation and undoubtedly fulfils these requirements. Although quite a recent invention, it is already installed or on order for 150 000 lines.

AUTOMATIC TICKETING REQUIREMENTS

What are the requirements to be fulfilled by a system of automatic ticketing ? The minimum of information to satisfy both subscriber and Administration is as follows :—

Called subscriber's town and number,
Calling subscriber's number,
Charge for call or charge per unit time,
Date,
Time of day when call was made,
Duration of call.

In certain applications, the charge per unit time may be omitted from the ticket and left to the Accounting Department to determine. In other cases, it may prove advantageous to multiply the charge per unit time by the elapsed time units and print the full charge for the call on the ticket.

From a practical point of view, the design of the system must permit of its introduction in existing exchanges with the minimum of modification to the equipment already installed and in operation. As far as new exchanges are concerned, equipment for automatic ticketing can be readily incorporated in the standard designs, or provision can be made for its future introduction.

These practical requirements are admirably illustrated by three areas in Belgium, namely: Brussels, Antwerp and Malines (see Figs. 1, 2 and 3).

AUTOMATIC TICKETING—MALINES

Taking the case of Malines first (see Fig. 4), this is a new Rotary exchange using single motion switches and equipped for 3 000 lines. Equipment for automatic ticketing was foreseen from the outset, and was therefore embodied in

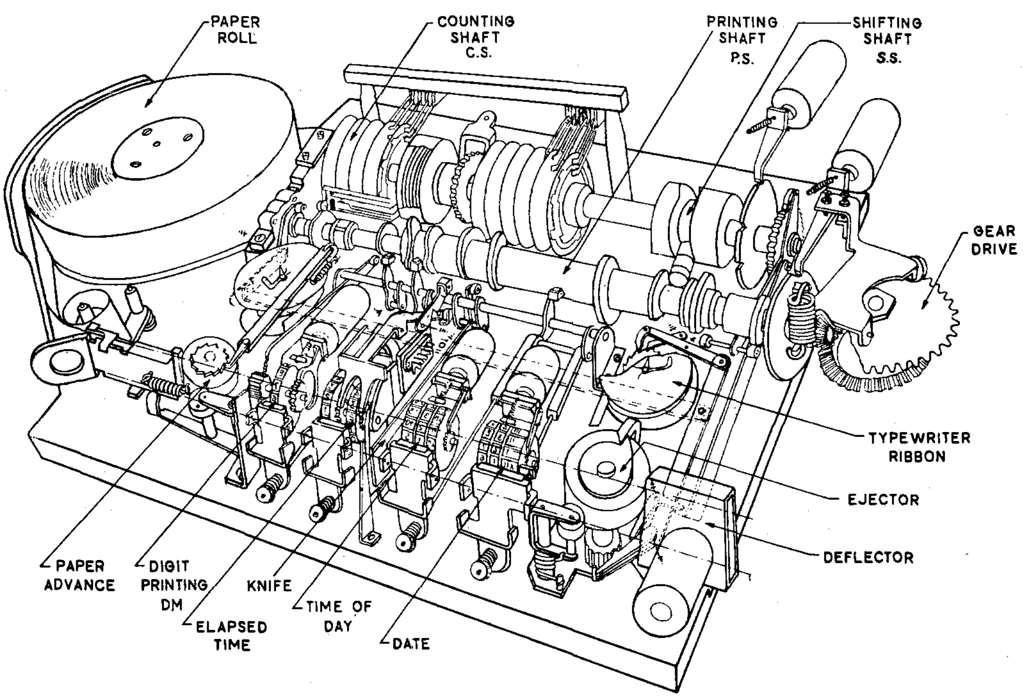


Fig. 6—Perspective drawing of Malines type printer.

the standard design. Malines is located midway between Antwerp and Brussels, and approximately 25 per cent. of the total originating traffic is outgoing to these two towns.

Surrounding the Malines city exchange, within a radius of 10 km, there are six other exchanges for which Malines is the trunking centre. For the purpose of this article, these subsidiary exchanges have been omitted and Fig. 4 shows, in simplified form, a junction diagram of that part of the Malines exchange equipment which is involved in an outgoing automatic toll connection. The 3 000 subscribers are connected to 30 groups of 100-point line finders which are in turn connected to 88 link circuits, each link comprising a second line finder and a first group selector. Register circuits, 27 in number, are provided for dialling and selection. With the exception of the fact that the registers are designed to accept both the called subscriber's town and number, making eight digits in total, the above equipment is standard for local service.

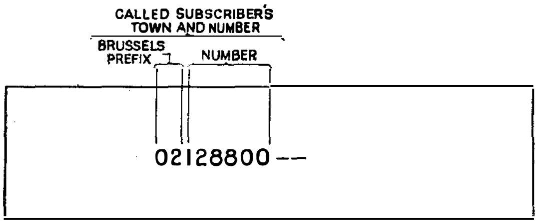
The special equipment for full automatic toll service and automatic ticketing is as follows:

Ticket printers are connected to outlets leading from the first group selector to the toll network. These outlets also include means to select the required direction, and for this reason are termed "selective trunks." It will be seen from Fig. 4 that the method of selecting an outgoing toll line is different from that usually employed. To obtain increased line efficiency, each toll line is provided with a 100-point finder which is made to hunt for a selective trunk.

The ticket printer receives the data to be recorded on the paper strip from a small group of common circuits termed "printer control circuits."

Printing Called Subscriber's Town and Number

A Brussels subscriber is obtained by dialling the toll prefix 02 allotted to this city, followed by the directory number of six digits. The prefix selects a line to Brussels and the directory number selects the required subscriber. Dial impulses are sent simultaneously to the toll line and the printer control circuits, whence they are relayed to the ticket printer and printed, thus fulfilling the first requirement. The paper strip now appears as shown below:



Printing Calling Subscriber's Number

The next step is to identify the calling subscriber. The ticket printers are common to the exchange and, therefore, common to 3 000 subscribers, any one of whom may have originated the connection. The problem is, therefore, to trace this connection back to the subscriber's line equipment, there to identify the line and then to transmit the directory number forward to the ticket printer.

Without entering into too much circuit detail, it may be stated that the connection is traced back to the subscriber's line by impressing a low level voice frequency tone, 450 p : s, on a convenient part of the circuit. This may be the private or "c" wire. In the latest type of Rotary equipment, the subscriber's message register is connected over a separate wire, and this forms a convenient path for the voice frequency tone which is connected by the printer control circuit. Tone impressed on this wire therefore characterizes a subscriber's line to be identified, and for this a separate small group of finders is provided. The message register wires are connected to the arc terminals of these finders, the brushes of which rotate until they find a terminal on which there is tone.

The process of identification is completed in not more than ten seconds, and may be accomplished at any time during conversation. The number of identification finders required is therefore small, and three per five hundred lines have proved quite sufficient.

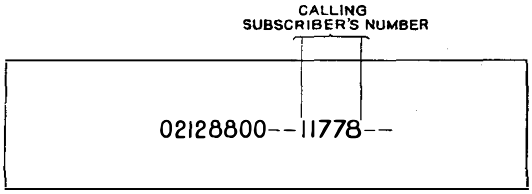
Determination of the subscriber's directory number is made by first locating the particular group of one hundred lines to which he is connected, and then the position his line terminal occupies within the group. The first step determines the thousands and hundreds digits, and the second step the tens and units digits.

The ten thousands digit, being common to the whole exchange, requires no special determination.

In exchanges where the subscribers' line equipments are connected to the line finders in numerical order, as is the case in Malines, determination of the directory numbers by this method is easily possible. The position of the brushes of finder " A " of the identification control circuit gives the group indication immediately, and the position of the brushes of finder "B" the line terminal indication.

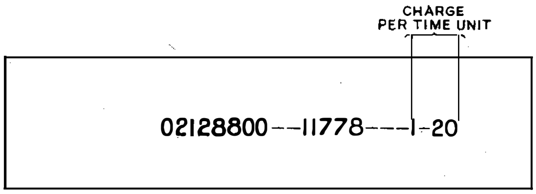
With the calling line identified, it remains to send the directory number to the ticket printer recording the particular connection. To prevent crossing of the calling subscribers' numbers, when two or more connections are being identified simultaneously, this information is sent over the same path which links the printer with the identification circuits, i.e., the message register wire.

A low level tone of another frequency is employed to convey the number from the identification circuit to the printer circuit, where it is converted to direct current and relayed to the ticket printer. The digits are printed in succession on the paper strip which now appears as follows :



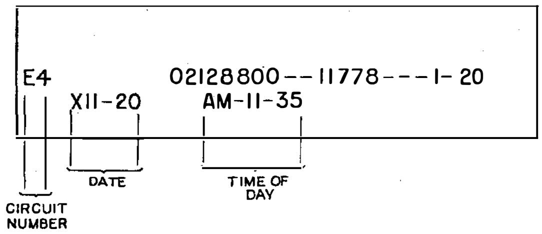
Printing Charge per Time Unit

In a large zone where there are tributary exchanges distant from the zone centre, and where the ticket printers are centralized in the zone centre, determination of the charge per time unit may depend on two factors, i.e., the exchange of origin and the called town. Malines, however, is classed as a small zone with the same tariff for all exchanges within the zone, and is, therefore, completely determined by the prefix of the called town. The printer control circuit records this prefix and is, therefore, able to determine the charge per time unit and to send this information to the ticket printer. In Belgium, toll connections are charged per time unit of three minutes, the charge, of course being expressed in francs and centimes ; a connection from Malines to Brussels is Fr. 1.20 per three minutes. The record now appears as follows :



Printing the Date, Time of Day and Circuit Number

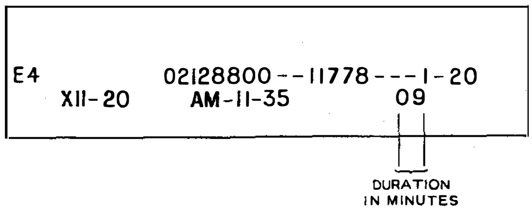
The next operation is of a routine nature, and prints on the paper strip the date, the time of day and the circuit number. The record now appears as follows :



Recording Effective Duration of Call

A connection is considered effective when the called subscriber replies, and the time to be charged is counted from this moment until the calling subscriber releases. The beginning of each one minute period is signalled to the printer, and the total effective time is printed in minutes on the ticket at the termination of the call.

When the calling subscriber restores his receiver and releases the connection, the paper strip is cut, the ticket is ejected from the printer and conveyed to the ticket filing desk. The completed ticket appears as follows :



APPLICATION OF "NUMBERCATOR," TO MANUAL TOLL SERVICE

Although the aim of a number of European countries, notably, Belgium, Holland and Switzerland, is complete automatization of their national telephone networks, it will be some years before this is accomplished. In the meanwhile long-distance service will be continued on a manual basis with the facility of no-delay or C.L.R. service for the great majority of calls. On no-delay service of this class, it is the practice to check the calling subscriber's number, either by means of number checking equipment or by reversing the connection.

Expressed in simple terms, the function of the identification equipment previously described, is to find the calling line and to transmit its directory number to the ticket printer. The same equipment, functioning in the same manner, can also be used to identify subscribers on no-delay toll calls established by operators. The subscriber's number is transmitted to a "Numbercator" (an electromagnetic counter with six or seven number wheels, one per digit) which is mounted, either in the toll board keyshelf or in a convenient place in the multiple field. The counter displays the number before the operator, and in another form of design it can be used as a stamp to print the number directly on the ticket.

This method of determining the calling subscriber's number was first used in the Ostend exchange which was put into service in June, 1938; it is also used in Malines and will be a standard feature of all new Belgian exchanges.

In addition to the saving of number checking equipment, this method has the advantage of considerably decreasing the operator's load and accelerating the service. It is no longer necessary to ask the calling subscriber for his number, and the operation of checking by dialling or key-sending this number to the checking equipment is eliminated. The difficulties usually met with on calls from private branch exchanges, where

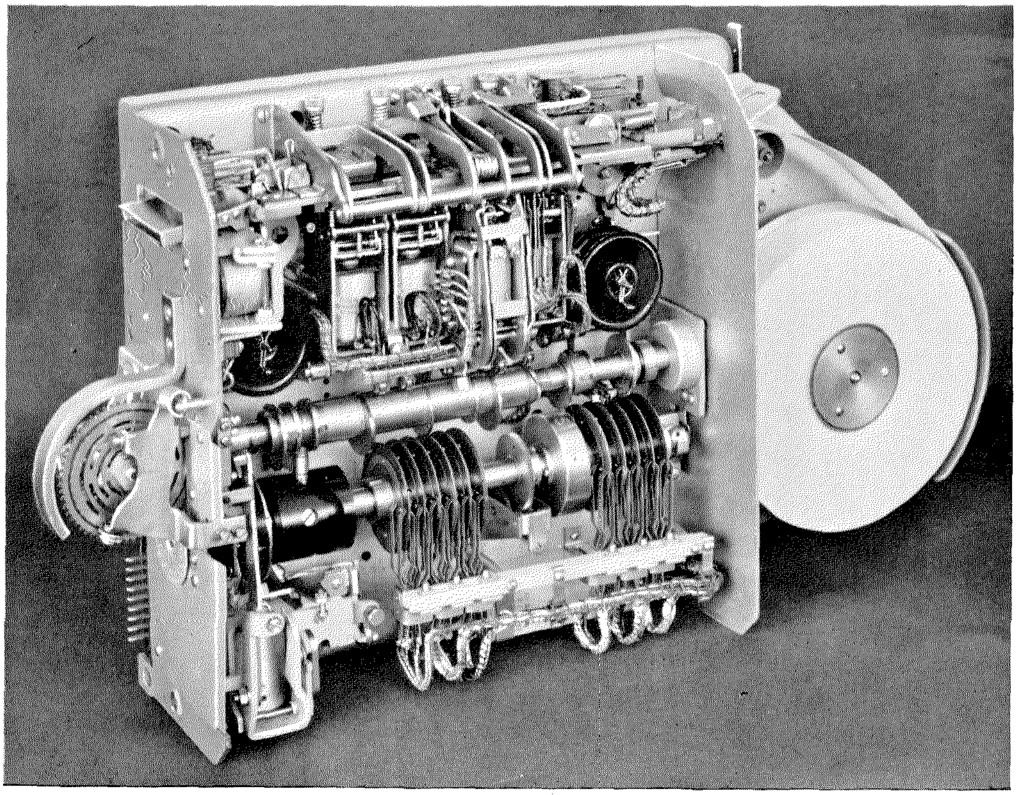


Fig. 7—View of Malines type printer.

one directory number is common to several exchange lines, also disappear.

APPLICATION TO EXISTING EQUIPMENT IN BRUSSELS

The urban network of Brussels (see Fig. 5) contains fifteen exchanges of the Rotary type, some dating back to the year 1922. The present capacity is 115 000 lines, and this network furnishes a good example of the manner in which automatic ticketing can be added to existing equipments. Antwerp, Liége, Charleroi and other Belgian towns will follow the method adopted for Brussels.

As in most early installations, intermediate distributing frames are installed in the Brussels exchanges, and the subscribers' lines are jumpered to line finders in the well-known manner. Moreover, some of the exchanges are equipped with 60-point finders and others with 100-point finders. As the lines are not numerically connected to the line finders, determination of the directory number is more conveniently achieved by the final selector or connector. For this reason, a new method of identification has been developed which has the important advantage of not requiring the addition of special switches. Two or more final selectors or connectors in each group are made to function as number identification switches when not in use for regular calls. Further, these selector circuits do not require modification.

The period for which a selector is occupied, when determining a subscriber's number, is not more than ten seconds, and this slight additional load can easily be carried without more switches. It is of interest to note that this new method is also applicable in principle to some step-by-step systems.

A subscriber's directory number can be completely determined from the position of his line terminal in the final selector or connector arc, and the process of finding this position can be resolved into three steps, a group indication, a level indication and a line terminal indication.

In the Rotary system, the final selectors are in groups serving two hundred lines, and the levels are of twenty lines. A multi-element condenser is provided for each final selector level in the exchange, and thus in a 10 000-line exchange 500 such condensers will be required.

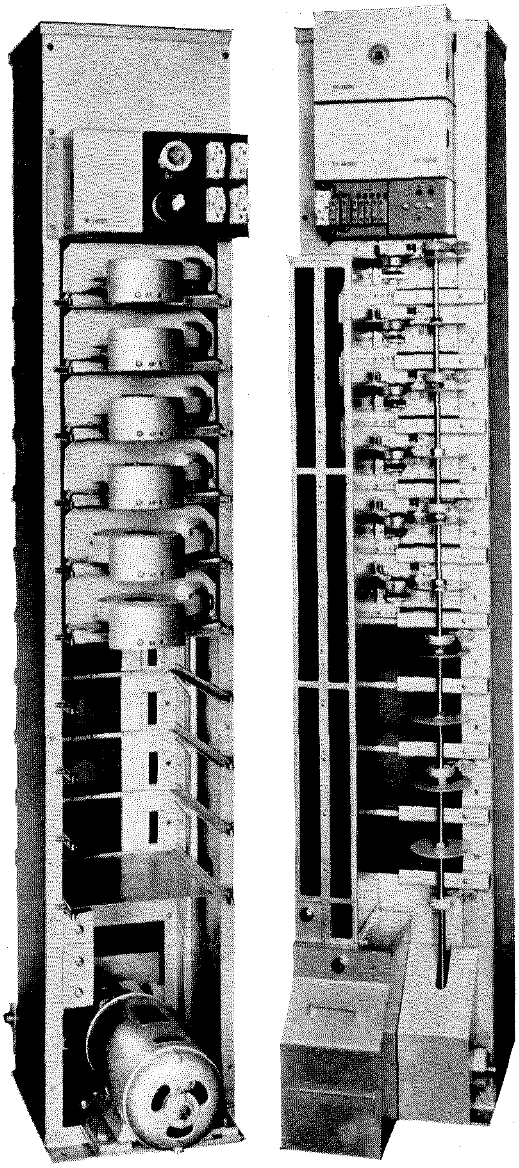


Fig. 8—Ticket printer bay—front and back views.

Each condenser contains twenty elements of 0.3 μF capacity, which are commoned together on one side and, on the other side, are connected separately to the private wires of each one of the twenty lines.

If the common point of the multi-element condenser can be found, then this will at once indicate the level of twenty lines and the group of two hundred lines. If the particular element can be found, it will indicate the line terminal. These multi-element condensers are relatively inexpensive and the dimensions such that they can be conveniently mounted on existing switchracks close to the final selectors, thus reducing wiring to the minimum.

When a long-distance connection has progressed to the stage where identification of the calling subscriber is required, a signal from the toll exchange causes circuit changes in the local exchange equipment, as a result of which a voice frequency tone is impressed on the private wire of the subscriber's line circuit, thus " marking " one of the multi-element condensers. The common points of these condensers are connected to the arcs of finder switches, designated B in Fig. 5, associated with identification control circuits. The brushes of these finders explore arcs of 500 points in search of a terminal on which there is voice frequency tone. The position in which the brushes come to rest is signalled to the control circuit, and indicates the particular group and the particular level.

A free final selector in the given group is now connected to the control circuit, and the brush carriage is caused to rotate on the given level of twenty lines. The control circuit now grounds the common point of the multi-element condenser, and the voice frequency tone is thereby restricted to the particular line to be identified. The selector brush carriage rotates until it finds a terminal on which there is tone, and during rotation sends back revertive impulses to the control circuit. When the line is found, the control circuit is in possession of all the data required to determine the directory number of the line in question.

With the exception of this new method of identification, automatic ticketing in Brussels follows much the same lines as already described for Malines. The ticket printers are centralized in the toll exchange, and will serve for both outgoing long-distance and outgoing short distance connections.

THE TICKET PRINTER

It is obvious that the ticket printer (see Figs. 6, 7 and 8) may be designed in a variety of forms. The energy required to print legible characters may be obtained from a common power drive or from an individual motor. If it is not essential to print the result in ticket form, commercial typewriters or teleprinters may be employed.

The ticket printer in use in Belgium derives its energy from a common power drive, following regular Rotary system practice. The essential parts of the printer comprise a paper roll, a paper advancing mechanism, a typewriter ribbon, a knife and a spring type ticket ejector. The information to be printed on the paper strip is received by four electro-magnets which position digit wheels, and the printing operation is performed by rotating a printing shaft which carries a series of cams to bring the paper strip and the typewriter ribbon in contact with the digit wheels.

The digit printing magnet, DM (Fig. 6), prints in succession the called party's number, the calling party's number and the charge per unit time. These operations advance the paper strip 22 steps under the control of the counting shaft, and for each operation the printing shaft makes one revolution.

The different cams on the printing shaft are brought into the active position in the following sequence, as determined by 5 positions of the shifting shaft as follows :

1. Printing from digit magnet,
2. Printing date, time of day and circuit number,
3. Printing elapsed time,
4. Paper advance,
5. Cutting and ejection.

CONCLUSION

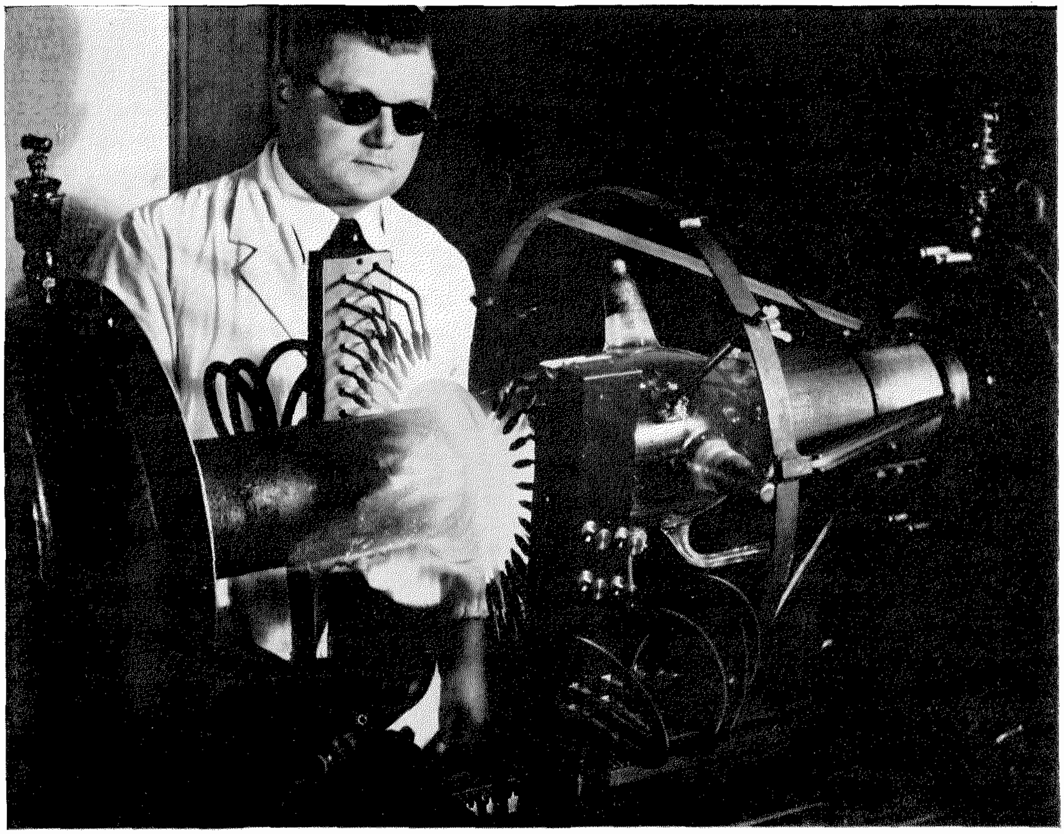
The first installation of automatic ticketing was put into service in Bruges in 1936, and was rapidly followed by installations in Ostend and twelve other towns in Belgium. During the period July 1st—September 15th, 1937, a check of 62 000 ticketed calls revealed 80 tickets, or 0.13 per cent., bearing incomplete or incorrect details, and these results go far to prove that full-automatic methods can be applied to long-distance service with the same success as to local service.

The tickets provide the Traffic Department with valuable information, and also give a remarkably clear picture of the operating efficiency of the exchange. Each long-distance call is recorded, whether an effective connection or whether resulting in busy, no answer, wrong number or premature release. Equipment faults which might otherwise remain unsuspected and undetected are brought to light by the indisputable evidence of the ticket.

Naturally, further developments in this field are to be anticipated. It may prove advantageous to use a small number of high speed printers which are engaged only at the termination of a call.

This may be done economically by storing the complete record of the connection in some suitable part of the circuit until ready to be transferred to a printer. With this method, the printer will be subjected to much heavier use, and needs to be designed more on the lines of telegraph than of telephone equipment. The trend of future development will depend almost entirely on the cost of storage equipment, compared with the cost of printers.

A form of ticket may be produced which can be automatically sorted, and there is no doubt that, ultimately, mechanized accounting will further dispense with the need for human intervention. Finally, it is anticipated that automatic ticketing will prove immensely valuable in Europe when the time is ripe for the development of international long-distance service on a full-automatic basis.



Making the glass-to-metal anode seal on a 200 kW vacuum tube. The high precision lathe used is a design of Laboratoires L.M.T., Paris.

Methods and Apparatus for Measuring Phase Distortion*

By M. LEVY,

Laboratoires L.M.T., Paris, France

The following study of methods for measuring phase distortion is in two sections. The first part opens with the properties and characteristics of phase and with the conditions for distortionless transmission. It is then shown that phase distortion is a function of phase delay and envelope delay, and that these quantities must satisfy certain conditions in order that phase distortion shall not occur. Phase measurements determine the satisfactory performance of feed-back amplifiers. Variations in these determining factors allowable in order that phase distortion may not cause interference, are then reviewed. The second part investigates the methods for measuring phase distortion, and a description is given of two measuring instruments which have been made by the author. The methods for measuring phase shifts, the times of phase transmission and the times of group transmission, and the methods for automatically plotting Nyquist's diagram are dealt with in turn. The paper contains a description of two new equipments : a phasemeter for frequencies between 100 *cycles and* 5 000 *kc/s, and a Nyquist recorder for the automatic tracing of Nyquist diagrams within a range of* 20 *to* 4 000 *kc/s.*

INTRODUCTION

IN the early days of telephony an almost exclusive importance was attached to amplitude distortion. Each circuit was characterized by its response curve, that is to say, by the curve of the ratio between the output and input voltages, plotted as a function of the frequency.

Phase distortion caused practically no interference provided that the values of the amplitudes of the signals were maintained throughout the transmission of a signal, and the phase could vary within very considerable limits without adversely affecting intelligibility [18].†

As, however, the length of transmission systems increased, new phenomena arose, and became more and more marked as the distances were extended.

The effects observed were as though parasitical or transient phenomena were in evidence. It was observed that these phenomena persisted even after as perfect a correction as possible had been made of the amplitudes of the response curve. A systematic investigation then showed that these effects arose from phase distortion.

Another field in which these phase problems soon became of great importance was that of repeaters and, in particular, those employing feed-back systems.

These questions become important as a result of Black's work [1] on negative feed-back, as applied to amplifiers, it being found that certain of its characteristics may be improved under certain conditions. These conditions are found to be a function of the response curve and of the phase-shift curve.

Nyquist has also enunciated a stability criterion of feed-back systems. In order to know whether a feed-back system is stable or unstable, it is necessary to trace Nyquist's diagram and to see the relative position of this curve with relation to a determined pole, the diagram being derived from the curves of response and phase shift.

Since Nyquist's and Black's work, the use of negative feed-back has been extended to other fields outside telephony and the use of the stability criterion has become current.

It is, however, in television, in particular, that phase characteristics have become of fundamental importance. It may be said that these characteristics have as much importance in television as have amplitude characteristics in ordinary telephony.

Parallel with these techniques, a series of measuring instruments has been developed for the recording of phase characteristics, for the measurement of phase and group velocities and

* Paper presented at I.R.E. Meeting at Bridgeport, Conn., U.S.A., on June 2nd, 1939.

† All numbered references are given at the end of the paper.

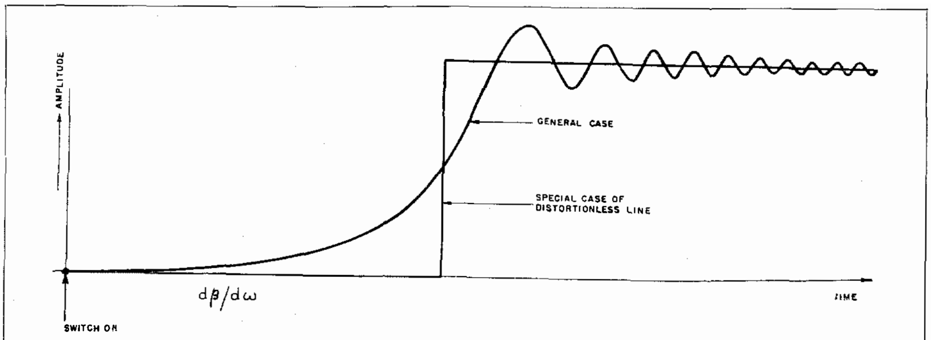


Fig. 1.

for the tracing of Nyquist's diagrams.

It is of interest to go into the whole question and to describe the principal factors that enter into it. This paper has therefore been divided into two main parts. In the first, the conditions of distortionless transmission are reviewed and the parameters given which occur in the measurement of distortion; the conditions necessary for the stability of feed-back systems are also considered.

In the second part, a description is given of a series of methods for the measurement of these parameters. The investigation includes a description of the two equipments which have been designed, namely:—a phasemeter for operating over a frequency range of 100 cycles to about 5 megacycles, and a recorder for the automatic tracing of Nyquist's diagrams.

PART I.—PHASE DISTORTION

THE SIGNIFICANCE OF PHASE

In order to indicate the significance of phase, as applied to transmission networks, it is convenient to consider the transmission of a signal over a transmission line.

Considering an ordinary transmission line having series resistance R per unit length, inductance L per unit length, shunt conductance G per unit length, and shunt capacity C per unit length, then it may be shown that if a sinusoidal *E.M.F.* is applied to one end and the far end is suitably terminated, then after the signal has been applied for infinite time the ratio of the sending voltage Vs, to the received voltage Vr is $\frac{Vs}{Vr} = \varepsilon^{p}$ where p is called the propagation constant. It may further be shown that

$$p = (a + j\beta) = \sqrt{(R + j\omega L)\,(G + j\omega C)} \ldots . \ (1)$$

and, by equating the real and imaginary parts, α and β can be evaluated in terms of R, G, L and C.

Considering again the ratio $\frac{Vs}{Vr} = \varepsilon^{p}$, since p is equal to $(\alpha + j\beta)$

$$\frac{Vs}{Vr} = \varepsilon^{\alpha} . \ \varepsilon^{j\beta}$$

$$= \varepsilon^{\alpha}\left\{\frac{\varepsilon^{j\beta}}{2} + \frac{\varepsilon^{-j\beta}}{2} + \frac{\varepsilon^{j\beta}}{2} - \frac{\varepsilon^{-j\beta}}{2}\right\}$$

$$= \varepsilon^{\alpha}\left\{\cos\beta + j\sin\beta\right\}$$

which shows that the resultant voltage at any point along the line is a periodic function of β and has a scalar value of ε^{α}. For convenience, therefore, α is termed the attenuation constant and β is termed the phase shift.

From equation (1) it will be seen that β is approximately equal to $2\pi f\sqrt{LC}$ and since $\cos\beta$ is equal to $\cos\left[\beta\,(1 + 2\frac{\pi}{\beta})\right]$ it follows that the rise and fall in potential along the cable will occur at intervals of $2\frac{\pi}{\beta} = \lambda$, where λ is termed the wavelength. And since it has been shown that $\lambda f = \upsilon$ where υ is equal to the velocity of propagation of the wave along the cable, it follows that

$$\lambda f = \upsilon = \frac{1}{\sqrt{LC}} \, .$$

From the foregoing it follows that a sinusoidal wave is transmitted along the cable without distortion, that is to say it is received as a sine wave, but its amplitude is reduced by ε^{α}; and

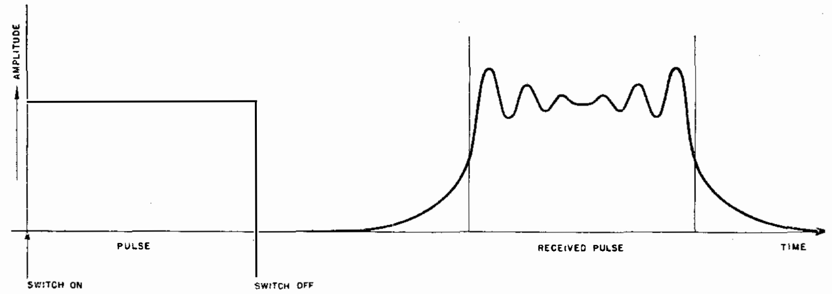


Fig. 2.

the time of transmission of any particular portion of the wave occurs in time $t = \frac{2\pi}{\beta}\sqrt{LC}$.

TRANSMISSION OF NON-SINUSOIDAL PERIODIC PULSES

Considering an infinite series of similar non-sinusoidal pulses applied to a line, it follows from Fourier's theorem that the pulses may be represented by the series

$$f(x) = \frac{a_0}{2} + a_1 \cos x + a_2 \cos 2x + \text{etc.}$$

$$+ b_1 \sin x + b_2 \sin 2x + \text{etc.}$$

$$\text{where } a_o = \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x)\, dx$$

$$a_n = \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \cos nx\, dx$$

$$\text{and } \quad b_n = \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \sin nx\, dx\ .$$

That is to say, the periodic pulses may be represented by a constant $\frac{a_o}{2}$, which may be zero, together with a number of sinusoidal waves having different amplitudes, the frequencies of the said waves being multiples (or harmonics) of the period of the fundamental component of the non-sinusoidal wave. The general expression for any sinusoidal component of the periodic pulses is therefore

$$\frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \sin (nx + \varphi) \sin nx.\, dx\ .$$

Neglecting the effect of attenuation on the line, but assuming a phase shift of β, then the expression for the received signal for any one of the sinusoidal components will be given by

$$\frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \sin (nx + \varphi - \beta) \sin nx.\, dx\ .$$

If x and β are both functions of frequency, let x be equal to ωt and β equal to $a_1\omega$, then the sent and received components will be

$$\frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \sin (n\omega t + \varphi) \sin n\omega t.\, d\omega$$

$$\text{and } \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \sin (n\omega t + \varphi - a_1\omega) \sin n\omega t.\, d\omega$$

respectively; or the received current is given by

$$\frac{1}{\pi}\int_{-\pi}^{+\pi} f(x) \sin \left\{\omega(nt - a_1) + \varphi\right\} \sin n\omega t.\, d\omega\ .$$

Thus, if a_1 is independent of frequency, each component will be delayed by a term a given by $a_1 = (\beta/\omega)$ and the original wave shape will be preserved; but the pulse will be delayed.

Thus, if in a transmission system the phase

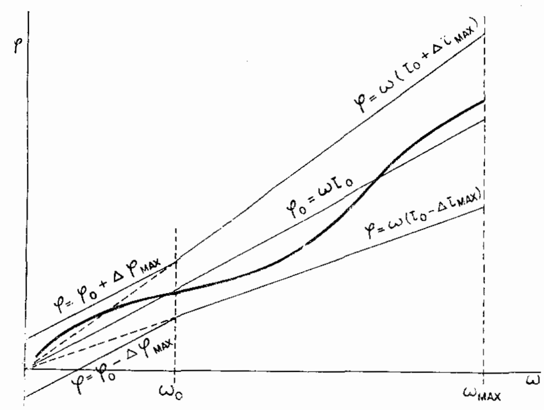


Fig. 3.

shift is a linear function of frequency, no distortion due to phase changes will occur, but any particular portion of the signal being studied will be found to be delayed by a time interval equal to β/ω. In other words, the condition for transmitting non-sinusoidal infinite wave trains without phase distortion is that β/ω should be constant.

The foregoing analysis, however, is for the steady-state condition, and only applies to a signal that has not only been sent for an infinite period, but will continue to be sent for an infinite period. Thus, the expression indicates the time taken for a particular portion of the signal to traverse the network.

If for the frequency of each component contained in the sent wave the value of β/ω is not the same, then the phases of the various components concerned arriving at the received end will vary, and will produce a signal which may have very little resemblance to the one which was sent, the amount of distortion depending upon the non-linearity of β with respect to ω.

TRANSMISSION OF A GROUP OR TRAIN OF WAVES

In actual practice the conditions outlined above do not hold, and it is of greater interest to study the transmission of a finite wave train than that of an infinite train. A method of studying this phenomenon has been proposed by J. R. Carson in a paper entitled "The Building-up of Sinusoidal Currents in Long Periodically Loaded Lines"; the method of approach is as follows:

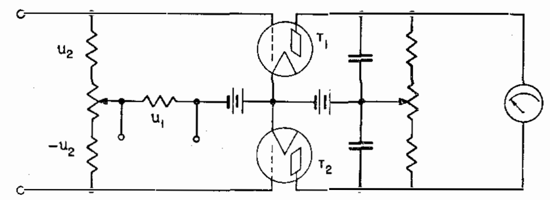


Fig. 5.

The effect of applying to a transmission network a sinusoidal signal of single frequency at a given time is considered, and it is found that at the receiving end of the envelope the resultant is of the form shown in Fig. 1. Furthermore, it is found that, assuming certain conditions, the same form of curve applies to all frequencies, but that the elongation or contraction of the curve in the direction of time is a function of $\frac{d^2\beta}{d\omega^2}$ and that its position in time is determined by $\frac{d\beta}{d\omega}$.

The curve shown in Fig. 1 is plotted in terms of the final amplitude, which depends, of course, on the amplitude of the signal that was sent and the attenuation introduced by the transmission system. If, therefore, the values of $\frac{d\beta}{d\omega}$ and $\frac{d^2\beta}{d\omega^2}$ are known for each component of the sent signal, then the form of signal received at the far end can be determined.

Considering the case of a finite wave train transmitted over a circuit which introduces phase distortion, it is obvious that the sent signal and the received signals will have a different form. Thus they might be as shown in

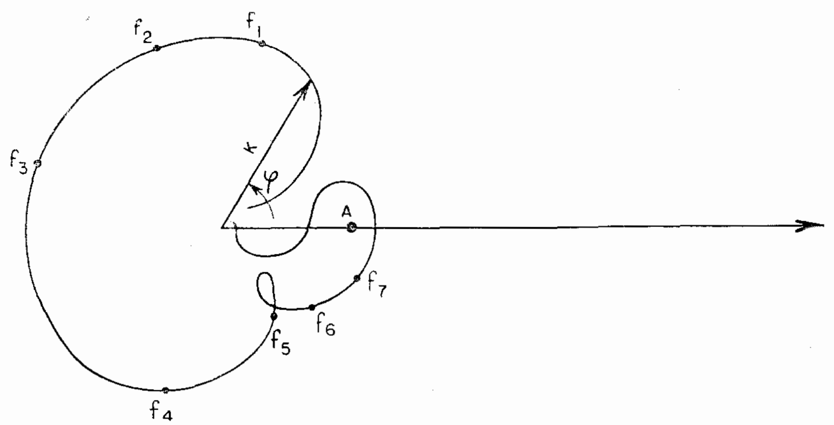


Fig. 4.

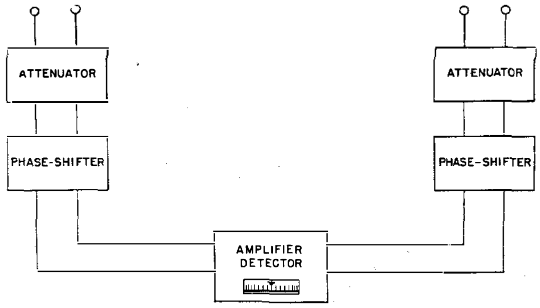


Fig. 6.

Fig. 2 where they are plotted as a curve, with the ordinates representing the amplitude and the abscissæ time. Since, if the distortion is bad, these shapes differ widely, it is obviously not possible to say when the signal commences or finishes, or to identify any one portion of the sent signal with that received. The problem of defining the propagation time is, therefore, difficult.

For reasons which go beyond the scope of this paper, it has been found convenient to define the propagation time for such a signal as $\frac{d\beta}{d\omega}$ since this factor, in effect, locates the arrival curves in time. It therefore appears that there are two propagation times, depending upon whether the signal is an infinite or finite wave train. For the infinite train the propagation time is equal to β/ω and is called, for convenience, the "phase delay"; and for the finite train it is equal to $\frac{d\beta}{d\omega}$ and is called the "envelope" or "group delay." Both expressions have hitherto been referred to as being the time delay, but since this nomenclature seems confusing, it is avoided in this paper.

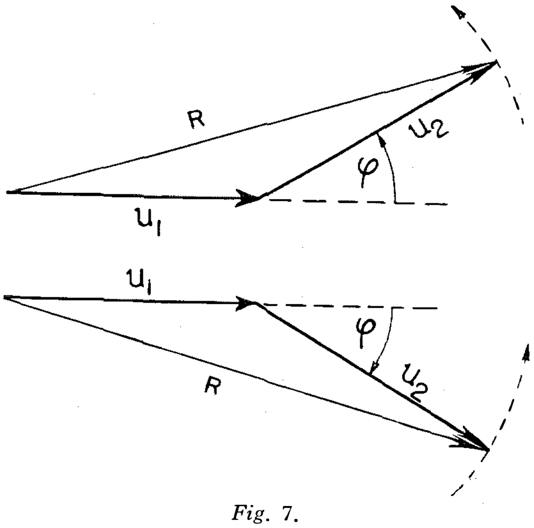


Fig. 7.

It is interesting to observe, therefore, that for the study of propagation it is not necessary to measure phase shift as such, but to measure either the phase delay, or the envelope delay;

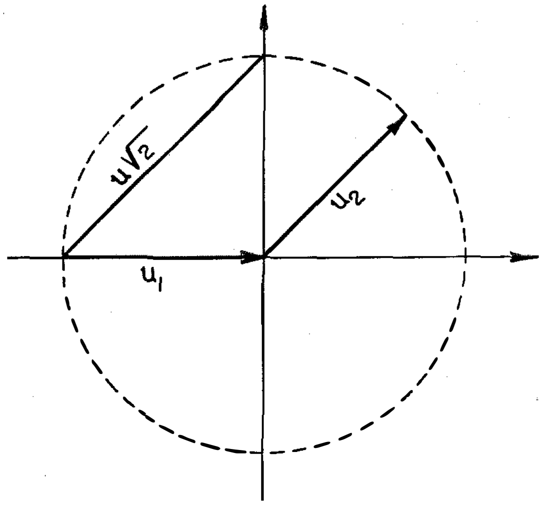


Fig. 8.

phase shift measurements as such are thus not of direct interest. Further, it will be observed that in the distortionless case when β/ω is a constant $\frac{d\beta}{d\omega}$ is a constant and $\frac{d^2\beta}{d^2}$ is zero; hence the form of the envelope shown in Fig. 2 then becomes that shown in Fig. 1 and is so located in time that it occurs at time $\frac{d\beta}{d\omega}$ after switching on; that is to say, the phase delay and envelope delay are equal in the ideal system.

In practice, however, the non-ideal system is generally of interest, and hence for practical purposes it is more useful to consider the variation of $\frac{d\beta}{d\omega}$ than of β/ω with frequency. As a guide to possible limits for a practical line-transmission system for television signals, limits for both β/ω and $\frac{d\beta}{d\omega}$ have been suggested by Messrs. Saphores and Clavier, as shown below. The range of frequencies transmitted should be divided into two bands by a certain frequency f_0 (Fig. 3).

Then for all frequencies the phase should be a linear function of the frequency with deviations which do not exceed a few degrees, the same applying for all frequencies below f_0; for frequencies greater than f_0 two conditions should be simultaneously fulfilled, one relating to the time of phase transmission, and the other to the time of group transmission.

The time of phase transmission should lie within two values $(\tau_0 + \delta\tau)$ and $(\tau_0 - \delta\tau)$, τ_0 being the mean transmission time. In the same way, the group transmission time should lie within two limits $(\tau_0 + \delta\tau)$ and $(\tau_0 - \delta\tau)$.

Although phase shift measurements as such have no direct application to the study of wave propagation they are of great use in the development of certain portions of line terminal equipment. In particular, they are of interest in connection with the negative feed-back amplifier, and it is therefore of value briefly to consider the principle of operation of this amplifier.

Take the case of an amplifier whose output is connected to the input by a coupling impedance by means of which a fraction of the output voltage is applied to the input circuit.

If the closed circuit is cut at any point and considered as the input, it is possible to define an amplitude characteristic $k(\omega)$ and a phase characteristic $\varphi(\omega)$ for the whole; the amplifier

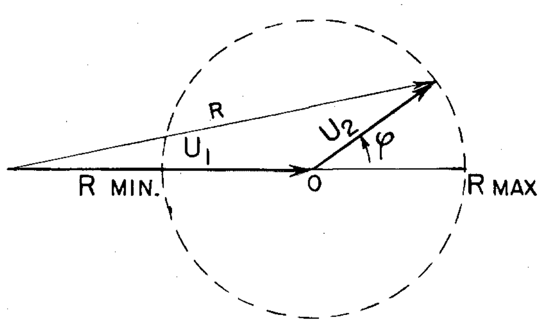


Fig. 9.

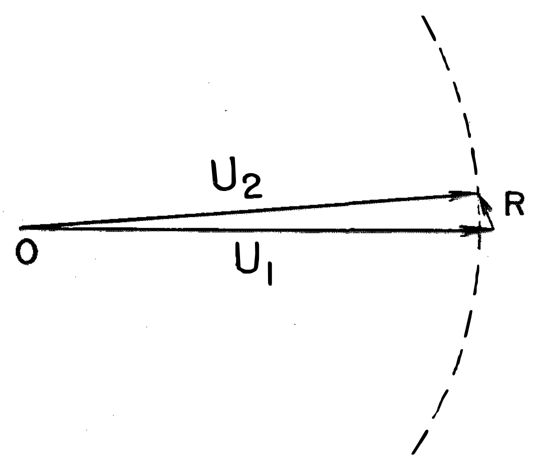


Fig. 10.

and coupling circuit being considered as placed in series.

This means that in order to estimate the degree of stability of the system it is necessary to trace the polar diagram $k(\omega)\ \varepsilon^{j\phi/\omega}$ and to see the relative position of this curve and of the point A whose co-ordinates are $k = 1$, $\varphi = 0$ (See, for example, Fig. 4). Then it may be shown that *if the curve encloses the point A* (0, 1) *the system cannot be stable and will tend to oscillate, while in the contrary case it will be stable.*

This criterion is of great value. Since Black's paper, which has shown that the frequency characteristic of amplifiers may be corrected and their operation improved by negative feed-back, the use of the latter has become general.

In high frequency carrier telephony, for example, only negative feed-back repeaters are now-a-days employed, and the amount of negative feed-back in these repeaters is made to reach as high a value as possible in order to improve the characteristics to the maximum extent. An important difficulty, however, arises; the repeater tends to oscillate. In order to ascertain what causes this lack of stability the most rational method is to trace the preceding polar diagram and to determine the relative position of the curve and of the point A. If the curve encloses the point A, it will be necessary suitably to modify the repeater in order that the portion of the curve in the neighbourhood of the point A no longer encloses this point.

Hence the importance of these diagrams in long-distance telephone systems. In the remainder of this paper these diagrams will be termed "Nyquist's diagrams."

PART II.—METHODS OF TESTING

I.—METHODS OF PHASE MEASUREMENT

In general, when investigating the properties of a quadripole, the amplitude characteristic is often plotted at the same time as the phase characteristic. It is therefore an advantage to be able to make phase measurements and amplitude measurements simultaneously. An examination will therefore be made of the methods of measuring phase, whilst also allowing for their possibilities in regard to the measurement of amplification or attenuation.

A consecutive study will be made of all measuring methods at a given frequency, and then over a frequency range.

A.—Methods of Phase Measurement at a given Frequency

The earlier methods primarily intended for the examination of electrical machines and mains will be passed over, as these methods, as a rule, require power outputs which are too high to be of any use in the examination of high-frequency circuits (repeaters, television circuits, etc.). Similarly, no mention will be made of the methods of phase measurement using Lissajous' figures since these lack accuracy.

This leaves the following principal methods available for study:—

(*a*) *Wattmeter Method*

If two voltages $u_1 \varepsilon^{j\phi_1}$ and $u_2 \varepsilon^{j\phi_2}$ are applied to a wattmeter, the apparatus will give a reading which is proportional to $u_1\, u_2 \cos\,(\varphi_2 - \varphi_1)$ or $u_1\, u_2 \cos\,\varphi$ on putting $\varphi = (\varphi_2 - \varphi_1)$. It will be sufficient to take values of $u_1\, u_2$ which always remain the same in order to obtain a reading which is proportional to $\cos\,\varphi$.

The fundamental circuit diagram of an electronic wattmeter is shown in Fig. 5. This consists of two detector valves arranged in push-pull and operating on the parabolic portion of their characteristics.

If the voltages u_1 and u_2 are applied as indicated in Fig. 5, the grid of valve T_1 receives the voltage $(u_1 + u_2)$ and the grid of valve T_2 receives the voltage $(u_1 - u_2)$. As the two valves are arranged in push-pull, the output voltage can be shown to be proportional to $u_1\, u_2 \cos\,\varphi$.

In order to determine the direction of the phase shift (relative position of the vector u_1 in advance for retarded phase in respect to the vector u_2), it is necessary to produce a known supplementary phase shift, and to ascertain the direction in which the reading of the wattmeter varies.

This method has the disadvantage of not being very sensitive (potentials of one or two volts are necessary) and demands compensation of the valves.

(*b*) *Compensation Method* (16)

This consists in changing the phase

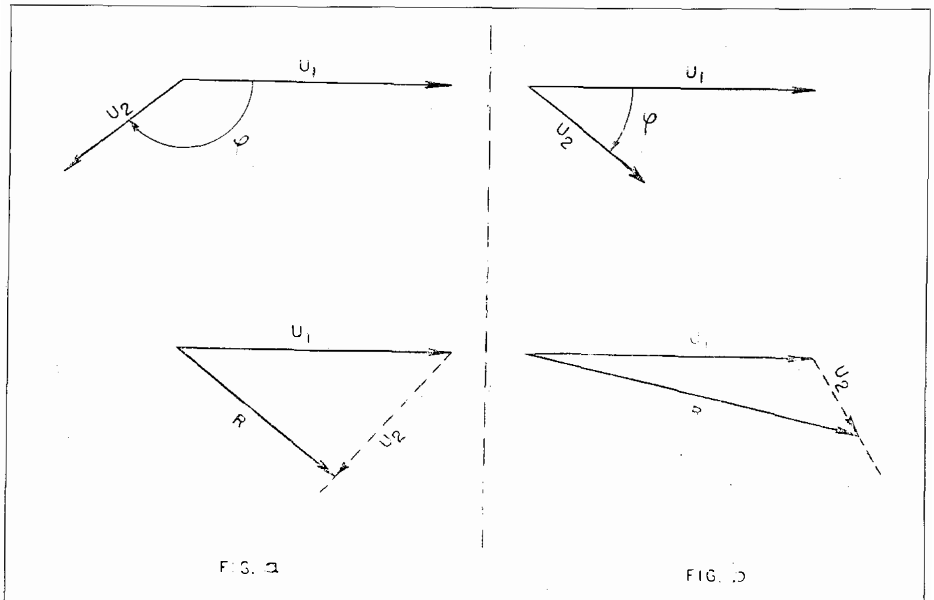


Fig. 11.

and the magnitude of one of the voltages at least, so as to make it equal and opposite to the other (Fig. 6).

The adjustment is made with precision by amplifying the result and listening through headphones, for example. In this way the difference in phase, the direction of the phase shift and the ratio of the voltages are measured simultaneously.

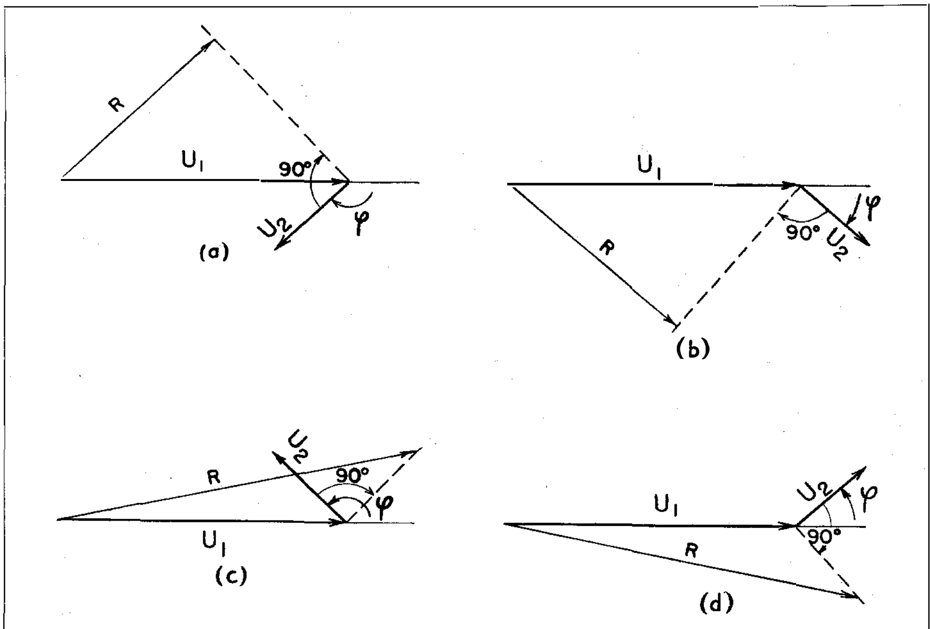


Fig. 12.

The method is accurate, but the adjustments are long and delicate by reason of the two conditions which have to be satisfied simultaneously.

(*c*) *Method of Resultants*

The two voltages u_1 and u_2 are measured, as also their resultant R (Fig. 7). The phase is then deduced from the equation:

$$R^2 = u_1^2 + u_2^2 + 2\, u_1\, u_2 \cos \varphi \ .$$

In order to simplify this it is advisable to adjust $u_1 = u_2 = u$ which gives the simple equation:

$$R = 2\, u \cos (\varphi/2) \ .$$

If the adjustment $u_1 = u_2$ has been made with a calibrated attenuator, the ratio of the two voltages will be measured at the same time.

The measurement of the direction of phase shift is most delicate. It would appear that the simplest method is to apply the two following rules [(9)].

1*st rule.*—A supplementary phase shift which progressively increases from an initially zero value is applied to one of the voltages, u_2 for example. If the resultant decreases, it means that u_2 is leading in phase with respect to u_1; if the resultant increases, it means that u_2 is lagging in phase with respect to u_1 (Fig. 7).

2*nd rule.*—u_2 is rotated by $+ 90°$. If the resultant is smaller than $u\sqrt{2}$, u_2 is leading in phase with respect to u_1; if the resultant is greater than $u\sqrt{2}$, u_2 is lagging in phase with respect to u_1 (Fig. 8).

It is understood with regard to these two rules that the supplementary phase shift which is applied to the vector u_2 will not change the magnitude of this vector.

The disadvantage of this method is that it is difficult to obtain a progressive phase shift which does not cause a variation in the attenuation, and that the note of the deflection in the measuring apparatus for a voltage equal to $\sqrt{2}$ is not accurately determined and may vary with time (i.e. the short-time stability is poor).

These two difficulties may be avoided by the two following methods:—

(*d*) *First Minimum Method*

The principle is as follows: In Fig. 9 let u_1 and u_2 be the vectors representing the two voltages applied to the detector voltmeter, and let R be the resultant of these two vectors. The voltmeter will indicate the value of the resultant. Irrespective of the phase shift φ, if a supplementary phase shift is produced which is made to increase (by means of a variable phase shifter), the vector u_1 will turn around the point 0 in a definite direction, in the direction of the arrow

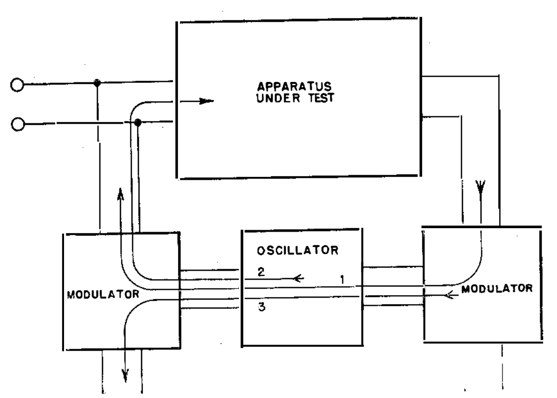


Fig. 13.

in Fig. 9, for example. There is always a position for which the resultant becomes a minimum, and one for which it becomes a maximum. *The method consists in noting the value of the supplementary phase shift introduced to obtain the minimum resultant.* Using the conventions given in Fig. 9, this phase shift is equal to the supplement of the angle φ in magnitude and in sign.

It will be noticed that this method gives measurements which are independent of the magnitudes of the vectors u_1 and u_2.

It should also be noted that the accuracy is great if the vectors u_1 and u_2 have magnitudes which are in the neighbourhood of one another, or are very slightly different. In order to see this it will be sufficient to examine and consider Fig. 10.

This method is particularly suitable when it is desired to measure phase only, without measuring the magnitudes of the vectors u_1 and u_2.

(*e*) *Second Minimum Method* (9)

Consider the resultant of the two vectors u_1 and u_2 and a variation in magnitude of u_2 beginning at zero. How will the magnitude of the resultant vary? Two cases must be considered according to whether the angle of the two vectors u_1 and u_2 is obtuse or acute (Figs. 11a and 11b) :—

1*st case : φ obtuse*.—The resultant, equal in the first instance to u_1, decreases as u_2 increases, and passes through a minimum Rm ; it then increases indefinitely with u_2. It is easy to note the minimum position, and Rm may be accurately measured. The phase angle is then given by :

$$\sin \varphi = \frac{Rm}{U_1} .$$

2*nd case : φ acute*.—There is therefore no minimum; but if the vector u_2 is rotated through 180°, it will be found that the preceding case is obtained.

As u_1 has already been measured (for the calculation of φ), if u_2 is regulated by means of an attenuator so as to obtain the same deviation as for u_1, the ratio of the two potentials u_1 and u_2 may be deduced therefrom.

In order to determine the direction of the phase shift, the following procedure is used : The vector u_2 is rotated by $+ 90°$; if the resultant then shows a minimum (Figs. 12a and 12b) u_2 will be lagging in phase with respect to u_1 ; if the resultant does not show a minimum (Figs. 12c and 12d) u_2 will be leading in phase with respect to u_1. It is easy to make an accurate rotation of 90°, particularly as, if the sensitivity is changed while doing so, this is of no importance. From the point of view of practical results, this method is therefore more simple than the foregoing one.

(*f*) *Method of the Vectorial Sum and Difference*

This method was developed by Mason (12), (14). A single source feeds two circuits : one containing an attenuator and the other the circuit producing the phase shift to be measured. These circuits terminate in a detector preceded by an attenuator.

First of all, the two voltages applied to the detector are adjusted so as to make them equal. Then, using a changeover switch, the vector sum and the vector difference of the two voltages are measured. From the attenuation which has to be introduced before the detector to make the two vectors equal, the value of the phase angle may be deduced.

This method is particularly useful for the measurement of small angles. It has, however, the disadvantage of being rather lengthy in operation.

B.—Method for Phase Measurement over a Frequency Band

Consider now the question of the application of these methods to extensive frequency ranges.

The first point which arises is that, irrespective of the process used, the performance of the measuring apparatus will vary if the range is very wide, due to the introduction of phase shifting networks, particularly in cases (b) and (f). For methods (c) and (e) it is less obvious that errors will occur if it is assumed that it is possible to produce circuits and attenuations free from phase shift over very wide ranges. It is possible from the results and the arrangement to determine the sense of the direction of the phase shifts (a rotation of 90° for example).

These above methods cannot be used in the case of very wide bands, but the difficulty may be overcome by using the method of frequency changing which will now be described [16].

Frequency Changing Method

This consists in bringing the frequency of the two voltages u_1 and u_2 to a frequency which is fixed by means of an auxiliary oscillator and two modulators (see Fig. 13).

Let $u_1 \cos(\omega t + \varphi_1)$ and $u_2 \cos(\omega t + \varphi_2)$ be the two voltages, and let $u \cos(\omega^1 t + \varphi)$ be the voltage supplied by the auxiliary oscillator to the two modulators. At the output terminals of each of the two modulators, a component of the beat frequency $(\omega - \omega^1)$ is found which is respectively proportional to :

$$u\, u_1 \cos[(\omega - \omega^1)t + \varphi_1 - \psi]$$
$$u\, u_2 \cos[(\omega - \omega^1)t + \varphi_2 - \psi]$$

if $\omega > \omega^1$ and to

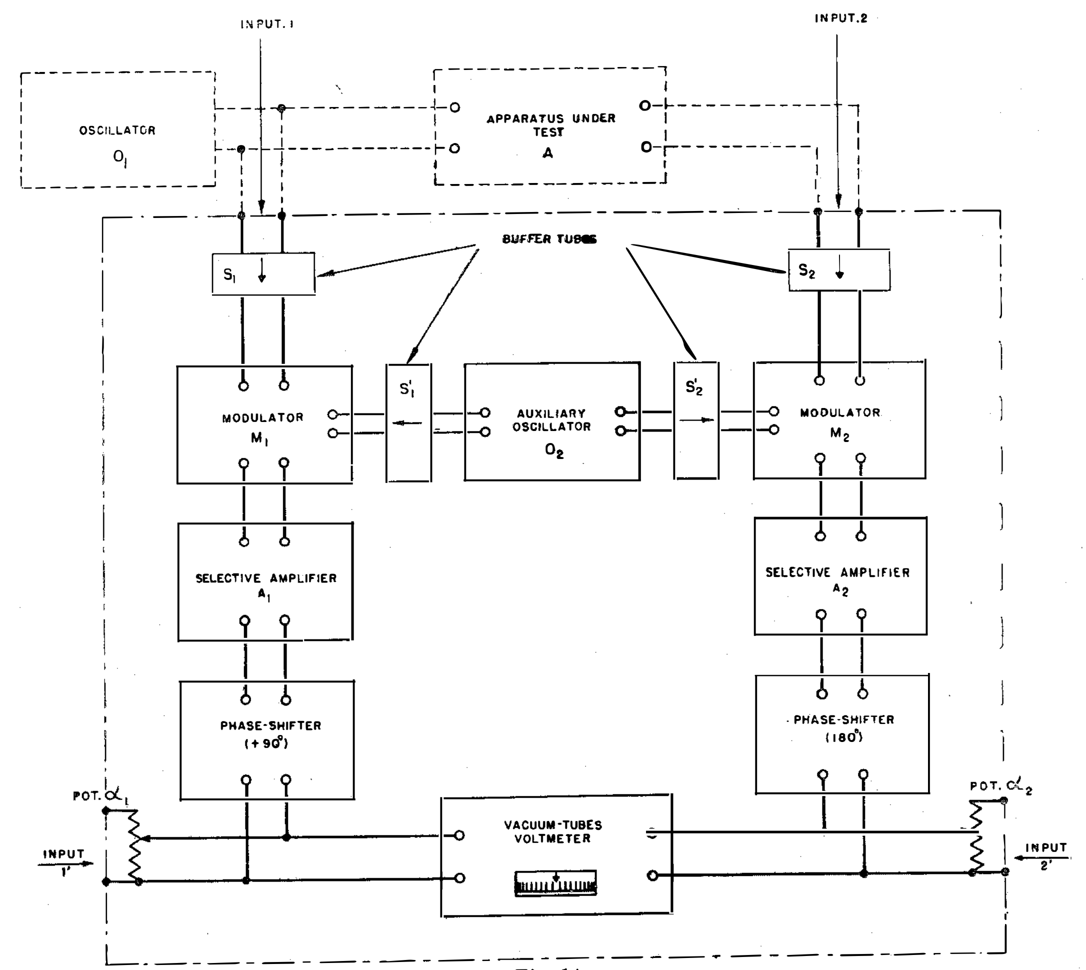


Fig. 14.

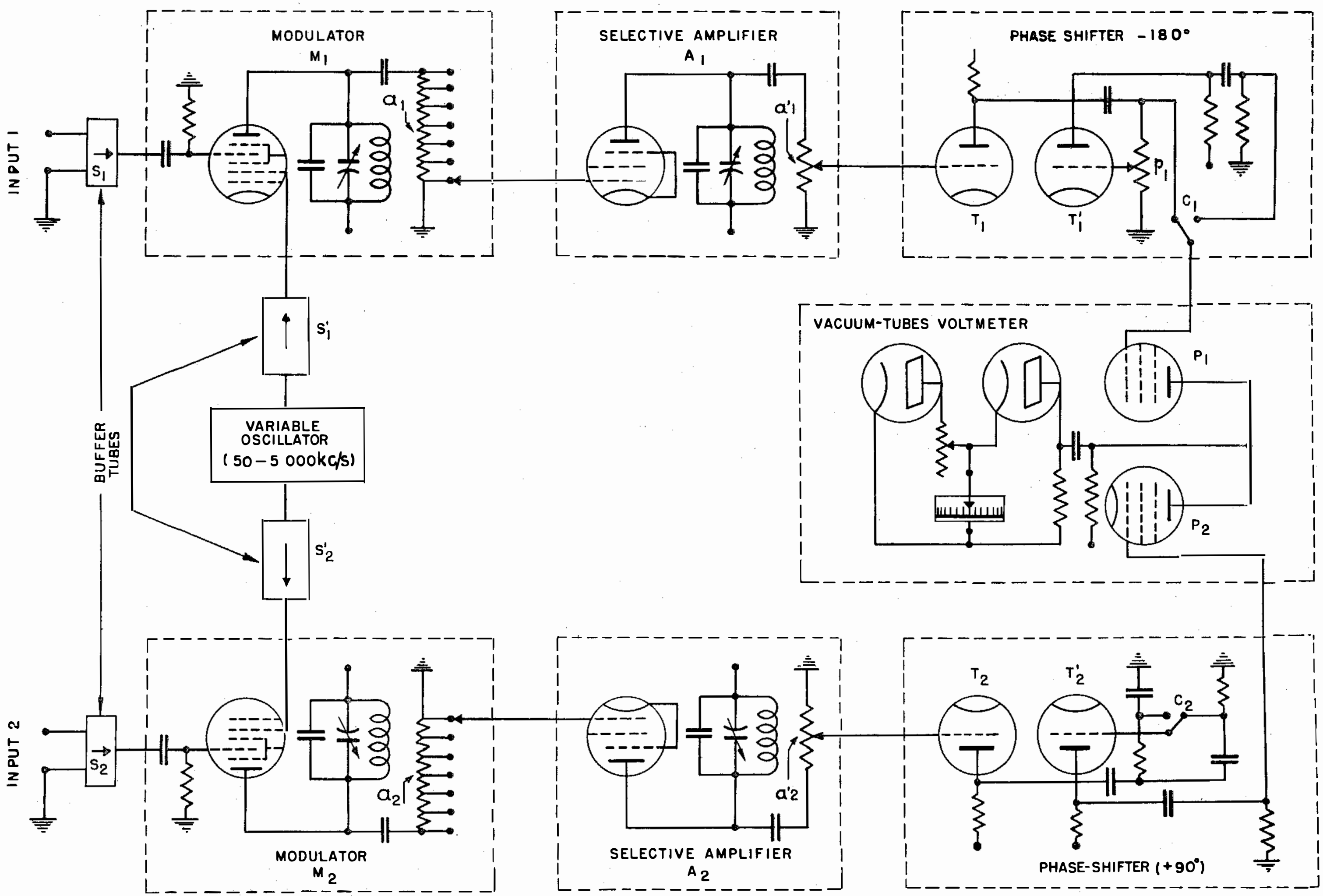

MODULATOR
M1
a1
SELECTIVE AMPLIFIER
A1
a'1
PHASE SHIFTER -180°
T1
T'1
P1
C1
INPUT 1
S1
S'1
BUFFER TUBES
VARIABLE OSCILLATOR (50 – 5 000kc/s)
S'2
VACUUM-TUBES VOLTMETER
P1
P2
INPUT 2
S2
a2
MODULATOR
M2
a'2
SELECTIVE AMPLIFIER
A2
T2
T'2
C2
PHASE-SHIFTER (+90°)

Fig. 15.

$$u\ u_1 \cos\ [(\omega - \omega^1)t + \psi - \varphi_1]$$
$$u\ u_2 \cos\ [(\omega - \omega^1)t + \psi - \varphi_2]$$

if $\omega < \omega^1$.

The difference in phase between the two voltages is accordingly:

$$(\varphi_2 - \varphi_1) \text{ if } \omega > \omega^1;$$
$$-(\varphi_2 - \varphi_1) \text{ if } \omega < \omega^1.$$

The frequency change does not, therefore, introduce any supplementary phase shift; it can only change the sign of the existing phase shift, a change which can be avoided by making $\omega > \omega^1$.

This method accordingly makes it possible to apply the measurement of phase for a single frequency to a frequency band.

Application to High Frequencies

The process of frequency changing was proposed by the Bell Laboratories and applied by them (in combination with method (a) for phase measurements at a given frequency), in the range 0.5 – 50 kc/s [16].

At very high frequencies some difficulties are encountered. One of these is the coupling

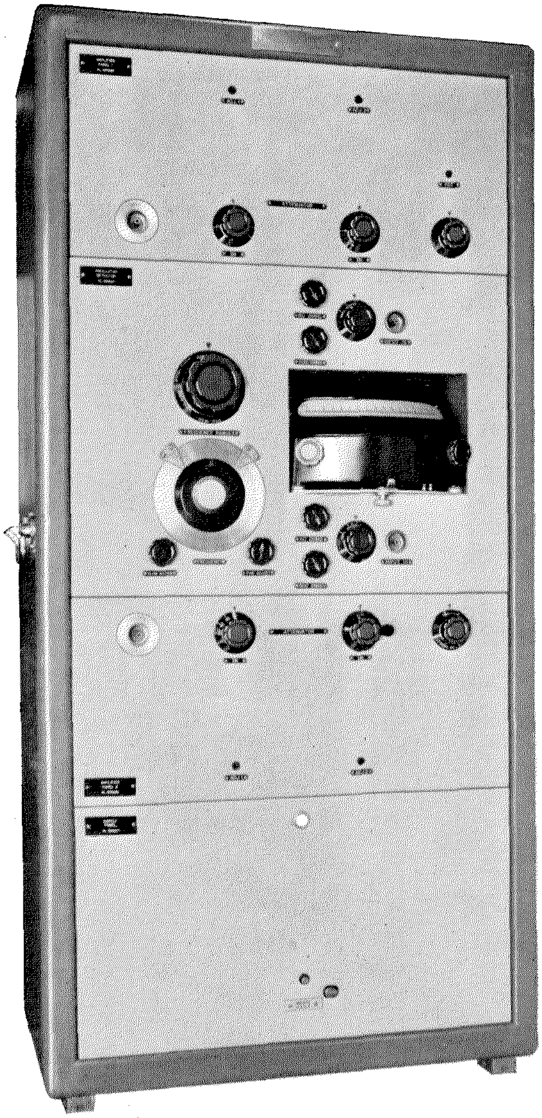


Fig. 16.

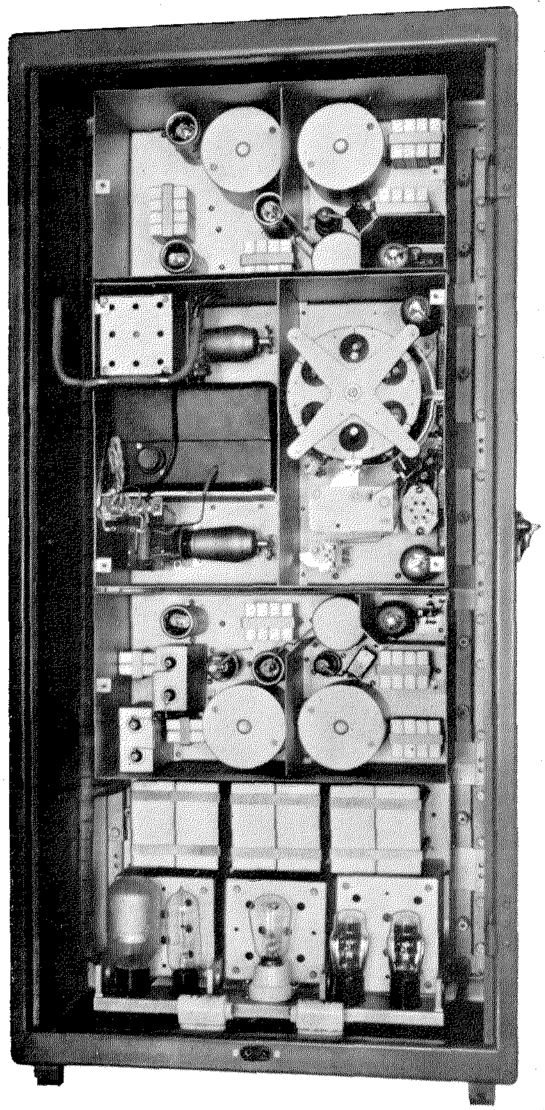


Fig. 17.

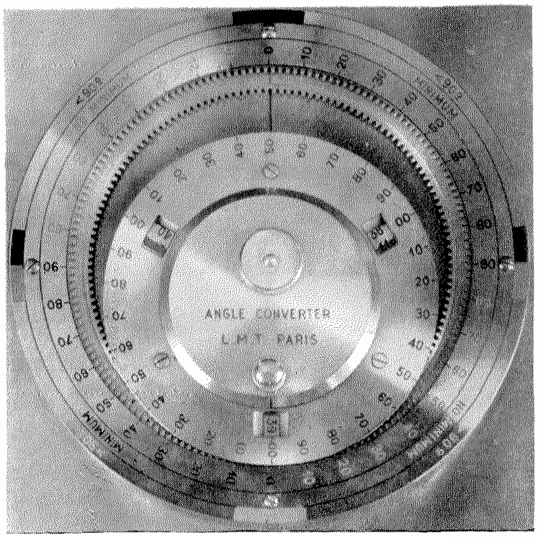


Fig. 18.

which occurs between the input and output of the apparatus to be investigated (Fig. 13, arrow 1) through the output modulator, oscillator, and the input modulator.

Another difficulty arises from the fact that a fraction of the voltage of the auxiliary oscillator O_2 passes to the input of the apparatus through the input modulator (arrow 2, Fig. 13). This voltage, which might attain a few volts at a few megacycles, may saturate the apparatus to be investigated, and may modulate the voltage supplied by the second oscillator.

Finally, another difficulty arises in that a fraction of the output voltage passes from the first output modulator to the input modulator (arrow 3, Fig. 13) and produces an interfering voltage which may entirely falsify the measurements.

In order to overcome these difficulties four buffer valves are introduced, as shown in Fig. 14. These valves only permit free transmission of the voltages in one direction, and are arranged so as practically to remove the spurious transmission channels mentioned above.

C.—Description of the L.M.T. Phasemeter

The principal methods of phase measurement having been described, and the simplicity and advantages of the methods of measurement by minima shown, it is proposed to describe the phasemeter, based on the second minimum method, which was evolved in the L.M.T. Laboratories [9].

Only a simplified description, together with its characteristics, will be given. In passing, very brief mention will be made of certain interesting technical improvements introduced into the elements of this apparatus.

The L.M.T. phasemeter was designed to operate within the two ranges, 100 to 50 000 p : s, and 50 to 5 000 kc/s. The apparatus, in particular, has been designed for operation in the second wave range, but has been adapted so that it may also be used in the first range.

(1) *Fundamental Arrangement*

The diagram of the fundamental arrangement of the equipment is shown in Fig. 14.

One section of the circuit alone serves for measurements within the range from 100 to 50 000 p : s. The whole of the circuit is necessary for measurements in the range from 50 to 5 000 kc/s.

Measurements within this range will first be considered :

(*a*) *Range* 50 *to* 5 000 *kc/s.*—The method used is that of frequency changing combined with the second minimum method. The diagram of the fundamental arrangement given in Fig. 14 shows clearly :—

(1) The frequency changing unit, modulator M_1, modulator M_2 and auxiliary oscillator O_2 ;

(2) A single-frequency phase-measuring unit using the second minimum method ; amplifiers A_1 and A_2, a system of phase rotation by + 90°, a system of phase rotation by 180° and a valve voltmeter.

(3) Finally, the system of four buffer tubes, S_1, S_2, S'_1 and S'_2, for the elimination of causes of error at high frequencies.

Oscillator O_1 which supplies the apparatus to be investigated (A) is, of course, outside the phasemeter, and does not form part of this apparatus. In Fig. 14 the phasemeter unit is framed by the chain dotted line.

(*b*) *Wave range* 100 *to* 50 000 *p : s.*—In this range only the valve voltmeter of the foregoing installation is used, and two attenuators $\alpha 1$ and $\alpha 2$ (see Fig. 14) ; phase measurements are made by the method of resultants.

In order to determine the direction of the phase shift it is necessary to produce a supplementary phase shift by means of an exterior circuit.

If calibrated attenuators are used it is possible to measure the difference in level between the two applied voltages.

(2) *Elementary Electric Circuit Diagrams*

(*a*) *Range* 50 *to* 5 000 *kc/s.*—In Fig. 15 the fundamental electric circuit diagram of the arrangement used in this wave range has been shown. The diagram has been simplified to a maximum extent in order to show the fundamental elements more clearly.

The following are easy to distinguish: the buffer tubes S_1, S_2, S'_1, S'_2; the modulators M_1 and M_2; the amplifiers A_1, A_2; the triodes T_1 and T'_1 for phase rotation through 180°; the triodes T_2 and T'_2 for the rotation of + 90°; the valve system of P_1 and P_2, whose plates are connected in parallel, whereby the resultant of the two voltages transmitted to the grids of these valves may be obtained and applied to the valve voltmeter; and finally, the valve voltmeter with its measuring apparatus.

The regulating devices included are as follows: The attenuator units a_1, a_2 (5 steps of 0, 20, 40, 60, and ∞ db.), and a'_1, a'_2 (a continuously calibrated potentiometer) covering a range of 20 db.; the switch c_1 for the phase rotation of 180°; the switch c_2 for the phase rotation of + 90°; the four circuit "trimmers" tuned so as to obtain exactly the same phase shifts; and, finally, the compensating potentiometer p_1 for providing the two triodes T_1 and T'_1 with the same degree of sensitivity, i.e., so as not to alter the amplification when the switch c_1 passes from one position to another.

For the sake of clarity the circuit of the oscillator has not been shown.

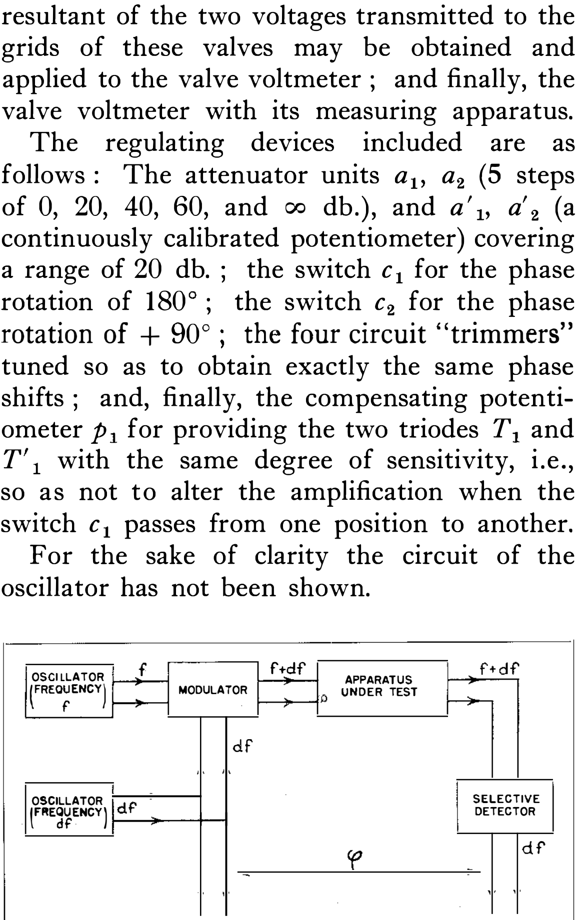


Fig. 19.

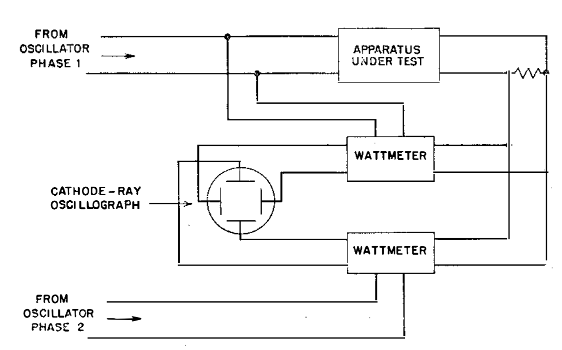


Fig. 20.

(*b*) *Wave range* 100 *to* 50 000 *p:s.*—The fundamental circuit diagram is shown in Figs. 14 and 15. Figure 15 shows the two tubes in parallel, P_1 and P_2, and the measuring apparatus, which also forms part of the foregoing arrangement (a switching system, which is not shown in the diagram, makes it possible to change the circuit from one arrangement to the other according to the range which it is desired to use); and the diode detection system [11]. Figure 14 shows the input potentiometers α_1 and α_2.

(3) *Characteristics*

(1) *Sensitivity.*—0.1 V in the range 100 to 50 000 p: s, and 0.0005 V in the range 50 to 5 000 kc/s.

(2) *Input Impedances.*—With coaxial input leads, this is of the order of 50 $\mu\mu F$. (For high-frequency measurements, two external valves of the kind used in high-frequency valve voltmeters are provided. With these valves the input impedance has a capacity of about 6 $\mu\mu F$.)

(3) *Precision.*—About 2° throughout the wave range.

In addition to phase measurement, amplification and attenuation may be measured with this apparatus. It is also possible to use it as a harmonic analyzer.

The following are its characteristics for these uses:—

(1) It is possible, by a direct reading, to measure differences in level between 0 and 80 db. in the wave range 50 to 5 000 kc/s.
(2) The harmonic analysis may be made

within the range 50 to 5 000 kc/s using a method recently discovered [8] by the author. With this method it is possible to detect and measure levels of harmonics of about 90 db. below the fundamental.

The front and back views of the apparatus are shown in Figs. 16 and 17. Figure 18 shows the calculator designed by Monsieur Lalande to simplify the calculation of the true value of the phase shift, allowing for the factor $2K\pi$ for angles between 0 and 5 000°. This apparatus is of great use in plotting curves of phase shift in television transmission systems.

II.—METHODS FOR THE MEASUREMENT OF PHASE AND ENVELOPE DELAYS

A.—Measurement of Phase Delay

A very brief summary will be given of the methods of measuring phase and envelope delay. A complete and very interesting study has been made by Nyquist and Brand [14]. The reader is advised to refer to this paper for further details.

(1) *Method by Measuring the Phase Shift and Frequency*

The phase shift φ and the frequency f are measured and the quotient taken: $\tau = \varphi/2\pi f$

What are the limits of this method? They are a function of the error obtained during measurement.

We have $$\frac{d\tau}{\tau} = \frac{d\varphi}{\varphi} - \frac{df}{f}.$$

Let us first of all take into account the errors due to measurement of the phase shift. The phasemeters, as a rule, give an absolute error $\triangle\varphi$ which may be considered as practically independent of the value of the phase shift φ. On this hypothesis it will be seen that the relative error due to the measurement of phase shift increases with diminishing phase shift, that is to say, generally at low frequencies.

According to the problem which arises, this may or may not cause discrepancies.

Take, for example, the case of television transmission. It is known that below a certain frequency f_0 (Fig. 3), phase deviations of a few degrees are permissible, and that above, the phase delay must be a constant deviation of $\triangle\tau_u$.

If the phasemeter gives accurate readings to about a degree, the condition imposed by frequencies less than f_0 may be verified; on the other hand, for frequencies greater than f_0 the accuracy is certainly sufficient since it is so for the frequency f_0. In point of fact, the

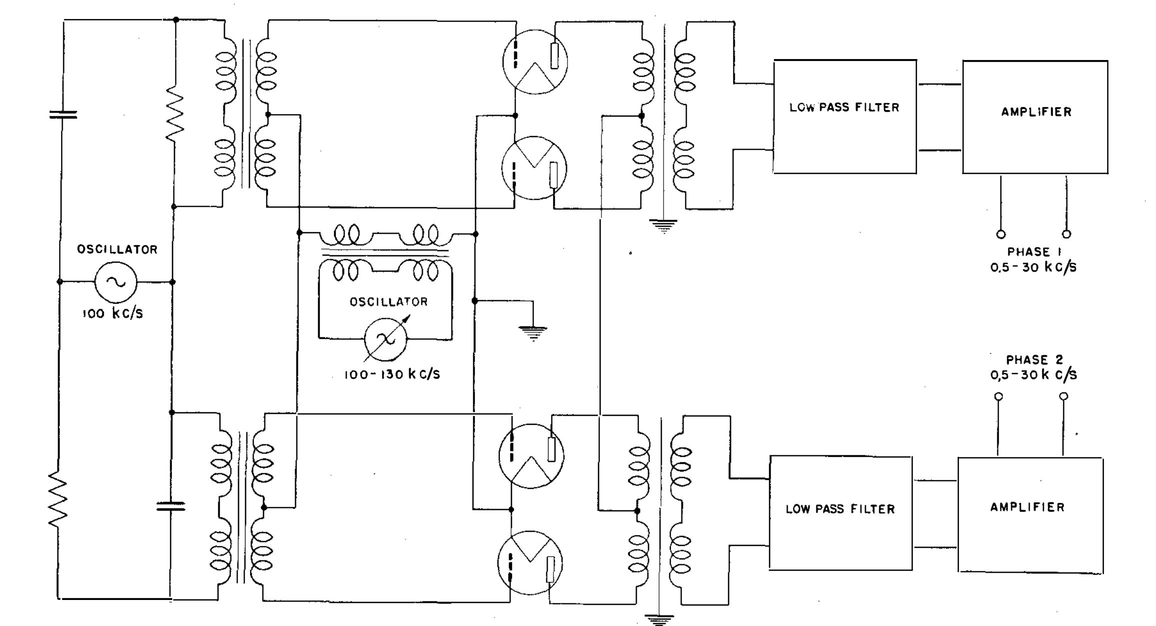


Fig. 21.

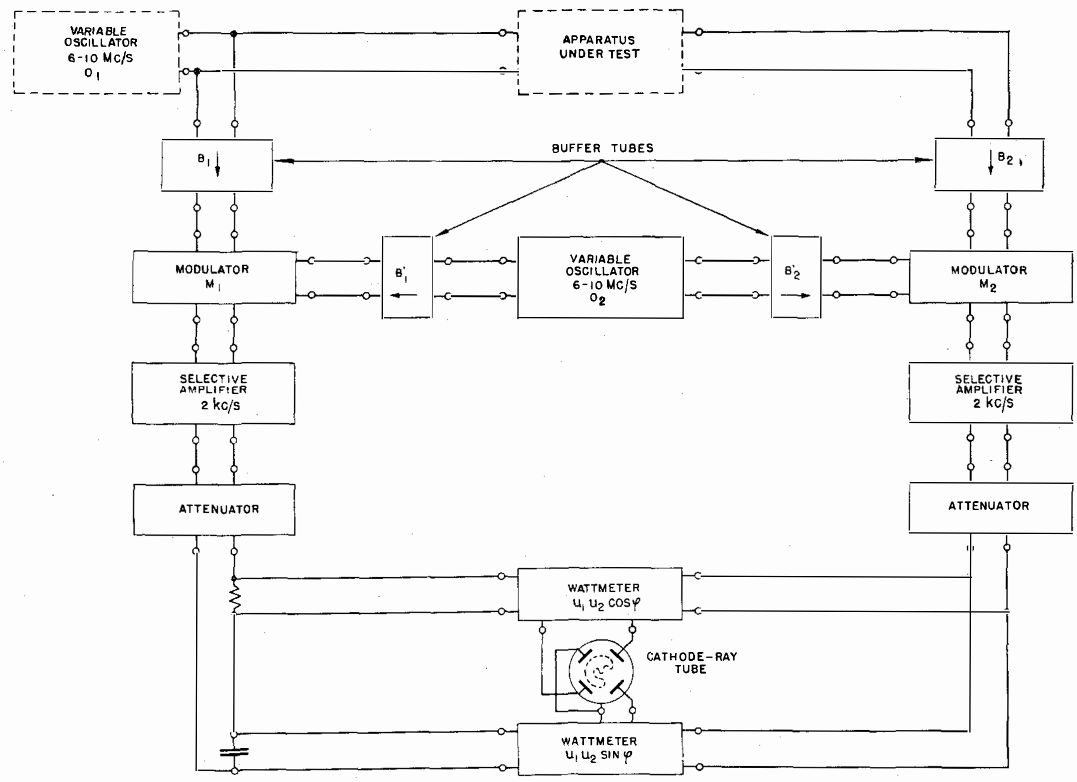


Fig. 22.

accuracy of the measurement of the phase delay by this method increases with the frequency (since φ increases and $d\varphi$ remains constant) whilst the permissible difference remains constant. If, therefore, the accuracy is sufficient for the frequency f_0, it is certainly so for higher frequencies.

The errors due to the frequency measurements must also be taken into consideration. They will be relatively negligible according to whether $\frac{\Delta\tau_u}{\tau}$ is great or small.

Continuing to take the case of television transmission as an example, in this case f_0 is about 100 kc/s and the phase shift φ for this frequency, and for a coaxial cable of $7\frac{1}{2}$ miles is about 2 000°, the error $\frac{d\varphi}{\varphi}$ is therefore less than $\frac{1}{2\,000}$ for $f > f_0$, assuming that $d\varphi$ is about one degree. As the permissible difference $\frac{\Delta\tau_u}{\tau}$ is then about $\frac{1}{1\,000}$, frequency measurements must be made to a degree of accuracy greater than 1/2 000. This accuracy is greater than is normally obtained by a good oscillator in laboratory use. Precautions must therefore be taken with regard to the choice of oscillator.

With these precautions, and within certain limits, this method may therefore be used for measurement of the phase delay in television transmission systems.

(2) *Direct Measurement*

This method consists in sending a sinusoidal wave simultaneously over an artificial line of adjustable length and the system to be studied, and of adjusting the length of the line so that the phase shifts are the same at the receiving end. This adjustment is, for example, made by the first minimum method.

The elements of the artificial line may be calculated in order that the phase delay shall be the same for all the frequencies to be transmitted.

The length of the line on balancing the phases at the output therefore gives the value of the phase delay directly. There is obviously an uncertainty, but it is easy to remove it by considerations of continuity.

This method may easily be applied to high frequencies. It is possible, for example, to produce, without difficulty, artificial lines giving a total delay of some micro-seconds, which is constant up to a few megacycles.

B.—Measurement of Envelope Delay

(1) *Method by Measuring the Impedances*

Consider a quadripole which can transmit in both directions. Assuming that the input is closed on its characteristic impedance, and the output may be either open or short-circuited, then if a sinusoidal signal is applied to the input, it will pass through the system, be reflected and return to the input. Whilst covering this path, it will be subjected to a phase shift 2φ, φ being the phase shift produced by the system.

The apparent impedance at the input will be a function of this reflected current. Assuming that the attenuation of the system varies very little with the frequencies, if the frequency of the input signal is made to increase, the phase of the reflected signal will increase progressively and the apparent impedance will vary in the same way, i.e. in a series of maxima and minima. An increase of phase shift of 2π corresponds to each successive maxima, which makes it possible easily to calculate the mean envelope delay in the corresponding frequency interval.

(2) *Methods by Measuring Phase Shift*

The principle is as follows:—A sinusoidal voltage is applied simultaneously to two circuits, one consisting of an attenuator and a phase-shifter, and the other being the circuit to be studied. The outputs of these two circuits are applied to a detector.

The method of procedure is then as follows: In one of these methods the phase shifter is absent. The attenuator is adjusted so that the voltages at the outputs of the two branches are equal. In this way the frequency is regulated so that the two voltages are in phase opposition. The frequency is accordingly varied progressively, and the necessary variation to bring the two potentials into phase opposition is measured. This method is suitable for the measurement of envelope delays of high value.

In another method a phase-shifter is used to compensate the phase variation produced by a given frequency variation. This method is suitable for the measurement of envelope delays of small value.

(3) *Direct Measurement Method*

The direct method is the most attractive and the most logical.

It is deduced from the actual definition of the envelope delay. It is known that this envelope delay is that of a signal consisting of a "frequency group" contained within a small interval df around the mean frequency f. In particular, the envelope delay of the beat of two very close frequencies f and $(f + df)$. Hence the method is one whereby the envelope delay

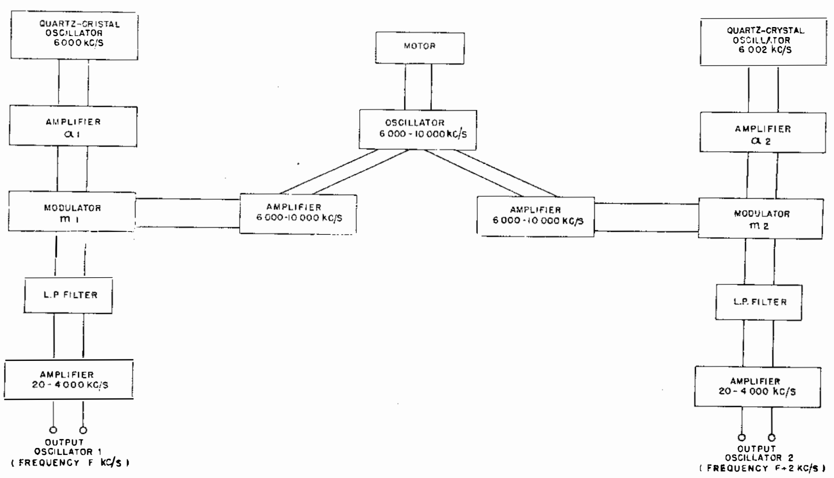


Fig. 23.

of the beat of the two close frequencies f and $(f + df)$ is measured.

Various methods may be adopted for making this measurement, the simplest being to measure the phase shift which occurs for the frequency df between the input and output of the system.

The fundamental circuit arrangement is accordingly that shown in Fig. 19. One source of adjustable frequency f supplies the quadripole to be investigated through the medium of a modulator M. A second source of fixed frequency df modulates the frequency f by means of the modulator M. A demodulator, followed by a selective amplifier tuned to the frequency df is connected to the output of the quadripole.

The problem then reduces to a measurement of the phase shift which exists between the frequency source df and the output of a selective amplifier, a process which is very simple.

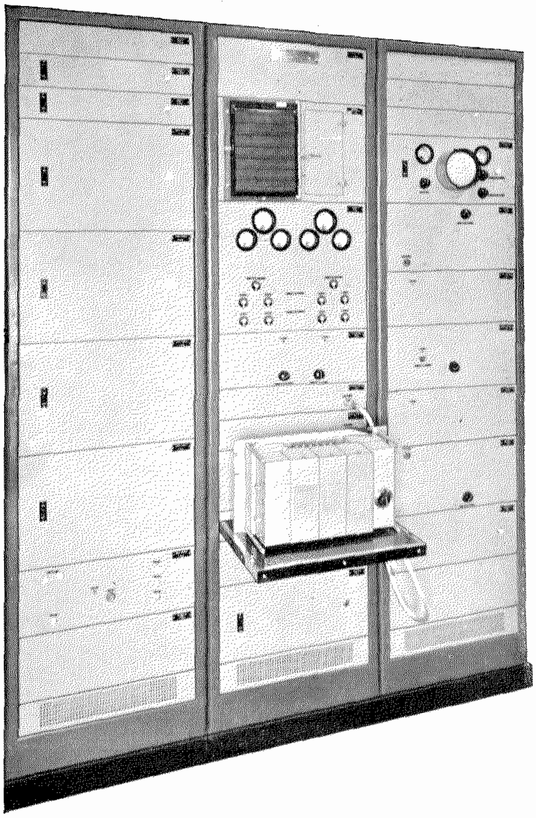


Fig. 24.

III.—METHOD OF TRACING NYQUIST'S DIAGRAMS

Fundamental Principle of the Indicators

The American methods of Peterson, Kreer and Ware, and that which has been adopted by us, will be examined in turn. As far as we know, there are no others.

(1) *Peterson, Kreer and Ware's Method*

Let $u_1(\omega).\ \varepsilon^{j\phi_1(\omega)}$ be the voltage at the input of the quadripole under investigation and $u_2(\omega).\ \varepsilon^{j\phi_2(\omega)}$ the voltage at the output.

In the method used by Peterson, Kreer and Ware a voltage proportional to

$$u_1(\omega).\ u_2(\omega).\ \cos(\varphi_2 - \varphi_1)$$

is applied to one of the pairs of quadrants of a cathode-ray oscillograph, whilst

$$u_1(\omega).\ u_2(\omega).\ \sin(\varphi_2 - \varphi_1)$$

is applied to the other pair. If the co-efficient of proportionality is the same for the two voltages, the spot will indicate the extremity of a vector forming an angle $\varphi = (\varphi_2 - \varphi_1)$ with the axis of origin, and having a magnitude proportional to $u_1\, u_2$. This point is then the point of Nyquist's diagram corresponding to the frequency of the two voltages. When this frequency is varied, the spot is displaced on the diagram.

In order to produce voltages proportional to $u_1\, u_2 \cos\varphi$ and $u_1\, u_2 \sin\varphi$ two electrostatic wattmeters are used: voltages u_1 and u_2 are applied to the first, whilst to the second are applied voltages of the same magnitude, but in phase quadrature with u_1 and u_2.

The circuit diagram of the electrostatic wattmeter is shown in Fig. 5. It consists of two detector valves arranged in push-pull and operating on parabolic characteristics. If the potentials u_1 and u_2 are applied as shown in Fig. 5, the grid of valve T_1 will receive the voltage $(u_1 + u_2)$ and the grid of valve T_2 the voltage $(u_1 - u_2)$. As the valves are arranged in push-pull, and if the detection is parabolic, the current and consequently the output potential are proportional to $u_1\, u_2 \cos\varphi$.

The circuit connections of the wattmeters are shown in Fig. 20. Assume for the moment that there are two oscillators 1 and 2, supplying two voltages u_1 and u_2 of the same frequency and in phase quadrature.

The voltage u_1 is applied to one of the wattmeters and to the quadripole to be studied whilst the voltage u_2 is applied to the other wattmeter. The voltage at the output of the quadripole is applied to both wattmeters. These in turn feed the cathode-ray oscillograph.

The construction of the two oscillators 1 and 2 is shown diagrammatically in Fig. 21. An oscillator with a fixed frequency (100 kc) feeds two identical systems, each composed of a resistance and a capacitance. The voltage across one of these resistances is transmitted to a modulator and the voltage across one of the capacitances is transmitted to the other modulator. The two modulators are also fed from an oscillator variable between 100 and 130 kc/s whose voltage is practically constant throughout the range. Each modulator is followed by a low pass filter and an amplifier.

The voltages supplied by the fixed frequency oscillator to the two modulators are in phase quadrature, but the voltages supplied by the variable frequency oscillator are in phase. It follows that between the two beat frequencies, at the output of the two modulators, there is a phase shift of 90° irrespective of the frequency of the beats. If the two low-pass filters and the two amplifiers are identical, this phase shift will be maintained at the outputs 1 and 2.

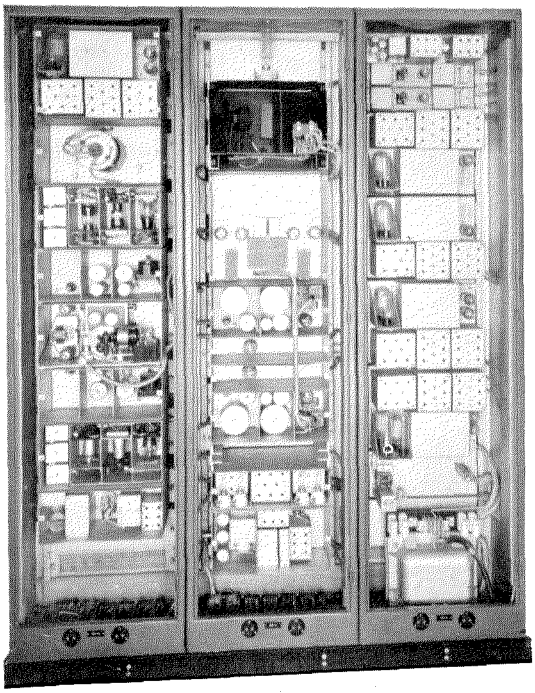


Fig. 25.

(2) *L.M.T. Method*

It was decided to produce an indicator for the frequency range from 50 to 4 000 kc/s. In order to understand the principle, the first necessity is to consider the case of automatically measuring the transfer factor at a single frequency.

Two electrostatic wattmeters feed a cathode-ray oscillograph (see Fig. 22). The voltage u_2 is applied simultaneously to the two wattmeters, whilst the voltage u_1 is applied to a system consisting of a resistance and a capacitance placed in series. The voltage at the terminals of the resistance is applied to the first wattmeter; that at the terminals of the capacitance is applied to the second wattmeter. Thus a phase shift of 90° is obtained between the voltages u_1 applied to the wattmeters, so that the output voltages of these wattmeters are proportional to $u_1\ u_2 \cos \varphi$ and $u_1\ u_2 \sin \varphi$.

The preceding system only functions at a single frequency. In order to make it operate over a very wide frequency band, it is sufficient to add a system of frequency changing. The arrangement is shown in Fig. 22. A variable frequency oscillator O_1 feeds the quadripole to be investigated, and also the modulator M_1. The output voltage of the quadripole is applied to the modulator M_2. A second variable frequency oscillator O_2 also feeds the two modulators.

A process, which will be described later, makes it possible to maintain constant between the two oscillators O_1 and O_2 a frequency difference of 2 kc/s. The frequency of the first oscillator is variable between 20 and 4 000 kc/s, and the frequency of the second between 22 and 4 002 kc/s. Under these circumstances the phase shift φ between the input and output of the quadripole is equal to the phase shift after modulation, and the voltages after modulation are proportional to the same voltages before modulation.

In order to obtain two oscillators whose frequencies differ constantly by 2 kc/s the arrangement shown diagrammatically by Fig. 23 is applied.

The aggregate consists of two quartz oscillators, two modulators, two filters, two amplifiers and a variable frequency oscillator.

The two quartz oscillators are tuned respec-

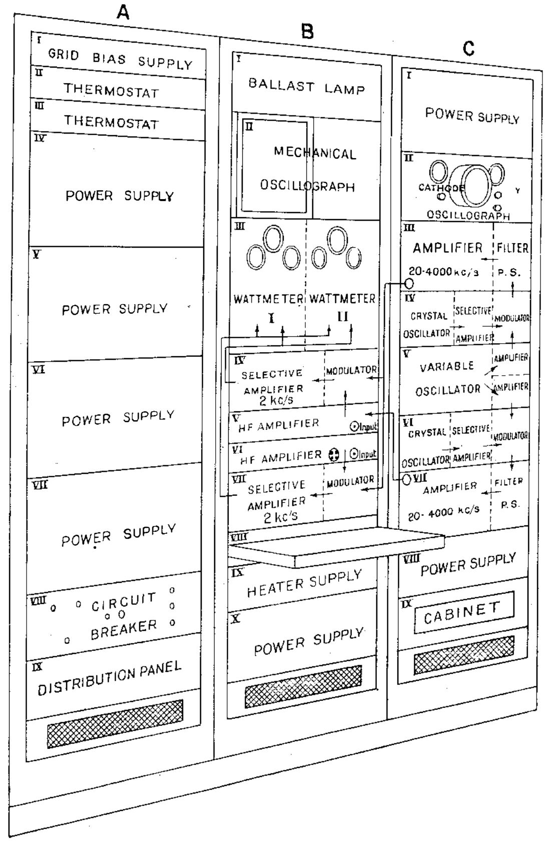


Fig. 26.

tively to 6 000 and 6 002 kc/s, and the variable frequency oscillator to any frequency between 6 000 and 10 000 kc/s approximately.

The fixed frequency oscillator at 6 000 kc/s, and the variable frequency oscillator feed a modulator M_1. The beat of these two oscillators is filtered at the output of the modulator M_1 and amplified. The oscillator at 6 002 kc/s and the variable oscillator in turn feed the modulator M_2. The beat is also filtered and amplified. Thus two sources of current are obtained of frequency F and $(F + 2)$ kc/s, F varying between 20 and 4 000 kc/s. These two sources are applied to the wattmeter circuits of Fig. 22.

Remarks.—When an attempt is made to construct an apparatus based on this principle certain difficulties arise which it may be advisable to mention.

In the first instance the variable frequency oscillator should, in principle, supply a voltage which is independent of the frequency. A process whereby this result may be very simply obtained [7] has been indicated. In reality, in consequence of the characteristics of the modulator which are variable with the frequency, an oscillator voltage is necessary which increases with the frequency, which can very easily be produced.

Another difficulty is the following : The two systems M_1 F_1 A_1 and M_2 F_2 A_2 are substantially identical, and a small fraction of the voltage of each oscillator passes into the opposite member. For example, some of the 6 000 kc/s passes into the member $M_2 - F_2 - A_2$ and some of the 2 kc/s appears by beat detection amongst the 6 000 kc/s interference and the 6 002 kc/s.

In order to eliminate this 2 kc/s the simplest method is to make the amplifiers with an attenuation peak of 2 kc/s. This result is easily obtained by applying anti-resonant circuits to the cathodes of the amplifying valves.

This precaution has a disadvantage. The two sources (at the output of the amplifiers) do not supply a potential which is independent of the frequency, except above a certain frequency which is greater than 2 kc/s. In the apparatus referred to this frequency was of the order of 20 kc/s.

Frequency Calibration.—Each point of a Nyquist diagram corresponds to a definite frequency. In order to evaluate this frequency, it is necessary to graduate the diagram to a scale of frequencies.

We have studied and produced a calibration system based on the following principle : The diagram is traced on a cathode-ray tube, by the luminous spot, for the frequency series 50, 100, 200, 1 000, 1 500, 2 000, 2 500, 3 000, 3 500 and 4 000 kc/s ; the grid of the cathode-ray tube is then highly polarized and the spot extinguished. Thus a dotted line diagram is obtained on which the marking of the frequencies is comparatively easy.

This improvement causes a complication of the circuit. It may be avoided by simply marking on the diagram a series of points corresponding to known frequencies. This result is easily obtained by adjusting the oscillator frequency successively on each of the frequencies marked. This method is particularly useful when it is desired to photograph the diagram. The

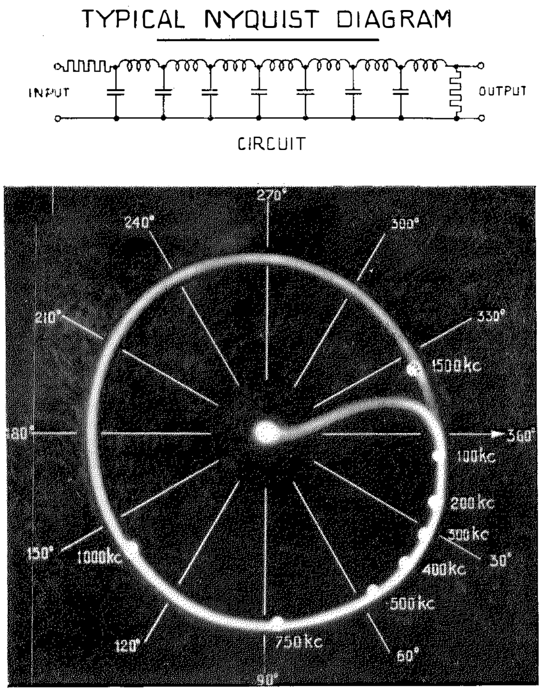


Fig. 27.

following procedure is then adopted. The curve is photographed and a new impression made on the photographic plate for a series of marked frequencies. When the plate is developed, these frequencies appear in the form of points which are clearly visible on the curve. Figs. 27 and 29 represent examples of the calibration obtained by this method.

SUMMARY AND DESCRIPTION OF L.M.T. NYQUIST INDICATOR

In the apparatus which we have constructed, the plotting of the diagram is entirely automatic. The condenser of the variable-frequency oscillator is rotated by a motor. Moreover, the indicator has two oscillograph instruments; a cathode-ray oscillograph for constant vision, and an electro-mechanical instrument for photography. These oscillograph instruments are visible on the photographs of the apparatus (Figs. 24 and 25) and on the apparatus diagram of Fig. 26.

In order to plot a diagram it is sufficient to place the quadripole on the desk, make the input and output connections, set the motor going, and take the photograph whilst controlling the curve on the cathode-ray tube.

The arrangement of the different elements in the apparatus is shown in Fig. 26. The left-hand unit contains all the power supply elements of the system. A part of the detail of the chassis is shown in Fig. 25.

All the elements of Fig. 22 are located in the central unit, with the exception of the oscillators C_1 and C_2 and the cathode-ray tube. This unit also contains an electro-mechanical oscillograph which has been designed with a view to the photographic recording of diagrams; it also contains the frequency calibrating device. Finally, the right-hand unit contains all the elements of Fig. 23, together with the cathode-ray tube.

Characteristics

The apparatus is adapted for the study of repeaters, transformers, filters and, in general, for all electric quadripoles.

The circuits are designed not to introduce any interference (coupling, impedance, reaction) on the quadripole to be studied. The impedance of the branch circuit in the output of the quadripole may have a capacity of about 8 $\mu\mu F$.

The voltage supplied by the input system of the quadripole is substantially constant at $\pm$ 0.3 db. from 100 to 4 000 kc/s. Consequent

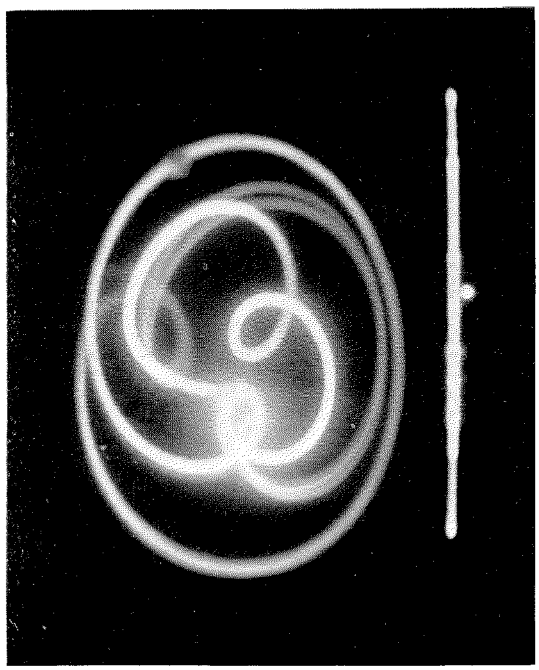


Fig. 28.

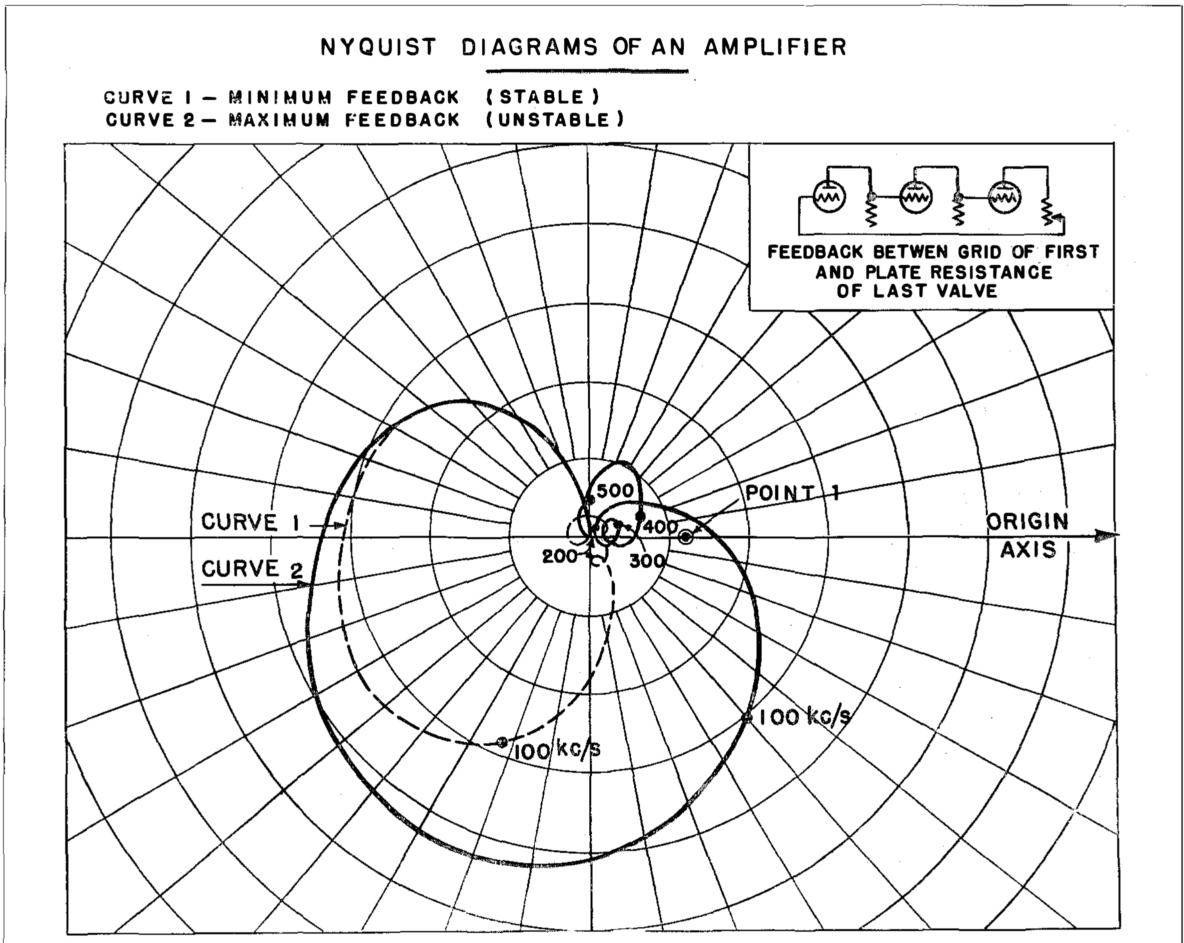


Fig. 29.

upon the distortion due to the wattmeter/cathode tube unit, the radial distances, that is to say, the magnitudes of the vector $Ke^{j\phi}$, are subject to error. On the other hand, the value of the phase shift is exact to within $\pm 2° - 3°$ for all points of the diagram.

Finally, the relative position of the diagram and the point A of co-ordinates (0, 1) is exact : even if the point passes in the immediate vicinity of the curve, it may be said with certainty that the installation is stable or unstable according to the relative position of the point A (0, 1) and of the curve.

It should be mentioned that the point A is easily obtained on the cathode tube by connecting the output of the indicator to the input.*

* It is merely necessary to take the precaution of regulating the oscillator to the frequency for which the diagram meets the axis OX of reference.

Examples of Diagrams Plotted with the Apparatus

Figure 27 shows a Nyquist diagram of an artificial line plotted with the indicator. The real curve makes several turns, but the photograph has been re-touched for demonstration purposes so as to show a single turn only, and also the frequency calibration points.

Figure 28 shows the diagrams of an artificial line in which interfering reflections have been introduced, by coupling two non-adjacent sections by a capacitance. In order to separate the different turns of the curve from one another as far as possible, and thus to make the diagram more intelligible, the characteristics of the indicator (sensitivity which increases with the frequency, etc.) have been slightly modified. This photograph does not contain any frequency calibration points.

Figure 29 gives a diagram, corresponding to a repeater, obtained by plotting on a transparent sheet placed on the cathode-ray tube.

Curve 1 does not enclose the point A (0,1) and corresponds to a stable condition. Curve 2 obtained with another feed-back adjustment encloses the point A and corresponds to unstable operation. We have found that the repeater jams on a frequency of about 60 kc/s, which corresponds to the intersection of the curve with the axis of reference.

The plotting of each curve takes a very short time, since the tracing is automatic and almost instantaneous.

Acknowledgments

The foregoing study was made at the L.M.T. Laboratories, where the author received the moral encouragement and material aid which is so necessary to research work.

The author desires to express his thanks and appreciation to the management, and wishes also to thank his chiefs, Messrs. Van Mierlo and J. Saphores, for the advice and assistance which they never failed to give him.

Finally, the author would thank Messrs. Dombray and Brion for their able collaboration, whereby he was able satisfactorily to solve many problems in the construction of the Phasemeter and the Nyquist Indicator.

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Impulse Regeneration

By E. P. G. WRIGHT, M.I.E.E.,

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INTRODUCTION

PERHAPS the two most formidable problems which have faced the telephone engineer in the course of development work are the attenuation and distortion of the speech and impulsing currents.

With the introduction of the speech repeater, it has been found possible to adopt fundamental transmission layouts specifying the maximum loss between the various switching points because the speech repeater has provided the necessary amplification to compensate for losses which cannot easily be avoided.

In a manner generally analogous, the impulse regenerator has been used to eliminate the distortions which have arisen as a result of line and exchange conditions.

It is desirable to explain that there is an important difference of principle between an impulse corrector and an impulse regenerator.

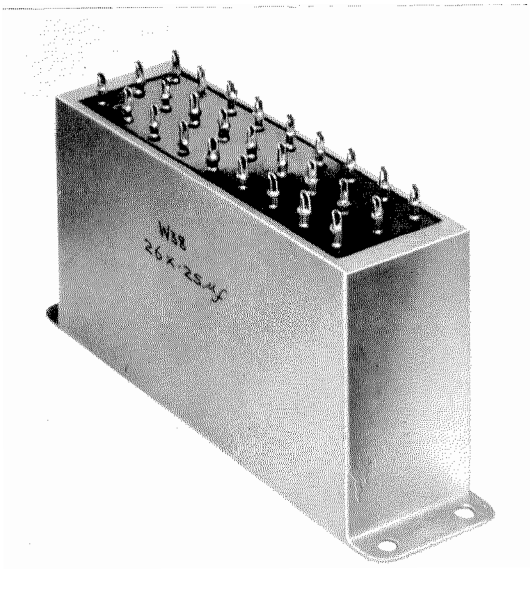


Fig. 1—Multi-element condenser.

The impulse corrector operates to ensure that a specific time period, such as the "make" period between impulses, does not fall below some predetermined minimum, whereas the regenerator operates to restore all the impulsing characteristics to their nominal duration. For this reason, it is necessary for the regenerator to store the information because, clearly, it cannot otherwise retransmit trains of impulses more slowly than it receives them. The relative merits of regeneration and correction are not weighed entirely by the question of expense, fault liability and quality of performance, but also by their inherent capabilities.

For example, with impulse correction there is not appreciable delay between the sending of a train of impulses and their reception and, in consequence, a backward signal can be inserted with the full assurance that it will be received by the register sender or other transmitting circuit without fear of interference by following trains of impulses. On the other hand, the regenerator, having stored the impulses on arrival, has the means of determining whether to retransmit the digits as received or whether to operate differently. This characteristic of the regenerator classes it as a type of register which also serves in its original form as a means for improving impulsing, and in its subsequent development as a means for translating the digits dialled in order to effect economies in switching.

The essential differences between the regenerator and the register are that the former is usually in a conversational circuit, and, therefore, available from the beginning of the call to the end, while the latter is usually associated only during the setting-up process. As a result, the regenerator does not often include an elaborate translating field, but, on the other hand, it is adapted to retransmit as many trains of impulses as it receives. This feature assumes

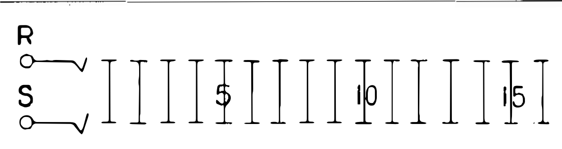


Fig. 2.

considerable importance in certain circumstances, as will be shown later.

Two types of impulse regenerator have been developed, one operating on an electrical, and the other on a mechanical basis. This article describes some of the possible applications of the electrical type.

PRINCIPAL APPLICATIONS OF THE REGENERATOR

The following gives an idea of the principal uses to which the regenerator can be put :—

(1) Impulse storage and regeneration (ratio and speed).
(2) Storage while forward circuits are being prepared.
(3) Storage under delayed search action.
(4) Storage of digits totalling more than available switch contacts.
(5) Alternative trunking.
(6) Conversion of dialling conditions.
(7) Digit discrimination in satellite exchanges.
(8) Toll dialling.
(9) Circuit timing.

GENERAL PRINCIPLES

As has already been made clear, the regenerator needs some form of storage element on which to hold the information received until it is retransmitted. In the electrical regenerator the storage is performed by a multi-element condenser (Fig. 1); the receiving and retransmitting are carried out by two standard uniselectors and an impulse generator.

The process of regeneration can be followed by reference to Fig. 2. The receipt of a digit such as 5 advances the receiving switch *R* from terminal 1 to terminal 6. The impulse generator now sends impulses forward, and for each impulse the switch *S* takes one step. When the switch *S* reaches the terminal 6 it finds a potential which operates a relay and stops the sending. If the second digit is 4, the switch *R* advances from terminal 6 to terminal 10 and subsequently the sending switch *S* makes a corresponding movement. If the third digit dialled is 3, then the *R* and subsequently the *S* switches advance from 10 to 13, and so on.

Now it is clear that, if the digit dialled is large, such as 0, and the sending speed is slower than the receiving speed, there is a possibility that the receiving switch will have re-stepped before the sending switch arrives at the advanced position. It is for this reason that the condensers are provided. When the receiving switch *R* has completed its steps and the slow releasing series impulsing relay *C* has released, the corresponding condenser is charged with a negative potential (see Fig. 3). This potential is sufficient to operate a relay *T* associated with the sending switch *S*, even

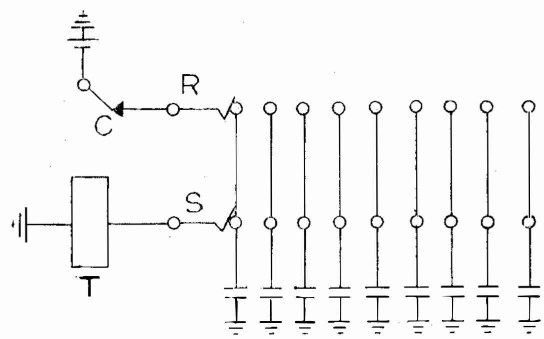


Fig. 3.

though the receiving switch has already stepped again.

When the sending switch is in line with the receiving switch there is a steady current flowing and the sending circuit is maintained open, but, if only a charged condenser is found, then the relay will release after a time period (giving the interdigital interval) and the sending will recommence.

The storage capacity is limited to the number of bank terminals on the switches, so that, since the speed of send ng is not controlled by the speed of receiving, it is possible for the receiving switch to get so far in advance of the sending switch that ultimately the latter is overtaken.

This is brought about by one or both of two causes :—

(1) Interdigital time between series of impulses less than provided on regeneration.

(2) Speed of impulses greater than that of the regenerated impulses.

The first case has an influence where a large quantity of low numbers is stored, whereas the storage of high numbers is affected by both cases.

With a capacity of 25 terminals and 25 condensers it is possible to store 25 single digits, 12 digits 2, or 8 digits 3, etc., without using the same terminal more than once, but with the higher digits such as 0 it is only possible to obtain two storages without re-using the terminals.

Figure 4 shows the switch movements for a succession of four 0's dialled at 14 steps per second with interdigital time of 600 ms. and regenerated at 10 steps per second with 800 ms. interdigital time. It will be seen that there are 7 terminals to spare at the moment when the receiving switch reaches the end of the 4th digit and the sending switch has just commenced sending the 3rd digit, but more terminals become available before another digit can arrive.

Storage while Forward Circuits are being prepared

As a general example of this facility, the case where a subscriber normally has to wait until a second dial tone is received when setting up a connection, may be cited—the regenerator stores the digits received without any delay being required of the subscriber.

Other examples of this ability to store information in order to provide additional time for selection to take place are shown in Fig. 5.

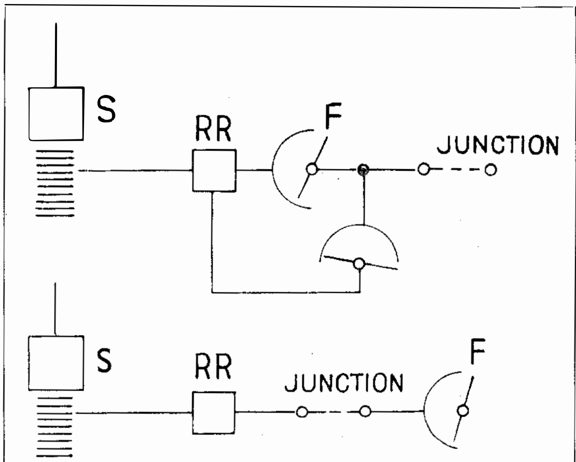


Fig. 5.

The outlets from a particular selector level pass to a regenerator which is connected to a free junction line by means of a finder switch. With such an arrangement full availability can be provided without difficulty. In other cases the finder may be in the second exchange.

Storage under Delayed Search Action

For certain calls, more particularly those set up by operators, it is desirable that the attempt to set up the connection should not be abandoned if all outlets are in use, but should be delayed until an outlet becomes free. The regenerator performs this function by its storage and retransmission abilities.

Storage of Digits totalling more than Available Switch Contacts

In certain storage conditions it is likely that a capacity of 25 terminals will be inadequate, but this capacity can be readily increased to 50 terminals by using the larger uniselector, and a capacity equivalent to approximately 90 terminals can be obtained by the use of positive and negative charges which are detected by means of a polarized relay.

Figure 6 shows the storage of the digits 5 4 3 0 7 on 16 terminals. It will be observed that odd

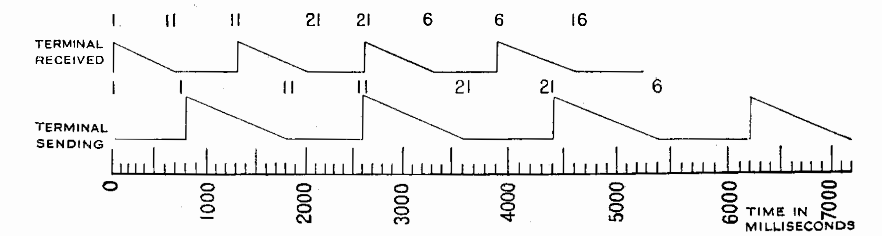


Fig. 4.

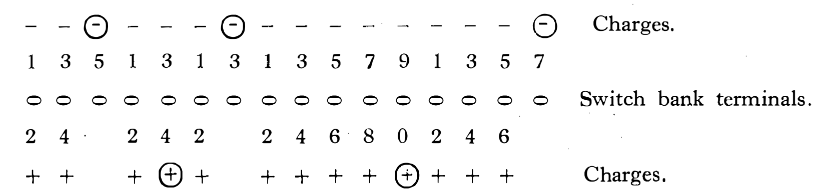


Fig. 6.

numbers are given a negative charge and even numbers a positive charge. Because it is impossible to charge a terminal with both potentials effectively, each new digit starts with the next terminal. As an example, the 50 terminals will hold the following digits without re-using terminals :—

1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8

or

0 0 0 0 0 0 0 0 0 0

In connection with the storage of numbers, the small capacity condensers used hold the charge for more than 15 minutes.

Alternative Trunking

Another application of the storage capacity is used in association with the addition of a routing digit for alternative trunking purposes.

Figure 7 shows 3 exchanges *A*, *B* and *C* connected together by junctions, such that calls are normally passed from *A* to *B*1 via an impulse repeater *IR* when first choice outlets from selector *A* are taken. Alternatively, when later choices of selector *A* are used, the call is routed via exchange *C* by means of the regenerative repeater *RR*, which inserts a digit before transmitting the received digits. The call then proceeds via the selector *C* and impulse repeater *IR* to exchange *B*2 selector whose bank contacts are multipled with those of *B*1.

Figure 8 shows how two groups of junctions from a selector *S*1 can be combined by means of the regenerator *RR*, which by path of access discrimination sends a preliminary signal or train of impulses to operate uniselector *H* to pick up either impulse repeater *IR* or selector *S*2; afterwards the regenerator transmits the received digits.

Conversion of Dialling Conditions

Besides converting poor impulses back to the standard speed and break-make ratio, the regenerator can be made to vary the speed and ratio to meet special conditions. For example, the break-make ratio may be changed from 66 : 34 to 50 : 50, and the dialling speed may be changed from 10 to 20 impulses per second or

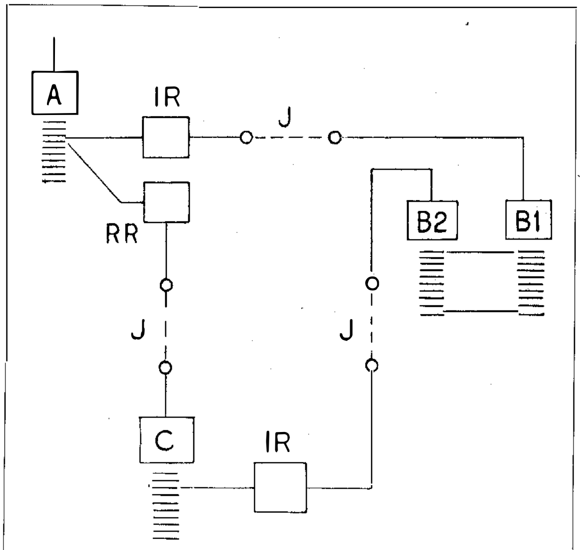


Fig. 7.

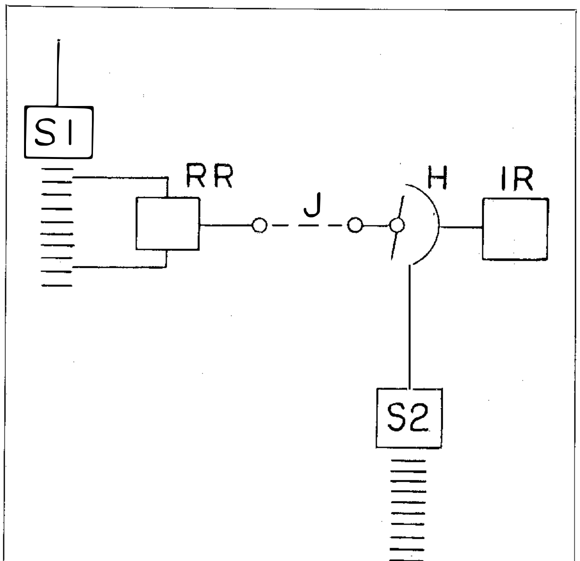


Fig. 8.

vice versa. Another example of its usefulness may be the conversion of impulses from reversed numbered dials to provide standard impulses. In this case the subscriber's dial, read clockwise, is numbered :—

0 1 2 3 4 5 6 7 8 9

whereas the impulses sent are :—

10 9 8 7 6 5 4 3 2 1

but the regenerator enables standard numbered selectors to respond by transmitting the complement of the number received. The latter action can be produced by homing the sending switch between digits.

Digit Discrimination in Satellite Exchanges

Figure 9 shows an application of the regenerative repeater to satellite exchanges. The circuit is connected to a calling line by means of a finder *F*. If the digits dialled indicate a local call, the hunting switch *H* finds a free local selector and the regenerator retransmits only those digits following the satellite code. If the digits indicate a main exchange call, the hunting switch *H* finds a junction to the main exchange and the regenerator repeats all the digits. In such a case the retransmission does not commence until the selector has found a free circuit. By this arrangement the main exchange junctions are not engaged unless required to set up a call.

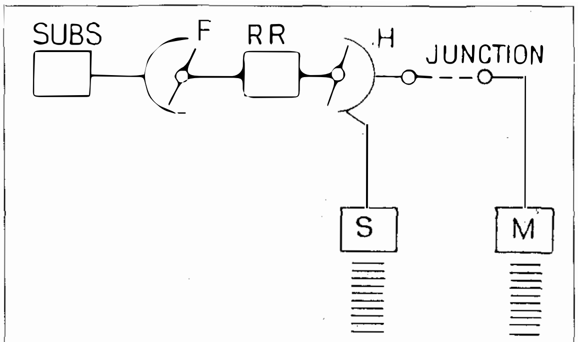


Fig. 9.

Toll Dialling

An interesting application of a combination of some of the features already mentioned is shown in Fig. 10.

In large areas the numbering scheme needs to be carefully planned owing to the large expense incurred by not using numbers in the most efficient manner. The dialling codes for giving access to the surrounding zones are often very limited, and it may be necessary to prefix all such calls by a code such as TOL. The number of digits to follow might vary, as it is a common practice to use mixed digit numbers in non-director areas. In consequence difficulty is found in indicating to the director when the full number of digits has been dialled. With a regenerative repeater inserted between the *A* digit selector and the director, calls prefixed by the special code do not use the director, but are routed to the toll exchange by a special translation from the regenerator.

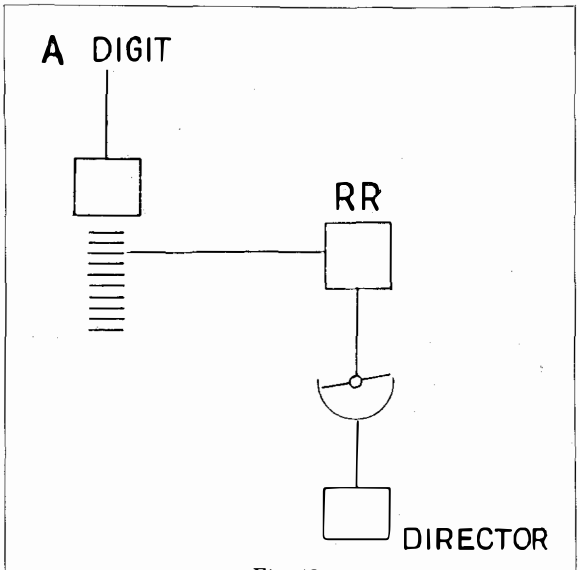


Fig. 10.

Circuit Timing

The uniselectors provided for regenerative purposes may also be used for timing purposes.

Figure 11 shows an example of the wiring between receiving and sending switching, in

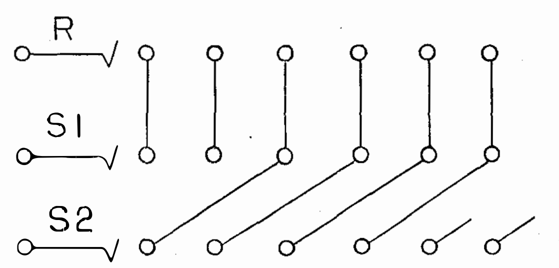


Fig. 11.

order to provide additional timing periods. It will be seen that the switch R can advance 3 steps before a circuit is completed over the wipers R and $S2$ in series; thereafter the switch $S1$ can advance until a circuit is completed over the wipers R and $S1$ in series.

In voice frequency signalling and dialling systems it is not required to signal and dial simultaneously, and the regenerator switches can be used to time the length of prefix and suffix signals and also to time the space between repetitions.

The electrical regenerator does not introduce any appreciable maintenance anxiety. Experience shows that the normal life of a condenser is very long, and no maintenance or adjustment is necessary. The uniselectors are usually of the stepping type only, which eliminates the interrupter spring adjustment.

For certain circuits it is desirable to arrange that in the case of a premature release the regenerator should restore to normal without retransmitting any digit already stored. This arrangement can be provided by means of homing uniselectors.

By use of a sequence relay and interrupter springs, the interdigital pause can be measured very accurately. The importance of an exact measurement concerns the holding time of the selectors engaged in the connection. The arrangement does not involve additional expense as the sequence relay does the work of two relays otherwise required for timing purposes. The regenerator can be made self-contained and independent of common sources of loop and magnet impulses by means of the vibrating relay which provides two pairs of springs and mounts in two relay positions in the relay set. This piece of apparatus is illustrated in Fig. 12.

The first model of the electrical regenerator, providing all the functions of an auto-auto repeater with impulse regeneration, was placed in service in 1936. Since that date further installations have taken place, and have given a very satisfactory grade of service under working conditions.

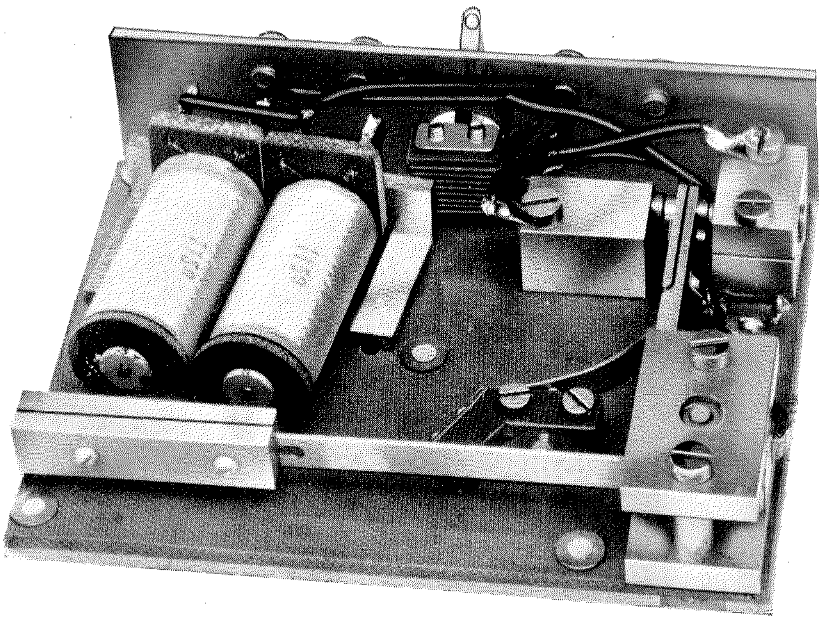


Fig. 12—Vibrating relay.

The Full-Automatic Exchange at Frederiksdal

By L. J. SALTOFT, B.Sc.,

Assistant Chief Engineer, Technical Department, Copenhagen Telephone Company

IN order to gain experience in the operation and maintenance of full-automatic rural exchanges, the Copenhagen Telephone Company (C.T.C.), in 1925, erected the first Danish full-automatic exchange in Fuldby on Seeland. The C.T.C. have since extended their experiments with various systems, including semi-automatic exchanges, and at the end of 1938 fifteen minor rural exchanges with capacities ranging from 50 to 400 lines had been installed in the C.T.C. area.

When new tariff regulations were introduced for Copenhagen regional exchanges, it was provided that exchanges adjacent to an exchange in District 1 could, if desired by a majority of subscribers, enter this District as "incorporated" exchanges, to be reached directly via a centralized service called "Omegnen"(Regional).

Growth of the incorporation process has been particularly noticeable in the regional exchanges north of Copenhagen, the residential area of a

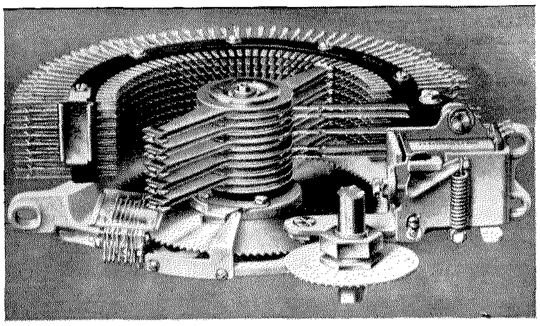


Fig. 1—Rotary type 100-point switch.

great number of people having their work in Copenhagen itself. Increased building activity consequent on suburban railway electrification also encouraged the demand for incorporated exchanges. As a result, in February 1939, a full-automatic exchange was cut over in place of the old magneto exchange at Frederiksdal, which was overloaded. If successful, this new exchange will take its place in a full-automatic rural area comprising Copenhagen Regional, and will further interwork with the semi-automatic system of Copenhagen, which will be completed in the near future.

The Frederiksdal experimental exchange is of the Rotary (7-D Urban) type; the switching equipment was supplied by the Standard Electric A/S., Copenhagen, while the erection and testing of the equipment were carried out by the C.T.C.

The exchange has initial equipment for 1 000 subscriber lines, but the present building permits an extension up to 2 000 subscriber lines.

The switch calculation is based on the following figures:—

The number of call minutes per subscriber in busy hours is 2, corresponding to 200 call minutes per busy hour per group of 100 subscribers, of which 78 per cent. is reckoned to be outgoing traffic (= incoming), and the remaining 22 per cent. local traffic. The average conversation time is 3.5 minutes.

From these figures the number of machines has been fixed at four first line finders, five combined line finders and finals, and four regular finals per 100 subscribers; and, for the whole of the exchange, 54 links, 12 registers, 48 penultimate group selectors, 42 incoming and 42 outgoing junctions to Lyngby, in which exchange the incoming and outgoing traffic is handled via six special manual positions installed in the same room as the Lyngby exchange itself. When the Lyngby exchange is converted, these positions will be replaced by automatic switching equipment.

A characteristic feature of the 7-D Urban system is the combined line finder and final, which, as the name indicates, is capable of working either as line finder or as final selector, as the traffic necessitates at any moment. It

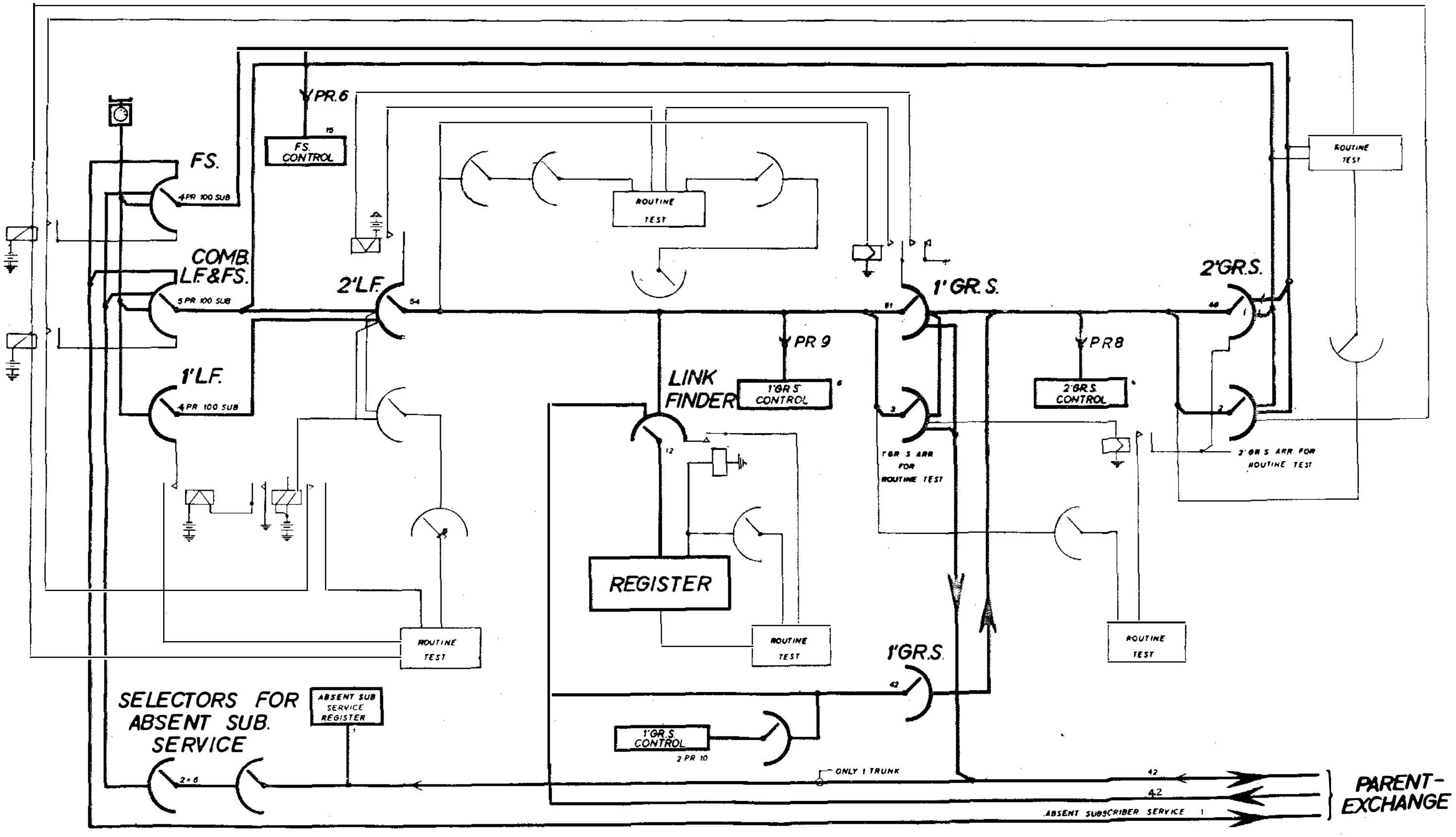


Fig. 2—Junction diagram, Frederiksdal Exchange.

should further be noticed that the switches of this system, whether used as finders or as selectors, are identical except that a home contact is provided on the selector. (See lower left portion of Fig. 1.) These switches are 100-point 5-brush gear driven switches of the well-known Rotary type.

For transmission reasons, a 48-volt low resistance supervisory bridge was decided upon, necessitating the introduction of a new type subscriber set with low resistance transmitter.

The maximum permissible loop resistance on junctions and subscriber lines, including subscriber set, is 1 200 ohms and the minimum leakage 10 000 ohms.

The operation of the system is as follows :—

The local numbering is 4-digit, the first digit being 6 ; by dialling 0, connection is obtained with the special positions at Lyngby exchange, where connections to all other exchanges, including Copenhagen, are obtained directly. By studying the junction diagram, Fig. 2, it will be seen that the subscriber, on lifting the microtelephone from the hook, will be engaged by a first line finder, or, if these are all busy, by a combined line finder and final, which connects the subscriber line to the link circuit via the second line finder, and further to a register via the link finder. Dialling tone is now obtained from the register, indicating that the subscriber may start dialling. All dial impulses are received by the register, which ultimately retransmits the impulses in the correct sequence to the various control circuits guiding the first group selector, penultimate group selector and final selector. The first digit controls the setting of the first

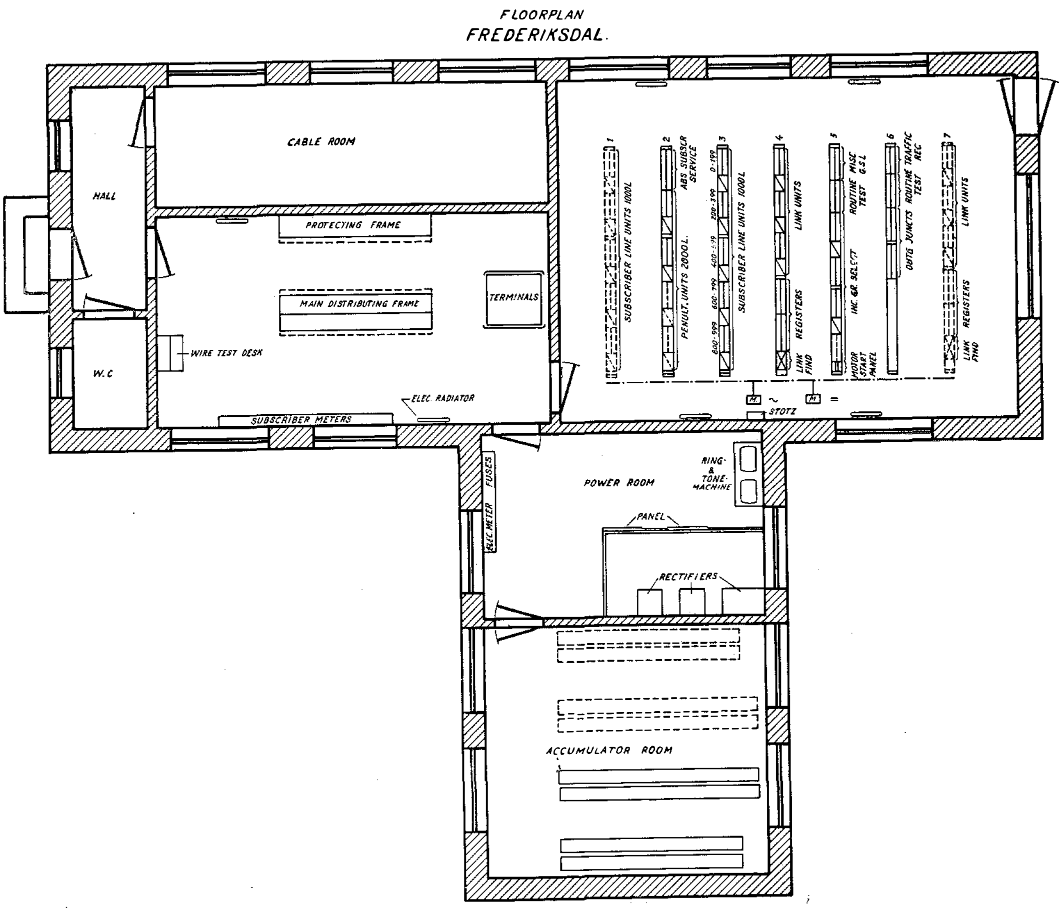


Fig. 3—General lay-out of building, Frederiksdal Exchange.

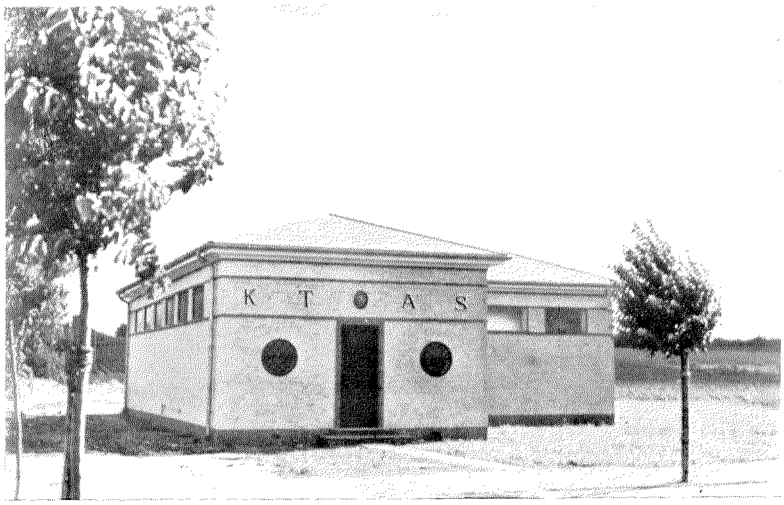


Fig. 4—Exterior view of Frederiksdal Exchange.

group selector and decides, as mentioned above, whether a local connection (1 000-group) or a connection beyond the local exchange is wanted.

In cases where the digit 6 has been dialled, the link circuit picks up a free penultimate group selector and its associated control circuit, which latter accepts the second digit from the register and directs the penultimate group selector to a free final selector in the wanted 100-group and its associated control circuit. The final control circuit then accepts the last two digits from the register and directs the final F.S. to the wanted line, after which the register releases, and the penultimate group selector takes care of ringing or busy tone, as the case may be.

When 0 is dialled the first group selector is directed to a free outgoing junction (see arrow on Fig. 2), whereby the subscriber becomes connected to an operator in the special positions referred to above at Lyngby (parent) exchange. On incoming traffic (see arrow, Fig. 2) a free register becomes attached via the link finder and accepts the impulses from the dials equipped in each position. As will be seen, the incoming junctions are provided with group selectors of their own. In view of the inter-urban traffic, the incoming junctions are arranged to permit the operator to listen in on, and possibly break down, an existing connection. Further, all junctions are provided with adaptor circuits for giving the required clearing signals to the magneto type manual positions.

The subscribers of the C.T.C. exchanges enjoy the facilities of "absent subscriber service," temporary as well as permanent, and, for a limited time, "changed number service." The problem of incorporating these facilities was solved by co-operation between C.T.C. and Standard Electric on principles hitherto unknown in automatic telephony. The equipment for the "absent subscriber service" comprises a special junction connected to a control circuit (see Fig. 2) with a common access switch for 2 000 subscribers, and, further, 6 marking finders extensible to 8 per group of 500 subscribers, i.e., a maximum of 8 subscribers per 500 can be given this service simultaneously on a temporary basis. The 6 marking finders so far provided per 500 subscribers have proved to be sufficient.

When "absent subscriber service" on a temporary basis is to be established, the operator enters the special junction, receives dialling tone from the control circuit and dials the normal 4-digit subscriber number followed by digit 1, which introduces a 1 200-ohm resistance on the e-wire of the subscriber, which condition characterizes "absent subscriber service." When the subscriber is being called, the 1 200-ohm resistance causes the engaged final to continue to the home position and to direct the call over a special junction (see Fig. 2) terminating in the manual position at Lyngby, where the operator gives the required information.

If the "absent subscriber service" is of a permanent character, (for instance, a subscriber is away for a long period) or if cross reference to another number is wanted, a 1 200-ohm resistance is permanently connected direct to the subscriber's line.

Amongst other special facilities may be mentioned the "malicious call service" permitting the identification of subscriber numbers from which malicious calls originate. Mention should also be made of the permanent glow circuit, the object of which is to release the register after 30 seconds in the case of false calls (short-circuited subscriber lines and the like); eight permanent glow circuits have been equipped.

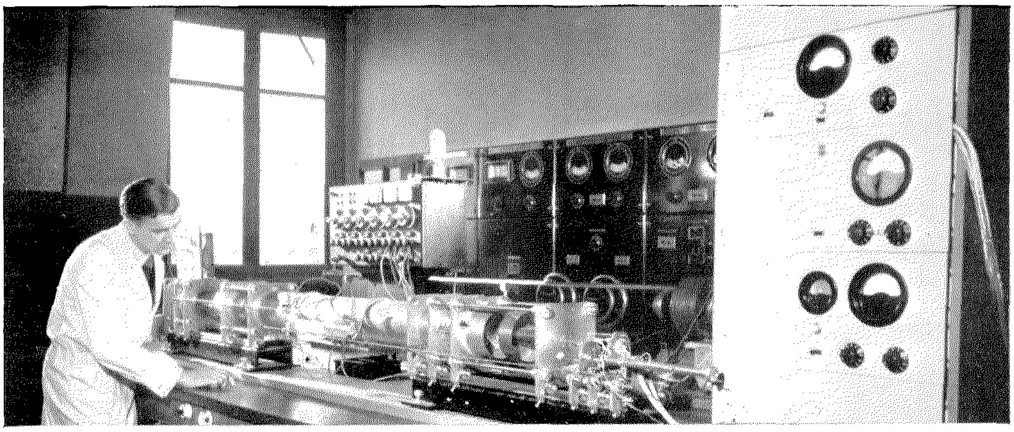
All subscribers' lines are provided with electrical message registers operating when the called subscriber answers a local call, or when the operator answers. The metering is not under the control of the operator; all calls to the operator are metered immediately she answers, irrespective of whether the call can or cannot be established. In addition, time and zone metering have been foreseen for the time when the exchange forms part of a full-automatic area.

In order to ensure proper service and quick testing of the exchange, special bays with routine test circuits have been equipped, enabling successive automatic testing of the various circuits (first line finders, links, registers, control circuits, finals, etc.) by depressing a key. In case of faults the routine test circuit remains on the particular circuit and gives the alarm. These routine test circuits are shown in thin lines on Fig. 2. In unattended hours, the alarms (urgent and non-urgent) are automatically transferred via a junction to the parent exchange, whence the maintenance man can be called if required.

The bays of this exchange are 3.6 m high and are mounted on three switchrack rows. The common motor drive for the exchange consists of one 380-volt A.C. motor and one 48-volt D.C. motor; the latter is automatically started if the mains supply fails.

The power plant consists of two 50-volt batteries, each having an initial capacity of 363 Ah, designed for a maximum charging current of 90 amperes. Space is available for doubling the initial battery capacity. Two dry rectifiers (each having an output of 40 amperes) are used for battery charging, the primary side being connected to 3 × 380-volt 50-cycle A.C. One battery is discharged while the other battery is charged by the two rectifiers in parallel. In addition each battery is trickle-charged during discharge, by a small rectifier having an output of 12 amperes at 50 volts; this rectifier takes care of the night load, thereby avoiding night-time calls for maintenance.

Figure 3 shows the general layout of the building. Figure 4 shows the exterior of the building which, as previously mentioned, is intended for 2 000 subscriber lines, but can be extended by making additions to the switchroom and battery room.



Apparatus used in the Laboratoires L.M.T., Paris, for demonstrating the properties of dielectric wave guides.

Facsimile Telegraphy

Some New Commercial Applications

By JOHN H. HACKENBERG, B.E.E.,

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THE many advantages inherent in the facsimile process for the transmission of intelligence have long been recognized and need not be repeated here. Even before the advent of the vacuum tube these qualities were appreciated, and facsimile methods were employed experimentally in the transmission of photographs as well as written matter. With the many improvements made possible by the vacuum tube, facsimile soon reached the stage where it could be employed commercially.

For a number of years, facsimile methods have been employed in specialized commercial applications. All the larger news gathering organizations in the United States, and many abroad, employ such systems for the transmission of news photographs. In recent years this device has played an increasingly important rôle in the newspaper business.

In spite of the rather general use of facsimile methods in news gathering and in other special applications, few systems have been offered as a public service. This has been due largely to the relatively high cost of the recording methods employed. Nearly all these systems employ some form of photographic recording. In addition to being costly, this type of recording, being a wet process method, is far too slow for most commercial telegraph purposes.

Several years ago, the Western Union Telegraph Company undertook the development of a facsimile recording medium which would be fast enough and cheap enough to overcome these important objections, and thus form the basis for the development of a facsimile system suitable for general telegraph use.

The first important result of this undertaking was the development of a dry coated paper which is capable of being marked by the passage of an electric current through it. The coated paper now in use is light grey in colour, and recording appears black, no processing of any kind being required either during or after recording. This paper, known as "Teledeltos," is sensitive only to electrical impulses, and is not affected by light or moisture in any greater degree than ordinary writing paper. It produces a clear cut and permanent record. It is extremely fast in action, and in this respect can be compared only to photographic film. Its current-density characteristic is such that fairly good half-tone reproduction may be obtained if desired without special circuit arrangements. The cost of this material is a fraction of that of photographic film. Recording equipment is extremely simple. The amplified facsimile tone signals may be applied directly to the paper by means of a stylus riding continuously on the surface of the paper.

While the development of recording media for high speed facsimile is being continued, this paper is sufficiently satisfactory to have warranted the development of apparatus employing it as the recording medium. The following systems have all been designed to utilize this new development, but are capable of being readily converted to use other recording media as they are perfected.

Facsimile is employed by the Western Union in two ways: first as an alternative method of handling regular telegraph business, and second, as a means for the reproduction at a distant point of material which cannot be handled in any other manner.

In the first case, regular telegraph rates are charged and the addressee may receive either a teleprinter or a facsimile process telegram, depending upon the transmission method employed in the final handling.

In the second case, special rates are charged and facsimile copies are delivered. In this case the rates are based upon the area of the material to be transmitted; and sketches, drawings, blue-prints, tabulations and hand-written material are accepted and delivered as such.

The greater part of the elapsed time, from the instant a customer decides to send a telegram until it is delivered to the addressee, is consumed in getting the telegram from the customer to the central office in the city of origin, and from the central office to the addressee in the city of destination. Obviously, any material reduction in this time not only results in faster service, but in more economical service, and eventually in greater volume of business.

Facsimile lends itself very readily to automatic operation, and so it is logical that, having a satisfactory recording medium, an early effort should be made to adapt facsimile to this important task. For this purpose, machines must

Fig. 1—Automatic Telegraph Transmitter, wall mounting model.

Fig. 2—Automatic Telegraph Transmitter, table model.

be as simple, economical, and as nearly automatic as possible.

One of the most interesting of Western Union's developments along these lines is a system designed simply for collecting telegrams and transmitting them to a central office. This system employs transmitters which in appearance and function may be compared with the familiar mail box. To file a telegram the customer or agent simply presses a button and inserts the telegram into a slot in the front of the machine. That is all that is required of him.

Two types of transmitter are now employed for this service, a wall mounting type and a table model. The table model may be equipped with a pedestal to convert it into a floor model.

These transmitters, known as Automatic Telegraph Transmitters, Types 22 and 122, may be installed in customers' offices, in hotel lobbies, in railway and omnibus terminals, in office buildings; in fact in any public place. They occupy as little space and are as simple to operate as vending machines. The wall mounting transmitter, Type 22, is about 30 in. high, 15 in. wide and 8 in. deep. The table model, Type 122, is about 24 in. high, 16 in. wide and 12 in. deep. Figures 1 and 2 are from photographs of these transmitters. Figures 3 and 4 show them with the covers removed. The transmitters are complete in themselves, and require only a pair of line wires, a ground and a source of 110-volt, 50–60 cycle, A.C. for their operation. This source must be synchronous with that at the central office.

Both types of machine may be equipped for either attended or unattended operation. Where a machine is to be installed in a customer's office, or where an agent is employed to operate it, the machine is equipped with a push button for starting. Where the machine is to be installed for unattended service in an office building, it is equipped with a lock switch, and charge account patrons in the building are supplied with keys. In the case of an unattended installation in a public place, a coin-slot starting mechanism may be employed. Special sending blanks provided for these machines prevent the customer from inserting the telegraph blank improperly.

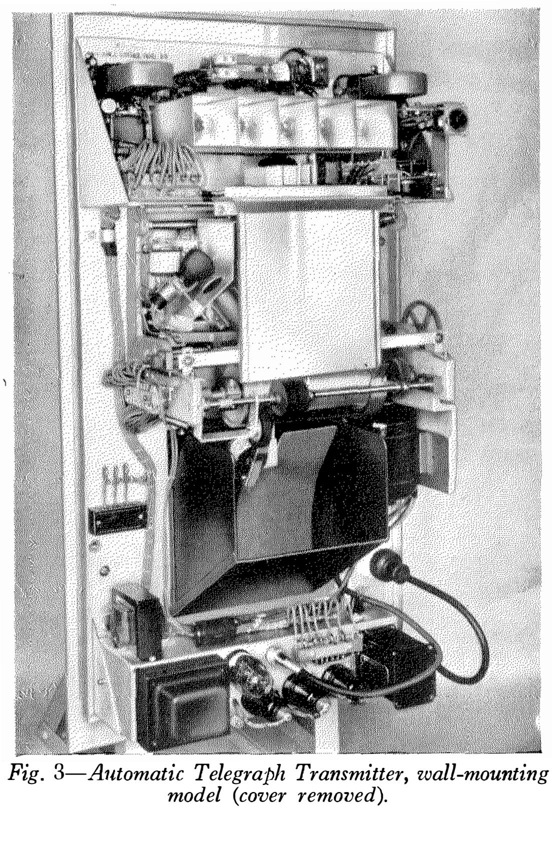


Fig. 3—Automatic Telegraph Transmitter, wall-mounting model (cover removed).

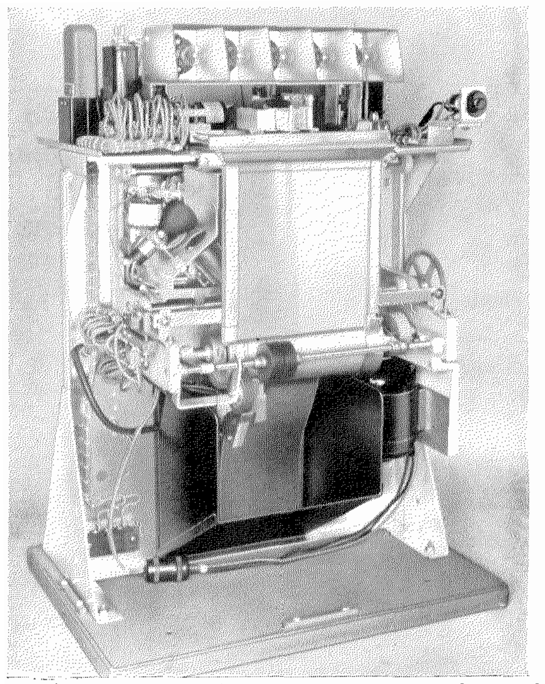


Fig. 4—Automatic Telegraph Transmitter, table model (cover removed).

To file a telegram in one of these transmitters, the customer, having written or typed the message on the blank provided, pushes the starting button or turns the key in the lock switch. A facsimile signal is generated immediately and is transmitted over the lines to the central office. A line amplifier at the central office registers the call and applies battery to one wire of the line pair which opens the chute at the transmitter and illuminates a panel telling the customer to deposit the telegram. As soon as the customer deposits the telegram in the chute, it closes automatically to prevent the insertion of another telegram before the first one has been transmitted. The message blank is automatically wrapped about a cylinder in the transmitter and is scanned by a photoelectric cell in the usual manner.

At the central office an operator picks up the call by plugging up a recorder to the circuit, adjusts the power level, records the message and causes the message blank to be removed from the drum of the transmitter and deposited into a receptacle in the bottom of the transmitter. A light in the transmitter illuminates a panel reading "Telegram Accepted," and the machine is then shut down by the central office operator to await the next telegram.

The transmitters have a number of interesting features. One is the provision for multipling a number of transmitters on the same pair of wires. Where the circuits carry a small volume of business, as many as four or five machines are operated on one pair of wires. This is accomplished by means of an interlocking relay arrangement in each transmitter.

When a call is placed by any transmitter on this circuit (by operating the push button or the lock switch), the answering signal received from the central office locks that transmitter in the operated position and locks all other transmitters on the same circuit in the unoperated position. An illuminated panel in each of the idle machines indicates that the line is busy.

Another interesting feature of these transmitters is that a complete test of the transmitter and the circuit to the central office is obtained upon starting the machine, and before it is possible to insert a telegram into the transmitter.

Circuits from Automatic Transmitters, Types 22 and 122, terminate at the central office in a Facsimile Receiving Concentrator, Type 161. This concentrator consists of a rack containing terminal equipment for ten lines, and two automatic facsimile recorders (see Fig. 5). Two such concentrators may be multipled together to form a 20-line 4-recorder receiving terminal. In this manner a few recorders are made to serve a large number of transmitters.

The recorders in this system, which are equipped with removable drums, are controlled by the central office operator by means of a rotary switch on the rack, which also controls the operation of the transmitters. Each recorder drum has wrapped about it a sheet of "Teledeltos." The paper is held on to the drum by

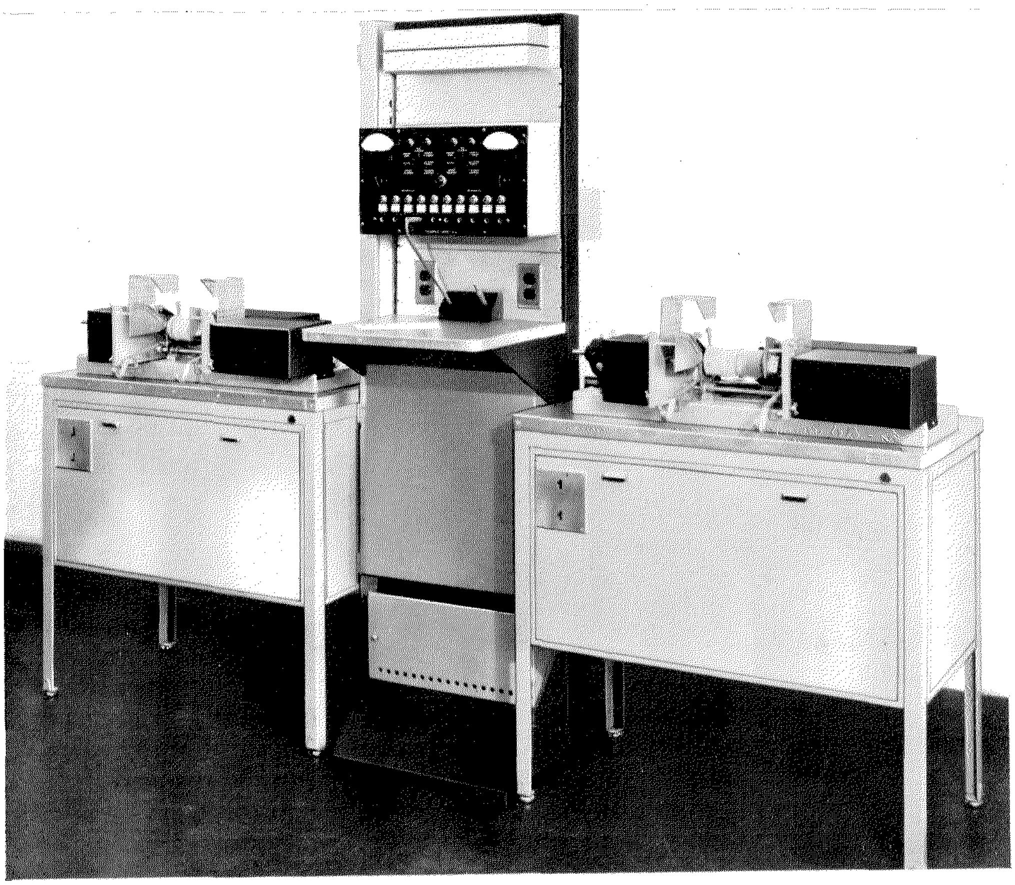


Fig. 5—Facsimile Receiving Concentrator.

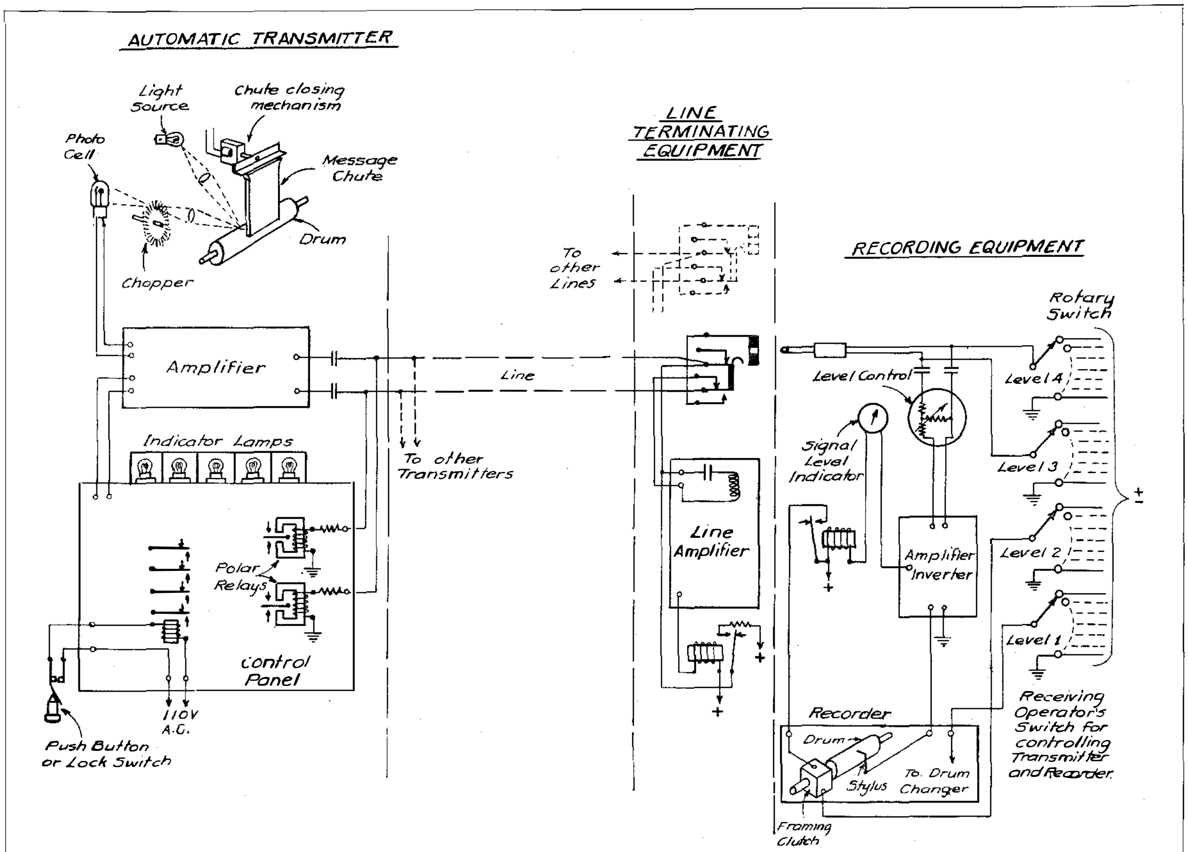


Fig. 6.

means of toroidal springs which roll along the drum as the recording progresses.

Upon receiving a call, which is indicated by an appropriate signal lamp in the turret on the rack, the central office operator connects an idle recorder to the circuit. By means of a pad and an associated meter, she adjusts the power level from the transmitter to the desired setting and starts to record. The recorder is equipped with a clutch which operates in response to an impulse generated from the special blank used at the transmitter. The recorder thus starts in frame with the *blank* on the drum of the transmitter.

After the message has been recorded, the operator at the central office ejects the drum from the recorder and another takes its place in the machine for the next message. With the rotary switch on the rack the central office operator controls all the functions of the transmitter, and shuts it down when the telegram has been recorded.

Figure 6 shows a schematic diagram of this system. The line pair is utilized to carry the tone signals from the transmitter to the recorder, and both wires of the pair are employed with ground return circuits for control of the transmitter. Three-position polar relays are used at the transmitter for control purposes. For the sake of simplicity and economy in construction of the transmitters, an inverted signal is transmitted over the line just as it is obtained by direct scanning of the original. This "negative" copy is converted into a "positive" at the central office by means of an inverter associated with the recorder there.

Another system, designed for pick-up and delivery of telegrams between a patron's office and a central office, has also been developed and placed in service. This system employs a Facsimile Transmitter-Recorder, Type 31, which is about the same size and shape as a teleprinter. This machine may be placed on a table or desk, or may be furnished complete

Fig. 7—Facsimile Transmitter-Recorder with pedestal.

with a pedestal. The machine is about 11 in. high, 16½ in. wide and 15½ in. deep, and weighs approximately 65 lb. Figures 7 and 8 are views of this machine.

The machine has three controls; a "Send-Receive" switch, a power control for adjusting the density of the recorded copy, and a starting switch. The horizontal drum extends outside the cover of the machine for loading purposes, and progresses along its axis while scanning until it is almost completely inside the cover when the entire blank has been scanned. These machines are designed primarily for use in patrons' offices or in other locations where direct wire service with a Western Union central office is desired; they require no special skill or training for their operation.

A telegram to be transmitted is wrapped by hand around the horizontal metal cylinder or drum of the machine in the manner indicated on the instruction card on the front of the machine. The "Send-Receive" switch is set to "Send" and the starting switch lever is moved to the right. Thereafter operation is entirely automatic. A call is registered at the central office in a Facsimile Concentrator, Type 152, which consists of a switching unit and a number of automatic recorders and manual transmitters. The number of transmitters and recorders employed is determined by the number of patrons' circuits and the amount of traffic handled by each. Figure 9 is from a photograph of a portion of one of these concentrators. The switching unit, one transmitter and one recorder are shown.

At the central office the switching unit, in which the patrons' lines terminate, automatically selects an idle recorder and connects the calling patron's circuit to that recorder. Recording commences immediately. If all recorders

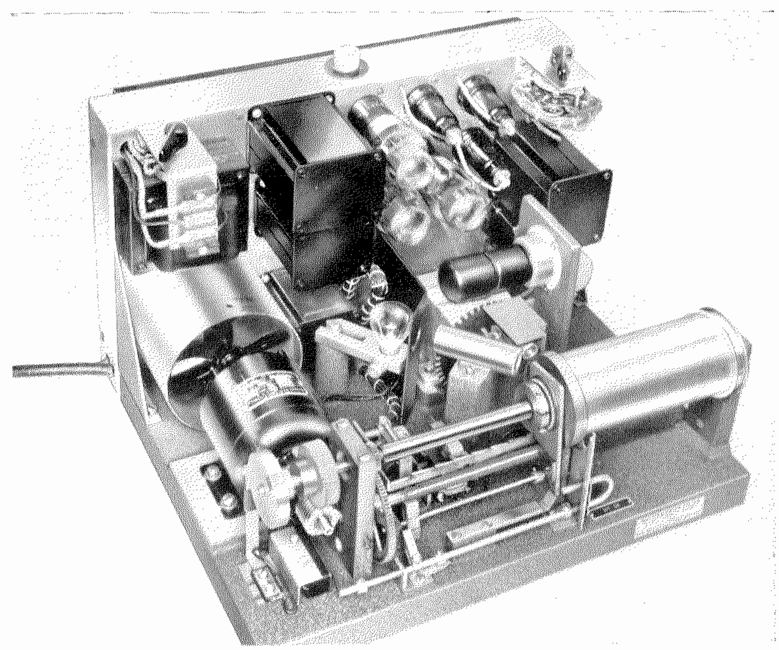


Fig. 8—Facsimile Transmitter-Recorder (cover removed).

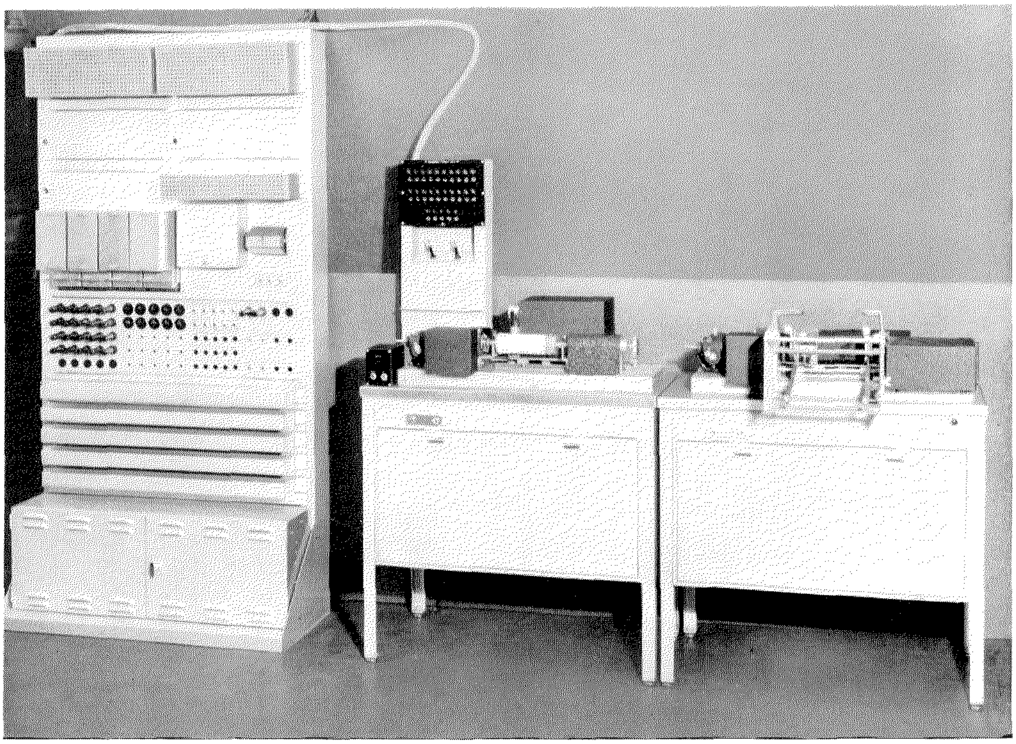


Fig. 9—Partial view of Facsimile Concentrator, showing switching unit, one transmitter and one recorder.

are busy, the call is held until a recorder becomes idle, at which time the circuit is automatically connected to the idle recorder. Recorders in this system are quite similar to those employed in the system previously described. As soon as the sending blank has been completely scanned, the transmitter shuts itself off and causes the drum to be ejected from the central office recorder. If the patron has written a short message and desires to send another immediately following it, he may stop the transmitter as soon as the message has progressed within the cover of the machine. If the "Send-Receive" switch has inadvertently been turned to the "Receive" position, a red signal lamp on top of the machine will light, and transmission will not begin until the machine is properly set.

The patrons' lines also terminate at the central office in a turret near the transmitters. To transmit a telegram from the central office to a patron, the operator at the central office places a drum with the telegram wrapped about it into a transmitter, and connects that transmitter with the patron's circuit at the turret. A call is set up in the customer's machine which causes a buzzer to sound, summoning the patron to his machine. Upon receipt of such a signal the patron wraps a receiving blank about the drum, sets the "Send-Receive" switch to "Receive," and moves the starting lever to the right. The drum begins to revolve and transmission from the central office starts automatically.

If the "Send-Receive" switch has been turned inadvertently to the wrong position, the red signal lamp will again light and recording will not begin until this switch is set properly.

As soon as the message has been completely recorded and the transmitter stopped, the red signal lamp on the patron's machine will light, and the machine may be stopped and the telegram removed. If the patron does not stop his machine, it will continue to scan until the entire blank has been scanned, when it will shut itself off automatically.

The patrons' machines are complete in them-

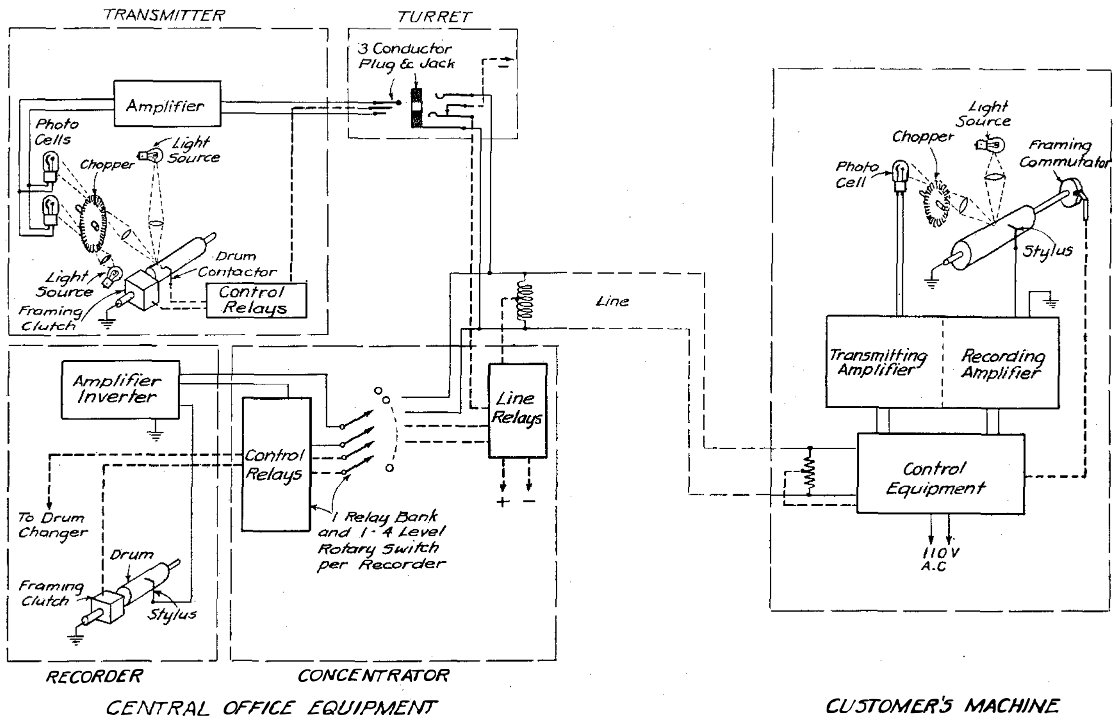


Fig. 10.

selves, and require only a pair of line wires, a ground and a source of 110-volt, 50-60 cycle alternating current. The source must be synchronous with that employed at the central office.

Figure 10 shows a schematic diagram of this system. For the sake of simplicity only one transmitter and one recorder at the central office, and one customer's machine are indicated. A simplexed line is employed in this system for control purposes.

Framing is accomplished by means of a commutator on the drum shaft of the customer's machine, and clutches on the central office transmitters and recorders, the patron always placing transmitting and recording blanks to a line scored lengthwise of the drum. In this system also a "negative" copy is transmitted over the line and converted into a "positive" at the central office.

Transmission from the central office to the patron is on a "positive" basis. This makes for simplicity and economy in construction of the patrons' machines.

A machine designed along these same lines for direct patron-to-patron working is known as Facsimile Transmitter-Recorder, Type 33. Two such machines operating over a line pair constitute a complete two-way communication channel. In external appearance this machine is identical with Transmitter-Recorder, Type 31, previously described, being the same size and shape.

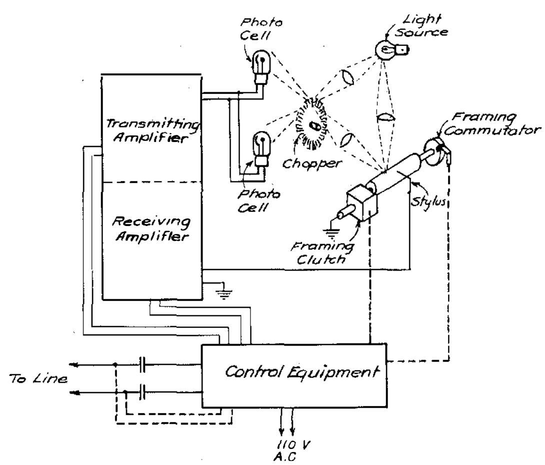


Fig. 11.

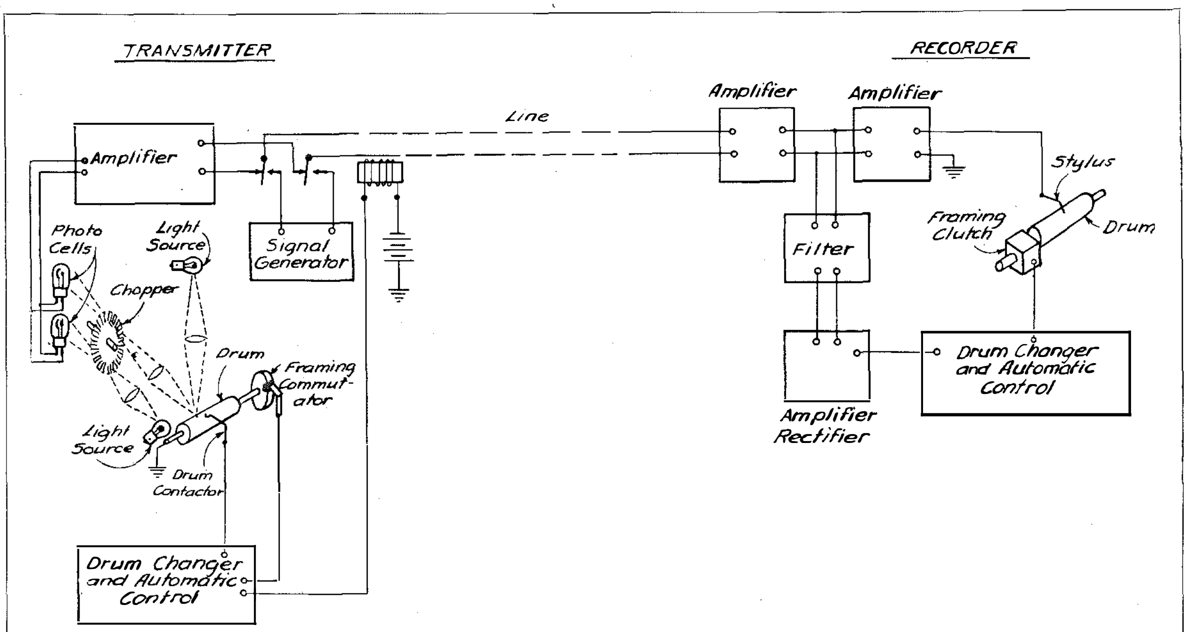


Fig. 12.

The same general construction is employed with the addition of a framing clutch, an inverter and a source of signalling battery. The Type 33 machine is also operated in much the same manner as the Type 31 machine, the same operations being performed in both sending and receiving a telegram.

Figure 11 is a schematic diagram of this machine. A balanced optical system is employed as an inverter, so that a "positive" copy is transmitted over the line. In this machine one line wire with ground return is used for control purposes in each direction, the tone circuits being taken off through condensers. Framing is accomplished by means of the commutator on the machine operating as the recorder, and the clutch on the machine operating as the transmitter.

These machines are particularly useful in large business organizations, between office and factory, salesroom and warehouse, main office and branch office, etc. In banking organizations, publishing houses, construction companies and many other types of business where information containing sketches, layouts, drawings, signatures, etc., must be transferred from one place to another, these machines perform a service of which other types of equipment are incapable.

Another type of equipment designed especially for use on long-distance trunk circuits is somewhat more elaborate than the equipment previously described. In order to conserve wire facilities on the longer circuits, it is generally customary to superimpose the facsimile circuit upon other circuits working on a grounded or metallic basis. In many instances the facsimile circuit is superimposed upon a carrier system providing a large number of metallic and grounded high speed telegraph channels.

In this case a different type of control is necessary between transmitter and recorder from that utilized on circuits where the facsimile system has exclusive use of the circuit. A second frequency supplied by an alternator or other signal generator, and within the frequency band employed for the facsimile transmission, is used for control purposes. This frequency is applied to the line at the end of each message and removed at the start of the next.

Automatic drum-changing type transmitters and recorders are employed in this system with racks holding as many as six drums in each machine. Telegrams to be transmitted are wrapped about these drums, positioned to a line scored lengthwise of the drum, and held in place on the drum by means of toroidal springs. The first drum is inserted into the machine by pressing a button which energizes relays and a motor driven cam system, causing a drum to be picked up and placed into the machine between centres.

Messages to be transmitted are punched just below the signature or last line of the message before placing them on the drums. A contactor riding on the surface of the message contacts the drum through this hole, and energizes the drum changing mechanism, causing that drum to be ejected from the machine and another to take its place. Operation continues automatic as long as loaded drums remain in the rack.

At the recorder the facsimile signals are amplified and applied directly to a stylus which rides on the surface of a drum loaded with a sheet of "Teledeltos." A filter tuned to the frequency of the alternator at the transmitter picks up that frequency at the end of each message. It is amplified and caused to energize relays which change drums at the recorder in the same manner as they are changed at the transmitter.

When the next message has been placed into the transmitter, the commutator on the transmitter causes the drum-changing frequency to be removed from the line, which in turn causes a clutch on the recorder to be engaged, thus framing the received copy.

Where the machines at the two ends of the circuit are not operated from electrically connected power systems, constant frequency forks are used to drive amplifiers supplying power to the driving motors. A schematic diagram of this trunk circuit equipment is given in Fig. 12.

Figure 13 is from a photograph taken in the operating room of the central office in New York City. It shows a section of the facsimile equipment employed on long-distance trunk circuits.

Material for transmission by Western Union facsimile is prepared on blanks 8 in. to $8\frac{1}{2}$ in.

Fig. 13—*Operating room in New York showing some of the facsimile equipment employed on long-distance trunk circuits.*

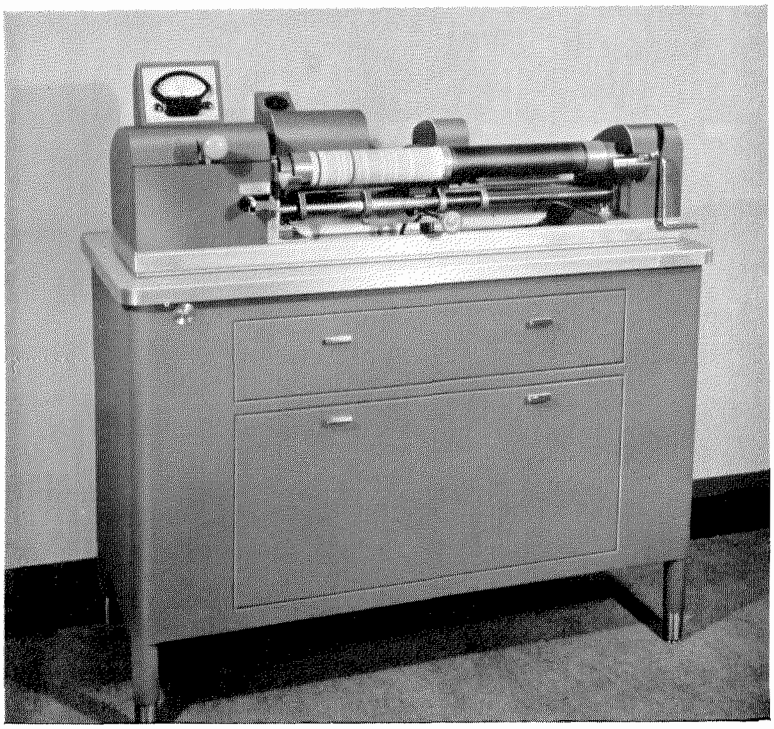


Fig. 14—Duplicator, employing facsimile transmitter and percussion type recorder mounted on the same carriage.

wide, and not longer than 13 in. With the maximum useful width thus fixed at approximately 7½ in. (allowing for margins) the day rate at present between New York and Chicago, and between New York and Buffalo, is 37½ cents per linear inch (7½ sq. in.) with a minimum of $1.50 for 4 linear inches (30 sq. in.). The night rate at present is 25 cents per linear inch, with a minimum of $1.50 for 6 linear inches (45 sq.in.). These rates are experimental and subject to change.

The drum speed of practically all Western Union facsimile equipment has been standardized at 180 r.p.m., with a scanning pitch of 100 lines per inch. Thus, 1.8 linear inches or about 14 sq. in. are scanned per minute.

Among other types of recording which have been employed is one which is useful in instances where a large number of copies of the received matter are desired. In this type of recording a mimeograph stencil, or a hectograph carbon over a sheet of white paper, is placed on the recording drum. An electromagnetic percussion unit, driven by the impulses from the transmitter, recreates the original as a mimeograph stencil or a hectograph master copy. Either type of received copy may then be used to produce a large number of copies. With this type of recording mechanism, a drum speed of 90 r.p.m. is generally used, scanning about 7 sq. in. per minute.

It often happens in the development of ideas that a by-product results which is a perfectly logical outgrowth of the original idea, but which was not visualized at the outset. Such a by-product of Western Union's facsimile development is the incorporation of a facsimile transmitter and a percussion type recorder into a business machine. This machine, known as Duplicator 3-A, provides a means whereby mimeograph stencils or hectograph master copies may be made of all manner of drawings, sketches, blue-prints, etc. From the stencil or hectograph master, a large number of copies may be made.

Figure 14 is from a photograph of this machine, which employs a facsimile transmitter and a percussion type recorder mounted on the same carriage. A double length drum is employed, the material to be reproduced being wrapped about the drum at one end, and the stencil or hectograph carbon at the other. As the optical system and photocell scan the copy on one half of the drum, the percussion unit reproduces it on the other half as a stencil or hectograph master copy.

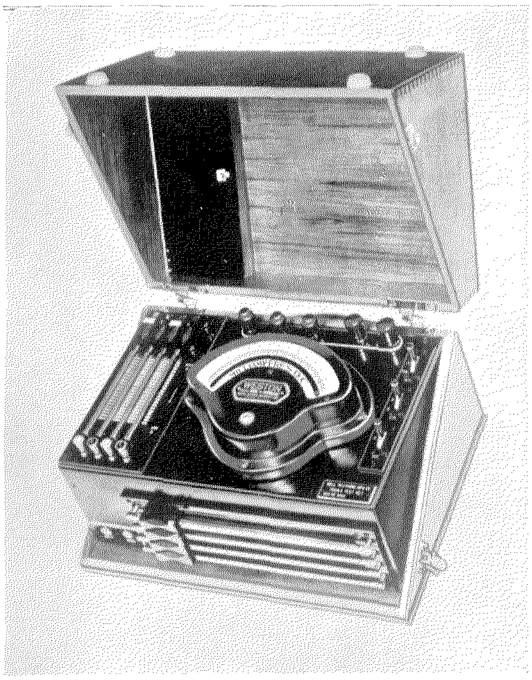
This machine is complete in itself, requiring only a source of 110-volt, 50-60 cycle alternating current for its operation. It is provided with a minimum of controls, and is accurately calibrated so that the same uniform results may be secured day after day.

Facsimile installations have been made and are now in operation in several of the larger cities of the U.S.A., and others are expected in the near future. Ease of operation, accuracy of transmission and economy are the factors which make this development promising for the future of the telegraph industry.

Recent Telecommunication Developments of Interest

Current Flow Relay Testing Set.—This portable instrument, developed by the Bell Telephone Manufacturing Company, Antwerp, provides means for quickly and accurately checking the operation of telephone relays in the field. It is primarily intended for testing relays in automatic and manual exchanges and P.A.B.X.'s.

The relay to be tested is connected to the test sets by flexible cords and clips. By means of rheostats, keys and a multi-range milliammeter, up to four different current conditions may be set up on the instrument. Any one of the four can then be applied to the relay under test by operating the appropriate push-button. Two of the push-buttons are provided with optional locking to permit the setting up of holding and release values. Relay operation is indicated audibly by a built-in buzzer connected to the relay contacts with an auxiliary cord.



Portable current flow relay testing set.

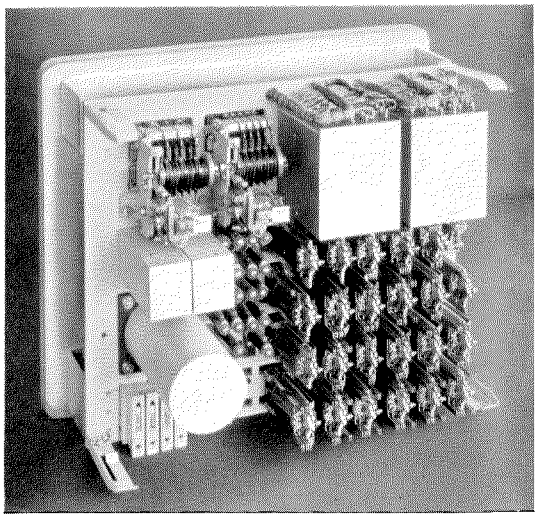
Features include: Duraluminium chassis; tropical, moisture-proof finish throughout; choice of four pre-set current conditions; coarse and fine rheostats for each of the four current conditions; reversing key for polarity tests; audible buzzer signal (for connection to relay contacts); special three-scale Weston milliammeter (0–30, 0–150, 0–750 mA); circuit breakers to protect each meter range; waxed teak carrying box (removable cover).

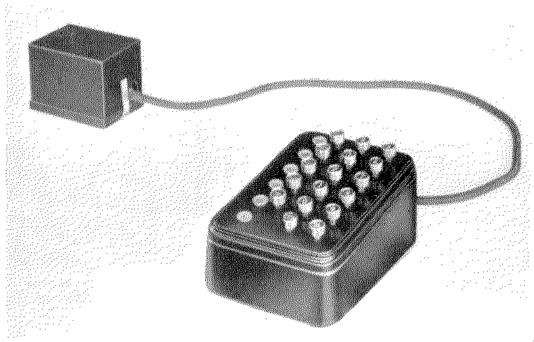
All normal service conditions, such as operation, holding, saturation and release, may be reproduced in any desired sequence with this test set.

• • •

Key Set Controlled Impulse Sender. — A new development in the field of P.A.B.X. equipment is the electrical key set controlled impulse sender recently produced by the Bell Telephone Manufacturing Company, Antwerp, whereby P.A.B.X. attendants can set up a number by means of a key box. This system is easier to manipulate and less liable to human error than that using a dial. At the same time, the solution of the problem in an electrical form has considerable advantages, both in manufacture and in operation, as compared with mechanical types of key sender.

The illustrations show the impulse sender,





(Left) : Key set controlled impulse sender with cover removed. (Above) : Type 2004-A key box associated with the impulse sender.

with cover removed, and the type 2004-A key box associated with it. The latter comprises ten number keys, five prefix keys with associated check lamps, a starting key for initiating the impulse train, and a cancelling key whereby a number partly or completely set up may be cancelled at any time during the calling process. A signal lamp is also provided which flashes as long as the impulse train is being sent out on the line. The type 2004-B key box is similar, except that it is not provided with prefix keys and their associated check lamps.

The key set controlled impulse sender thus forms a self-contained unit, and can be used to replace dial operation in conjunction with any type of P.A.B.X. connected to any type of loop dialling exchange. It will no doubt prove even more useful in the case of CB and LB manual switchboards or P.B.X.'s connected to automatic exchanges.

Erratum

Electrical Communication, Vol. 18, No. 1, July, 1939.

"A New Hard Valve Relaxation Oscillator":

Page 52, equation (4), first line, the last term should read :

$$+\frac{V_1R_3}{R_0}$$