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The Mackay Radio and Telegraph Company Communication System

By COMMANDER MILTON H. ANDERSON
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THE Mackay Radio and Telegraph Company is the successor of the radio communication business of the Federal Telegraph Company. Federal Telegraph commenced activities in California in 1909; it was organized by a group of Stanford University men who had secured the U. S. rights to the patents of Poulsen and Pedersen of Copenhagen, Denmark. Up to that time, the only practical method of radio communication had been by the use of damped waves generated by spark type equipment. Operation was confined largely to radio communication with ships at sea; the use of radio for point-to-point communications was very limited, largely because of the inability to cover reliably long distances, particularly in the daytime.

The Danish inventors had developed an arc type of high frequency generator which made possible the first successful method of communicating with sustained or undamped waves, giving the Federal Telegraph Company a definite advantage over others. It established commercial radio telegraph services interconnecting San Francisco, Los Angeles, San Diego, and Portland (Oregon) in 1911, and San Francisco and Honolulu in 1912, and competed for business with the existing cable and land line companies. Traffic growth necessitated expansion of facilities for the purpose of duplex operation, and the addition of transmitting and receiving equipment at San Francisco and Los Angeles to provide an increased number of communication channels.

The immediate success of the long distance circuit between San Francisco and Honolulu encouraged the United States Navy Department and the Federal Telegraph Company in 1912 to install a Federal arc transmitter at the naval radio station at Arlington, Virgina, as a result of which this station was able to communicate with the San Francisco and Honolulu stations during daylight hours, a feat never before accomplished. The success of these trials prompted the Navy Department to adopt the Federal arc system as standard for its services. In 1913, an extensive construction program was started, including a chain of high power naval radio stations for connecting Washington, D. C., with the Canal Zone, California, Hawaii, and the Phillippines. These ranged in power from 100–350 kw and were supplemented by a system of medium power equipments located at all important naval establishments on U. S. territory and on ships of the Fleet. The climax of this development was reached when the Navy Department built the large radio station near Bordeaux, France, during the World War, for which the Federal Telegraph Company supplied two transmitters of 1,000 kw each.

In 1914, the Federal Telegraph Company entered the marine radio field at San Francisco, enabling ships plying the Pacific to secure daylight communication over great distances. Activity in this field developed rapidly.

When the United States entered the War in 1917, Federal Telegraph's radio stations were taken over by the U. S. Navy, but Federal continued its domestic telegraph business by utilizing leased wire circuits. After the war, in 1921, the Company constructed a new communication system along the Pacific Coast with three complete duplex channels between San Francisco and Portland and three between San Francisco and Los Angeles.

Other cities were connected by local wires to this main radio trunk system, so that by 1923 the Federal network included offices in Seattle, Tacoma, Portland, San Francisco, Oakland, Los Angeles, and San Diego, with marine radio stations at Portland, San Francisco, and Los Angeles.

Service Efficiency

When the Federal Telegraph Company established its domestic rate schedules in 1911, it offered fifteen words at minimum rates instead of the customary ten. In 1926, the service was extended to include Day and Night Letters, permitting sixty words instead of the usual fifty at minimum rates. This rate schedule, modified to include serial messages on a similar basis, is still in effect over the domestic circuits of the Mackay Radio and Telegraph Company.

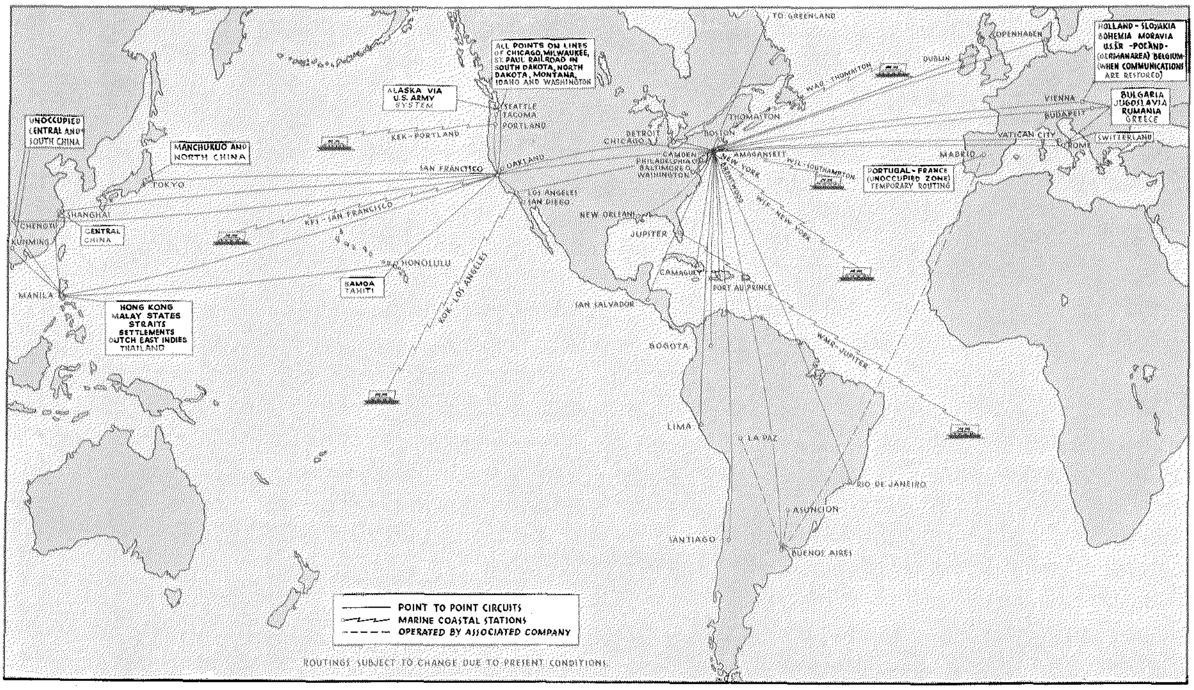
With rapid and dependable service, combined with substantially lower rates, earlier indications were confirmed that radio could meet the stringent requirements imposed on a commercial telegraph system. Public recognition of this fact was clearly demonstrated by the rapidly increasing business volume which, by 1927, was variously estimated as 40% of the total telegraph file involved in points served jointly by three domestic companies. This participation was the more remarkable when it is considered that the Federal Telegraph branch office coverage was less comprehensive than that of its competitors.

Acquisition by International Telephone and Telegraph Corporation and Subsequent Expansion

In 1928, the Federal Telegraph Company's system was acquired along with other properties by the International Telephone and Telegraph Corporation, the name having been changed to the Mackay Radio and Telegraph Company (California) during the year 1927. The change in ownership occurred at the time when high frequency vacuum tube transmitters were coming into use, resulting in reduction in the cost of establishing radio circuits. This enabled Mackay Radio to inaugurate an expansion program which enhanced its importance in the national and international fields.

Growth of the area served and increase in facilities were rapid. By agreement, the extensive terminal facilities of the Postal Telegraph System in the U. S. A. became available for the pick-up and delivery of Mackay Radio messages. The Mackay Radio and Telegraph Company of Delaware had been organized to care for expansion in the eastern part of the United States, as well as services to Europe and to South America, Central America, the West Indies and ships at sea.

During the years 1928–40, the Mackay Radio and Telegraph Company continued its existing services and inaugurated point-to-point radio telegraph services, as indicated in the accompanying map, through radio transmitting and receiving stations near New York, Washington (D. C.), New Orleans, Chicago, Seattle, San Francisco, Los Angeles, Honolulu, and Manila.



Circuits of Mackay Radio and Telegraph Company and Associated Companies.

It operates to the points shown in Europe, El Salvador, and Haiti through traffic agreements with Foreign Government Telegraph Administrations. Connecting stations in South America and Cuba are owned by subsidiary companies of the International Telephone and Telegraph Corporation. In the Orient, Mackay Radio has traffic agreements with the Chinese and Japanese Telegraph Administrations.

The area served through these main circuits is extended by local facilities in the United States, making a total of sixteen principal offices as follows:

New York, N. Y.	New Orleans, La.
Chicago, Ill.	San Francisco, Calif.
Washington, D. C.	Los Angeles, Calif.
Philadelphia, Pa.	Oakland, Calif.
Baltimore, Md.	San Diego, Calif.
Camden, N. J.	Seattle, Wash.
Boston, Mass.	Tacoma, Wash.
Detroit, Mich.	Portland, Ore.

The Atlantic and Pacific groups of offices are interconnected by radio trunk circuits between New York and San Francisco, New York and Los Angeles, and Chicago and San Francisco. This closely knit Domestic System serves main business and population centers and the contiguous districts, totaling over 800 communities.

The foreign cities shown on the map represent the respective points of connection with the national systems of the various countries so that messages may be sent on direct circuit to any point in the country controlling the foreign station. By agreement, messages also may be sent to certain foreign stations for points in other countries to be distributed on circuits operated locally from the connecting station. Thus through the network shown, messages may be filed with Mackay Radio for all points in the following countries:

Albania	Denmark	Lithuania
Argentina	Estonia	Norway
Bolivia	Finland	Paraguay
Brazil	Haiti	Peru
Bulgaria	Hawaii	Philippine Is.
Chile	Honduras	Portugal
China	Hungary	Rumania
Colombia	Japan	Salvador
Cuba	Jugoslavia	Spain
Czechoslovakia	Latvia	Sweden
		Vatican City

Mackay Radio, moreover, is in a position to accept messages to any country in the world. In the case of points not reached directly, they are turned over to Associated Companies, mainly All America Cables and Radio, Inc. and the Commercial Cable Company.

Ship-Shore Services

The third division of Mackay Radio Service—communication with ships at sea—is carried out by powerful coastal stations at Thomaston, Maine; Amagansett, Long Island; Jupiter, Florida; Clearwater, California; Palo Alto, California; and Hillsboro, Oregon. These stations are equipped to communicate with ships at sea wherever they may be. A coastal station at 67 Broad Street, New York City, serving ships in and near New York Harbor, is operated in conjunction with the Central Marine Routing Bureau.

A ship may hear the coastal station, but for adequate communications the station must also hear the ship. Due to many causes, technical and economic, ship radio equipment varies in power, effective range, and completeness. The range and efficiency of communication with any ship depends primarily on the power and efficiency of the ship radio equipment.

To insure adequate, standardized radio equipment for ships and thus increase their communication efficiency and safety at sea, Mackay Radio maintains a Marine Division through which ship owners and operators may secure modern ship radio equipment, either by direct purchase or through rental contract, properly installed and adjusted to obtain the maximum range of communication. In addition, Mackay Radio supplies radio direction finders and emergency installations for the ships and their lifeboats.

Mackay Radio's Marine Division also supplies a ship radio maintenance and operating service. It provides for maintenance of the entire ship radio equipment and supervision of the operation of the ship radio station in all its branches, including personnel and accounting.

To assist in accomplishing the above, Marine Division Service Stations, located at major seaports and manned by trained personnel, are available on call for the installation, repair and adjustment of radio equipment on ships to insure its functioning at high efficiency for both routine and emergency requirements.

War Repercussions

Because of the vital importance of communications in international relations, international communication systems immediately reflect the repercussions of war. This is particularly true of radio with its sole dependence on nationally contained terminals and its freedom from intermediate restriction.

Thus, changes involved in the present war in Europe affected the Mackay Radio System even before hostilities began. On August 25th, 1939, the connecting station in Prague ceased operation, and the German Administration subsequently arranged for the routing of messages to Bohemia-Moravia and Slovakia via Vienna. When Great Britain and France declared war, the cable route for traffic to Germany became inoperative, and all messages for Germany had to be transmitted via radio circuits. The first indication that Germany was invading Denmark came in the form of a service message from the Copenhagen Station which then ceased operations. Service was resumed within a few weeks.

On April 18th, 1940, Julienhaab, Greenland, cut off from Denmark, asked by radio for a Mackay Radio circuit for communication directly with the United States. When Holland, Belgium, and France were invaded, communication with these countries ceased. Subsequently, communication was re-established through stations in Germany or in other countries.

Italy entered the war June 11th, 1940, and on June 14th, a direct New York-Rome circuit via Mackay Radio commenced handling traffic after the normal cable route had become inoperative. As the attack on Great Britain developed, Eire, requiring direct facilities for communication with the United States, requested a Mackay Radio Circuit. One was inaugurated on July 4th, 1940, for handling Government traffic.

During active hostilities, international communications are suspended, and alternate routes avoiding transit through hostile or belligerent countries are sought. Under such circumstances, the situation may change with such rapidity that a detailed communication map may become obsolete before it can be completed.

Domestic and Foreign Traffic

The domestic, international, and marine communication facilities of Mackay Radio are available in the United States through the regular public telephone service. In cities served by Mackay Radio, messages can be telephoned directly; in other locations, messages are handled through Postal Telegraph Branch Offices, private teletypes, and other terminal services. In the case of messages sent through Postal it is necessary merely to indicate that Mackay Radio service is desired by using the Mackay Radio Green Blank, by writing "Via Mackay Radio" on a Postal blank, or by requesting, "Send via Mackay Radio."

Messages sent through the Postal Telegraph terminal system are passed to Mackay Radio operating centers where, by fast belt conveyors, they are carried to the appropriate circuit. Here an operator converts the written letters into the characters of the International Code, and transmits them automatically by radio for recording by automatic reception devices. After retranslation into the original messages, the latter are sent to the Postal terminal organization for local delivery or to a circuit for retransmission if addressed to a foreign country or to a ship at sea.

Partly to prevent interference from the multitude of electrical devices in a modern city, the radio transmitters and receivers used for distant communication are located away from the centers of business activity and population. For convenience and efficiency, on the other hand, it is desirable that the operating centers be located in business districts. These divergent requirements are met by the arrangements described below.

Operating centers are conveniently located in cities, and messages are transmitted to distant points by automatic control of the transmitters in the isolated transmitting stations. Control is exercised by two methods: one via wires, and the other via low-power radio equipment adjusted to operate in the ultra-high frequency band (140–170 megacycles). In the latter case, for example, the automatic sending machine in the operating center manipulates the low-power radio transmitter conveniently located nearby. The directed beam of this transmitter is received at the isolated transmitting station, amplified and used to control the high-power transmitter which sends a directed beam to the distant destination.

Conclusion

Mackay Radio, pioneer in the application of radio to domestic telegraph service, today continues its traditional policy of rendering up-to-date telegraph services in the following fields: Domestic, International, and Marine. Further, it supplies, installs, operates, and maintains marine radio and ship control equipment and, in addition, provides maintenance facilities at all important seaports. Thus, aided by the inherent flexibility, relative simplicity and economy of radio, Mackay Radio stands ever ready to adapt its services to the requirements of a changing world.

Illumination of Presidente Rivadavia (Moron) Airport (Province of Buenos Aires)

By PRIMITIVO B. PADILLA

Chief Engineer, Argentine Civil Aeronautics Authority

and

E. T. G. PALMER

Compañía Standard Electric Argentina, Buenos Aires, Argentina

THE rapidly growing use of air transportation in South America, especially to bridge the long gaps over comparatively wild country, and in the international service, has emphasized the necessity of providing adequate facilities for night flying. While heretofore only daylight schedules have been operated by the commercial air lines, there is increasing discussion of the necessity of introducing night flights to cut down the total time of the longer journeys, such as New York to Buenos Aires. Furthermore, some of the daytime hops are so long that weather influences sometimes have presented the problem of taking off or landing, either early in the morning or late in the afternoon, when the light conditions at airports were relatively those encountered where night schedules are maintained.

Travel by air is even a bigger time saver in South America than in the northern continent. This is due to various factors, including the relatively fewer and slower facilities for ground transportation, and the greater dependence upon water travel as the only alternative. Distance in terms of time is one of the most serious handicaps with which the peoples of South America have always been confronted in carrying on their normal commercial relations with other continents, as well as among themselves. Aviation is one of the various benefactions which modern science has contributed toward overcoming this definite disadvantage.

A significant step has recently been taken by the Argentine Civil Aeronautics Authority toward reducing air time-distances, thus not only speeding up the mail, passenger and parcel services, but paving the way to more extensive use of the sky routes, to say nothing of enhancing the safety factor through the installation of complete and thoroughly up-to-date lighting and field marker equipment at the Presidente Rivadavia Civil Airport in the town of Seis de Septiembre, a suburb of Buenos Aires.

This new equipment was provided and installed by the Compañía Standard Electric Argentina and was put into service on the 15th of March 1940. Together with existing illuminations, especially those that had been provided to avoid collision with certain small obstacles on or near the airdrome, and some other objects in neighboring territory, such as radio towers, it may be stated that the Presidente Rivadavia airport today has one of the world's most complete and up-to-date lighting systems, both because of the arrangement and the power of the apparatus.

At four points around the airport powerful projectors are grouped, each consisting of five separate 3-kW units which may be used to light the landing field regardless of wind direction. A "T" type illuminated wind direction indicator shows the pilot the most favorable direction of approach for landing. This is in the shape of an airplane mounted on a solid concrete base and illuminated by a series of white lights which have a combined power of 1,500 watts. To increase daytime visibility, it is painted with red and white diagonal stripes.

A powerful spherical revolving beacon operates from the top of a 30 meter steel tower and serves to guide approaching airplanes toward the airdrome. The horizontal beams thrown out by this beacon have a normal average range of more than 100 kilometers. The beacon also projects an oscillating vertical beam, exceptionally potent in penetrating clouds, its purpose being to orient approaching airplanes when a low ceiling prevails.

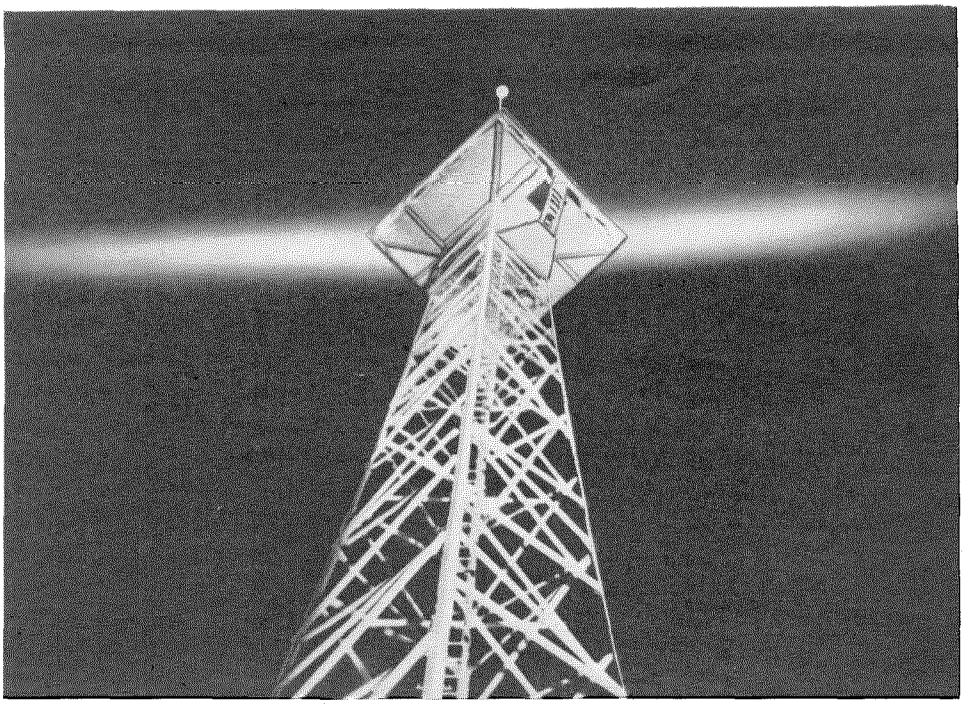
Night view of floodlight bank, showing Panair plane about to take off on Buenos Aires-Rio de Janeiro run.

To measure the altitude of the ceiling, a special projector throws a beam of light at a fixed angle against the clouds. An indicator equipped with a graduated quadrant registering the height of the ceiling functions in conjunction with the projector.

The landing field is outlined by amber colored prismatic globes mounted on metal cones, which are painted with red and white bands in a manner similar to the wind direction indicator, thus marking the field in the daytime. The globes are of the type recently approved by the Civil Aeronautics Authority of the United States; the Presidente Rivadavia field is the first in Latin America to be equipped with these lights which have exceptional penetrating power under conditions of poor visibility.

The general control board and control desk for the illumination installations are located in the Civil Aeronautics control station. This equipment serves to inform the control operator of the wind direction and velocity, also of the exact position at any moment of the "T" indicator. An illuminated indicator on the control desk designates the group of projectors that should be lighted in accordance with the wind direction. The key of the automatic projector control permits only the lighting of those projectors specified by the "T" indicator, and does not allow any other group of projectors to be lighted simultaneously. Accordingly, possibility of the pilot of an approaching plane attempting to make a landing opposite to the wind direction is eliminated. A map of the airport installed on the control desk indicates by means of lighted signals the points at which the projectors are illuminated. Further, individual keys on the control desk may be used to govern the illumination of each lighting unit.

An immediate practical benefit derived from this lighting system is that airplanes of the Pan American Airways, which make flights from



View of Beacon Tower, showing effect of main horizontal beams.

Buenos Aires to Rio de Janeiro via Asunción, Paraguay, can take off before dawn. This allows more time for reaching the Brazilian capital well before dark on days of poor visibility at destination.

The following gives a more detailed idea of the character of the installations at Buenos Aires:

Landing Projectors

Each of the four floodlight banks has a power of 15kW, divided equally among five lights. These are Crouse-Hinds projectors of the DCE-24 type, each unit being equipped with a 3 kW/32V incandescent lamp. The projectors are mounted over transformers which reduce the 380V power supply to the 32V required by the respective projectors. The pilot cables which connect the projectors with the control board also enter in the stand containing the transformers. At this point too, corresponding to each of the projectors, are individual switches that can be used to disconnect separately any one of the lights within the group. Four of the projectors in each group are equipped with a lens with a 30 degree spread, while the fifth light, occupying the center of the group, throws a beam with an 80 degree spread. Superimposed on the central projector of each group is a twin red prismatic obstacle light.

Revolving Beacon

The Presidente Rivadavia revolving beacon is of the Bartow type. It consists of a sectionalized glass sphere designed to emit four beams of light: two principal ones projected horizontally in opposite directions, and two secondary of lesser strength inclined at an angle of 12 degrees with the horizontal and visible at an angle of 90 degrees. A lens on the upper part of the globe throws a sharp oscillating beam inclined 10 degrees with respect to the vertical. As previously indicated, the purpose of this vertical beam is to identify the airport to pilots flying more or less directly over the field under conditions of poor visibility.

The range of visibility of the principal beam is approximately 120 kilometers in clear weather and 30 kilometers in fog or heavy clouds. The beacon has a 1000W/30V lamp and is equipped with a device for changing the lamp automatically in case the principal one should burn out.

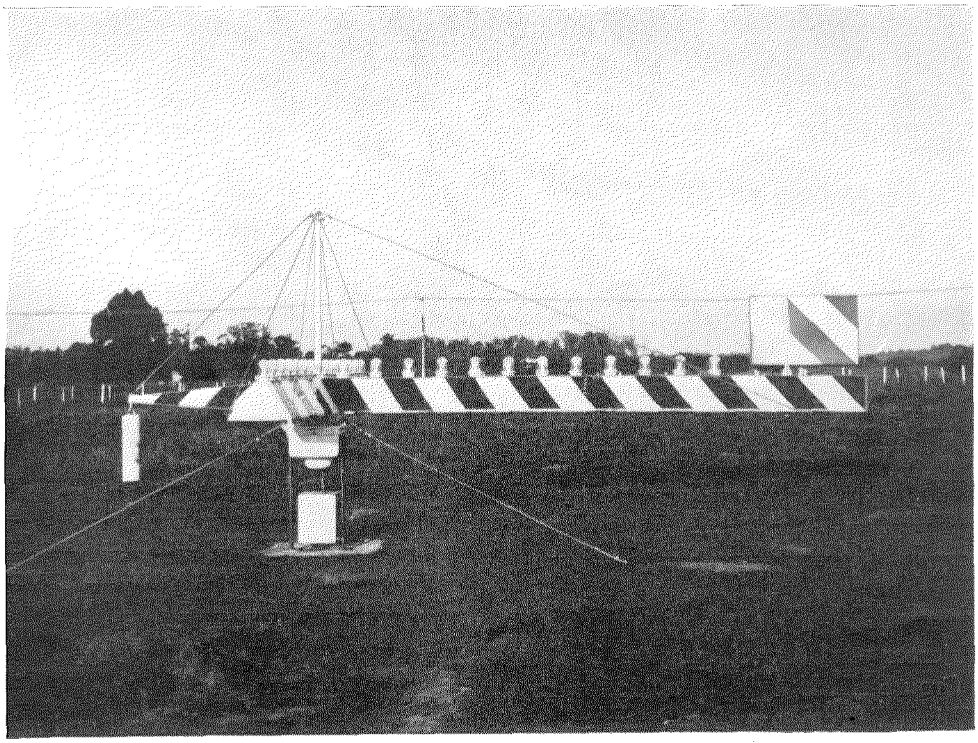
"T" Wind Direction Indicator

When illuminated, this indicator as seen from above has the form and general appearance of a grounded airplane. The red and white stripes serve to distinguish it from an airplane in the daytime, as the lights do at night. It is pivoted to move easily with the changing direction of the wind. In addition to serving as a guide to the approaching pilot, it transmits automatically to the control board at all times the direction in which the indicator is pointing, as well as which one of the four groups of projectors ought to be lighted.

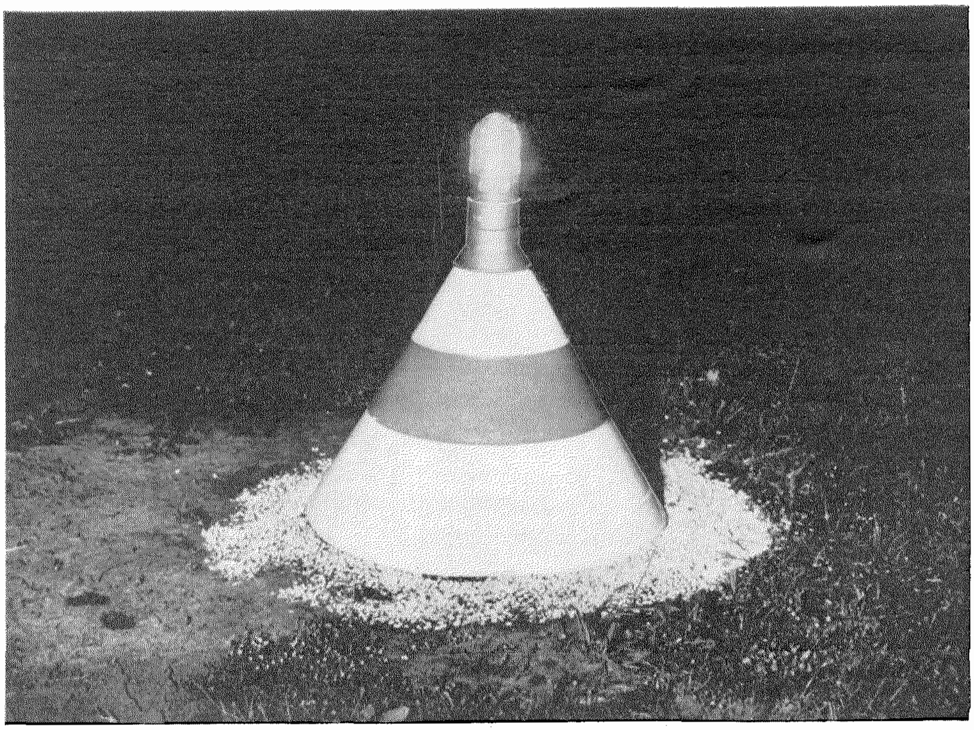
In the event of dead calm or a breeze too light to be effective, the "T" indicator is equipped for manipulation from the central control desk and is blocked in any predetermined position. Upon the wind attaining a velocity of over 5 km per hour, the blocking device is automatically released and the indicator follows the actual wind direction.

Field Marker Lights

For designating the limits and the shape of the landing field to the pilot, 48 Crouse-Hinds APB boundary lights outline the airport. Each boundary light consists of a prismatic globe which throws out an amber light with a very high coefficient of penetration that renders it plainly



Wind Direction Indicator.



Night view of Boundary Light.

visible even under conditions of minimum atmospheric transparency.

As a safeguard against possible interruption in the circuit feeding the boundary lights, in the event that one of them should be struck by an airplane, each light is plugged into a special socket set in the ground. This socket becomes disconnected in case the unit is upset and the circuit is closed automatically. The design of the unit is such that disconnection takes place without the likelihood of any serious damage to a plane which might collide with one of them.

Ceiling Measuring Projector

The projector used for this purpose is of the DCE-16 Crouse-Hinds type, provided with a 420W/12V lamp. It emits a beam at an angle of approximately 67 degrees to the horizontal, throwing a circle of light on a low ceiling. The gauge for measuring the height of the ceiling is situated at a distance of 150 meters from the projector and is fitted with a pointer which is directed to the circle of light projected on the ceiling. The height of the clouds above the landing field is determined by means of a quadrant graduated in meters.

General Control Board

This board is situated in the general control station at the airport, and is equipped with an automatic interrupter for each circuit involved. The automatic switches are all governed from the general control desk.

General Control Desk

The keys for the individual and manual control of all the illuminating equipment installed at the airport are mounted on a desk in the general control station. At the back of this desk are located the control instruments, i.e., voltmeter, ammeter, wind velocity indicator, wind direction indicator and the dial which shows the position in which the "T" indicator is pointed. Here also is located the automatic control for illuminating the landing floodlights. It functions in the following manner:

Corresponding with the position of the "T" wind direction indicator, a pilot light shows which of the four floodlight banks should be lighted. On the operation of the automatic switch which corresponds to the floodlights, the light is turned on in the particular group designated by the "T" indicator. It is then impossible to light any other of the three groups.

Any or all of the floodlight banks, nevertheless, may be lighted at will by the technical operator should it be desired for any reason, using the individual switches provided for that purpose. However, the control switch of the floodlight system must first be placed in the "normal" position. With this switch in the "automatic" position, it is impossible to illuminate any of the groups of projectors other than the one indicated by the "T" apparatus.

Installed on the right of the desk are the individual switches which control the projectors and "T" indicator, and also the boundary lights, revolving beacon, ceiling projector and obstacle lights. Spare switches are provided for future circuit additions. Each switch is equipped with its corresponding pilot lamp.

The map of the landing field installed in the desk to the left of the operator is equipped with a light corresponding with the location of each of the field illuminations. Simultaneously with the lighting of any one of these field illuminations, the corresponding lamp shows a light on the map.

Control Desk.

To the fore of the desk in front of the map are four lamp signals, each corresponding with one of the floodlight banks. These are illuminated automatically in accordance with the movement of the "T" indicator. The control desk is likewise equipped with facilities for connection with loudspeakers, alarm sirens, an internal telephone system or an outside telephone line.

A wattmeter, in the front of the desk, records graphically the hour-by-hour and day-by-day current consumption of the illuminating installation.

The cable plant for power distribution to the field illuminations comprises the following elements:

For main feeder ring and floodlight banks—3,950 meters 4×70 mm^2 armored underground cable, 1,000V type.

For boundary lighting circuit and reserve circuit in the revolving beacon—4,700 meters 4×16 mm^2 armored cable, 1,000V.

For feeding "T" indicator, ceiling projector, etc.—600 meters 3×6 mm^2 armored cable, 1,000V.

For pilot cables, obstacle lighting circuit, etc.—14,000 meters $2\times2\frac{1}{2}$ mm^2 armored cable, 1,000V.

A New Unit Type Multi-frequency 5 Kilowatt Transmitting Equipment

By DEVEREAUX MARTIN

Federal Telegraph Company, Newark, N. J.

Introduction

TRANSMITTING equipment designed for operation on a number of predetermined fixed frequencies has been available for some time. Frequency switching is accomplished by relays in radio frequency circuits, sometimes in conjunction with motor-driven tuning mechanisms. This conventional multi-frequency equipment, fundamentally, comprises a transmitter with a multiplicity of radio frequency circuits and a single complement of vacuum tubes.

This type of equipment has definite inherent limitations. It is complex, relatively costly, and quite inflexible in that only one frequency may be utilized at any one time. Unhappily also, for services requiring very few operating frequencies, it has been necessary to employ an elaborate equipment with capabilities not likely to be fully utilized.

Largely as a result of economies in the design and manufacture of modern power tubes, a new technique of multi-frequency transmitter design has been evolved, minimizing some of the objectionable features of earlier types and also providing greater flexibility, adaptability, and dependability as regards uninterrupted operation. Basically, the new unit design, applied both to electrical and mechanical features, consists of a series of individual units all operating from a common power supply, but each complete with respect to all stages, tuned circuits and tubes. The functional electrical design of this multi-frequency unit type equipment is shown schematically in Fig. 1; a typical arrangement of units is illustrated in Fig. 2. By increasing the rating of the power supply unit, simultaneous operation on more than one frequency channel with independent modulating or keying circuits becomes practicable. Such operation, obviously, requires individual antenna sys-

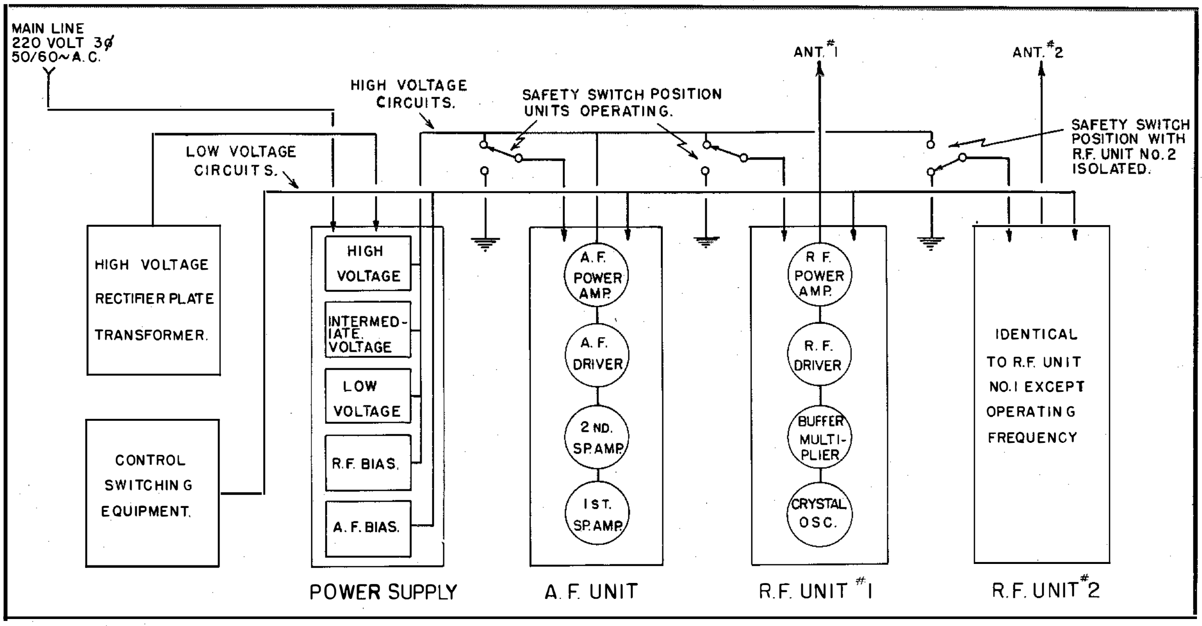


Fig. 1—Functional Schematic Diagram of 5 Kilowatt Unit Type Equipment.

tems permanently associated with individual channels.

Among other advantages, switching of radio frequency circuits is eliminated in the new design. Thus a frequently troublesome operation is obviated and a definite gain in dependability is achieved. (Frequency shifting, as explained under Electrical Design, is accomplished in the power circuits.) Moreover, the equipment, potentially, forms the nucleus of an expanding system, and is thus inherently economical. Further, since power, radio frequency and audio or modulating equipment are respectively sectionalized electrically and mechanically, com-

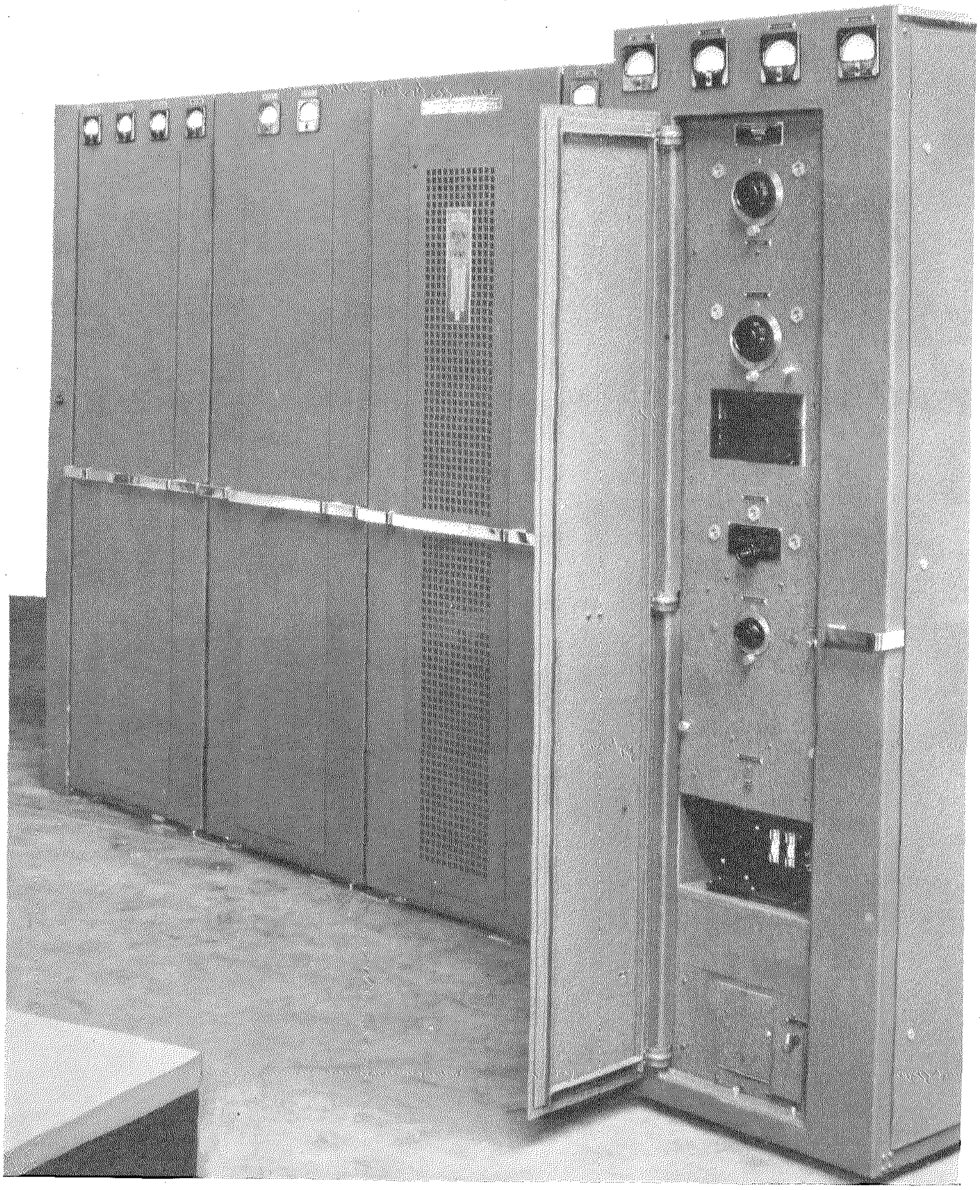


Fig. 2—Five Kilowatt Multi-Unit Equipment. R. F. Door Open.

binations more definitely meeting specific service requirements can readily be effected. In addition, simplicity in design of individual units makes possible manufacturing economies which in turn have resulted in prices lower than those of earlier types of design.

Units may be switched and operated independently of other units, and also may be isolated for adjustment or servicing, the latter without disturbing the operation of the system as a whole except in the case of the Power Supply Unit. Isolation of units is accomplished by a safety switch which simultaneously disconnects high voltage feeder cables and grounds the internal wiring.

Five kilowatt and three kilowatt designs, both incorporating essentially identical features, are available. This article describes the 5 kilowatt equipment, Type FT–500.

Electrical Design

As previously indicated, the new design was evolved from the concept of segregating transmitting equipment, both mechanically and electrically, into basic Power Supply, Radio Frequency, and Audio Frequency units. The Power Supply Unit is capable of delivering all plate and bias power to one or two Radio Frequency Units, each operating with 6 kilowatts power amplifier plate input, for simultaneous telegraph service. It is also arranged for supplying filament primary power to all units from auto-transformers which may be adjusted to suit prevailing line voltages. A single Radio Frequency Unit may be operated at the same input, in conjunction with an Audio Frequency Unit, for ICW telegraph or telephone service with 100% modulation capability.

The standardized Power Supply Unit is designed for a supply line rated at 200/220/240 volts, 50/60 cycles, 3 phase a-c. Protective features include a d-c high voltage rectifier overload relay, bias rectifier under-voltage relays, and transformer primary circuit fuses, as well as two thermally controlled switches. The latter respectively prevent internal cooling by the unit blower when the internal ambient temperature is less than 90°F, and the application of primary power when the internal ambient temperature exceeds 150°F. The high voltage rectifier plate supply transformer is arranged with primary circuits which may be Y or delta connected. The former permits operation at reduced voltage during tune-up and while making initial adjustments.

Each Radio Frequency Unit is a complete transmitter, less power supplies and audio equipment, for operation on a single fixed frequency in the range of 2.8 to 15 megacycles. Although any set of inductances can cover a band of frequencies, complete 2.8 to 15 megacycle frequency coverage in a single Radio Frequency Unit is not intended.

Power capability is based on an allowable maximum input of 6 kilowatts to a radio frequency power amplifier for either telegraph or telephone service. The output circuit may be adapted to loads from 60 to 600 ohms, either balanced or grounded.

There are only four radio frequency stages: a low power pentode oscillator, a beam pentode buffer stage which always functions either as a frequency doubler or tripler, a balanced power pentode penultimate stage, and a neutralized push-pull parallel power amplifier. Air cooled tubes are used throughout, and forced ventilation is used to prevent excessive temperature rise.

Provision is made for the adjustment of proper excitation to all stages and for the adjustment of balance in the loading of the power amplifier stage. Tuning controls for all stages except the oscillator, which is aperiodic, are located on the front panel.

Channel selection, or the operation of switching from one Radio Frequency Unit to another, a function comparable to frequency switching in equipment of earlier design, is accomplished entirely in the power circuits. The system is arranged so that primary voltage for slow-heating low power filaments and plate voltage are applied at all times except when a unit is isolated by means of its safety switch. The application of primary power to quick-heating filament circuits puts a Radio Frequency Unit in readiness for operation. Simultaneously with this switching, the disabling blocking bias is removed from the grids of low power stages so that only normal blocking bias appears at any grid. The unit is then ready to be keyed. During

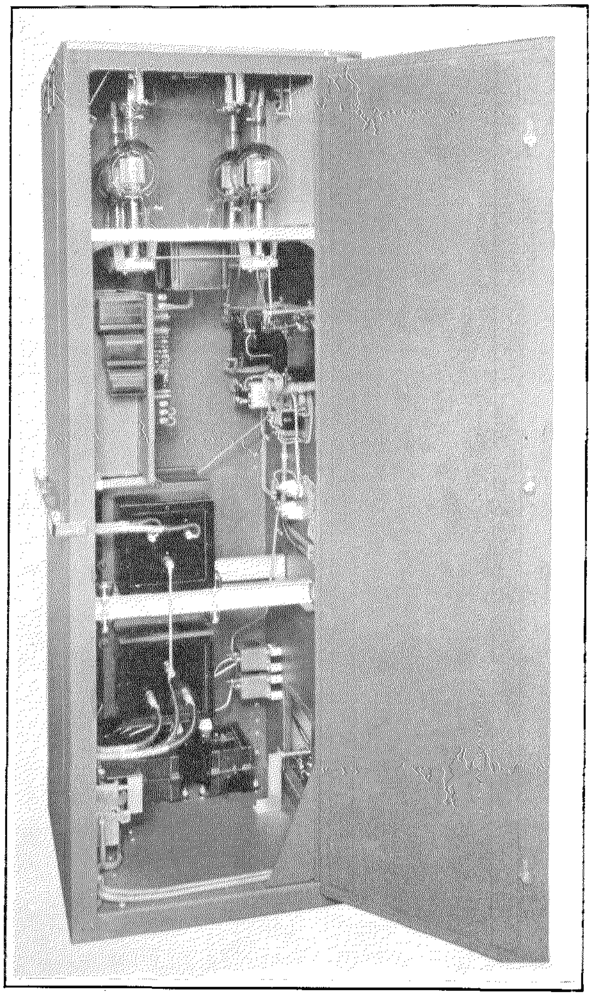


Fig. 3—Side View of Audio Frequency Unit.

channel selection no tube is permitted to draw plate current.

Keying is accomplished in the frequency multiplier buffer amplifier. For manual keying speeds, a form of bias keying is employed. When high speed keying is required, an electronic keyer is available for speeds up to approximately 300 words per minute. The oscillator-buffer compartment and circuits are so thoroughly filtered and shielded that there is no appreciable interference to local receivers due to idle radiation from the oscillator which is not keyed.

Radio Frequency Unit protective features include transformer primary circuit fuses, intermediate and high voltage plate circuit fuses, a power amplifier cathode circuit overload relay, and a channel control relay thermostat switch. The temperature controlled switch is normally closed but protects the equipment from possible damage due to excessive heating by making the unit inoperative when the internal ambient temperature exceeds 150°F. Protective devices are planned, generally, so that faults in individual units will not necessarily disable the entire equipment.

A single milliammeter, arranged for switching across shunts permanently wired in the d-c circuits which require metering, is adequate for normal adjustment and maintenance.

Audio Frequency Units are similar to Radio Frequency Units in the sense that they are electrically separate entities. Each Audio Frequency Unit functions as a high gain speech amplifier and audio power amplifier or modulator. The modulating audio amplifier equipment associated with the 5 kilowatt equipment is rather unique in that it actually comprises two complete and identical systems with input and output circuits connected, respectively, in parallel. This unusual design was adopted as a result of consideration of the power ratings of individual stages; it also has the advantage that either of the two parallel amplifier systems may be used singly for reduced power operation under emergency conditions. Distortion effects introduced by parallel operation are negligible compared with those produced by either system alone.

Each amplifier (Fig. 3) consists of two voltage amplifier stages, a power driver stage, and a class B audio power amplifier or modulator stage. All stages are balanced. An input signal level of −25 db (referred to a 6 milliwatt zero level) produces full output at 1,000 cycles. The input circuit is adapted to match a 500 ohm audio line. Overall frequency response is flat within 3 db from 300 to 4,000 *p : s* for commercial telephone service, and actual overall distortion at 1,000 *p : s* is less than ten percent at maximum output. Residual noise is approximately 40 db below full modulation level.

Protective devices incorporated in the Audio Frequency Units are practically identical to those of the Radio Frequency Units. In order to provide complete flexibility of control functions, audio channel control relays are used in a manner similar to those incorporated in the Radio Frequency Units. Keying or "push-totalk" switching in the Audio Units is accomplished by removing blocking bias from the driver stage grids. Inasmuch as remote control of switching functions is required in most multi-frequency applications, all switching is done electrically by means of relays. Local test switching, however, may be performed manually at the unit panels. The following may be electrically controlled:

In the Power Supply Unit—

A. Energizing all filament primary circuits;
B. De-energizing all filament primary circuits;
C. Applying plate primary voltage;
D. Removing plate primary voltage (by interlocking with function *B*).

In each Radio Frequency Unit—

E. Energizing the channel control relay;
F. Keying the radio frequency carrier power.

In each Audio Frequency Unit—

G. Energizing the channel control relay;
H. Keying the audio frequency channel.

No remote control equipment as such is incorporated in the equipment.

Mechanical Design

The equipment is also mechanically sectionalized so that the Radio Frequency Units, Audio Frequency Units, and Power Supply Unit, as well as the Central Cooling Unit, are individual assemblies, identical in size and similar in appearance (Fig. 2). Each unit in the 5 kilowatt equipment is 72 inches high, 22½ inches wide and 34 inches deep.

Individual units are mounted on ball bearing rollers which rest on metal floor plates, permitting ready withdrawal of any unit from an installation array. A vertical rear partition extends over the entire width of each of the group of units and is attached to the floor plates. The partition carries terminal blocks which facilitate interconnection of units and serve as terminals for the flexible cables connecting individual cabinets. A horizontal wiring trough accommodates rigid inter-unit wiring.

The partition and floor plates and, when required, the common air duct associated with the Central Cooling Unit, hereinafter described, are sectionalized so that the assembly may be expanded to accommodate additional units. End panels contribute towards an overall finished appearance. Units are removable for easy access to the constituent apparatus so that the complete equipment may be installed against a wall. Fig. 4 shows a typical partition, floor plate, common air duct and wiring trough assembly for an array of five units.

Incorporated in the system of floor plates are tripping devices actuating unit safety switches as soon as the cabinets are started forward.

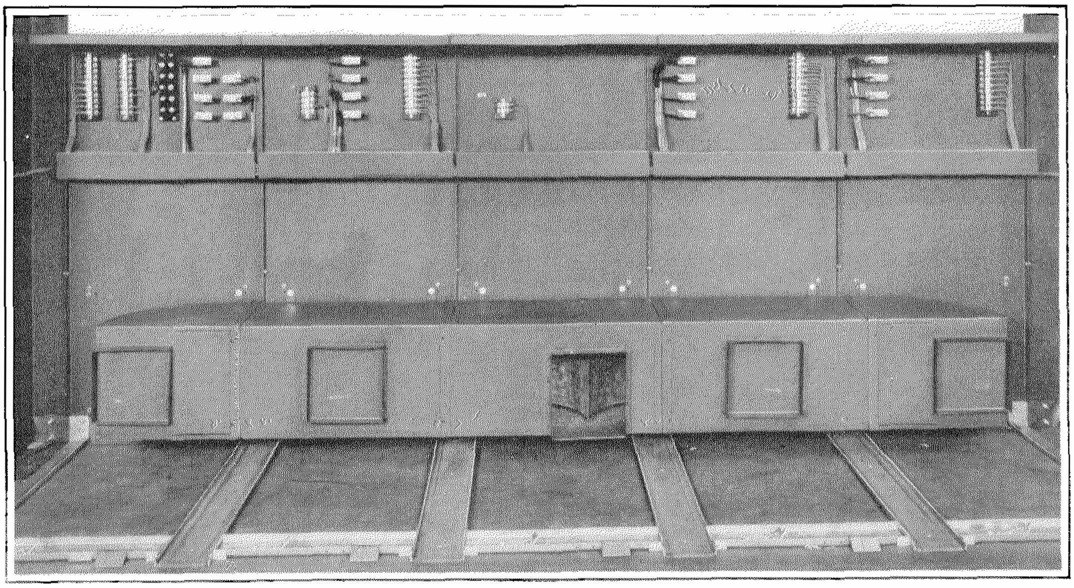


Fig. 4—View of Floor Plate, Rear Partition, Wiring Trough and Air Duct Assembly.

This switching arrangement disconnects feeder cables at voltages above 220 and grounds corresponding internal circuits. In their normal position safety switches may be operated at will, but when a unit is withdrawn it is necessary deliberately to release a catch in order to apply power to that unit.

In both Radio Frequency and Audio Frequency Units, high voltage plate circuit fuses are accessible through small doors integral with the switches. Accidental contact with high voltage is impossible since fuse access doors are mechanically interlocked with the safety switches so that the latter must be "Off" and the associated circuits must be grounded before the doors can be opened.

All high voltage cable terminals are arranged with protective covers, both internal and external to the cabinets, so that accidental contact is not a hazard to personnel.

When withdrawn, assemblies are prevented from unlimited forward extension by track latches. These may be released in order to remove a unit completely, but the flexible cables must first be disconnected.

The standardized equipment is designed for individual unit cooling by means of forced ventilation. A blower located at the lower rear of each cabinet forces air up through the assembly and exhausts it through a screen at the top. Air taken into the blower is cleaned by a replaceable spun glass filter. Individual blowers are arranged to operate only when channel selector relays are energized and the respective units selected are prepared to deliver power.

In some instances it is desirable to utilize a Central Cooling Unit rather than individual blowers. This Cooling Unit includes a heavy duty blower and a large air intake filter, and supplies cleansed air to all the units in the group through a common air duct.

In the Radio Frequency Units, the crystal oscillator and buffer-multiplier stages are assembled on a removable chassis resembling a drawer. Wiring to the chassis is completed through wiping spring contacts which engage when the chassis is in place.

The main or high voltage rectifier plate transformer is a separate unit, intended for installation in a vault or other location external to the main equipment. The transformer is housed in a perforated metal case approximately 27 inches long, 16 inches wide, and 27 inches high, and is air-cooled. "Knockouts" provide for placing necessary cable conduits, and mounting lugs on the base of the unit facilitate installation.

Eleven of these equipments have been supplied by the Federal Telegraph Company to the United Air Lines and are in operation at key points on its New York-Chicago-Pacific Coast and Seattle-San Diego Airways.

They were installed by United Air Lines to insure the best possible reception by planes in flight, since they are the maximum powered aeronautic voice transmitters permitted by the Federal Communications Commission for airline operation and higher powered than any previously used for this purpose in the United States.

What Is FM?

By WM. H. CAPEN *

Radio broadcasting in the United States of America is in the process of a major revolution, due to the development of a practical method of utilizing frequency modulation with ultra-high frequency radio waves in place of amplitude modulation with medium waves. The following article gives a brief history of the development of frequency modulation and explains the theory and technical characteristics of FM transmitters and receivers, as well as the practical applications and results.

Basic Theory

MOST engineers and many others scientifically inclined have a clear concept of the mechanism of amplitude modulation, both transmitting and receiving, as this is the method which has been universally employed since radio became a major factor in the industrial and social life of mankind.

The recently introduced frequency modulation method of radio transmission, now generally spoken of as FM, involves a new concept and may at first appear more difficult to visualize clearly. Basically, however, the mechanism of modulation and demodulation is not difficult to grasp.

Referring to Fig. 1, there is shown the unmodulated carrier and also the carrier as it appears after the amplitude modulation by an audio signal of lower frequency. This modulation results in an instantaneous change in amplitude of the carrier wave proportional to the magnitude of the signal wave at any instant. By the familiar process of detection at the receiver, the carrier is eliminated and the original signal wave with all its amplitude and frequency variations is again obtained.

Referring now to Fig. 2, again there is the unmodulated carrier, but the other wave is this same carrier frequency modulated. It will be observed that the amplitude of the carrier does not change but that its instantaneous frequency does. The mechanism for this accomplishment will be discussed later. In frequency modulation a mean carrier frequency is established, and by suitable circuits the amount by which the carrier frequency swings above and below this mean value is proportional to the amplitude of the signal frequency. The frequency at which the carrier varies, between the maximum and minimum values, is determined by the instantaneous frequency of the modulating signal.

For example, with a mean carrier frequency of 40 mc per second, assuming that the transmitter is arranged to allow a swing of 75 kc above and below the mean value for 100% modulation, then for a modulating signal of half the maximum (50% modulation) the carrier would vary by 37.5 kc either side of the 40 mc value or between 39.9625 mc and 40.0375 mc. If the frequency of the modulating signal is 2,000 cycles per second, then the carrier will swing between the above two values 2,000 times per second. If the signal amplitude remains the same but its frequency changes to 10,000 cycles per second, the carrier will swing between these same two values of carrier frequency but at the rate of 10,000 times per second.

How the original modulating signal is reconstructed from the transmitted frequency modulated carrier will be discussed later.

It may be of interest, before going into more technical details of transmitting and receiving circuits, to consider how frequency modulation came to be of such importance, apparently in a very short time, also the claimed advantages, its effect on broadcasting and its application to other services.

History

Frequency modulation is not new. The idea is basically old, patents having been taken out as far back as 1902. The early continuous wave Poulsen arc telegraph transmitters, in which the

* This article was prepared shortly before the Author's death. (An outline of Mr. Capen's career is given in Electrical Communication, Vol. 19, No. 3.)

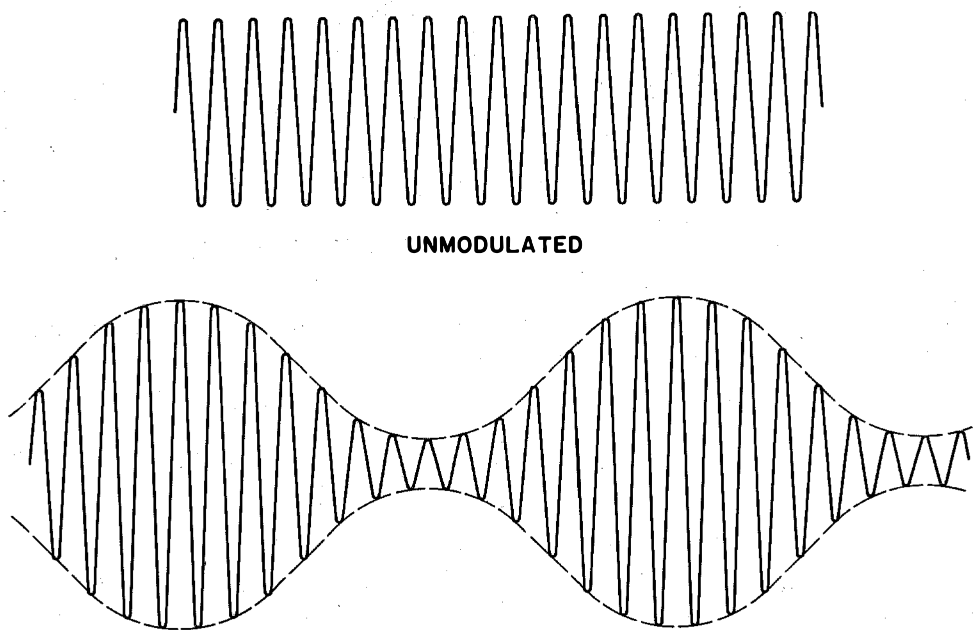


Fig. 1—Amplitude Modulation.

frequency was shifted from one value to another when keyed, was a frequency modulated transmitter. However, the general use of frequency modulation for radio telephony was abandoned after early considerations and unsuccessful experiments. The introduction of the vacuum tube made the use of amplitude modulation relatively simple so that the subject of frequency modulation was largely forgotten.

It was not until about 1920 that the matter again came to the front, and then largely with the thought of using it for the reduction of the frequency band needed for the transmission of a given amount of intelligence. Major Edwin H. Armstrong, who is primarily responsible for FM as it exists today, at that time made suggestions as to such a possibility.

With the advent of the vacuum tube amplifier, giving all necessary gain, the question of noise-to-signal ratio became a limiting factor to satisfactory transmission. At first it was thought to be a simple matter to eliminate static, but the nature of static was not understood at that time. As soon as it was realized that static disturbances cover the whole spectrum of the transmitted signal, it became evident that the many methods which had been suggested for eliminating static could not work.

Major Armstrong had suggested various static elimination schemes which it is now easy to see were not workable. Later on, he gave consideration to the type of modulation produced by static, and it developed that this was largely amplitude modulation. Major Armstrong's studies then led him to the idea of using FM for the signal on the theory that such a signal would be unaffected by the static disturbances which were of a different type of modulation. This, combined with the idea of a large frequency change in the modulated signal, produced the first feasible frequency modulated system. It was realized, however, that there must be close coordination between the transmitter and the receiver to make such a system feasible.

In addition to natural static, man-made static is a source of disturbance, i.e., the operation of electrical equipment, such as diathermy apparatus and automobile ignition systems. Disturbances of this nature are also eliminated or minimized by the use of FM.

Major Armstrong's conception, requiring a very wide radio frequency band (200 kc), prohibited the use of this system on medium waves for broadcasting purposes, inasmuch as the space required in the radio spectrum would be so large that the existing set-up of broadcasting stations would not permit it. For the development of such a system it therefore was necessary to go to the ultra-short wave band where the required spectrum space is available.

By the fall of 1935 Major Armstrong, who had already contributed the superheterodyne and super-regenerative circuits to the radio art, had developed frequency modulation to a point where he could demonstrate it before the Institute of Radio Engineers in New York. During this same year tests were made by him of reception by frequency modulation on ultra-short waves at a point some thirty miles or more from New York, including comparison during heavy static conditions with reception of the same program over medium waves with amplitude modulation. Although such tests were not considered completely convincing, due to the well-known fact that less static disturbance is encountered on ultra-short waves than on medium ones, the results did indicate the possibility of essentially static-free broadcast reception under conditions making reception from existing broadcasting facilities quite impossible.

Technical Advantages and Disadvantages

The technical advantages of frequency modulation broadcasting are: very low background noise; lower powered transmitters for a given primary coverage; the possibility of employing more stations for a given number of available frequency assignments, due to the characteristics

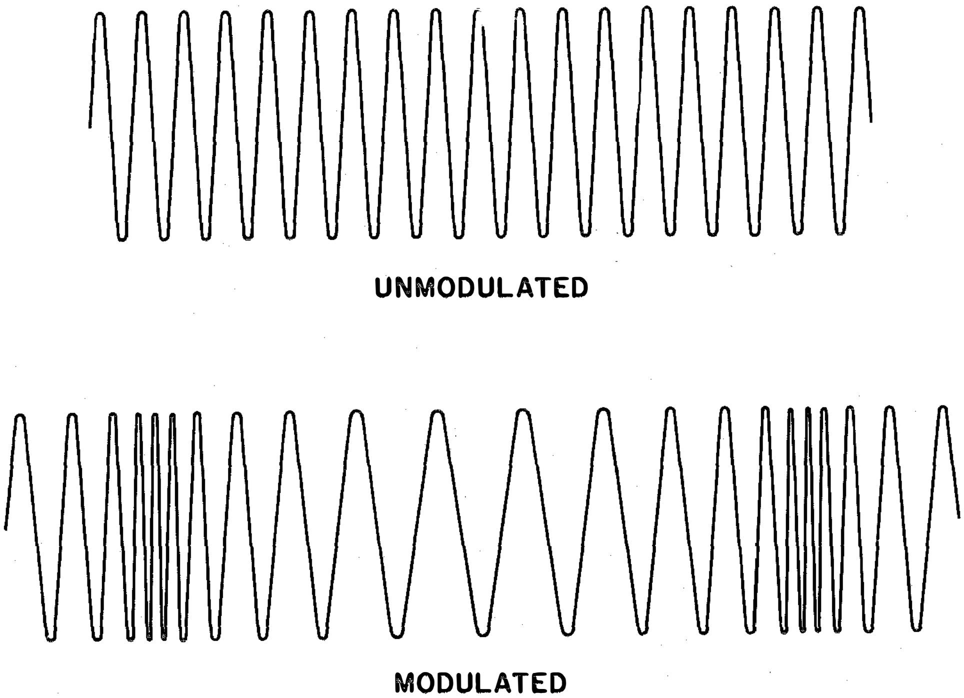


Fig. 2—Frequency Modulation.

of ultra-short wave propagation and of FM which eliminates interfering stations having signal strengths weaker than one-half the desired signal; and increased dynamic audio range. Furthermore, FM broadcasting, as adopted in the U.S.A., makes improved audio quality practicable due to the use of a wider band (30–15,000 cycles instead of 30–5,000 cycles). It should be emphasized, however, that bands equally wide could be transmitted either with amplitude modulation or with frequency modulation at the radio frequencies adopted for FM. In other words, the wide spacing assignments possible at ultra-high frequencies, and not FM, make the wide audio band a practicable proposition.

To offset these advantages, FM requires a wide radio band (some 200 kc instead of 10 kc as with existing amplitude modulation) with a consequent limiting of the available frequency assignments. To obtain the full advantage of FM, the receivers may be more expensive. Adopting FM means a major revolution in the present broadcast system and duplication of broadcasting services, at least for a considerable period of time.

Steps Toward Commercializing

Following the early demonstrations above referred to, Major Armstrong continued his researches and obtained the cooperation of a few who felt that FM would be a cure for many of the existing ills of broadcasting. Included among Major Armstrong's early supporters was the General Electric Company which, as a result of extensive tests, became convinced that his claims were sound and that, as compared with AM, greater primary coverage with essentially no interfering noises from natural or artificial causes could be obtained with FM.

After a considerable number of tests by Major Armstrong with an experimental 500 watt FM broadcast station located in Yonkers, New York, a 40 kw transmitter was installed by him at Alpine, New Jersey, on the high Palisades of the Hudson River some distance north of New York City. The coverage obtained with this transmitter, and the many demonstrations which were given, added further impetus to the commercialization of FM.

During this period, Mr. John Shepard, 3rd, President of the Yankee Network, whose headquarters are in Massachusetts, was convinced through the studies of Mr. Paul DeMar, the technical head of this network, that the prospects for FM were promising, and consequently installed a high power frequency transmitter (50 kw) on a mountain some forty-five miles west of Boston, Massachusetts. A frequency modulation system of lower power with directive antennas was used to transmit the programs from the Boston studio to the broadcast transmitter. After operation of this station for several months, sixteen hours a day, it was found that it gave better reception over the whole Yankee Network area than that given by the several AM transmitters in the same area. These excellent results over a wide coverage, obtained at times under the most severe static conditions, gave the broadcasting industry added confidence in FM, and some of the radio receiver manufacturers began to put out a limited number of FM receivers.

By this time the question of FM became the main topic of discussion in broadcast circles, and, although there were some who still were not convinced, the industry as a whole appeared anxious to adopt it.

F.C.C. Decision

Although the Federal Communications Commission had assigned channels for experimental FM broadcasting, the advocates of this type of broadcasting felt that more channels should be allotted. The F.C.C. therefore called a hearing for consideration of the matter, which was opened on March 18th, 1940. As a result of the data presented the F.C.C. announced, on May 19th, 1940, its favorable decision, and assigned for the exclusive use of FM broadcasting the radio frequencies between 42 and 50 mc, which are to provide forty channels, each 200 kc in width. Since this decision, rules and regulations have been put out by the F.C.C. and the date of January 1st, 1941 was set for full commercialization of frequency modulation broadcasting, placing it on a par with the existing broadcasting service on medium wave lengths.

Present Commercial Status

As a result of this decision, the radio industry is undergoing quite a commercial revolution, the

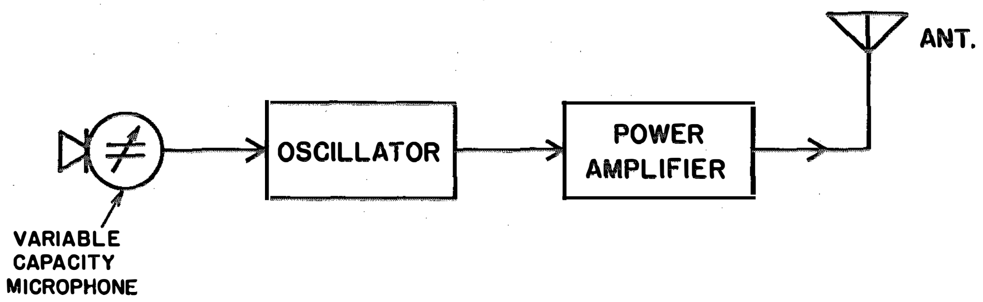


Fig. 3—Frequency Modulation By Condenser Microphone.

effects of which will be far reaching. A considerable number of FM transmitters are already in operation and many more applications are pending before the F.C.C. The major manufacturers of broadcasters are offering FM transmitters and most of the receiver manufacturers are preparing for or are now in production of FM receivers.

In order to adequately cover the country with high quality transmitters, consideration is being given to the building up of a network of FM links using relay stations.

This trend in broadcasting would appear to be a boon to the receiver manufacturers, as it will necessitate the manufacture of a higher quality, hence higher priced, radio set than the majority of sets recently sold. In fact, the very low prices of the majority of recent types of broadcast receivers, because of keen competition, have tended to depress quality and eliminate profit in the radio receiver business.

Although there has been much discussion regarding the desire of any large proportion of the public for high quality radio reception, a number of factors have convinced the FM advocates of a considerable potential demand. Aided by suitable publicity, it is their feeling that the inherent advantages of FM should make possible the maintenance of high quality in FM receivers as well as a reasonable price structure. Thus, the industry would be placed on a healthier foundation.

So far, the general public has only begun to be aware of the new method of broadcasting, and it of course remains to be seen whether its desire for the improved quality, made possible with FM, will manifest itself in the purchase of new sets.

Most manufacturers are putting out sets combining amplitude modulation with frequency modulation since it is not expected that the existing amplitude modulation (AM) transmitters will become obsolete in the near future. It is more likely that there will be a gradual shift to FM over a considerable number of years. It is further not expected that FM will completely replace AM because some sort of service, even though of inferior quality, can be given by high power medium wave AM transmitters over considerable distances, whereas FM is limited to a primary coverage area within a radius of 50 to 75 miles at most, except in a few unusual cases where the transmitting antenna can be located at an exceptionally high point. However, within this primary area, it should be emphasized that the service obtained from FM is practically noise free and of high audio quality which, in general, is not the case even in the so-called primary service area of high quality AM transmitters over the same distance.

Technical Considerations

The scope of this article does not permit a detailed consideration of the circuits involved, but the general fundamentals can be covered.

Referring to Fig. 3, the simplest form of a frequency modulated transmitter is shown. The transmitting oscillator as a part of its resonance circuit employs a condenser microphone. As the capacity of this microphone is varied by the speech or music sounds impinging on its diaphragm, the frequency of the transmitter oscillator changes accordingly. The radio carrier leaving the antenna will therefore have the characteristics of a frequency modulated carrier, as discussed previously.

Although such a scheme can be made to work after a fashion, there are a number of practical drawbacks. The circuit requires a condenser microphone which has many recognized limitations. Furthermore, it is important that the mean carrier frequency be very stable and that the excursions of the carrier to either side of the mean value be symmetrical. It is not possible to obtain satisfactory results with the simple circuit of Fig. 3.

In order to permit the use of any type of microphone, the circuit of Fig. 4 is used. Here the output of the speech amplifier is applied as a control grid bias of a vacuum tube so connected to the oscillator tuned circuit that the variations in the grid bias alter the effective inductance of the oscillator tuned circuit and hence causes its resonance frequency to change proportionately to the modulation amplitude.

In order, however, to insure that the mean or rest frequency of the oscillator remains constant, which is highly important, it is necessary to add a crystal control circuit which, briefly, operates so that the frequency of the oscillator, when not being modulated, is compared to the crystal controlled reference oscillator of somewhat different frequency from that of the mean carrier frequency. Through suitable circuits and rectification, the resulting d-c voltage is used as the normal bias of the control element of the modulator tube which is the element to which the audio modulation is fed, as referred to above. Any change, therefore, in the mean carrier frequency will cause a change in the normal bias of the control element of the modulator tube which, as previously stated, functions as a variable inductance in the oscillator resonance circuit; hence, the oscillator mean carrier frequency will be brought back to its correct value, provided the circuits are properly designed. This ingenious method was developed by the General Electric Company.

Major Armstrong prefers quite a different method which is shown in block schematic in Fig. 5. To thoroughly explain the operation of the circuit would take more space than is available here. However, the basic idea may be obtained by consideration of this schematic.

The output of a crystal oscillator of say 200 kc is amplified as shown and then the amplified 200 kc is multiplied in frequency by means of frequency doublers and triplers to the desired final frequency before it is amplified to the required final output power. This arrangement produces an unmodulated carrier in the antenna.

The audio frequency from the speech amplifier and a part of the output from the crystal controlled oscillator are combined in a balanced modulator of such design that it produces no output unless there is audio voltage from the speech amplifier. The output of the balanced modulator is then applied to a phase shifter which changes its phase 90°. This amplitude modulated wave which is 90° out of phase is then applied to the amplified unmodulated carrier as indicated. It may be shown that the combination of these two out-of-phase waves of the same frequency will produce a frequency modulated wave, the frequency of which is proportional to the amplitude of the modulating audio frequency.

At first glance, this system would appear to be more involved and require more apparatus than

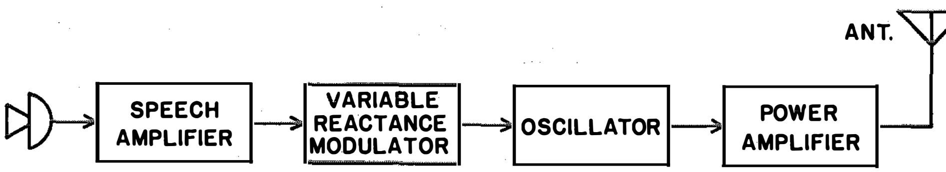


Fig. 4—Frequency Modulation Using Variable Reactance Modulation.

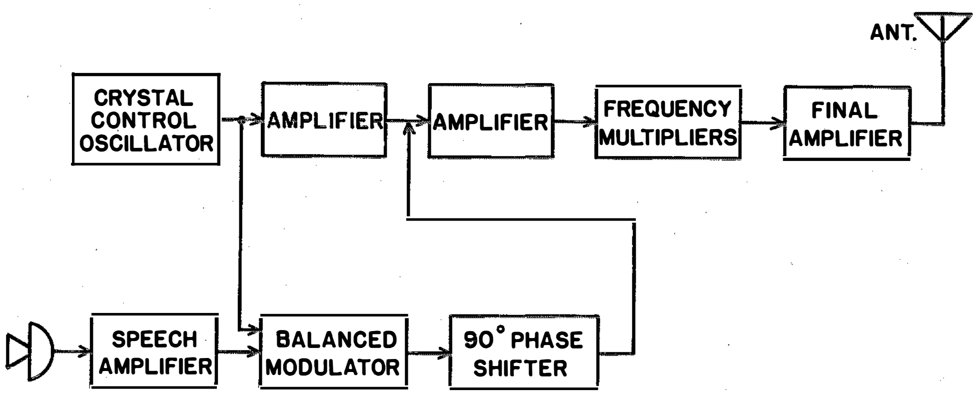


Fig. 5.—Armstrong Frequency Modulated Transmitter Using Phase Modulation.

the General Electric method. Both systems have their advocates. It should be noted, however, that all of the operations up to the final power amplifiers are accomplished with receiver type tubes, and in actual practice transmitters of this design have given most satisfactory results, both as to performance and ease of maintenance, and would not appear to involve an excessive amount of equipment.

A third method of frequency modulating a transmitter has been developed by the Western Electric Company, known as synchronized frequency modulation. This is shown in block schematic in Fig. 6.

In this case, the output of the speech amplifier frequency modulates the output of a tuned tube oscillator having a frequency in the neighborhood of 5,000 kc if the final carrier is 40 mc per second. The frequency modulated 5,000 kc is stepped up to the final frequency by means of frequency doublers. The stabilizing of the mean frequency is accomplished by means of a unique arrangement as follows:

A small amount of the modulated 5,000 kc frequency is reduced by frequency dividers to some value, say of 5,000 cycles, having variations of only a few cycles. This low frequency is then compared with the output of a precise crystal standard by means of a modulator which produces a rotating magnetic field whose speed and direction of rotation correspond exactly to the deviation of the frequency in both sense and amount. This rotating magnetic field is then applied to a small motor which drives a rotating tuning condenser of the 5,000 kc modulated oscillator and comes to rest when exact synchronism is attained. The variations due to frequency modulation are at too rapid a rate to cause more than slight oscillations of the rotating field and, because of the armature inertia, do not affect the motor. However, the slightest variation in the mean carrier frequency causes the armature to rotate and correct that frequency. Tests have shown that if the output frequency (40 mc) should vary for some reason as much as 400 kc from the assigned value, it would return to exact synchronism within a few seconds.

One other important consideration in the design of frequency modulated transmitters is the pre-emphasis of the high audio frequencies. All transmitters, irrespective of the method of modulation, employ a standardized amount of pre-emphasis of the higher audio frequencies, and all manufacturers of FM receivers employ a corresponding amount of de-emphasis.

The reason for this is that there is more static interference in the higher audio frequencies. With the wider audio range used in FM, such interference tends to be more disturbing. Even with the means to be explained later for reducing the effect of such disturbances, it was felt that the use of pre-emphasis was advisable since it is more effective in reducing disturbance when

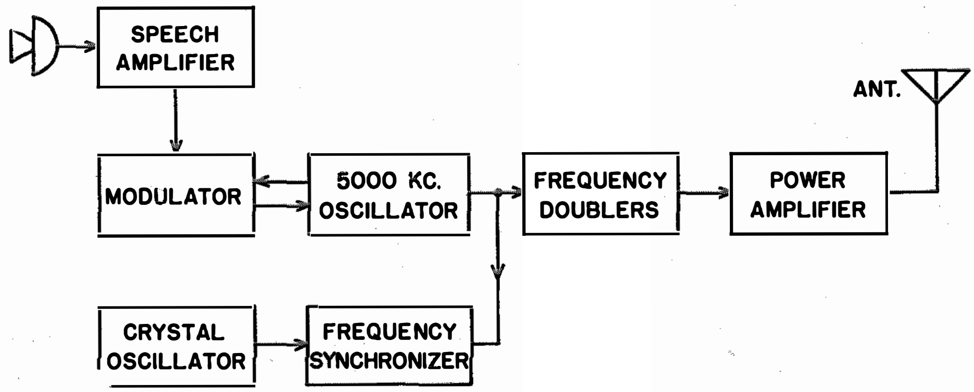


Fig. 6—Western Electric Synchronized Frequency Modulated Transmitter.

applied to FM than to AM. The precedent set in the first FM transmitters has become the accepted standard practice.

A frequency modulation receiver, although involving certain functions different from those of the amplitude modulation receiver, is not as complex a circuit as might be imagined.

Fig. 7 shows the block schematic of such a receiver. Except for the limiter, it is the same basically as the well known superheterodyne AM receiver. The incoming frequency modulated radio carrier, after being amplified in the radio frequency amplifier, is stepped down to an intermediate frequency by the usual superheterodyne method in the converter oscillator. However, due to the wide band width (200 kc), a much higher intermediate frequency must be used for FM than for AM. Instead of between 400 and 500 kc for the converter oscillator frequency, 2 mc or more is used. The intermediate amplifier must of course be designed to handle this high frequency with the wide band.

Up to this point the operation of the receiver differs in no way from that of the conventional AM receiver. The fact that the incoming wave is frequency modulated instead of amplitude modulated does not affect the heterodyne action, and the amplified intermediate frequency is also frequency modulated.

The next function, which is performed by the limiter, is unique for the FM receiver. The use of this limiter, or its equivalent, is perhaps the most important part of the FM system. The function of the limiter will be considered in more detail shortly, but, briefly, it limits or eliminates any unwanted amplitude modulations due to interference voltages, such as static, and permits only the frequency modulations to pass to the discriminator-detector. In an AM receiver, this discriminator-detector unit merely produces the original audio currents by detection of the intermediate modulated frequency. In the FM receiver, this unit must first convert the frequency modulations to amplitude modulations which are then detected as in the AM receiver. For this conversion various types of circuit arrangements are available.

In both receivers these audio currents are then amplified and fed to the loudspeaker. However, in the FM receiver, due to the much wider audio band available, the audio amplifier and loudspeaker system must be designed so that they are capable of handling this wider audio band or else the full advantages of the system will not be realized.

Returning now to the further discussion of the all important limiter of the FM receiver: Although giving a certain amount of additional amplification to the intermediate frequency, the tube used in the limiter stage is primarily an amplifier so biased that it overloads when the amplitude of the impressed wave exceeds a certain value. By the selection of a suitable tube and circuit, signals of comparatively small amplitude will cause plate-current cut-off on one-half of the cycle and plate-current saturation on the other half. In this way, the magnitudes of the plate-current variations in the limiter tube are strictly limited. However, this in no way limits the frequency changes in the intermediate frequency. If, however, the impressed intermediate frequency is of insufficient magnitude to cause the cut-off points to be reached, amplitude variations will pass through and the limiting effect is not obtained. This is the case where an incoming FM signal is weak, and is the reason why FM receivers must be designed to give adequate radio frequency and intermediate frequency amplification. Otherwise, the full benefits of FM as a means of reducing interfering noises will not be obtained.

Propagation Characteristics

Consideration will now be given to the propagation of ultra-high frequency waves of the frequencies used in FM.

As a result of many studies, both theoretical and experimental, it is generally conceded that ultra-high frequency radio waves have characteristics somewhat akin to light in that their propagation is more or less limited to optical paths, and objects having dimensions comparable to the wave-length may be expected to cause reflections and shadows. Such waves are therefore generally considered to give very weak fields below a point on the horizon not within the optical view of the transmitting antenna. Hence, the desirability of placing the transmitting antennas on high buildings or on the tops of hills so that maximum coverage may be obtained.

As a result of the bending effect due to the atmosphere and refraction of the waves around obstructions, the line of sight requirement is not strictly applicable. Satisfactory FM reception has been obtained immediately behind hills and at points well below the horizon. The noise eliminating characteristics of FM, as previously discussed, make satisfactory FM reception possible where under similar conditions AM reception would not be satisfactory. These points have been confirmed by many observations.

It has been found that radio frequencies in the 42 to 50 mc range are not generally reflected from any Kennelly-Heaviside layers, and therefore the transmission of radio waves of these frequencies is quite strictly limited. This fact, combined with the characteristic of FM that no interference between two stations will occur if the desired signal is twice as strong (6 db) as the undesired signal, makes possible the interference free so-called primary coverage area.

There are, nevertheless, occasional reports of reception of these wave-lengths at considerable distances due to the effects of the troposphere. For instance, there are reports of reception of Major Armstrong's Alpine Station in Washington, D. C., a distance of some 250 miles. However, it seems probable that the effect of such sporadic transmissions will cause slight difficulty in practice because of the discriminating characteristic of FM in favor of the stronger signal.

Tests have shown that where two FM transmitters are operating at the same frequency and within a short distance of each other (15 or 20 miles), the zone where neither station can be satisfactorily heard because the signals are less than 6 db apart in intensity covers a very narrow area, perhaps two or three miles. Outside of this area the stronger station completely dominates the reception.

Tests have further shown that, if two FM

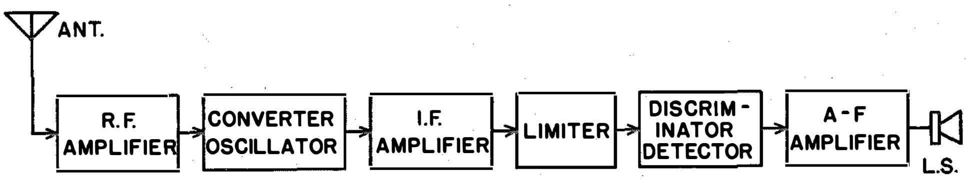


Fig. 7—Frequency Modulation Receiver.

transmitters are separated not more than 200 kc in mean frequency, the distant station, if its signal strength is sufficient to operate the limiter of the FM receiver, can be received even under the antenna of the other station without interference from the nearer station.

Practically, all of this means that, with a suitable high transmitting antenna (700 or 800 ft.), an FM transmitter will give greatly superior reception over a greater primary area than an AM transmitter of medium wave-length and of much greater maximum output power. It should be remembered that the FM transmitter is always operated at its peak power, whereas an AM transmitter has a non-modulated carrier of about one-fourth the peak power to permit the transmitter to handle the 100% amplitude modulated peaks. An FM transmitter is, therefore, inherently cheaper than an AM transmitter of equivalent rating. There is growing evidence that a 1 kw FM transmitter with a suitable antenna will give better service than a medium wave AM transmitter of many times its power over a primary area of considerable extent.

Transmitting Antennas

The transmitting antennas used for ultra-high frequency broadcasting should be designed to send out nearly uniform radiation in all directions. It is customary generally to radiate as nearly as possible in a horizontal plane in order to confine the transmission of energy to useful directions. Antenna systems have been developed, especially by the International Telephone and Radio Manufacturing Corporation (formerly the International Telephone Development Company), accomplishing this result with a high degree of efficiency.

Receiving Antennas

Naturally, the quality of reception from FM depends not only on the type of FM receiver but also on the antenna. Generally, the higher the receiving antenna the better, although with these very short waves dead spots must be guarded against. Losses in the transmission line also must be considered.

Although in some cases relatively near to a transmitter the type of antenna is not of great importance, a simple dipole horizontal or vertical antenna is preferable. The horizontal dipole is directional and it must, therefore, be placed at right angles to the direction of the incoming wave for maximum signals. A vertical dipole is non-directional but is generally considered to be more subject to ignition interference from automobiles.

FM Application to Other Services

The above discussion has centered primarily around the use of FM for broadcasting services since this is the application on which the greatest effort has so far been expended. However, FM also may offer advantages for other services, such as police, aviation, military and facsimile, and considerable attention is now being given to its adaptation to these fields.

The State of Connecticut has placed an order for some ten fixed FM stations and a large number of mobile receivers and transmitters for police cars to give complete two-way telephone communication throughout the State. This installation was decided upon after thorough investigation and tests of FM for this service. Other police departments, such as that of the City of Chicago, are also studying the application of FM to their services.

Aviation and military services have also expressed interest in the application of FM and are now studying the possibilities.

The Finch Laboratories have adopted FM for their facsimile service and in tests of mobile facsimile transmission have used an FM link. Also, they are regularly broadcasting facsimile from their New York FM transmitter in which they transmit the facsimile simultaneously with the audio broadcast by a multiplexing scheme.

For these services a narrower carrier swing has proved adequate (±15 kc). The audio band used for telephony is in the neighborhood of 3,000 cycles. This narrower band, while satisfactory for such services, is not sufficient to give the high quality reception desired for broadcasting.

Conclusion

It has been possible to cover only briefly the main points of this development. Many details necessarily were omitted. So far as the United States of America is concerned, there seems to be little doubt that FM will be one of the major factors determining the trend of radio broadcasting in the next few years; and, in view of the considerable amount of opposition and skepticism that has been and still is shown with regard to its application, its present rapid development would appear to support the old adage that "nothing succeeds like success."

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Continuous Wave Interference with Television Reception*

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INTERFERENCE with television reception can be very severe due to the large band width employed for this service, and is a much more serious problem than interference with sound broadcasting. Fortunately, however, both have much in common in the methods which can be used to effect suppression.

Interference may be divided into two main categories, damped wave or impulsive type interference and continuous wave interference. The former is caused mainly by radiation from the ignition systems of motor vehicles, sparking in electrical machinery and appliances and from harmonics of spark type transmitters on certain ships. Thermal agitation, noise in circuits and Schott noise in tubes also produce interference of this type within television receivers. The latter type of interference is caused by radiation from short-wave radio or television receivers of the superheterodyne type, medical diathermy apparatus used in hospitals, and harmonics from powerful broadcast and amateur transmitters. Continuous wave interference patterns may also be produced within television receivers, quite apart from any outside sources, due to unwanted couplings between certain circuits causing harmonics of the sound or vision intermediate frequencies to react with the incoming signal,[1] or due to hum voltages derived from the power-supply frequency and its harmonics, or voltages derived from the harmonics of the scanning frequencies, being injected into the receiver picture amplifier.

Fig. 1—Typical Example of Continuous Wave Interference.

Methods of Reducing Interference

Interference-free reception of sound or television can only be effected if it is possible to locate an aerial in a position where the signal-interference ratio is sufficiently large and where the signal strength is sufficiently strong to swamp the effects of losses in the transmission line and interference encountered in the receiver itself; then, providing the receiver is well screened and the power supply adequately filtered, the receiver will reproduce the signal-interference ratio present in the aerial in the frequency pass band of the receiver. If the signal-interference ratio at the aerial is not sufficiently good, then advantage may be taken of the directional and polarizing properties of aerials and an aerial employed which receives waves coming only from the effective direction of the transmitter and with the desired angle of polarization.

Beyond this, the signal interference ratio cannot be improved without reduction of picture quality, by reduction of band width or the use of interference suppression circuits which limit the peaks of picture modulation or leave gaps in the picture where interference signals would normally appear. Such interference suppression circuits are, of course, only applicable to impulsive type interference.

Further improvement lies in the direction of suppression of the interference at the source, but before this can be undertaken with any certainty of success it is necessary to have an exact knowl-

* Reprinted from *Communications*, September, 1940.

[1] See Bedford, *Jnl. Tel. Soc.*, March, 1937.

edge of the degree of suppression which is desirable.

Continuous Wave Interference

By continuous wave interference is implied the production of spurious modulation frequencies superimposed on the picture signal in the output of the receiver and appearing as a steady or slowly changing pattern on the picture screen. The effect is often described as a herring bone or feather pattern superimposed on the picture. A typical example is shown in Fig. 1. Such interference is caused by the interaction of an unwanted signal with the carrier frequency of the television transmission, the unwanted signal usually heterodyning the carrier frequency directly, or the intermediate frequency, to produce beats in the video frequency range. In superheterodyne receivers, the effect is also produced by interference from signals in the second channel band, or image signal interference. The problem then is similar to the production of whistle interference in broadcast receivers.

The annoyance value of the interference, its property of destroying the entertainment value of a television program, depends clearly on the signal-to-interference ratio on the resultant picture, or what is almost the same thing, at the output of the receiver vision amplifier or at the grid of the light modulating device.

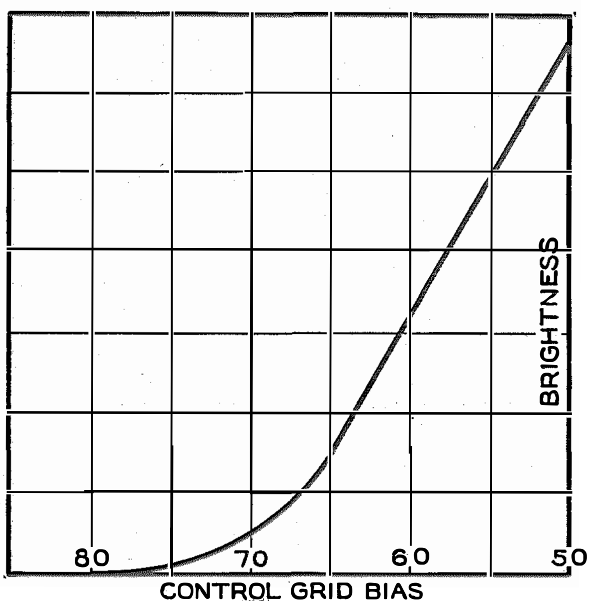


Fig. 2—Linear Light Voltage Characteristic.

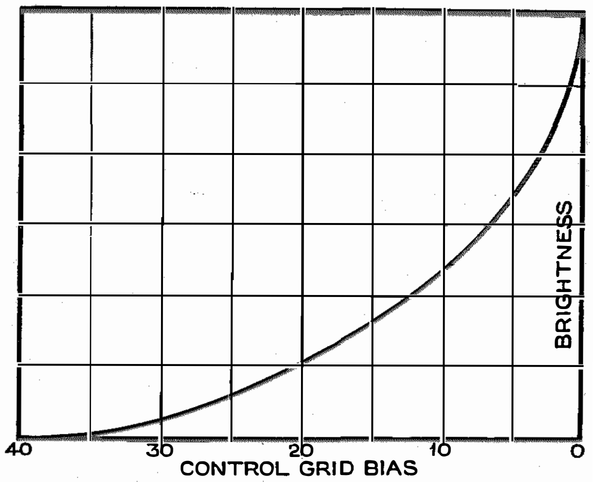


Fig. 3—Exponential Light Voltage Characteristic.

The signal-interference ratio at the output of the receiver will, in general, be slightly different from that at the input due to the various characteristics of the receiver. The amount of the change will depend on factors such as the magnitude of the incoming signal, the magnitude of the incoming interference, the type of frequency changer and detector employed, the band width of the circuits in various parts of the receiver, especially of the input circuits, and the relative frequencies of the signal and interference. A detailed analysis of the effects of these various factors can be carried out practically, or mathematically, for any given receiver design in accordance with known methods and so this work is limited to establishing the signal-to-interference ratio which may be tolerated at the grid of the light modulating device.

Measurements

A series of visual observations has been made, and photographically recorded, to study the effects of the interference on test signals and also on actual programs. No marked divergence of opinion was expressed by any of the observers as to what did or did not represent interference-free reception. Measurements were also made to determine whether c-w interference was more noticeable by reason of its effect on synchronization than on modulation of the picture brightness.

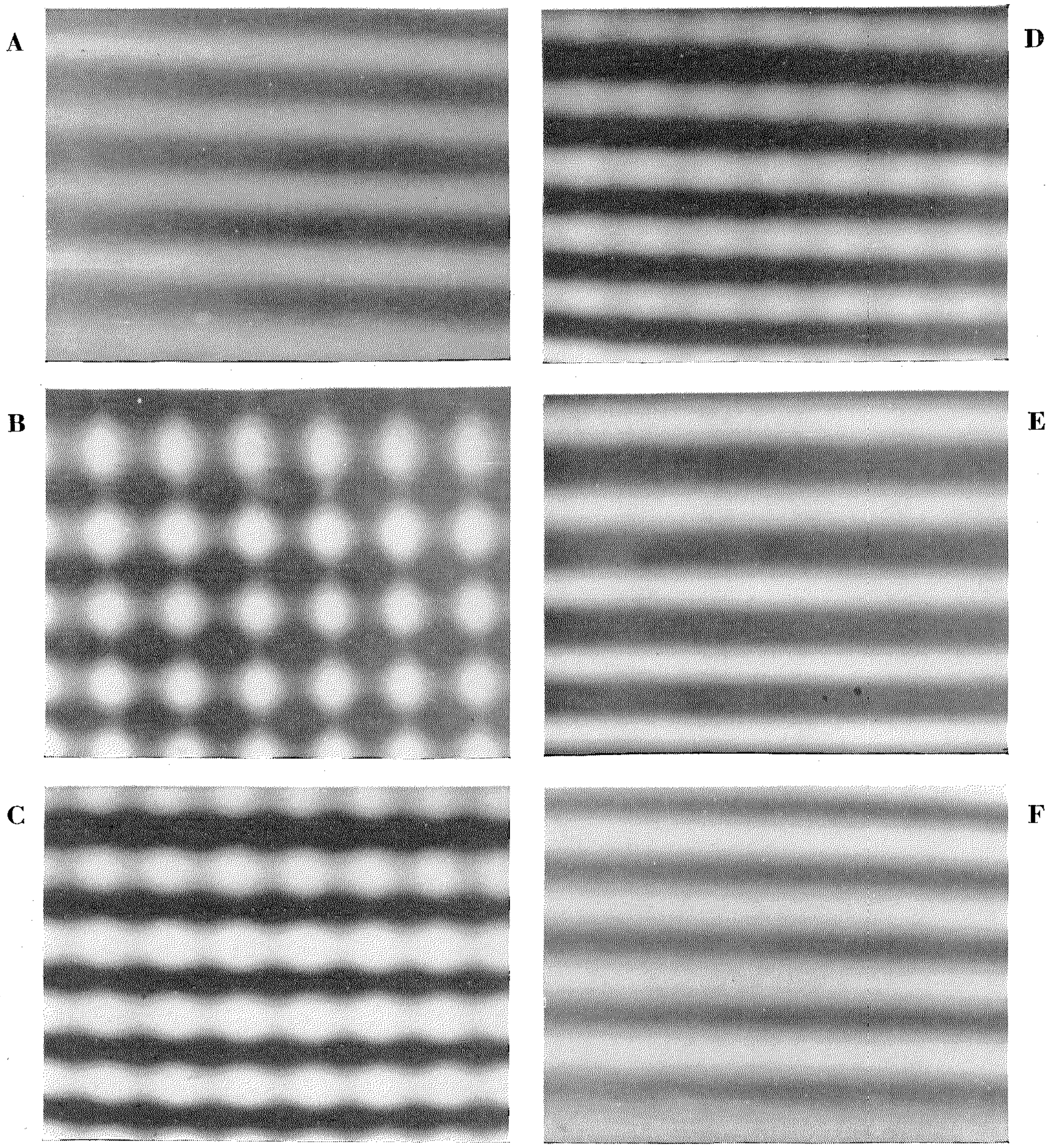
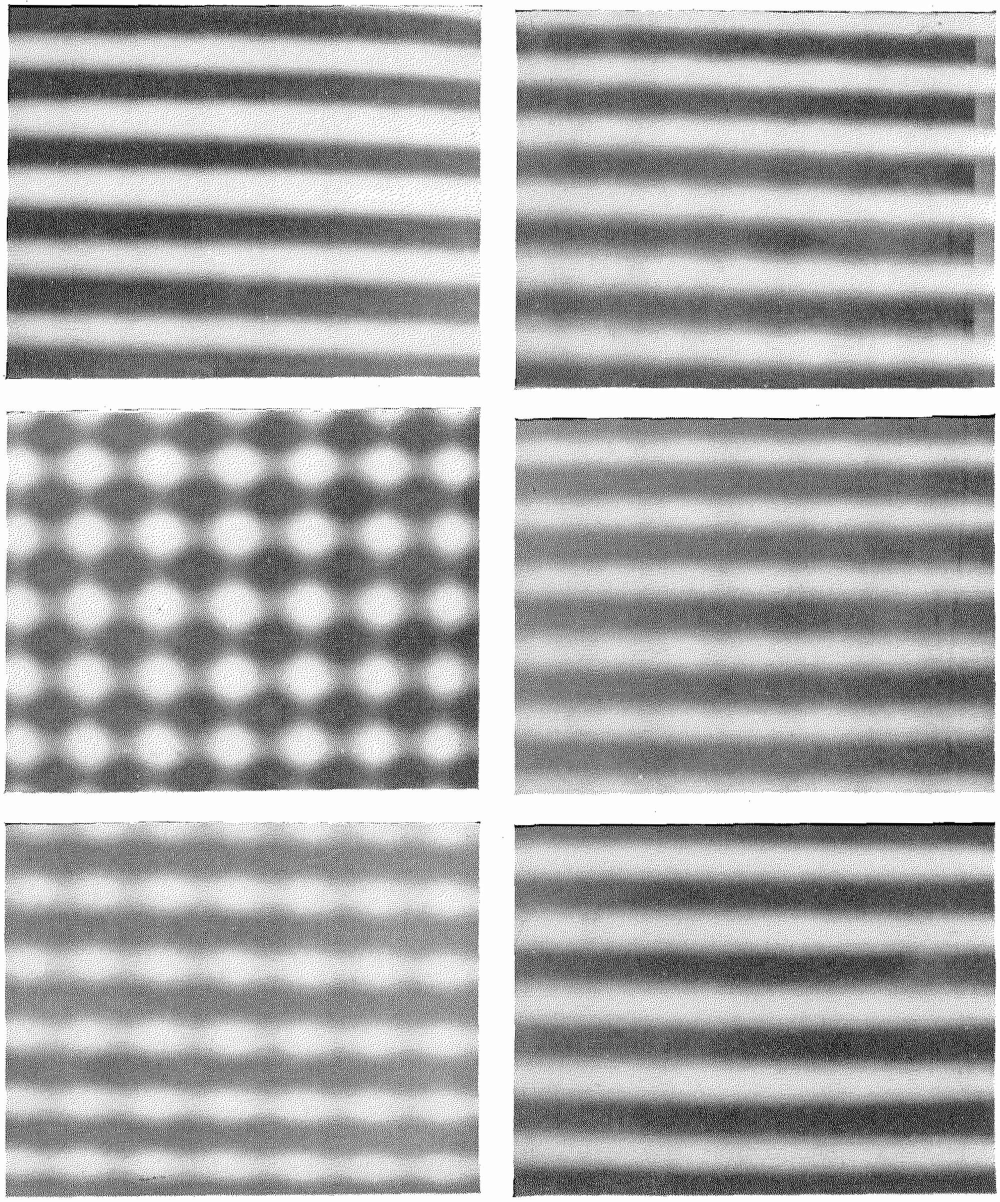


Fig. 4—Interference Tests. (a) Raster with Signal but without Interference. (b) Condition (a) but with Superimposed Sine-Wave Interfering Signal of Equal Amplitude. (c, d, e, f) Condition (b) but with Interfering Levels of -10, -20, -30, -40 db, Respectively.



A D
B E
C F

Fig. 5—Interference Tests. (a, b, c, d, e, f) Reproduction of Conditions of Fig. 4, but Using Cathode-Ray Tube with Exponential Characteristic (Fig. 3).

The conditions of the observations were as follows: two cathode-ray type television receivers were arranged for viewing signals from the London transmitter of the British Broadcasting Corporation. One was fitted with a cathode-ray tube having a linear light-voltage characteristic and the other with a cathode-ray tube having an exponential light voltage characteristic. (See Figs. 2 and 3.) The receivers were also arranged so that they could receive a 45-mc carrier modulated 30% at 400 cycles per second instead of the B.B.C. transmission. Both the B.B.C. signal and the test signals passed from the aerial through the normal h-f and l-f amplifying stages of the receiver. Peak voltmeters and cathode-ray oscillographic measuring gear were set up to measure the output signal applied to the c-r tube modulating grids.

Measured interfering voltages from a continuous-wave oscillator were also arranged to be injected into the cathode circuit of the c-r tube. Thus interference of any desired magnitude or frequency could be mixed with the incoming wanted signal. Hence, interference was not produced, as in practice, by beating of two signals within the receiver, but definitely mixed with

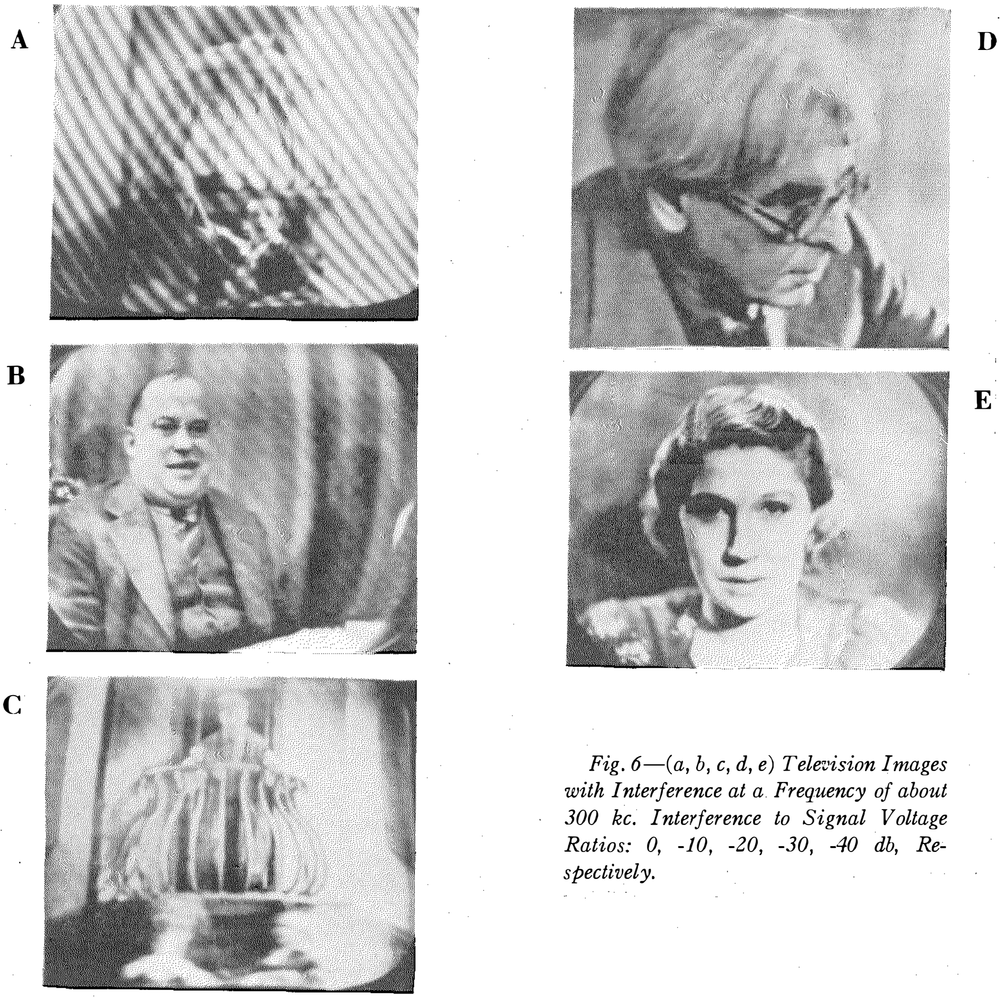


Fig. 6—(a, b, c, d, e) Television Images with Interference at a Frequency of about 300 kc. Interference to Signal Voltage Ratios: 0, -10, -20, -30, -40 db, Respectively.

A C

B D

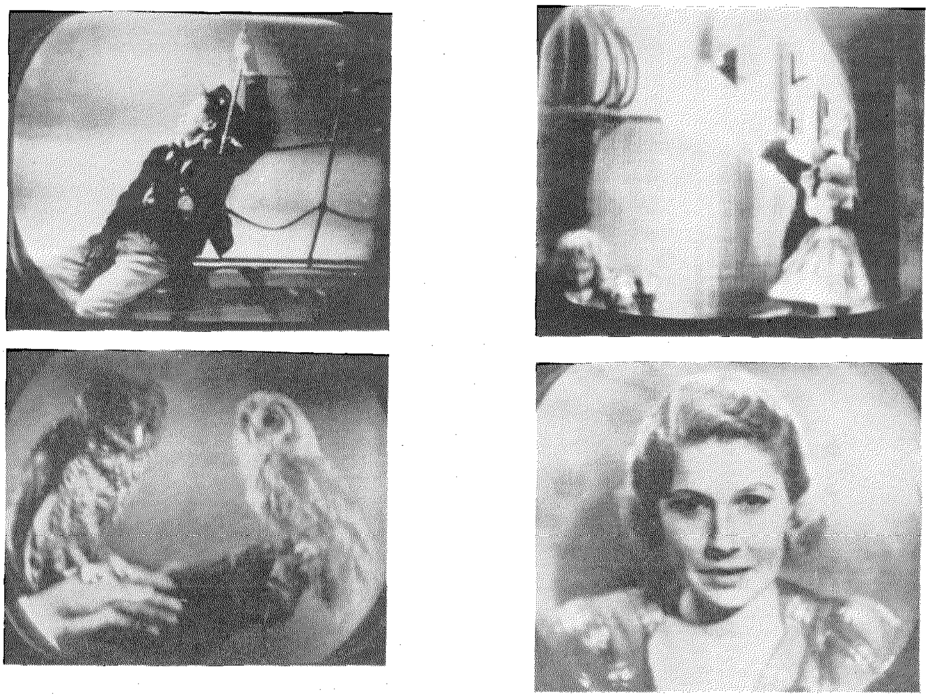


Fig. 7—(a, b, c, d) Illustrating Effects of Frequency on Interference.

the receiver output in known quantity and frequency. The conclusions are shown in the accompanying photographic reproductions.

In Fig. 4, *a, b, c, d, e, f* were obtained on the c-r tube with a linear characteristic (Fig. 2). The wanted signal originated from the 45-mc sine-wave modulated oscillator and produced the horizontal bars seen in the picture. A sinusoidal modulation was employed so that the interference would have every opportunity to present itself, whether in the black, white or half tones of the picture. (*a*) shows the raster with signal but without interference. (*b*) shows condition (*a*) but with an interfering sine-wave signal of equal amplitude superimposed. The frequency of the interference is about 100 kc and is synchronized with the horizontal scanning frequency to produce the vertical pattern. (*c, d, e, f*) reproduce the conditions of (*b*), but with interference levels of -10, -20, -30, -40 db, respectively. It is to be noted that (*f*) is indistinguishable from (*a*).

Fig. 5 (*a, b, c, d, e, f*) reproduces the conditions of Fig. 4 (*a, b, c, d, e, f*) exactly but on the receiver with the cathode-ray tube having an exponential characteristic (Fig. 3).

Fig. 6 shows various television images taken with interference at a frequency of about 300 kc. The interference was not deliberately synchronized with the horizontal scanning frequency but the interference pattern remained practically steady for the period of the observations. The ratios of interference to signal voltages are: (*a*) 0 db; (*b*) -10 db; (*c*) -20 db; (*d*) -30 db; (*e*) -40 db. It can be judged from a comparison of Figs. 4 and 5 that the difference in the appearance of interference is not sufficiently marked to make the reproduction of a series of television images for both types of c-r tubes necessary.

Fig. 7 (*a, b, c*) shows the effects of frequency on the appearance of the interference. The signal-interference ratio in each case is 20 db. (*a*) shows a very low-frequency interference such as may be caused by hum from the power-supply, (*b* and *c*) show frequencies of about .5 and 1 mc, while (*d*) shows a frequency of about 2.5 mc equal in intensity to the picture modulation.

In Fig. 8, (*a*), (*b*) and (*c*) illustrate interference applied to the picture modulation and to the synchronizing circuits in addition to the normal synchronizing pulses. In (*a*) the signal-interference ratio is 20 db, in (*b*) 30 db, and in (*c*) 40 db. In (*c*) the effect of the interference on the signal is still to be noted although it is no longer noticeable as a brightness modulation. These observations were made to determine whether the interference was likely to be more noticeable by reason of its effect on synchronization than on modulation; it will be appreciated that the effect of interference on synchronization will depend to a marked degree on the receiver design and that it is not possible to form any hard and fast conclusions in this connection.

Conclusions

The conclusions which have been deduced from these observations are as follows:

(1) If the interference is 40 db below the level of the picture modulation, it will not be visible.

(2) If the interference is 30 db below the level of the picture modulation, it is noticeable but not sufficiently severe to cause reduction of entertainment value when the picture is viewed from the normal distance.

(3) If the interference is 20 db below the level of the picture modulation, it will seriously interfere with the entertainment value of the picture.

(4) If the interference is 10 db below the level of the picture modulation, the resulting picture is worthless for entertainment purposes.

(5) If, due to the receiver design, the interference is superimposed on the synchronizing pulses, a signal-interference ratio of 40 db will not seriously distort the picture although it may be just noticeable. A ratio of 30 db will cause serious distortion in certain types of receivers.

(6) The frequency of the interference does not affect its annoyance value providing it is higher than about 5 times the frame frequency and of lower frequency than that required to provide equal resolution in horizontal and vertical directions. If the frequency is very low and synchronous with the frame scanning (e.g., derived from power-supply hum) a signal-interference ratio of 20 db may not seriously interfere with reception; while at very high frequencies—higher than the highest modulation component in the system—

Fig. 8—(a, b, c) Illustrating Interference Applied to Picture Modulation and to Synchronizing Circuits.

the picture is not seriously distorted even by interference equal to the signal.

(7) The annoyance value of the interference is not affected by the brightness level at which the picture is reproduced providing the picture is reproduced with reasonable fidelity.

(8) A simple picture such as black lettering on a white background without any half tones can be reproduced without appreciable loss of detail in the presence of considerable interference if the amplifier or light source is over-modulated in both the black and white directions.

(9) The characteristic of the light source does not affect the annoyance value of the interference in general but only determines the parts of the image in which the interference is most visible (i.e., black or white parts), in the same way that the characteristic affects the reproduction of half tones in the image itself.

(10) For the condition of interference-free reception (i.e., signal-interference ratio in excess of 40 db) the signal-interference ratio at the input of the receiver is not in general different from that at the receiver output, due to the fact that with so minute an interfering signal little cross modulation is likely to occur in the receiver itself.

The steps which can advantageously be taken to reduce the occurrence of continuous wave interference may be summarized as follows:

First, the receiver must be adequately screened against the effects of electromagnetic or electrostatic induction fields, the power supply must be carefully filtered and the filter currents earthed independently from the aerial earth system of the television receiver, otherwise filtering of the power supply may defeat its own object and only result in increased induction into the receiver circuits. Directional and polarized aerials must be employed where necessary, and the receiver fitted with adequate pre-selection before the first amplifier tube (if necessary by the addition of a band-pass filter in series with the aerial transmission line) thus preventing unwanted frequencies from introducing cross modulation by overloading of the first tube in the vision amplifier. Finally, in the receiver itself, much can be done by a careful choice of intermediate frequency to avoid the effects of second channel interference from outside, and harmonic interference occurring inside superheterodyne receivers.

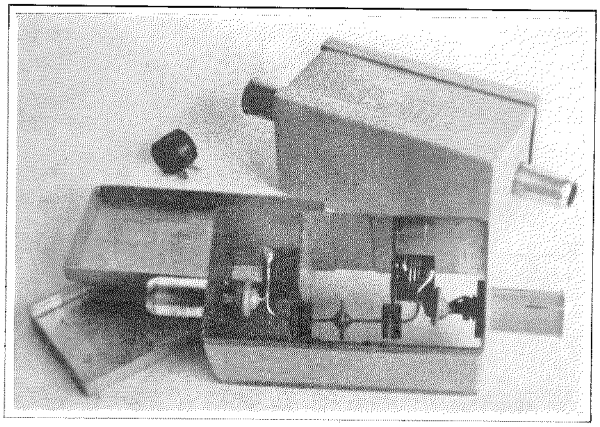


Fig. 9—High-Pass Filter.

At the source, interference suppression should be effected so that the interference field at a reasonable distance from any electrical apparatus cannot exceed a level 40 db below the field strength which it is desired to protect. In order to achieve this, it is necessary: to suppress the radiation of oscillator frequencies and harmonics from broadcast and television receivers by means of screening, power-supply and aerial filtering, and by planned layout of circuit and other components, including earthing and routing of the wiring; also to prevent radiation from medical diathermy apparatus by complete screening and power-supply filtration, and to eliminate radiation of harmonic frequencies from broadcast and amateur short-wave transmitters.

A view of a simple high-pass filter with a cut-off frequency of 40 mc is shown in Fig. 9. Such a filter, inserted in the aerial circuit, will help very considerably in reducing unwanted signal pickup and in preventing oscillator radiation in television receivers in which the oscillator frequency is lower than the signal frequency.

Hyperfrequency Waves and Their Practical Use*

By LÉON BRILLOUIN, Dr. ès Sc.

1. What Does Hyperfrequency Mean?

THE first question to be answered is concerned with the meaning of the word hyperfrequency. This has been commonly used for frequencies above 10^9 c/s. (1000 Mc/s.), which correspond to electromagnetic waves of wavelengths shorter than 30 cm. What shall actually be studied in this paper is the behavior of electromagnetic waves whose wavelengths are comprised between approximately one centimeter and a few decimeters. This region of the electromagnetic Spectrum holds for the moment a great deal of interest, due to many different reasons:

A. The physicist is especially anxious to study wavelengths of the order of one centimeter and shorter. Very little is known of this region until one reaches wavelengths of 0.1 mm. which correspond to the extreme infrared. Emission and absorption spectra are to be determined, together with optical properties of chemical compounds. Some very remarkable results have already been obtained, such as an absorption spectrum for ammonia and a strong change in the dielectric properties of water. These researches will become still more interesting when wavelengths of a few millimeters or fractions of a millimeter can be produced with sufficient energy. It is to be foreseen that all chemical compounds having an electrical dipole should show a typical variation of their electrical properties in this region. These waves should enable us to build up new methods of investigations on molecular structures.

In a few words, the physicist is waiting for the gap to be filled between radio and optics; he still wants to link these two different fields together. This has already been tried using damped waves, but precise measurements can be made only with continuous or undamped waves, and this is what we are now seeking.

B. The *radio engineer* is not less interested than the physicist. The tendency in radio has been, for the last twenty years, to push to shorter and shorter wavelengths. Where is the practical limit to be found? No one to-day can tell; but it has already been demonstrated that wavelengths of some centimeters may prove very valuable for radio communication, television, signalling (radio beacon), obstacle detection, not to forget dielectric cables. This is more than sufficient to arouse great interest and promote very active technical research.

2. Some Characteristics of Hyperfrequency Waves

Wavelengths of some decimeters were first used by Hertz to repeat optical experiments, such as prismatic deflection or diffraction; and this *similarity of short radio-waves with optical waves* has been, since that time, emphasized by a great many experimenters. Optical lenses, mirrors, parabolic reflectors are very effective as soon as they can be built with dimensions of a few wavelengths. Another and more recently discovered point is the *analogy between hyperfrequency radio-waves and acoustics.* Since the wavelengths are of the same order of magnitude in both cases, we can now note the very important use of electrical apparatus curiously similar to acoustical instruments: hollow pipes, like organ pipes; hollow resonators (also called tank-resonators) reminiscent of Helmholtz acoustical resonators and dielectric cables, which show a marked relationship with pipes as used in acoustics.

Hollow tank resonators have been suggested by several physicists, mostly on the basis that they give very slight damping. As commonly expressed by radio engineers, these hollow resonators show very high Q factors: a high Q means that the resonator oscillates freely a great many times before the amplitude of the oscillations is reduced to a small value.

There is another aspect of the question which

* Presented at a meeting of The Franklin Institute held Thursday, April 6, 1939. Reprinted from *Journal of the Franklin Institute,* June, 1940.

seems worth noticing; this is the possibility of first storing up energy in the resonator, and afterwards radiating this energy.

If one wishes to accumulate electromagnetic energy in a certain volume Φ, it can only be done by producing high electrical E and magnetic H fields inside this volume, the total energy being given by the integral

$$W=\frac{1}{8\pi}\int(\epsilon E^2+\mu H^2)d\Phi. \qquad (1)$$

The contributions of electrical and magnetic terms are usually of the same order of magnitude. But now there is one question to be raised, i.e., how far can we increase the fields? Let us suppose the dielectric medium to be air at atmospheric pressure. Its disruptive potential is about 30,000 volts per cm., that is, 100 c.g.s. electrostatic units. Practically, this upper limit will never be reached, and taking a reasonable safety coefficient we may assume the average field to attain perhaps 15 E.S. units. This means

$$W=\frac{1}{8\pi}15^2\approx 10 \text{ ergs per cubic cm.} \qquad (2)$$

or 1 joule per cubic meter.

Thus we accept as a reasonable order of magnitude,

$$W \text{ (ergs)}=10\Phi \text{ (cm.}^3\text{)}. \qquad (3)$$

Storing up a large amount of energy W means using a resonator of large volume, Φ.

Now, let us think of the amount of energy radiated per second. A well tuned resonator will yield a Q factor of the order of 1,000, which means a time constant θ of about one thousand periods, τ.

$$\theta=1000\tau. \qquad (4)$$

The energy radiated per second dW/dt is thus given by the relation

$$\frac{dW}{dt}=\frac{W}{\theta}=\frac{W}{1000\tau}=\frac{\Phi}{100\tau}, \qquad (5)$$

using formula (3). Let us design a resonator able to radiate a power of 100 watts (10^9 erg/sec.). Its volume will be related to the frequency by means of (5):

$$\frac{dW}{dt}=10^9, \qquad \Phi=10^{11}\tau. \qquad \text{C.G.S.}$$

This result may be more clearly understood if we compare the dimensions of the volume Φ to the wavelength λ. Supposing a cubic volume

$$\Phi=L^3$$

one finds

$$L^3=10^{11}\frac{\lambda}{c}=\frac{10}{3}\lambda, \qquad \text{C.G.S.}$$

where c represents the velocity of light, or

$$\left(\frac{L}{\lambda}\right)^3=\frac{10}{3\lambda^2}, \qquad \lambda \text{ in cm.} \qquad (6)$$

which yields the following results:

—long radio-waves, $\lambda\approx$ some meters, $\frac{L}{\lambda}\ll 1$ lumped circuits;

—short radio-waves, $\lambda\approx$ some decimeters, $\frac{L}{\lambda}\approx 1$;

—hyperfrequency waves, $\lambda\approx$ some cm. or some mm., $\frac{L}{\lambda}\geqslant 1$ tank circuits.

For short radio-waves, ordinary inductance capacity circuits can no longer be used, and the technical practice is to use parallel lines or coaxial lines as resonators: however, these lines can be built only if the distance between the two parallel wires is small with respect to the wavelength. This can no longer be obtained for hyperfrequency waves, and we are thus forced to work with tank resonators; even (due to $L>\lambda$) with tank resonators oscillating on their higher modes of vibration.

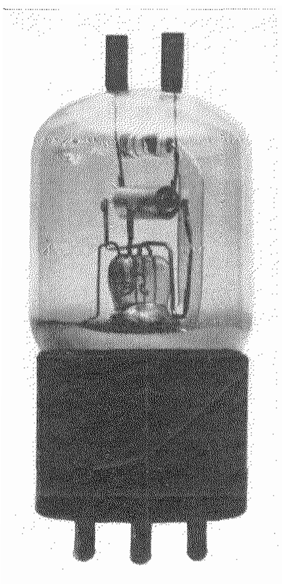


Fig. 1—Microray Oscillating Tube (St. Inglevert).

Other oscillators of great dimensions may be thought of, like conducting spheres or ellipsoids; these have been investigated in the early period of electromagnetism[1]

[1] M. Brillouin, "Propagation de l'Electricité," Hermann, Paris, 1904.

and their resonance frequencies have been thoroughly computed, but their damping is far too high (Q factor very low) for practical use.

If rather similar to acoustical apparatus, a tank resonator is fundamentally very different, and the whole theory of hollow resonators, hollow tubes, etc., has to be built anew for the case of electromagnetics. The difference rests on the fact that acoustics deals with longitudinal waves, while electromagnetics deals with transversal waves. An acoustical field can be defined by one quantity (say the velocity potential) while an electromagnetic field needs four quantities (vector and scalar potentials). Acoustical calculations, as so marvellously done by Lord Rayleigh, may be used as a guide or as formal examples, but they have to be completely translated into the language of transversal waves and Maxwell's field equations, a translation which often needs a good deal of mathematical skill and ability.

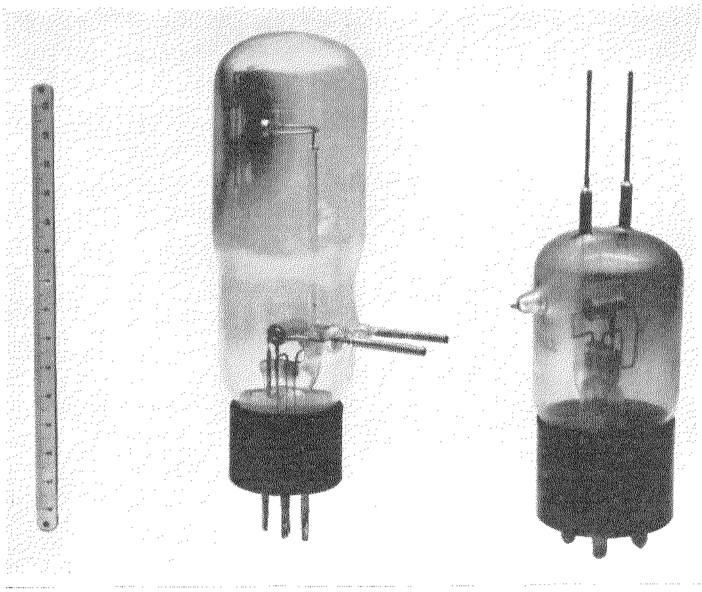


Fig. 2—Microray Tubes (St. Inglevert).

3. *Former Experiments by Clavier and Darbord*

The "*Laboratoires L.M.T.*," laboratories of "Le Matériel Téléphonique" in Paris, have been very active for a good many years in the field of hyperfrequencies. The researches were conducted by MM. Clavier, Darbord and various co-workers and resulted in radio transmission across the English Channel using a wavelength of 18 cm. The following pictures give a good idea of this installation. First experiments were carried out in 1931 and the system has been in commercial use since 1934. The tubes used were of the positive grid type as shown in Figs. 1 and 2. Their characteristics are described in Fig. 3, the dotted line corresponding to anode potential and the solid line to the output, both curves being plotted as functions of grid voltage. Figs. 4 and 5 show simplified schematics of the receiver (Fig. 4) and transmitter (Fig. 5); in both cases oscillations generated (or received) are conducted by a coaxial feeder to (or from) a small antenna disposed at the focus of a parabolic reflector. Details of this mounting may be seen in Fig. 6, which shows the oscillating tube and its feeder. Fig. 7 is a rear view of the reflector fitted with the preceding mounting, while Fig. 8 shows a front view of the same reflector together with a small hemispheric mirror reflecting waves back on to the parabolic system.

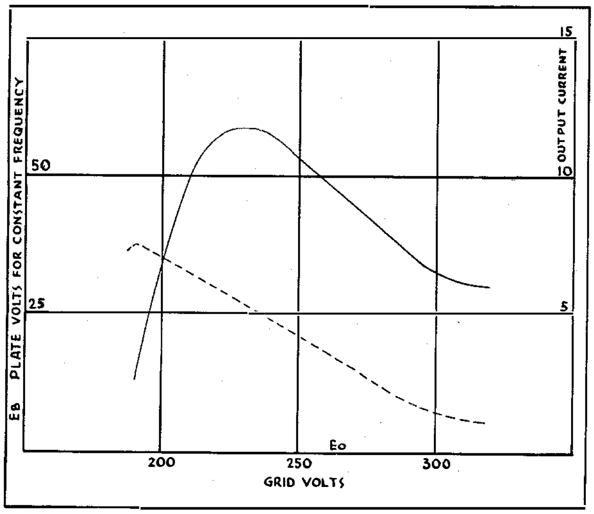


Fig. 3—Relation of Grid and Anode Potentials and Variation of Output for Constant Frequency. 19.4 cm Wavelength.

The reflectors produce a linear beam of very small aperture, directed from the transmitting station to the receiving station. The reflectors must be in direct sight. In the cross channel communications example, one of the stations is located at St. Inglevert on the French side, the other at Lympne in England, the distance being about 56 kilometers, and the sites so chosen that the line between the terminals is clear of obstacles. The electro-optical equipments are installed on suitable steel towers (20 meters high) shown on Fig. 9 (St. Inglevert) and Fig. 10 (Lympne). The link is used for two-way teleprinter messages as well as duplex telephony. All details about these stations have already been published in various papers.[2]

The results of operation were very good on this link, which represents the shortest wavelength circuit in commercial use. Atmospherics are never heard on the circuits, though sharp clicks, not to be traced to the apparatus, are sometimes noticed. No interference whatever is caused either by thunderstorms or motorcars; the back-

[2] A. G. Clavier, *Electrical Communication*, 1933, **12**: 3. A. G. Clavier, and L. C. Gallant, *El. Comm.*, 1934, **12**: 222. W. L. McPherson and E. H. Ullrich, *P. I. E. E.*, 1936—"The Institution of Electrical Engineers"—Proceedings of the Wireless Section, 1936, **11**: 253–291.

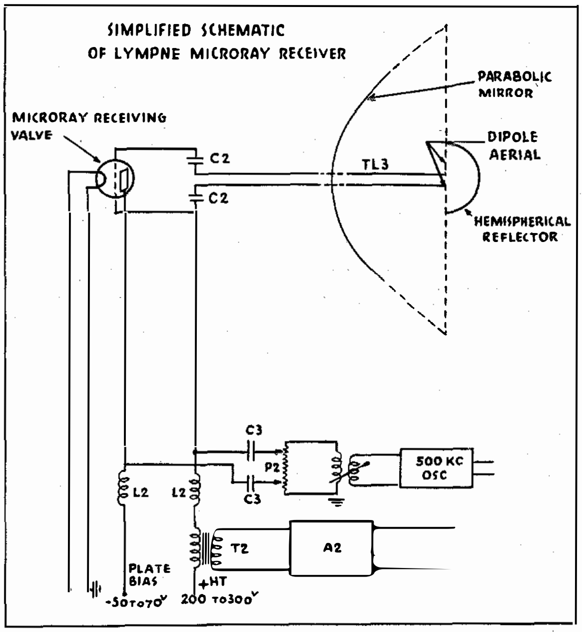


Fig. 4—P2, Demodular Potentiometer. T2, Demodulator Transformer. A2, 2-stage Audiofrequency Amplifier, Max. Gain 40 db. TL3, Tubular Transmission Line to Receiving Aerial.

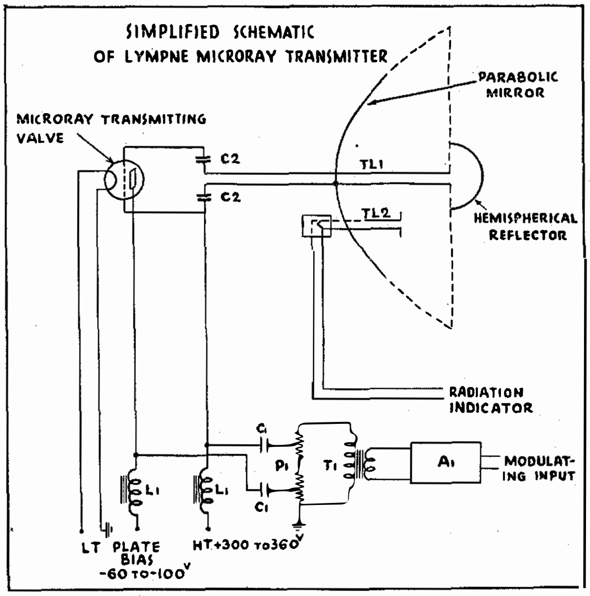


Fig. 5—P1, Modulation Potentiometer. T1, Modulation Transformer. A1, 3-Stage Audiofrequency Amplifier, Max. Gain 50 db. TL1, Tubular Transmission Line to Radiating Aerial. TL2, Tubular Transmission Line to Thermocouple.

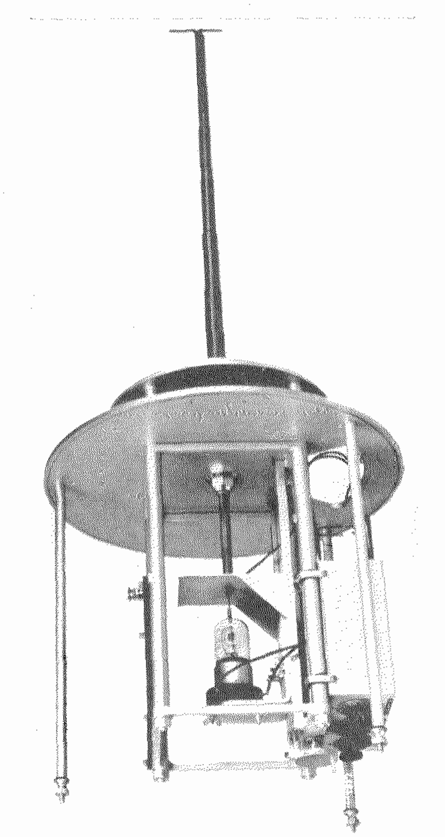


Fig. 6—Mounting of Oscillator or Parabolic Reflector.

ground noise in the receiver exactly resembles normal tube noise. Some slow fading has been observed, although it very seldom occurs that for a short duration of time the signal is unreadable for telegraphy. Rain and fog show no

Fig. 7—Reflector Rear View.

marked effect. As a rule, stable atmospheric conditions, whatever they might be, corresponded to stable communications while unsteady atmospheric states are usually accompanied by fading.

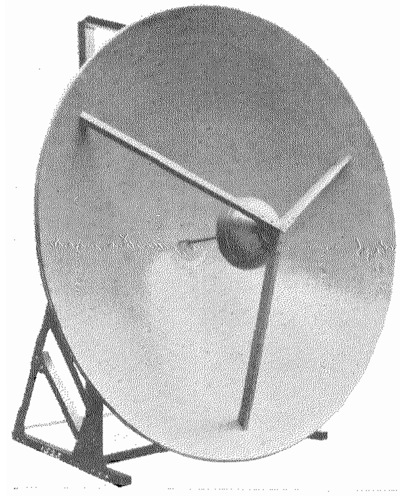


Fig. 8—Reflector Front View.

4. Dielectric Cables: Experimental

A very important step was taken when Southworth, Carson, Mead and Schelkunoff from the Bell Laboratories first began investigating short wave propagation along conducting hollow tubes (so-called dielectric cables). Very similar researches were started almost at the same time by Barrow at the Massachusetts Institute of Technology.[3] The first papers published by these scientists aroused the curiosity of many physicists. The author investigated wave propagation in rectangular tubes, then in tubes with elliptical cross section,[4] and a great many further studies have recently appeared. Researches conducted in the U. S. A. being already well known to the

[3] G. C. Southworth, *Bell System Technical Journal*, 1936, **15**: 284. Carson, Mead and Schelkunoff, *Bell System Technical Journal*, 1936, **15**: 310. W. L. Barrow, P. I. R. E., 1936, **24**: 1298.

[4] L. Brillouin, *Revue Générale de l'Électricité*, 1936, **40**: 227. *Electrical Communication*, 1938, **16**: 390. *Bulletin Soc. Franç. Électriciens*, 1938, **8**: 899.

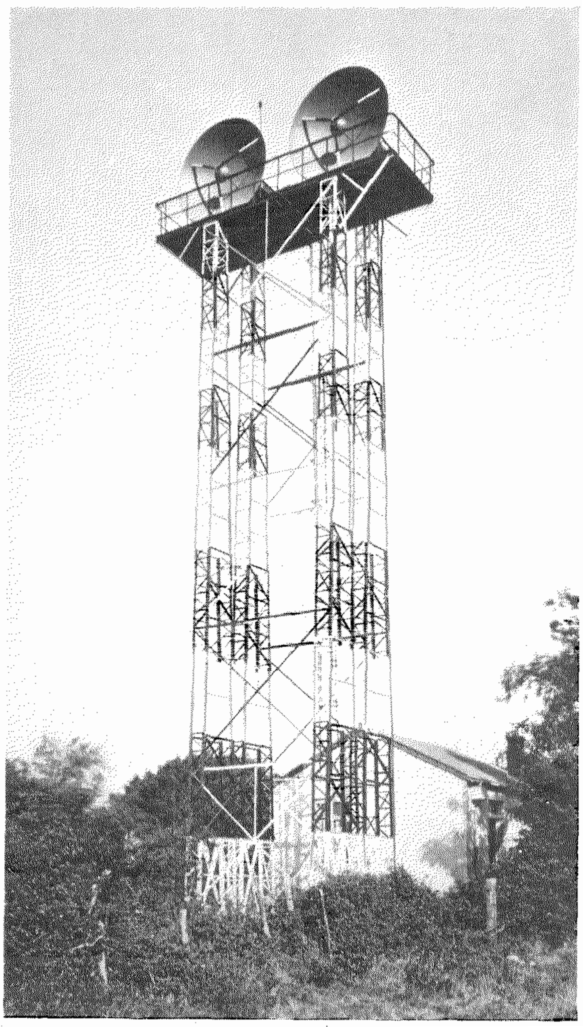


Fig. 9—Microray Towers at St. Inglevert (20 Meters High).

Fig. 10—Lympne Terminal.

readers, it may be desirable to give more detailed information on the work done in Europe, and more particularly on the researches of the author, in connection with A. G. Clavier[5] from the "Laboratoires L. M. T." in Paris. Mr. Clavier presented very brilliant experimental demonstrations before the "Société Française de Physique" in November 1938 using the equipment shown in the following figures.

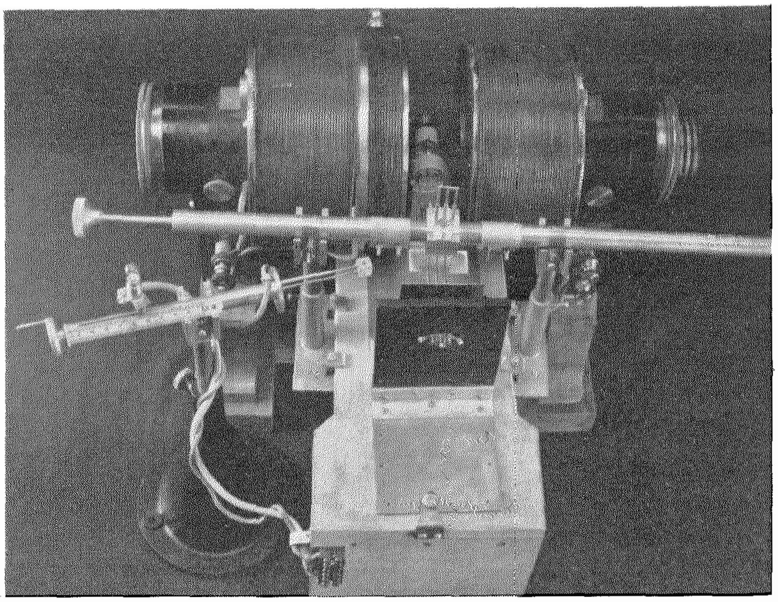
Very short waves were produced either with positive grid tubes of the type formerly described in this paper (Figs. 1, 2 and 3) or with magnetrons. Fig. 11 is a view of a magnetron equipment generating waves of 1.2 to 3 cm. wavelengths. These waves can be propagated inside a small copper tube 1.6 cm. in diameter. Near the magnetron is a coaxial line wave-meter having a moving piston for tuning. Fig. 12 shows a general view of the dielectric cable experiment as demonstrated before the French Physical Society. Two different guides were used; a large one, 12 cm. in diameter, is to be seen in the foreground of the picture and enabled Clavier to study before the audience the distribution of electrical lines of force inside the tube for different wave types. The smaller guide was the tube of 1.6 cm. diameter already described. Fig. 13 shows the generator (positive grid tube) for 8 cm. wavelength together with coaxial wave-meter. On the left is the coupling apparatus with the dielectric guide of 12 cm. diameter, with means for demonstrating the distribution of electrical lines of force for different types of waves. Fig. 14 shows the receiver. A small dipole antenna may be rotated inside the tube and received amplified signals are indicated by a small lamp which is correspondingly oriented with respect to an indicating placard. Fig. 15 shows a transformer for changing the type of wave from E_0 to H_0. The transformer itself consists of small radial antenna inside the tube, having a bent portion at the radius where the H_0 wave has its maximum electrical field value. The antenna system is located between two screens, one with radial wires stopping the E_0 wave but letting the H_0 wave through; the other screen (behind) is fitted with circular wires and stops the H_0 wave while the E_0 wave passes unperturbed. Fig. 16 is a drawing of the antenna system of the preceding transformer. More detailed information in regard to this equipment may be found in the paper by Clavier and Altovsky quoted above.

5. *Theory of Dielectric Cables*

A hollow conducting tube represents, for electromagnetic waves, an actual high-pass filter as only frequencies higher than a certain cut-off frequency can be transmitted through it. This result was one of the very striking facts from Southworth's first investigations, and may be readily seen from Fig. 17. The curve shows the

[5] A. G. Clavier, *Bulletin Soc. Fr. Électriciens*, 1938, **8**: 385. A. G. Clavier and V. Altovsky, *Rev. Gén. de l'Électricité*, 1939, **45**: 697–731.

Fig. 11—Clavier's Magnetron. Showing the Generator of Oscillation at a Wavelength of 2.5 cm (In Air) and Its Associated Wave Meter; Also, the Method of Coupling to a Dielectric Guide 1.6 cm Internal Diameter.



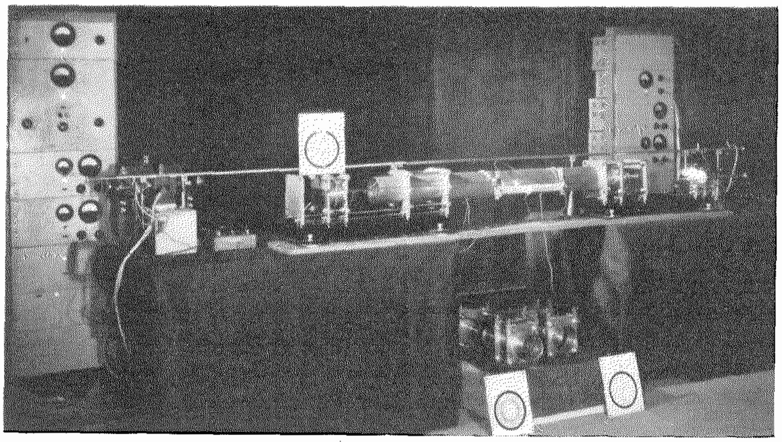


Fig. 12—Demonstration of Dielectric Cable Properties.

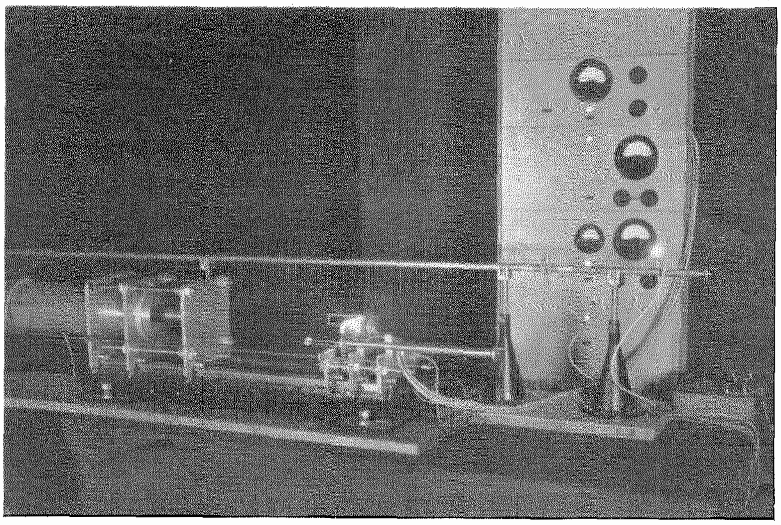


Fig. 13—Hyperfrequency Generator. Showing in the Middle a Generator (8 cm Wavelength) Together With Wave Meter. On the Left, the Coupling Apparatus to a Dielectric Guide 12 cm in Diameter. On the Right, the Receiving Apparatus of a Dielectric Guide 1.6 cm Inside Diameter.

variation of

$$\frac{W}{V}=\frac{U}{W} \quad (8)$$

as a function of the ratio λ/d of wavelength to diameter; W, light velocity in free space; V, phase velocity for guided waves inside the tube and U, the group or signal velocity for the guided waves. The solid curve is the theoretical one for E_0 waves in a tube filled with water ($\epsilon=81$, $\sqrt{\epsilon}=9$). Only wavelengths less than the cut-off wavelength can be propagated through the tube. Cut-off occurs here at $\lambda/d=1.7$ approximately. Fig. 18 shows a similar curve for H_1 waves in a tube filled with air, with cut-off about $\lambda/d=1.67$. Physical interpretation of these results will be given further on. It is to be noticed that theoretical curves on Figs. 17 and 18 are actual ellipses. Fig. 19 is also from Southworth's paper and illustrates the attenuation for different types of waves (called E_0, E_1, H_0, H_1) as propagated along a copper tube. Very remarkable is the decreasing curve for H_0 waves; the higher the frequency the smaller the attenuation. This un-

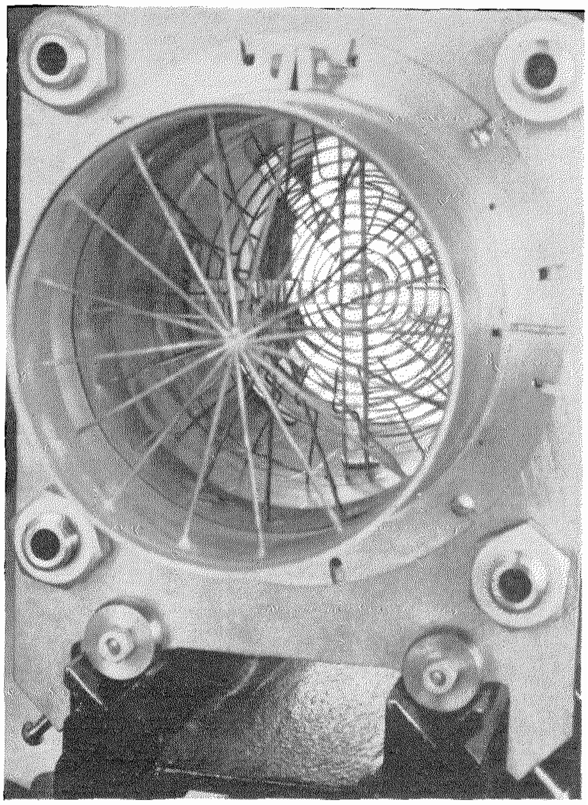


Fig. 15—Wave Transformer. Showing the Apparatus Used to Transform One Type of Wave Into Another (Here E_0 Wave Into H_0 Wave) and the Associated Filter to Eliminate the Unwanted Remaining Portion of the Original Wave (E_0). Transmission Takes Place Back to Front in the Apparatus as Shown.

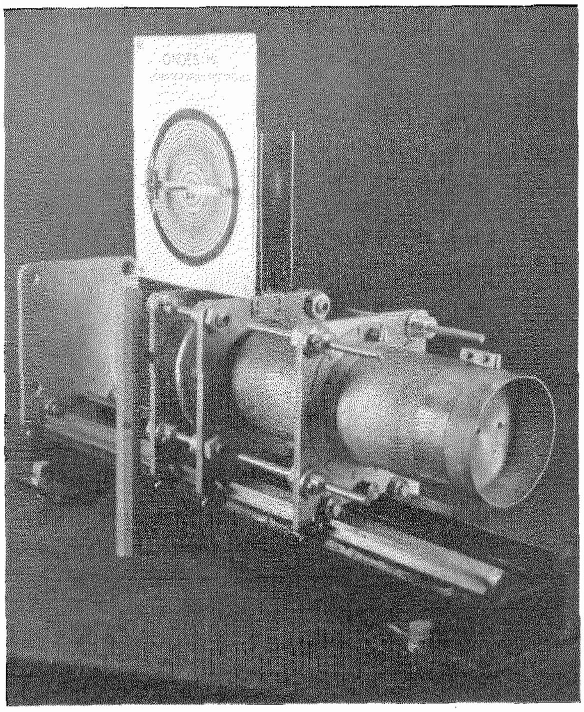


Fig. 14—Dielectric Cable Receiver. Showing the Receiving Side of a Dielectric Guide 12 cm in Diameter With Means for Demonstrating the Distribution of Electric Lines of Force for Different Types of Waves.

expected and rather surprising result might prove very valuable for long distance dielectric cable communications. When looking at this problem with more precision, such a result can be explained in a few words. Each type of wave induces electrical currents in the copper tube; these currents have to flow inside a very thin layer (due to skin effect) and this layer becomes thinner and thinner as the frequency increases. This results in increasing Joule's losses inside the layer for most types of waves. Hence the higher the frequency the greater the attenuation. H_0 waves behave differently, because the current intensity induced in the copper tube decreases very rapidly as the frequency increases, and this second effect more than compensates for the decrease in current penetration depth. Thus the attenuation decreases as the frequency increases.

Let us now return to the elliptic curves of Figs. 17 and 18, and explain their physical meaning. The remarkable point is that the wave velocity inside the tubes differs substantially from wave velocity in free space. What actually happens inside the conducting tube is that a system of moving interferences, a certain pattern of alternating maxima and minima, is built up

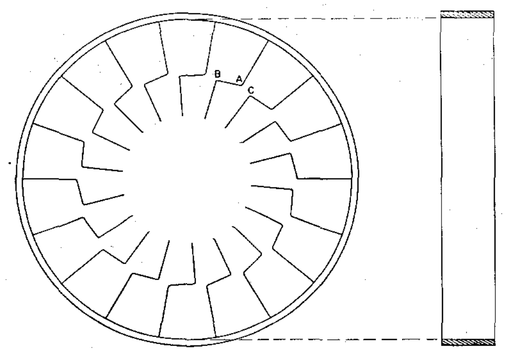


Fig. 16—Wave Transformer Design.

inside the tube, and then moves as a whole, drifting along the tube without any distortion. It is readily understood that the phase velocity (or propagation velocity) for such an interference pattern will be very different from the usual light velocity in free space. Some elementary examples will give simple instances of such properties; Fig. 20 describes interferences actually taking place in front of a mirror M, when an incident wave J falling at an angle θ is reflected, yielding a reflected wave R. There is an interference pattern

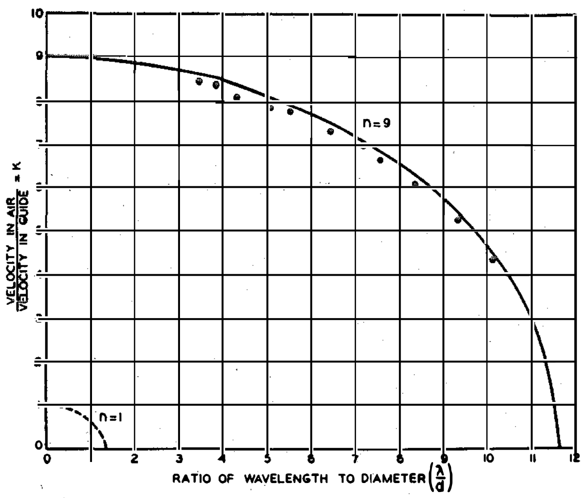


Fig. 17—Velocity Ratio for E_0 Type of Wave in a Metal Pipe Filled with an Insulator.

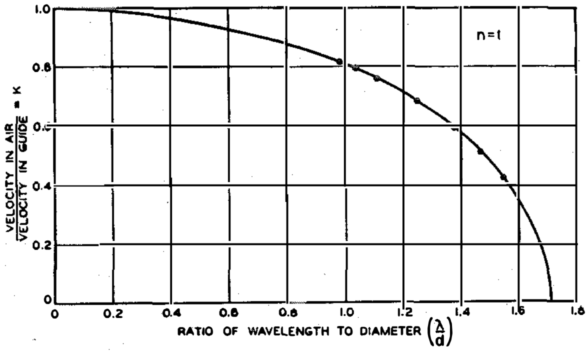


Fig. 18—Velocity Ratio for the H_1 Type of Wave in a Hollow Metal Pipe.

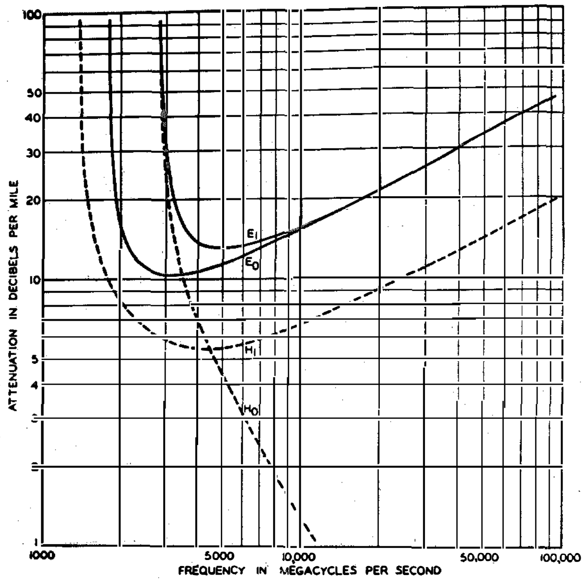


Fig. 19—Attenuations Suffered by Each of the More Common Types of Waves in a Hollow Copper Pipe 5 Inches in Diameter.

in a triangular region in front of the mirror where incident and reflected waves superimpose. Intensity maxima, as indicated by dark dots, are built up at the intersection of wave planes from both waves; λ being the wavelength of a free wave, there appears a longer wavelength Λ in the interference pattern, as representing the distance between two dots, measured parallel to the mirror. It should be noticed that the whole motion of this interference pattern occurs parallel to the mirror, the entire system gliding along with velocity V; this drawing immediately yields a very simple result:

$$\frac{W}{V}=\frac{\lambda}{\Lambda}=\sin\theta. \tag{9}$$

The dark lines parallel to the mirror are dark fringes, where no intensity is to be observed. They divide the triangular space into a system of parallel layers with practically no energy flow from one layer to the other, which proves once more that the resultant wave velocity V is directed parallel to the mirror. Fig. 21 shows such interference pattern, as actually observed with supersonic waves in water, when reflected on two rectangular mirrors.

There is no energy flowing through the dark fringes, and the same condition existing on the surface of the mirror is also fulfilled on each of these dark fringes. For instance, in the case of electromagnetic waves reflected from a conducting horizontal mirror M, the horizontal electric field vanishes at the mirror, it also vanishes on every dark fringe; thus we may, without disturbing the interference pattern, put a second mirror M', parallel to the first mirror M, in one of these dark fringes. This is shown on Fig. 22, which represents a system of interferences propagating between both mirrors with phase velocity V. This corresponds to wave propagation inside a conducting tube, if we imagine a tube of rectangular cross section, one of the sides of said rectangle being infinitely long. The phase velocity is always given by formula (9) and is definitely greater than wave velocity W in free space, by a factor $1/\sin\theta$.

The energy flow takes place with a different velocity U smaller than wave velocity W in free space

$$U = W \sin\theta, \tag{10}$$

a result which can be interpreted by considering the zig zag motion of a ray between mirror M

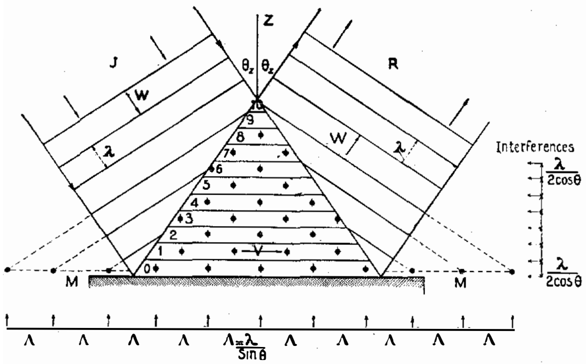


Fig. 20—Reflection on a Mirror M of an Incoming Wave J Producing a Reflected Wave R.

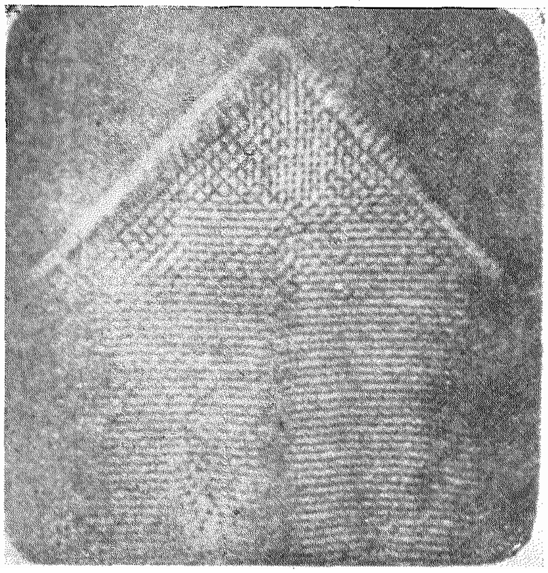


Fig. 21—Interferences Between Ultrasonic Waves Reflected on Two Mirrors at 45°.

and M' (Fig. 23). On the other hand, angle θ is connected with the distance d between the mirrors because the integral number n of dark fringes is fixed. Hence

$$d = \frac{n\lambda}{2\cos\theta} = \frac{nW}{2f\cos\theta}. \tag{11}$$

Formulae (9) and (10) yield relation (8). Eliminating θ from (9) and (11) one gets

$$\left(\frac{W}{V}\right)^2 + \left(\frac{nW}{2fd}\right)^2 = 1, \tag{12}$$

a relation represented by an elliptical curve as shown on Figs. 17 and 18, where ordinates are W/V and abscissae, $\lambda/d = W/fd$. Cut-off frequency f_1 corresponds to the limiting conditions

$$V = \infty, \qquad U = 0, \qquad f_c = \frac{nW}{2d}, \qquad \theta = 0. \tag{13}$$

This very simple example is important to consider, as it yields directly the most typical features of guided waves inside hollow tubes, and enables an elementary explanation of the velocity relation. It should be kept in mind as a very valuable visualization of guided wave properties.

6. *Rectangular Cross Section*

This problem may be studied next, and presents no mathematical difficulty. Inside the cross section a typical interference pattern may be

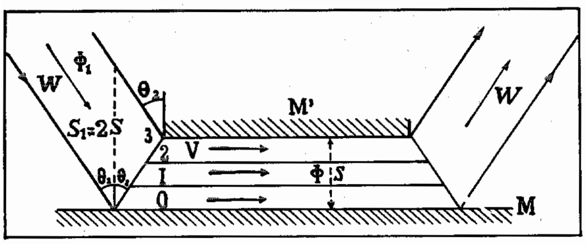


Fig. 22—Interference Fringes Between Two Parallel Mirrors.

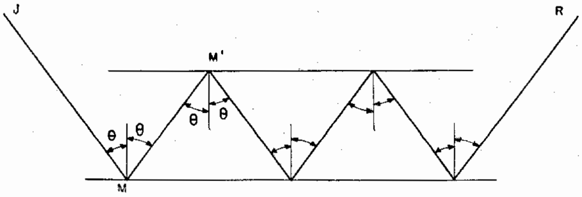


Fig. 23—Path Followed by a Ray Reflected Between Two Parallel Mirrors.

built up as shown in Fig. 24. Such a pattern is defined by two integers n_1 and n_2 giving the number of nodal lines in both directions. Theory yields the following relation for the phase velocity V inside the tube:

$$k^2 = \pi^2 \cdot \left[\left(\frac{n_1}{a}\right)^2 + \left(\frac{n_2}{b}\right)^2\right], \tag{14}$$

$$\left(\frac{W}{V}\right)^2 + \left(\frac{kW}{2\pi f}\right)^2 = 1. \tag{15}$$

a, b, two sides of rectangular cross section,

f, frequency,

k, proper value corresponding to the n_1, n_2 mode.

Formula 15 is represented by an elliptic curve, as shown in Fig. 25. Cut-off frequency f_c is obtained by making V infinite:

$$f_c = \frac{kW}{2\pi}. \tag{16}$$

Equations (14), (15), (16) are markedly similar to (12), (13) of the preceding section.

Writing down Maxwell's equations, one finds that each set of two integers $n_1 n_2$ may be used to define two distinct modes of vibration, one yielding an electrical wave and the other a magnetic wave. These names are derived from the fact that the first wave possesses a longitudinal component for the electric field and no magnetic longitudinal component. Conditions are reversed for the so-called magnetic wave; the only difference to be noticed is that the electrical wave completely disappears when any one of the integers $n_1 n_2$ is zero, while magnetic waves can still be formed in this case.

It is a general result that the inverse proper value k^{-1} and the cut-off wavelength λ_c are proportional to the transverse dimensions of the cross section if the shape of its boundary is maintained. This enables us to discuss the role played by the boundary shape, reducing the area

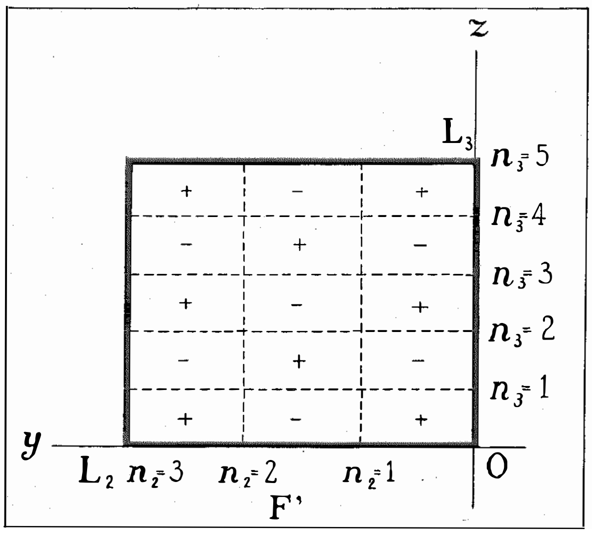


Fig. 24—Distribution of Vibrations in the Cross Section of a Rectangular Pipe.

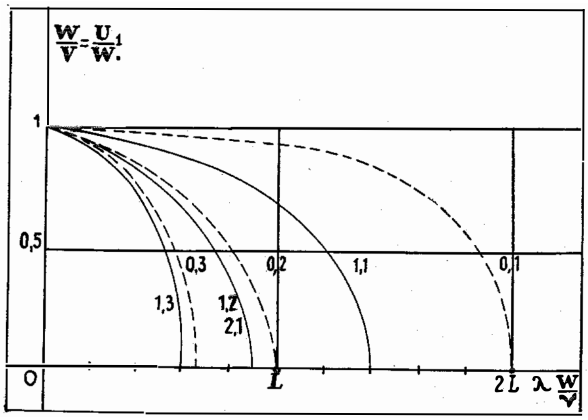


Fig. 25—Set of Elliptic Curves Giving the Ratio of the Velocity w of Free Waves to the Phase Velocity of Waves Propagating in a Rectangular Section Pipe.

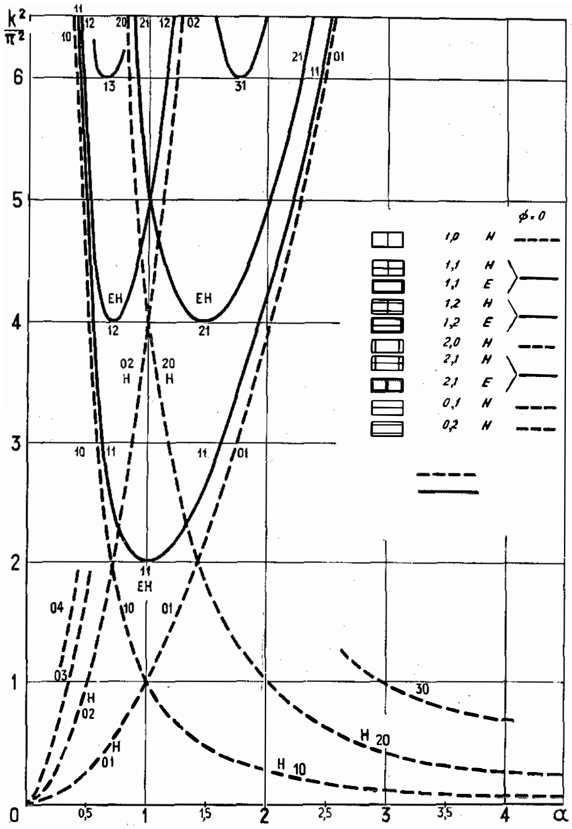


Fig. 26—Diagram—Rectangular Cross Section.

of the cross section to a constant value, by taking

$$ab = 1.$$

Such a chart has been drawn in Fig. 26, showing the dependence of $(k/\pi)^2$ as a function of a; a equal to one means square cross section; $a > 1$ represents a rectangle with longer horizontal side a then vertical b.

Such a diagram is very interesting to discuss. One point should be emphasized relating to the stability or instability of different waves with respect to a deformation of the cross section. Some curves ($n_1 = 1$, $n_2 = 1$ or 1.1 curve for instance) pass through a minimum for square cross section ($a = 1$) which means that a small alteration of the cross section will only slightly perturb the wave and its phase velocity. This wave type is stable; but other waves behave very differently. Let us consider the 0.1 and 1.0 waves which yield two distinct curves intersecting for the square cross section. Any distortion from square cross section to a slightly rectangular one will affect the wave by splitting it into two parts (0.1 and 1.0) with different velocities; such case corresponds to unstable waves.

7. *Circular and Elliptical Cross Sections*

If interesting in itself, the case of tubes of rectangular cross section is of no great practical value. Tubes are more likely to be built with circular cross sections so that deformations then consist of alteration to an elliptical form. This explains why different authors [6] insisted upon treating the problem of wave propagation inside tubes of elliptical cross section. Complete discussion leads to normal modes showing elliptical and hyperbolical nodal lines, as shown in Fig. 27. These proper modes of vibration are governed by Mathieu functions, on which numerical calculations prove rather troublesome. They yield charts similar in general aspect to the preceding one. Calling a and b the two semi-axes of the ellipse and keeping its area constant by taking

$$ab = 1,$$

one is able to draw the curves of Fig. 28 for electric waves and Fig. 29 for magnetic waves.

[6] L. Brillouin, *Electrical Communication*, 1938, **16**: 350. L. Brillouin, *Bulletin Soc. Franç. Electriciens*, 1938, **8**: 899. L. J. Chu, *Journal of Applied Physics*, 1938, **9**: 583. Schelkunoff, *Journal of Applied Physics*, 1938, **9**: 484.

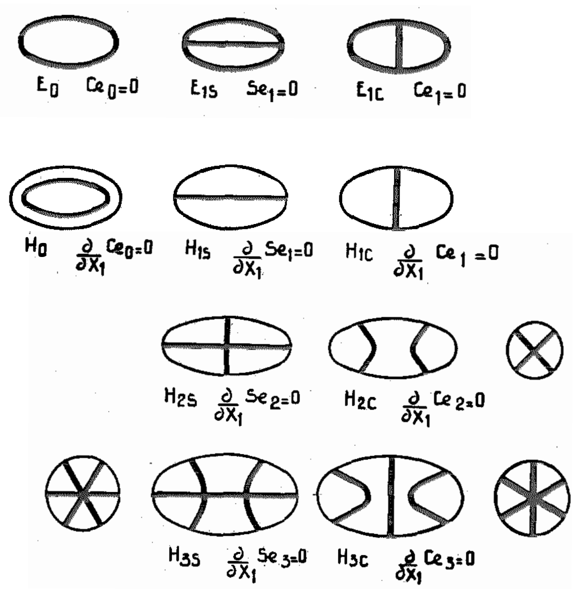


Fig. 27—Nodal Lines for Elliptic Cross Section.

Curves showing a minimum for circular cross section ($a=1$) correspond to stable waves, while the unstable waves are represented by intersecting curves. Thus the E_0 wave is stable; the E_1 wave is unstable (Fig. 28); the H_0 wave is stable, and the H_1, H_2 and H_3 waves are unstable (Fig. 29).

The very important point is the stability of H_0 waves, as these waves may prove to be of very great practical value, due to their small attenuation properties, as discussed in section 5 (Fig. 19).

A great many interesting features could be deduced from the consideration of curves and charts shown in the preceding figures, but it would exceed the scope of this paper.

What should be emphasized as a conclusion is the great interest of hyperfrequency oscillations and waves, both for the physicist and for radio or telephone engineers. A new field of research is being opened here, with very curious theoretical and technical problems and a prospect for important practical applications.

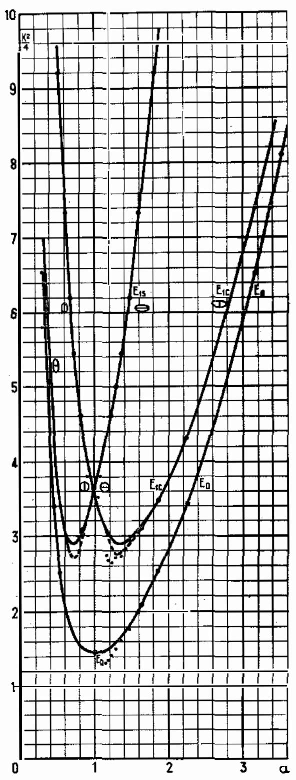


Fig. 28—Electric Waves.

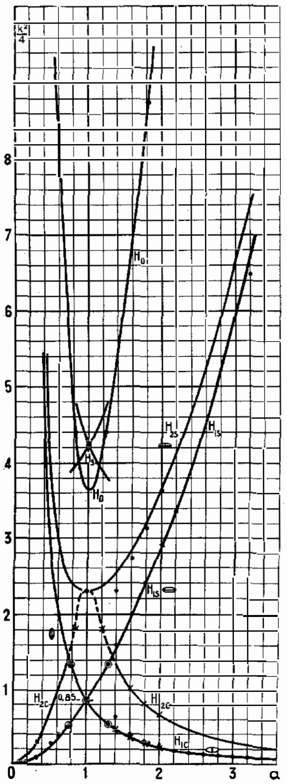


Fig. 29—Magnetic Waves.

The Evolution of the Supertension Cable*

By T. R. SCOTT, D.F.C., B.Sc., M.I.E.E.,
Standard Telephones and Cables, Limited, London, England

SINCE Ferranti installed the first 10-kV cable at Deptford in 1890 there has been a slow but steady improvement in the quality and performance of high-tension cables. The somewhat primitive insulation of the Ferranti cable soon gave place to the well-known "solid" or "mass impregnated" insulation, enclosed in a lead sheath, which is characteristic of the majority of paper-insulated cables for working voltages (e.g., 6.6 kV or 11 kV) normally employed in the mains of supply authorities.

Improvement in quality steadily proceeded, but little change in basic design was evident until about 1920. About this time it became questionable whether solid insulation could be developed to work at sufficiently high electrical stresses to enable 33-kV and 66-kV cables to be produced on an economical basis.

Electrostatic Screening

The introduction of electrostatic screening by Hochstadter, leading for example to the design of the now well-known beltless 33-kV 3-core cable, solved the problem as far as 33 kV was concerned. Nevertheless the doubt remained concerning higher voltages; in particular there seemed little possibility of solid cables being designed for working voltages of 132 kV.

Cable engineers therefore turned their attention to variations of the standard design. It was quite evident that primarily one problem had to be solved, viz., the prevention of ionisation of voids formed by the thermal expansion and contraction of the oil or compound in the insulation during variation of the load. In the solid type of cable the expansion of the oil, at least beyond certain limits, is known to cause permanent distension of the lead sheath and to introduce "unimpregnated" space within the lead sheath when the cable is subsequently working under low load conditions.

The first commercially developed attack on the problem consisted of the provision of devices for maintaining constant oil volume in the cable, the surplus hot oil being housed in conveniently situated reservoirs outside the cable until required for reimpregnation purposes during any subsequent drop in the applied load. The Chicago and New York oil-filled cables of 1923/5 brought this system into prominence.

Solutions to Insulation Problem

The primary problem can, however, be solved in a variety of ways and as a result there is now a multitude of types and sub-types of supertension cable. This has caused a certain amount of confusion in the mind of the non-specialist. The rival claims of oil-filled, gas-filled, gas-pressure, gas-cushion, etc., cables are debated in technical circles. Arguments are put forward for and against the various devices employed.

The necessity of excluding gas from the insulation is denied by those who claim advantages from the inclusion of compressed gas. A contrary view is expressed by others. It would appear that the supertension field is becoming more and more complicated instead of becoming, as one would logically expect, simplified.

There is a simple explanation of this situation and it would therefore appear to be opportune to analyse simply and without too great scientific detail the fundamental problem underlying this apparent state of confusion so that, perhaps, more rapid progress can be effected in the direction of simplification and standardisation.

It is impossible at this stage to forecast with any certainty the form which the standardised supertension cable will eventually take. A large number of types can undoubtedly be accepted as practical propositions. What is not yet known is the precise factor of safety of each type. A standardised and accepted factor of safety must be set up and the economics of each type must be worked out and contrasted. At present the tendency is to compare types on the basis of standardised thickness of insulation. This results

* Reprinted from The Electrical Engineer, March 1, 1940.

in varied factors of safety and distorted economic comparisons.

CHARACTERISTICS OF SOLID TYPE CABLES

It is useful at the outset to study in some detail the characteristics of the solid type cable. There are two justifications for this course. First, it is by no means certain that the range of application of the solid type cable will not be extended to include 132 kV; the solid type cable must therefore be considered as one of the types referred to above. Secondly, the characteristics of the solid type cable are worthy of study in that they serve to illustrate and exemplify some of the complicating factors encountered in the study of other types.

It is assumed by many that the weakness of the solid type cable is well known and that no antidote exists. It is alleged that expansion of the oil on load causes distension of the lead sheath, and that, on cooling, the oil contracts leaving voids which ionise and cause deterioration leading to eventual breakdown. The actual phenomena occurring are much more complicated, and from the complications benefits accrue which result in increased length of life.

Cushioning Effect of Gas

The first point worthy of attention is that despite the great care taken in respect of drying, evacuation and impregnation of modern cables there is nevertheless a residual atmosphere of water vapour and gas. This exists even if impregnation is effected after sheathing, so that it exists even in oil-filled cables. When the lead temperature increases and the oil expands this residual gas is compressed. Some of it is dissolved, and part of the increased volume of the oil is accommodated at the expense of a comparatively small increase in pressure within the sheath.

The magnitude of this cushioning action obviously depends on the efficiency of the impregnation process; the more efficient the process the less the cushioning effect. As a general rule some 25°C rise in conductor temperature may be effected without exceeding the limits of cushioning, and causing internal pressures of the order of magnitude necessary to effect serious distension of the sheath.

It may be interpolated here that the development of a cable compound whose coefficient of expansion was one-half of the normal value would extend this range to 50°C and would radically alter the status of the solid cable. It is by no means improbable that such a development will be realised.

It may also be noted that the gas-pressure ("compression") cable exhibits the same cushioning effect, and actually utilises the effect in its detailed operative design.

As stated above, if the solid cable impregnated with normal oil is heated to a temperature such that high internal pressures are recorded (e.g., 100 lb./sq. in.), the lead sheath is permanently distended and on cooling "unimpregnated" space is left within the sheath. It by no means follows, however, that the unimpregnated space is ionisable under the electrical stress applied. This may be partly due to a proportion (at least) of each space being outside the electrical field and partly due to the dispersion of the voids into small nuclei.

The former reason may perhaps account for the well-known superior performance of cables containing filler spaces or wormings situated outside the electric field. The latter may be due to emission of oil from the impregnated paper to the gaps and spaces existing between paper tapes.

Ionisation

More important still, as shown in a recent paper* by R. C. Mildner and the writer, cables may under severe working conditions exhibit a limited degree of ionisation without undue shortening of life.

This observed ionisation may be partly due to the unimpregnated space created by the distension of the lead sheath, but it may also be partly due to the "gas cushion" referred to above, i.e., the residual gas left in the dielectric at the end of impregnation.

It should be noted that ionisation tests are normally taken at atmospheric temperature, and that all oil-impregnated cables (whether solid type, compression type or oil-filled type) normally exhibit a small but finite ionisation factor

* T. R. Scott and R. C. Mildner, "Long Period Ageing Tests on Solid Type Cables," *I.E.E. Journal*, 85, No. 511, July 1939.

during acceptance tests. The ionisation factor is perhaps less than 0.0005 on acceptance test at 15°C, but this is at atmospheric pressure. The solid type cable will probably be at a pressure level less than atmospheric after a severe heat cycle, and the ionisation will therefore be aggravated. Incidentally the oil-filled cable would be similarly placed if anything happened during cooling to retard the restoration of the normal working hydrostatic pressure.

The paper referred to above seems to produce evidence that a well-impregnated solid type cable on life test or under working conditions exhibits a stabilised ionisation factor the value of which increases with increase in magnitude of the electrical stress constantly applied. This stabilisation may be due to a state of equilibrium set up by production of hydrogen gas, the absorption characteristic of the oil (in respect of solution of gas), the ambient pressure, etc.

When the stress is raised sufficiently to produce an ionisation factor greater than some critical value determined by the physical characteristics of the cable, cumulative effects come into action and breakdown occurs.

Such cumulative effects appear to be associated always with "coring" of the paper tapes after the manner of the phenomenon exposed by Robinson.* It may be that phenomenon is assisted by the expulsion of oil from the paper tapes on heating, and failure of the oil to return to the fibrous structure on cooling. The smaller the volume of oil in the paper tapes the easier it is for this coring action to take place.

Reduction of Gas Content

During the last ten to fifteen years the solid type of cable has been steadily improved in quality due to improvements in the materials, but, above all, due to improvement in the impregnation process. Ionisation factors have on the average been reduced to about one-fifth of the values existent ten years ago.

If, however, the gas cushion theory is correct—and there appears to be sound experimental evidence in support of it—then there may be danger in reducing the residual gas content too far lest excessive distension of the lead sheath should occur, ionisation increase rapidly and breakdown occur.

Against this suggestion may be adduced the equilibrium ionisation theory given above, which would postulate a permissible reasonable ionisation factor exhibited by the cable after subjection to a series of heat cycles commensurate with its full load capacity; this ionisation factor value is, of course, dependent on the value of the electrical stress constantly applied.

Factor of Safety

Experimental evidence appears to indicate that for solid type supertension cables intermittently loaded to 75°C conductor temperature, the critical stress value in respect of ionisation occurs at between 7 kV/mm and 8 kV/mm max. stress. The safe working stress can be evaluated by including factors of safety. For current loading this is usually obtained by bringing down the conductor temperature to a value 5°C less than the test value. For the electrical stress factor of safety there is yet apparently no standardised value; values from 1.25 to 1.737 ($\sqrt{3}$) are employed by various investigators. The effect on the economics of cable design are, however, marked, and it is useless to attempt to compare one type of cable with another until such a value is standardised.

It is no part of the writer's agenda to discuss the correct value for the factor of safety, but two points may be made; first, the employment of too high a factor of safety will militate against reduction of cable costs; secondly, and following on this, the question of thermal instability has to be considered. If somewhat expensive devices are incorporated in the cable system to inhibit ionisation, the limiting factor becomes in reality the temperature of the conductor at which thermal instability (see Brazier†) occurs. It may therefore be sound practice to set up a medium factor of safety on stress, e.g., 1.5, and to increase the factor of safety on temperature, e.g., increase the 5°C allowance referred to above either to 10°C or to 15°C.

If it be assumed that a standardised factor of safety has been set up (for example, 1.5 times working stress and 10°C excess conductor tem-

* D. M. Robinson, "Breakdown Mechanism of Impregnated Paper Cables," *I.E.E. Journal*, 77, 1935.

† L. G. Brazier, "Breakdown of Cables by Thermal Instability," *I.E.E. Journal*, July, 1935.

perature) and that all satisfactory cable types must meet this test by working under these conditions (with, say, two or three full-load applications per week) for several months so that their stability can be demonstrated, then it becomes possible to work out a true economic comparison between types.

The solid type cable will (according to the data published in the Scott-Mildner paper quoted above) at present be restricted to a limit of 5 kV/mm max. working stress and a maximum conductor temperature of 65°C. Against the economics of this design the economics of various types containing "anti-ionisation" devices may be contrasted.

METHODS OF DEALING WITH EXPANSION OF DIELECTRIC

There are two main methods of dealing with this problem—the provision of a gas cushion exterior to the insulation and the provision of a gas cushion within the insulation itself. Some modifications to this general classification will be noted later.

It may not be inconsistent to commence with the type most recently developed, the "gas-filled," since it may be argued that it is more closely related to the solid type of cable in its characteristics and, therefore, may be treated in a continuation of the argument developed above.

Perhaps the simplest approach to the underlying theory has been given by Shanklin.* Translated into the terms used here Shanklin states that all that is necessary is to increase the volume of the gas cushion in a solid type of cable, so that the hydrostatic pressure within the cable is maintained within certain maximum and minimum limits. For the lowest pressure type (unreinforced) a minimum pressure of 10 lb./sq. in. pressure is proposed. This type is advocated for a working stress of 75 volts/mil (3 kV/mm).

This is, of course, an average stress (in accordance with American practise) and does not compare with the maximum stress values referred to above. In Great Britain solid type 33-kV cables work at an average stress of 2.75 kV/mm, and the factor of safety is almost certainly in excess of 1.5. On the assumption that Shanklin's No. 5 test length could not exceed 100 volts/mil and achieve stability, the working stress should not exceed 66 volts/mil (i.e., 2.64 kV/mm). Wiseman in the discussion to Shanklin's paper suggests 55 volts/mil. The temperature of test is, however, 80°C.

Shanklin argues that increase of gas pressure involves additional cost and is uneconomical. On the basis of oil-filled cable design he postulates 10–15 percent increased cost for 40 lb./sq. in. pressure and 20–25 percent increased cost for 200 lb./sq. in. pressure. Moreover, his tests on cables containing gas at 200 lb./sq. in. were on the whole unsatisfactory. It is interesting to note that in the discussion Wiseman attributes the lack of success with high pressure gas to interaction between gas and oil; also Del Mar raises the question of the migration of oil from the paper.

* G. B. Shanklin, "Low-Gas-Pressure Cable," *Electrical Engineering*, July, 1939.

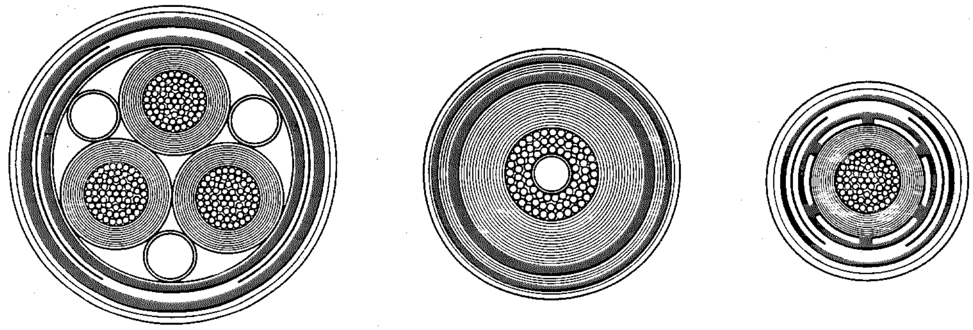


Fig. 1—Illustrating the Ducts in an Oil-Filled Cable.

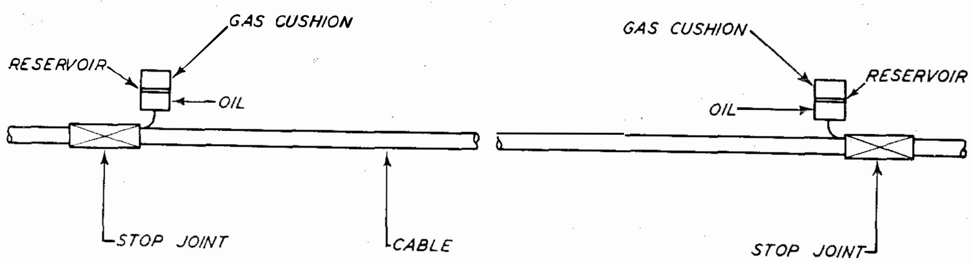


Fig. 2—Hydraulic System of an Oil-Filled Cable.

Turning from America to Europe we find a most interesting résumé of "gas cables" in a paper read at Paris in July, 1939, by Hunter, Dunsheath and Brazier.*

In this paper two gas-filled types similar to the Shanklin are referred to, viz., the Dunsheath type in which a longitudinal gas duct is provided throughout the whole length of the cable, and the Hunter-Brazier type in which a "demi-membrane," e.g., oiled silk, is provided at the exterior surface of the insulation to prevent migration of the cable oil in the insulation.

These cables are both of the high-pressure class.

All types referred to above use the gas filling simply as a gas cushion to take up the expansion of the oil. The oil is, however, the main impregnating fluid and according to the authors quoted the interaction of gas and oil is unimportant. On the published evidence such cables might be expected to work at 11.6kV/mm max. stress and 75°C conductor temperature (on the basis of factors of safety of 1.5 and test temperature less 10°C).

Gas-filled (Internal Gas Cushion)

These authors also refer to the Arman† cable which they designate as "gas impregnated."

This is a correct designation since there is no oil in this cable and the gas must be considered as the impregnating fluid. The gas cushion has been brought to high pressure and expanded to fill the whole insulation to the exclusion of oil.

The importance of the Arman cable lies in the fact that it represents the ultimate characteristics of the cables described by Shanklin, Dunsheath, Hunter, Brazier, etc., if the insulation is finally drained of oil. The ionisation factor, impulse strength and thermal resistivity values are therefore of importance. Generally speaking, if other factors are constant, thermal resistivity increases and impulse strength decreases as the gas content increases and the oil constant decreases.

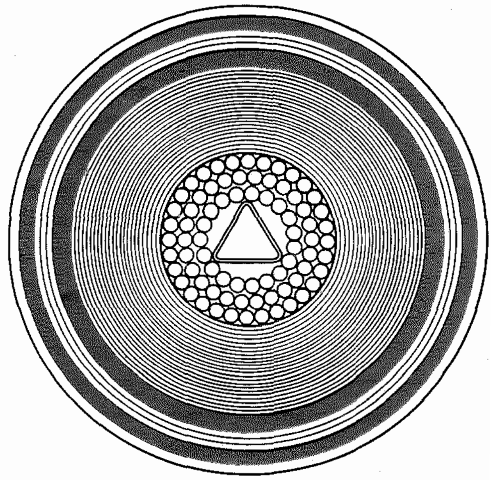
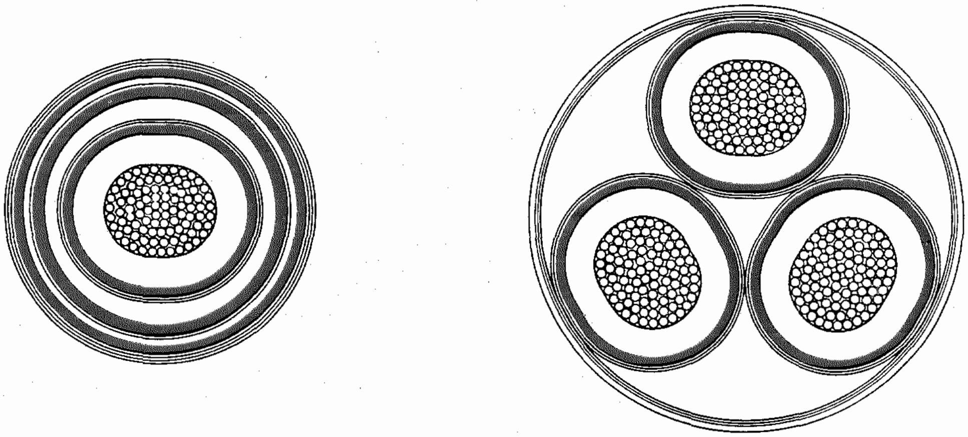


Fig. 3—Simple Form of Gas Cushion Cable.

It appears to be certain that in order to increase the gas cushion effect to a magnitude sufficient to deal with conductor temperatures of

* P. V. Hunter, P. Dunsheath and L. G. Brazier, "*Facteurs Intervenant dans la Conception des Cables à Remplissage Gaseux pour Hautes Tensions,*" C.I.G.R.E., 1939.

† A. N. Arman, "Gas-Impregnated Cables," *I.E.E. Journal*, 1937, Vol. 81, November, pages 625–640.



(a) (b)

Fig. 4—Sectional Views of Two Forms of Compression Cable.

the order of those expected from an economically designed modern supertension cable, allowance must be made for the gas acting as part of the insulation. This involves the use of pressure levels sufficiently high to ensure a satisfactory factor of safety at a stress value sufficiently high to compensate for the increased cost introduced by the necessary reinforcement. Pending further published information on the ionisation and impulse strength of gases under high pressure, it is difficult to estimate the eventual economic level of such cables.

There is, however, a sub-type of cable in this class; this is exemplified by the Beaver* cable.

In this sub-type the gas is allotted a definite role in the insulating of the cable. This role is not precisely one similar to the gas cushion effect described above. It is probably simpler in this case to consider that the insulation consists of tapes of solid material with the interstices filled with gas at high pressure. The gas expands and contracts under applied heat cycles, but it definitely constitutes a part of the insulation. Beaver employs tapes pre-impregnated with a compound which does not melt at any temperature within the working range of temperature. There is therefore no worry regarding migration of compound with potential subsequent "coring" of the tapes.

The writer† has suggested the use of paper tapes impregnated with polystyrene as an alternative.

The presence of gaseous paths (albeit circuitous) from conductor to screen or sheath, however, raises definitely queries regarding the thermal and electrical behaviour of gases under high pressure.

Compensation Devices (External Gas Cushion)

All these cables have this in common that they have, in relation to the solid type cable, increased gas content within the lead sheath. We now come to cables employing compensation devices in which the additional gas content is kept outside the cable. Such cables without exception are manufactured to give the lowest possible gas content within the sheath. They are thus fundamentally high quality solid type oil-filled cables.

One of the earliest types and one that is still the most popular employs ducts of low hydraulic

* C. J. Beaver and E. L. Davey, "The Gas-Filled Cable," C.I.G.R.E., 1937.

† T. R. Scott, "Esterified Styrenated Insulation in the Power Field," C.I.G.R.E., 1939.

resistance and external reservoirs placed at suitable points. The ducts are illustrated in Fig. 1 and the hydraulic system is schematically laid out in Fig. 2.

It will be seen that the additional gas cushion has been removed to the external reservoir and has been sealed off from contact with the oil. Since the additional gas cushion is not uniformly distributed along the length of the cable a time lag is introduced which, unless the hydraulic design has been carefully executed, may result in a serious reduction of pressure at points in the cable removed some distance from the feed points. The cable at such points will tend to behave as a solid type cable. Since, however, the insulation must be worked at a higher stress than that of the solid cable in order to cheapen the cable and so cover the cost of the feed points, there is much greater danger under such circumstances.

It will be noted that in estimating the factor of safety of this class of cables in relation to the economy of the cable, the hydraulic system must be taken into account.

If the cable route is hilly, or if the distance between feed points is great, the pressure level in

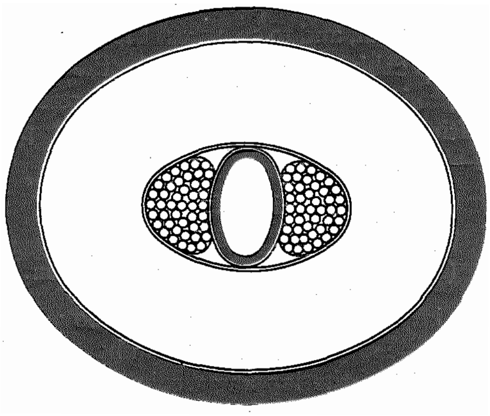


Fig. 5—Lead Sheath Cable Compensator.

the cable must be raised. This in turn introduces reinforcement of the cable sheath and additional cost (see Shanklin's remarks quoted above regarding cables working at 40 lb./sq. in. and costing 10–15 percent more). Because the pressure level is raised to 40 lb./sq. in. it does not follow that the cable is a "pressure cable." The 40 lb./sq. in. will not exist at certain times at certain points in the cable. In fact the condition at such points will be similar to those in the low-pressure oil-filled cable and may be little better than those in a solid type cable.

There is a Swiss design (Cortaillod) which works at even higher pressures than those quoted above, and this cable may have a fairly high pressure level as a minimum under all conditions of load and route. There is also the high-pressure Oilostatic cable exploited by the Okonite-Callender Company in U.S.A.

Fundamentally all these cables are in the same class; they all provide a gas cushion at feed points and endeavour to maintain a "minimum pressure" at the points hydraulically farthest distant from the feed point. They do not, however, necessarily maintain the rated pressure of the system at all points under all conditions.

In contrast to cables with longitudinal flow to and from the "gas cushion" there is a class in which the gas cushion is distributed along the length of cable. Unlike, however, the gas-filled types described by Shanklin, Dunsheath, Hunter and Brazier, the gas cushion is segregated from the oil. The simplest form of this type is illustrated in Fig. 3 and is usually associated with the name of Chase. The compensator is compressed as the oil expands and constant volume is maintained within the sheath. This simple type has not met much success commercially so far owing to material and cost difficulties.

The Compression Cable (External Gas Cushion)

The best and cheapest mechanism for compensation uniformly distributed along the length of cable appears to be the lead sheath. The best known type utilising this device is probably the "compression cable" formerly known as the gas pressure cable and described by Hochstadter, Bowden, and Vogel.* Two forms are illustrated in Figs. 4*a* and 4*b*. The gas cushion is exterior to the lead sheath which if suitably reinforced acts as a satisfactory diaphragm. The diaphragm must of course be non-circular in section under low-load conditions. The gas pressure need only be high enough to produce diaphragm action. In

* Hochstadter, Bowden and Vogel, Royal Society of Arts, November 17th, 1931.

practise, however, it is usual to apply excess pressure outside the diaphragm so that the insulation is compressed.

So far as can be seen at the present the use of a lead diaphragm is likely to lead to the cheapest form of "distributed compensator" for oil-filled cables. Another form of lead sheath compensator developed by the laboratories of Standard Telephones and Cables Ltd., but not hitherto described or put into commercial service, is shown in Fig. 5. The expansion of the oil tends to distort the oval lead sheath into a circle. On cooling, the pressure in the compressed "spring" (in the centre), restores the ovality.

The oil-filled compensated cables have the advantage, over cables in which gas is included in the insulation, that the thermal resistivity of the insulation is lower. In the discussion of Shanklin's paper it is pointed out that the value for well-made oil-filled cables is of the order of 450; ordinary solid cables after heat cycles resulting in unimpregnated or gas space exhibit values in the range 700–900; gas-filled cables must exhibit progressively higher values until the Arman cable (consisting of unimpregnated paper) is reached as the ultimate limit of high resistivity.

Of course, cables which provide an annular gas space outside the insulation must be rated in terms of the thermal drop across this gas space, unless it is thermally short circuited by the introduction of metal spacers (which, however, add to the cost).

There is in some quarters also a tendency to distrust the behaviour of the lead sheath in compensated oil-filled cables, particularly those which use the lead sheath as part of the compensating mechanism. It is true of all cables that defective lead sheath will lead to serious trouble, but the large mileage of Hochstadter compression cable operating in Germany and elsewhere proves conclusively that with sound design and manufacture there is no occasion for distrust.

USE OF PRESSURE

What has already been written indicates clearly that the use of the word "pressure" in connection with cables must be qualified by some comment on the purpose for which the pressure is applied. In all cables in which gas is introduced into the insulation, the purpose of the introduction of the gas is to increase the pressure of any voids or gas spaces which may be formed. Pressure is therefore an essential feature. The magnitude of the pressure is simply a question of economics and factor of safety.

In the oil-filled cable supplied with external compensators at feed points, the rated pressure of the compensator is concerned primarily with the maintenance of oil filling of the insulation at all points in the insulation however far (hydraulically) they may be from the feed point. Again the question of increase of pressure level so that no point in the insulation falls below that pressure level is simply one of economics and factor of safety. The type, however, has the disadvantage that a pressure drop longitudinally must occur under certain conditions, so that the minimum pressure level below which the oil never falls at any point in the cable must be lower than the level for which reinforcement is applied.

Hochstadter Cable

The compression (Hochstadter cable) is seldom if ever used purely as a compensating cable. Additional pressure is added to raise the minimum pressure level of the oil within the diaphragm sheath, and to compress the paper insulation. This cable would appear to be the only type so far produced which actually "compresses" the insulation. It therefore covers three points, viz.:—

(*a*) Compensation of oil expansion
(*b*) Increase of pressure level of oil
(*c*) Compression of paper insulation.

The importance of (*a*) and (*b*) above is self-evident; the importance of (*c*) can be ascertained by a study of the lapping weaknesses of cables as illustrated by the styrene wafer technique of Wyatt, Smart and Reynar.*

It can therefore be stated that dielectrically the compression cable offers prospects of working at higher electrical stresses than any other cable so far put forward.

This does not necessarily infer, however, that it is economically preferable. That point remains

* K. S. Wyatt, D. L. Smart and J. M. Reynar, "Mechanical Uniformity of Paper-Insulated Cable," A.I.E.E., January, 1938.

to be proved when the limitations of all other types have been fully explored.

These limitations may all be expressed in terms of electric stress. In a simple form they may be stated as the relative ultimate value of dielectric strength of:—

(i) Gas alone
(ii) Gas in oil
(iii) Oil substantially free from gas,
all these being under high hydrostatic pressure (e.g., 6–15 atmospheres).

At these pressures there is little variation in cost due to variation of pressure. The main economic factor is the electrical stress which can be employed, i.e., the minimum radial thickness of insulation which can be safely used for any given working voltage.

There is so far no direct comparison of (ii) with (iii) although, in comparison with the test values quoted above for the Hunter-Brazier cable, statements made recently by Hansson* appear to indicate that (iii) should be superior. Hansson's values, however, relate to condensers and direct comparison on the basis of cable results is still awaited.

Again, although cables designed on the basis of (i), e.g., the Arman cable should be inferior to both (iii) and (ii), deductions on a theoretical basis are unsafe in the case of the Beaver cable which, as previously mentioned, depends partly on gaseous paths and partly on "solid" tapes for its electric strength.

It was argued above that the compression cable possessed an additional advantage, i.e., the compression of the paper tapes. Before this advantage can be estimated economically, however, it is necessary to make allowance for the effect of thermal instability. It may be that this characteristic will prove to be the limiting factor in the rating of future cables. In other words, the limiting factor in respect of reduction of insulation thickness and increase of electrical stress may be thermal.

Hansson, in the article referred to above, suggests that thermal stability is improved by increase of pressure, but there is insufficient evidence at present to permit of definite quantitative estimation of such effects.

* Hansson, *A.S.E.A. Journal*, September, 1939.

ECONOMICS

Enough has been written in this article to illustrate the argument advanced herein that the time has not yet come when definite gradings of the numerous types of modern supertension cables can be established. Proof has still to be established of the ultimate strength of each type on the basis of established stability under intermittent loading, which exceeds the rated loading to the extent of 5° or 10°C excess conductor temperature. The ultimate stress which can be maintained "indefinitely" on each type under such conditions must be established.

The utmost simplicity of design (resulting in lowest cost) for these results has to be worked out. Cable users must accept and standardise an agreed factor of safety which reduces the stress rating to some proportion of the ultimate stress (as defined above) and which reduces the current loading to some proportion of that successfully applied in the pricing test. The hard facts of an economic study will thereafter eliminate type by type, until only the best from this point of view survive.

Internal gas cushions would, in the absence of direct comparative data, appear theoretically to be handicapped by the dielectric characteristics of gases in their struggle for superiority over external gas cushions, provided that a high pressure level is displayed in the latter, and provided that dielectric losses in the region 70°C to 80°C can be reduced to values which eliminate the possibility of thermal instability.

If the margin of inferiority is, however, slight, the cost of segregating oil from gas may leave both types in continuous competition. The evaluation of the comparative characteristics on a basis of directly comparable test results of the type described above would clear up this point and bring about the desired simplification of the supertension cable field. The evaluation of the paper insulated cable would be completed.

It should be observed, however, that in such economic studies factors other than those directly associated with cable design may well be of considerable importance. The cost of installing, jointing and terminating cables is a very large proportion of the cost of an underground transmission line. Also the capacitance of such a line may require neutralisation, and this neutralisation may be expensive. The higher the stress at which the cable is worked the higher in general the capacitance of the line.

There may therefore be an economic limit to the reduction of insulation. This may be expressed perhaps as a standardised higher factor of safety, in which case the elimination of inferior types will still proceed as outlined above. Alternatively since all the types at present under consideration comprise insulation of a fibrous nature (the permittivity of cellulose is approximately 7) we may see an effort made to substitute non-fibrous insulation of lower permittivity. The nature of the insulant proposed will undoubtedly influence the type of mechanism employed to inhibit ionisation.

So far, however, no such type has entered the lists against the gas-filled, oil-filled and compression types discussed in this article.

Recent Telecommunications Developments

APPLICATIONS OF STYRENE TO H. T. CABLE SYSTEMS.—The Laboratories of Standard Telephones & Cables, Limited, London, for over ten years have been working on problems associated with the utilisation of polystyrene as insulation for high voltage and high frequency equipment.

Development progress in the power cable field in connection with joints and terminations has been so rapid in recent years that the International Standard Electric Corporation (I. S. E. C.) has obtained permission from the British Government for Mr. T. R. Scott, Chief Engineer of the Power Cable Division, Woolwich, London, to visit the U. S. A. to assist in setting up arrangements whereby this technique may become available to American utilities and cable makers. Mr. Scott's schedule of addresses, beginning April 29, included the Power Group of the New York Section of the A. I. E. E.; Round Table Group, Michigan Section, A. I. E. E., Detroit; Edison Electric Institute, Chicago; Group Discussion, Commonwealth Edison Co., Chicago; Underground Distribution Engineers, Boston; Insulation Power Cable Engineers Association, New York; and local Sections of the A. I. E. E. in Cincinnati, Cleveland, Kansas City, Buffalo, Pittsburgh, St. Louis, and Toronto (Canada).

The I. S. E. C. proposes to install plant for the manufacture of styrenated papers, styrene/rubber, etc. (processed materials necessary for the applications indicated above), and is at present engaged in a study of the particular needs of American utilities and of the raw material situation with respect to quality and cost. It is expected that the cost level of the required materials is likely to decrease in the near future so that the utilisation of styrene, not only in the H.T. insulation field but also in the high frequency insulation field, may become more universal.

It will be remembered that Mr. Scott, in association with Mr. J. K. Webb, between 1937 and 1940 published a series of articles in this journal dealing with various aspects and stages of these styrene researches.

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LA PAZ (BOLIVIA) RADIO TELEPHONE SERVICE.—As a feature of Pan American Day celebrations, the Mayors of five South American capital cities extended their greetings by telephone to the Mayor of La Paz, Humberto Munoz Cornejo, on the inauguration of automatic telephone service in La Paz and the opening of radio telephone service between all telephones in La Paz and the rest of the world. Mayor Carlos Alberto Pueyrredon spoke from Buenos Aires; Mayor Rafael Pacheco Sty, from Santiago; Mayor Henrique de Toledo Dodsworth, from Rio de Janeiro; Mayor Horacio Acosta y Lara, from Montevideo; and Lieutenant Mayor Dr. Aurelio Garcia Sayan spoke on behalf of Mayor Luis Gallo Porras of Lima.

The linking of the new automatic system of La Paz with the short wave radio stations of Compania Internacional de Radio Boliviana (CIRBOL) marks the latest step in the progressive development of an intra-continental telephone service—a service that has brought the vast majority of South American telephone subscribers within speaking distance of each other, and also has made them a part of the virtually world-wide telephone network.

A dozen years ago international telephone service in South America was non-existent. It was initiated under the aegis of the International Telephone and Telegraph Corporation on October 12, 1929, when service between Argentina and Uruguay, on the one hand, and Spain on the other was established. Shortly thereafter (on April 3, 1930) telephones in Argentina, Uruguay, and Chile were inter-connected with those of the United States, Canada, Mexico, and Cuba. Today, international telephone service embraces all telephone subscribers in Argentina and Chile; in Rio de Janeiro, Sao Paulo, Santos and surrounding territory in Brazil; in Montevideo, its suburbs, as well as coastal resorts in Uruguay; in Asuncion, Paraguay; in Lima, Callao and various other Peruvian towns; in Bogota, Colombia; in Caracas, Venezuela; and now in the Bolivian capital, where heretofore international radio telephone service was available only from a centrally located booth in La Paz. Thus, South America's present day international telephone network can be depicted by an international map on a station-to-station basis that for completion lacks only a small minority of existing subscribers.

Bolivia's inclusion in the international telephone family was effected through CIRBOL's interconnection with Compania Internacional de Radio (Argentina), (CIDRA), one of several I.T.T. associated radio companies in South America. CIDRA, in fact, serves as Bolivia's telephonic outlet not only to neighboring republics, but to most Western Hemisphere countries and to continents overseas.

The transmitter of the La Paz station, located at El Alto de La Paz, is an International Telephone and Radio Manufacturing Corporation (formerly International Telephone Development Co.) type 100A with 1.5 kw carrier power, capable of delivering peak modulated energy of 5 kw to the antenna. For continuous wave telegraphy, it supplies 3 kw antenna power and can be operated on any frequency from 4,000 to 21,000 kc, thus permitting use under diverse conditions. It is equipped with air-cooled tubes and the operation is semi-automatic. A secondary transmitter is employed exclusively for telegraph traffic.

Five modern superheterodyne receivers have been installed for use both in the telephone and telegraph services. These receivers, as well as the transmitters, are maintained in adjustment by an operator at the station under the direction of the technical operator in the La Paz office.

The transmitting and receiving antennae are of the rhombic and "doublet" types; they have proved their effectiveness in reducing interference to a minimum under all conditions.

The secrecy inverters, control panels, and other telephone and telegraph apparatus are all housed in the Company's main building in the downtown section of La Paz where the commercial office is also located.

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RADIO TERMINATING EQUIPMENT.—For operating conditions in which voice operated anti-singing devices (VODAS) are not required or desired, the International Standard Electric Corporation has designed a simple unit type terminating equipment suitable for connecting radio telephone to wire telephone circuits on a two-wire or four-wire basis.

The equipment comprises a hybrid coil and balancing network panel, a low pass filter panel, a monitoring and control panel, and a line panel suited to the particular telephone network involved. All panels are arranged for mounting in a standard 19-inch cabinet or rack.

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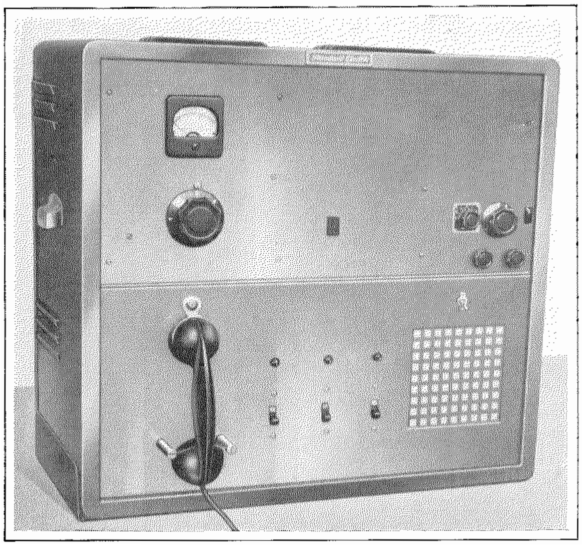
FERRYBOAT RADIO TELEPHONE EQUIPMENT.—Compania Standard Electrica, Buenos Aires, Argentina, recently designed, manufactured and installed short wave radio telephone equipments for use on the train ferries of the Entre Rios Railway, Argentina, plying between Buenos Aires-Ibicuy and Ibicuy-Zârate. The maximum distance covered is 140 km.



The radio transmitter and receiver are assembled in one compact unit, as shown in the accompanying illustration. The transmitter has a carrier power of 45 watts, is arranged for suppressor grid modulation and for rapid selection of four pre-set, crystal controlled frequencies (2,130, 2,280, 6,210, and 6,226 kc). Both the transmitter and receiver operate from 220 volt, 50 cycle, single phase a-c.

The metal cabinet, fitted with a removable cover permitting ready access to the equipment for routine testing, weighs approximately 80 kg (176 lbs.). It is 64 cm high, 66 cm wide, and 33 cm deep (25×25.7×13 in.).