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[1] Further announcements of other Officers and Committees will follow in a succeeding number of the PROCEEDINGS.

THE NAVAL RADIO SERVICE;

Its Development, Public Service, and Commercial Work[1]

By

Captain W. H. G. Bullard, U.S.N.

In considering the naval radio service, it may be well to recall that the Navy Department was the first government department to interest itself actively in radio matters. It is needless to add that from the earliest time on, that department has never lost its interest in this field.

In 1899, Mr. Marconi brought three sets of his apparatus to this country for the use of the "New York Herald" in reporting the international yacht races for that year between the "Shamrock" and the "Columbia." During these trials, the Navy Department directed a board of four officers to observe and report upon the working of the system. Following the report of this board, the department placed two ships and a torpedo boat at the disposal of Mr. Marconi for further experiments with a shore station established by permission of the Treasury Department on the grounds of the Highland Lights, near the entrance to the port of New York. This station consisted of an antenna stretched from the flag pole near the house of the lighthouse keeper, and has the distinction of being the first radio shore station used in the United States. Later a commercial shore station was erected near the same spot and its antenna was supported by a wooden mast, 165 feet (50 meters) high, which was destroyed by fire in November, 1905. A naval shore station was built near the same site in 1903, and abandoned in 1906. The three vessels: the armored cruiser "New York," the battleship "Massachusetts," and the torpedo boat "Porter" were the first vessels of the United States Navy on which radio apparatus was used.

From this beginning, sprang the extensive system of radio shore and ship stations controlled by the Navy Department;

[1] A paper presented before The Institute of Radio Engineers, Washington Section, October 14, 1914. A portion of the subject matter of this address is taken from an article by the author on the "United States Naval Radio Service" (which has appeared in the Proceedings of the United States Naval Institute).

which system now includes over 50 shore stations and approximately 250 ship stations.

On the Atlantic Coast starting, from the most northward station, there follow:

Portland, Maine.
Portsmouth (Navy Yard), N. H.
Boston (Chelsea), Mass.
North Truro, Mass.
Nantucket Lightship.
Newport (Naval Station), R. I.
Fire Island, N. Y.
New York (Navy Yard), N. Y.
Philadelphia (Navy Yard), Pa.
Annapolis (Naval Academy), Md.
Washington (Navy Yard), D. C.
Arlington, Va.
Norfolk (Navy Yard), Va.
Diamond Shoal Lightship.
Beaufort, N. C.
Frying Pan Shoals Lightship.
Charleston (Navy Yard), S. C.
St. Augustine, Fla.
Jupiter. Fla.
Key West (Naval Station), Fla.
Pensacola (Naval Station), Fla.
New Orleans (Naval Station), La.

On the west coast, on the Pacific, in the United States proper, are seen

San Diego, Cal.
Point Arguello, Cal.
Farallon Islands, Cal.
Mare Island (Navy Yard), Cal.
Cape Blanco, Oreg.
North Head, Wash.
Tatoosh, Wash.
Bremerton (Navy Yard), Wash.
Eureka, Cal.

In Alaska there are seven stations, situated as follows:

St. Paul, Pribilof.
St. George, Pribilof.
Unalga.
Kodiak.
Cordova.
Sitka.
Dutch Harbor.

In the Isthmian Canal Zone, there are Colon on the Atlantic, Balboa on the Pacific, and the high-power station at Darien under construction about half way across the Canal.

In the insular possessions, there are stations at

San Juan, P. R.
Guantanamo Bay (Naval Station), Cuba.
Honolulu (Naval Station), Hawaii.
Guam (Naval Station).
Tutuila (Naval Station), Samoa.
Cavite, Philippine Islands.
Olongapo, Philippine Islands.

In addition to the above, there is a station at Pekin, China, for communication between officials of the United States Legation and ships in Asiatic waters, a station at Beaufort, S. C., used for instructional purposes, in the Disciplinary School; and one at Yerba Buena, Cal., for the instruction of operators.

There are authorized, or under construction, a station at the Great Lakes Training Station north of Chicago, and one at Point Isabel at the mouth of the Rio Grande, Texas.

Under authorization is the so-called long distance chain of stations, which will be pushed rapidly to completion. This system comprises Arlington, Darien, San Diego, Honolulu, Guam, Samoa, and a station in the Philippines. Recent experiments seem to warrant the belief that some of these stations will not be necessary, and that the chain of communication between Washington and the Philippines will be complete without some of the island stations. If so, they will be fitted with but medium high-powered stations.

It cannot be said that the development of the so-called United States Coast Signal Service was the result of any original well-planned scheme, but it has grown up slowly according to the needs of the department. Other stations than those mentioned were built and later abandoned as their usefulness in the chain of communication became impaired. At one time it was proposed to have a coast station practically every 100 miles along our sea coast, but as apparatus improved and reliable ranges increased, such a chain meant but useless duplication, and many proposed stations were never built. The power of stations ranges from 2 kilowatts to 100 kilowatts; depending on the strategical location of the station; and the reliable communication range varies with the station's characteristics. Nearly every system of radio apparatus has been in use at one station or another, including apparatus of the earliest design as well as modern systems, using radio frequency sustained waves. Every endeavor is being made to bring the installation of stations up to modern requirements along standard lines, as funds become available.

From the time of the introduction of radio apparatus in the country, other departments of the government naturally became interested in the erection of stations; and a state of affairs arose that demanded some government action in the way of regulation and control, with the main idea of preventing interference which could not be overcome by the apparatus then in use.

In June, 1904, the President appointed a Board, since known as the Inter-Departmental Board to consider the entire question of radio telegraphy in the service of the national government. The Board recommended that the Navy Department should equip and install a complete coastwise radio telegraph system, covering the entire coasts of the United States, its insular possessions, and the Canal Zone in Panama. It also recommended that the Navy Department be directed to receive and transmit thru these stations, free of charge, all radio messages to or from ships at sea, provided such stations did not come in competition with commercial stations. It further suggested that the erection of private radio stations in locations where they might interfere with naval or military operations be restricted by the action of the President, until such time as legislation might be had by Congress on this subject.

On July 29, 1904, the President approved the report of the Inter-Departmental Board and directed that the several departments concerned put its recommendations into effect.

The approval of this report virtually put the control of all coast radio stations under the jurisdiction of the Navy Department, and from that time until the present no other department of the government has operated coast stations with the exception of a few signal corps stations in Alaska, which are a necessary part of the Washington-Alaska Military-Cable and Telegraph System.

PUBLIC SERVICE USES

It was but natural that such a chain of radio stations should find uses other than those based entirely on military considerations, and the operation of these stations was early devoted to shipping interests. They were also made available for the transmission of news to ships at sea including weather reports, dangers to navigation, and other matters; as well as for the reception of messages on similar topics, and calls from ships in distress.

TIME SIGNALS

The transmission of time signals to vessels at sea by means of radiotelegraphy was first accomplished in the United States in 1905, and this service, enlarged and extended, has continued to the present time. This service is of the greatest value to mariners, as it furnishes a means by which the time as given by the transmitted signals may be compared with a ship's chronometer and the error of the chronometer found. Similar comparisons over a number of days enable data to be obtained by which not only the error may be found but also the chronometer rate; that is, the rate at which it is gaining or losing.

The noontime signal on the Atlantic coast is sent out thru the coast radio stations by connection with Western Union telegraph lines from the United States Naval Observatory at Washington, D. C. By the operation of proper relays in electrical circuits, the beats of the seconds of a standard clock in the Observatory are sent out broadcast as a series of radio dots commencing five minutes before the time of the final signal. By omitting certain dots in a series, the comparison between the dots and the beats of the chronometer seconds can be checked until the instant of local noon (75th meridian time), is reached. This is marked by a longer dot which gives the time of exact noon. A comparison with the chronometer time at that instant gives its error referred to 75th meridian time. Applying the difference in longitude; namely, five hours, between the 75th meridian and Greenwich, which is the standard meridian (or 0° longitude), the error of the chronometer referred to Greenwich mean time is determined. Time signals are now sent out on the Atlantic coast only thru the radio stations at Arlington, Key West and New Orleans. Signals from Arlington, which reach a zone formerly served by other coast stations, are sent out every day in the year, twice a day; viz., at noon and at 10 P. M., 75th meridian time. Time signals from Key West and New Orleans are sent out daily, including Sundays and holidays, commencing 11:55 A. M., 75th meridian time, and ending at local noon.

In case of failure for any cause of the Arlington high power station, the signals are sent out by the small set in the same station, and the stations at Boston, Newport, Norfolk and Charleston are notified, and they each send the signals broadcast.

On the Pacific coast, time signals are sent broadcast to sea thru the naval radio stations at Mare Island, Eureka and San Diego, in California, and at North Head, Washington. The controlling clock for each station is in the Naval Observatory at the Mare Island Navy Yard. Signals from Mare Island are sent out every day from 11:55 to noon, and from 9:55 to 10:00 P. M., 120th meridian standard time. Those from North Head, Eureka and San Diego are sent out daily, except Sundays and holidays from 11:55 A. M. to noon, 120th meridian standard time.

It is not necessary that an elaborate radio installation be employed for the purpose of receiving these signals, nor that a skilled operator be in attendance. Any vessel provided with a small receiving apparatus with one or two wires hoisted as high as possible and insulated from all metallic fittings, or preferably stretched between the mastheads with one wire led down to the receiver, may detect these signals when within range of one of the seacoast radio stations. To get the maximum clearness of signals, the receiving circuit should be tuned to that of the sending station. Arlington and Mare Island send on a 2,500 meter wave; North Head and San Diego on a 2,000 meter wave; Eureka on a 1,400 meter wave; and Key West and New Orleans on a 1,000 meter wave. On the completion of the new radio station at the Training Station, Great Lakes, time signals will be transmitted from that station for the benefit of shipping on the Great Lakes, as well as the weather reports for that region now transmitted by Arlington after the Atlantic coast weather bulletin following the 10 P. M. time signals.

WEATHER REPORTS

Thru coöperation with local offices of the United States Weather Bureau, weather forecasts are sent broadcast to sea thru naval coast radio stations at certain times which vary with the locality. Coast stations are generally prepared to give local forecasts to passing vessels without charge on request. Storm warnings are sent whenever received.

Since July 15, 1913, a daily weather bulletin has been distributed by the naval radio stations at Arlington, Va., and at Key West, Fla., a few minutes after the 10 P. M. time signal.

The daily bulletin consists of two parts. The first part contains code letters and figures which express the actual weather conditions at 8 P. M., 75th meridian time, on the day of distribution, at certain points along the eastern coast of North America; one point along the Gulf of Mexico and one at Bermuda. The second part of the bulletin contains a special forecast of the probable winds to be experienced a hundred miles or so off shore, made by the United States Weather Bureau for distribution to shipmasters. The second part of the bulletin also contains warnings of severe storms along the coast as occasions for such warnings may arise.

The points for which weather conditions are furnished are designated respectively by their initial letter, except in the case of Nantucket, for which the letter T is used; accordingly the code is S, Sydney; A, Atlantic City; H, Hatteras; C, Charleston; K, Key West; P, Pensacola, and Br, Bermuda.

The report is made by means of a special code furnished to mariners, and is followed by a general forecast for different zones of the coast. With the information contained in these broadcast messages, mariners should be able to make their own forecasts in addition to that given by the official forecaster at the headquarters of the Weather Bureau at Washington.

A daily weather bulletin for the Great Lakes is distributed broadcast by the Arlington Radio Station, immediately following the bulletin for the Atlantic coast.

This bulletin is similar to that of the Atlantic coast and contains code letters and figures which express the actual weather condition at 8 P. M., 75th meridian time on the day of distribution at the following points, and which are designated as follows: D, Duluth; M, Marquette; U, Sault Ste. Marie; G, Green Bay; Ch, Chicago; L, Alpena; D, Detroit; V, Cleveland; F, Buffalo.

Preliminary arrangements have been made by which weather reports will be exchanged between a Russian station at Anadyr, Siberian Russia, and Alaskan naval stations. This weather reporting service will also be enlarged to include reports from various stations in the West Indies which will be sent out from the high power station at Darien, on the Canal Zone, for the benefit of ships in the Caribbean, on the Pacific side, and those which may be in transit to or from the Panama Canal.

HYDROGRAPHIC INFORMATION

Information concerning wrecks, derelicts, ice and other dangerous obstructions to navigation, whenever received from the hydrographic office or from a branch hydrographic office is sent broadcast from naval radio stations four times daily; viz., at 8 A. M., noon, 4 P. M., and 8 P. M., local (standard) time of station. Ships within range of such stations should be prepared to receive these hydrographic messages at the hours mentioned, and should avoid sending at these times. One vessel sending may prevent several others receiving information necessary to their safety.

Naval stations will furnish information to passing vessels on request whenever practicable at other hours than those mentioned above.

The International Convention on Safety of Life at Sea, which convened in London on November 12, 1913, invited the Government of the United States to undertake the management of the services of derelict destruction, study and observation of ice conditions, and ice patrol in the North Atlantic. By this convention, the master of every ship which meets with dangerous ice or a dangerous derelict is bound to communicate the information by all means at his disposal (the principal of which will be radio communication) to the ships in the vicinity, and also to the competent authorities at the first point of the coast with which he can communicate. This information will be forwarded to the Hydrographic Office, New York, and there made known to the maritime exchanges, and will be further forwarded to the headquarters at Washington to be broadcasted to sea from the Arlington radio station following the time signal and weather reports. At such times ships should be listening on the long wave of Arlington, 2,500 meters, and their receiving circuits should be tuned if they desire to receive these ice or derelict reports. In order to prevent delay in having such information reach as many ships as possible, the coast station which first receives the information will at once broadcast it, and with the increased power, should reach ships that could not be reached by the first reporting ships.*

Another provision of the convention requires that every ship fitted with a radio telegraphic installation which becomes aware of the existence of an immediate and serious danger to navigation, shall report it immediately to the Hydrographic Office, Washington, or to the Hydrographic Office, London. Such information reaching the Hydrographic Office, Washington, will be broadcasted thru appropriate naval stations. The reporting of information concerning ice and derelicts is *compulsory* under the terms of the London Safety Convention; the reporting of information relating to weather is voluntary. Information can be forwarded either in full or by means of a code adopted by the convention.

The radio stations which have to transmit to ships information involving safety of navigation and which is of an urgent character (reports of icebergs, derelicts, cyclones, typhoons, sudden changes in the position or form of fixed obstructions, or of land marks) are required to make use of the following signal, called the safety signal, repeated at short intervals ten times at full power —— —— —— (T T T). All radio stations receiving the safety signal are required, if the transmission of messages by them would interfere with the receipt by any other station of the safety signal and the following safety message, to keep silence, in order to allow interested stations to receive that message.

The safety message will be transmitted one minute after the safety signal has been sent out, and should be repeated thereafter, three times at intervals of ten minutes.

The above information will be sent out by naval stations as soon as it reaches them, and again later by such stations as transmit time signals. It will follow the weather reports.

[1] Ship owners should insist that receiving apparatus should be capable of being tuned to at least a wave length of 3,000 meters, in order to receive these valuable reports.

To provide for prompt warning of vessels in the immediate vicinity of obstructions at sea, as well as of those vessels which will eventually pass thru such danger areas during the course of their voyages, and to provide facilities for transmitting information to the nearest source of assistance promptly in case of vessels in distress, the following procedure is followed by all naval radio shore stations within the continental limits of the United States and Alaska.

Whenever a naval radio station receives information from a branch hydrographic office concerning any damage to navigation, wreck, light vessel off station, etc., that radio station immediately broadcasts such information for the benefit of shipping in the immediate vicinity, and again thereafter at the usual hours: viz., 8 A. M., noon, 4 P. M., and 8 P. M., local standard time. In all such cases the station on the Atlantic coast receiving such information forwards it by radio to Arlington addressed to the Hydrographer.

The Arlington station delivers the report to the hydrographer and broadcasts it at 10 P. M., daily, on 2,500 meters. All radio stations copy the broadcast message, and each in turn broadcasts it (on 1,000 and 600 meters) at the regular hours as given above, for the benefit of shipping in its vicinity.

The procedure on the Pacific coast is the same except that the Mare Island Navy Yard broadcasts to all Pacific stations, and the reports from coast stations are addressed to Mare Island for the Branch Hydrographic Office, San Francisco, and are delivered to that branch hydrographic office.

If information relating to danger at sea reaches a naval coast station by radio or flag signals from a passing vessel, that station at once broadcasts it and informs the nearest branch hydrographic office, if it is possible to do so by radio; which then relays it to Arlington or Mare Island stations for the procedure laid down in the preceding paragraph.

In order that the various naval radio stations may be informed as to the location of the nearest revenue cutter, which in many cases is the nearest source of assistance to shipping in distress, and which has to do with the removal of dangers to navigation, the captain of each revenue cutter equipped with a radio installation informs the nearest naval radio station at 8 A. M. each day, of the location of his ship and concisely her probable movements during the next twenty-four hours.

Each radio station receives such reports and keeps them constantly on hand for guidance in transmitting messages that may require action on the part of a revenue cutter.

GENERAL SHIP TO SHORE WORK

The installations of the naval coast stations, including those on the lightships at Nantucket Shoals, Diamond Shoals, and Frying Pan Shoals are placed at the service of the public generally and maritime interests in particular for the purpose of:

(a) Reporting vessels and intelligence received by radio telegraphy with regard to maritime casualties, derelicts at sea, overdue vessels, and the reporting of all matters pertaining to ships in distress.

(b) Receiving radiograms of a private or commercial nature from ships at sea, for further transmission by telegraph, telephone or cable lines.

(c) Transmitting radiograms to ships at sea from inland points.

Information contained under heading (a) is transmitted free of all costs as far as radio charges are concerned. Readings (b) and (c) relate entirely to commercial work and will be considered separately.

Lightship stations are authorized to transmit reports received from masters of passing vessels to their owners, agents, or maritime agency to the nearest naval radio station without charge, but in all such cases arrangements must be made by such owners or agents for the forwarding of messages by land telegraph from the coast station to the point of destination.

Lightships display storm warnings when information regarding such is furnished them from the Weather Bureau by means of radiograms thru coast stations. Ship owners desiring to use any special code of signals for communicating with lightships fitted with radio apparatus, the messages to be by them transmitted to shore and then to their destination, may make special arrangements with the Navy Department, Superintendent of Naval Radio Service. The radio service connected with the transmission is free, but arrangements must be made with the land lines for the forwarding charges.

Vessels in the trans-Atlantic trade, either incoming or outgoing, make extensive use of the radio installation of the Nantucket Shoal light vessel for reporting their positions. Such messages are relayed to the naval station at Newport, whence they are forwarded to their destination free of all radio charges.

Similarly, the light vessel off Diamond Shoals transmits messages to the naval radio station at Beaufort, N. C., from which station they are forwarded to their destination free of all radio charges.

During certain months in the year, when the whaling and sealing fleet is making its way into or out of Behring Sea, and passing thru Unimak Pass, a revenue cutter is stationed in that vicinity. Vessels fitted with radio apparatus may report the fact that they have passed thru the Pass to the revenue cutter, or forward this information by flag signals if not fitted with radio apparatus. The revenue cutter then transmits this information thru any naval radio station in Alaska and it is relayed to the naval station at North Head, which station transfers the message to its destination; generally the maritime exchanges at San Francisco or Seattle. This service is performed entirely free of all radio charges; owners or agents making the necessary arrangements for the payment of forwarding charges from North Head to destination.

COMMERCIAL WORK OF NAVAL RADIO STATIONS

In April, 1911, by order of the Navy Department, all naval radio stations with the exception of Boston, New York, Philadelphia, Norfolk, New Orleans, Yuerba Buena, Mare Island and Puget Sound, were directed to handle commercial messages under the following conditions:

(1) That no commercial station was able to do the work.

(2) That no expense was incurred by the government thereby.

(3) That no money or accounts in connection with this business was handled by any person in the employ of the government.

(4) That the handling of commercial business should not interfere with government business.

As this service was entirely free as far as the government radio stations were concerned, and commercial stations applied a comparatively high word rate, it was natural that many messages were forwarded thru these stations and transferred to land lines; all necessary arrangements for the collection of tolls being a private matter between the ships and the forwarding lines. The radiograms were placed on the land lines as domestic messages with charges collect. At that period, of course, neither operating companies nor the government were bound by the provisions of any international conventions, and radio matters were generally in a state of confusion. By the ratification of the Berlin

Convention of 1906, and the Proclamation of the President, all this changed, and it became necessary to follow all international agreements.

All business relating to government radio matters (both from the engineering and material point of view) as well as its operating features were conducted thru the Bureau of Steam Engineering of the Navy Department; which, for this particular work, had absorbed the duties of the old Bureau of Equipment. The officers in the Bureau of Steam Engineering were few in number, and soon found themselves swamped with work, and the attempt to handle all features of this service proved too much of a task. The passage of the Radio Act of August 13, 1912, and the joining of the London Radiotelegraphic Convention of 1912, threw extra work on the already overtaxed force. It was then determined to establish an office which would assume all the administrative and operating features of the service, the Bureau of Steam Engineering retaining all control over the engineering and technical details. Accordingly, in November 1912, by order of the Secretary of the Navy, the office of Superintendent of Naval Radio Service was established at Radio, Va.

The Radio Act of 1912 provided that the head of the department having control over the following named stations; viz., Arlington, Va.; Key West, Fla.; San Juan, P. R.; North Head and Tatoosh, Wash.; San Diego, Cal.; and those established or which may be established in Alaska and the Canal Zone *shall*, so far as is consistent with the transaction of government business, arrange for the transmission and receipt of commercial radiograms under the provisions of the Berlin Convention of 1906 and future international conventions or treaties to which the United States may be a party, at each of the stations referred to above and fix the rate therefor, subject to control of such rates by Congress. Further this Act provided that, "at such stations and *wherever* and *whenever* shore stations opened for general public business between the coast and vessels at sea under the provisions of the Berlin Convention of 1906 and future international conventions and treaties to which the United States may be a party shall not be so established, as to insure a constant service day and night without interruption, and in localities *wherever* and *whenever* such service shall not be maintained by a commercial shore station within 100 nautical miles of a naval radio station, the Secretary of the Navy, *shall*, so far as is consistent with the transaction of governmental business, open naval radio stations to the general public business described above, and shall fix rates for such service, subject to control of such rates by Congress. The receipts from such radiograms shall be covered into the Treasury as miscellaneous receipts."

In accordance with the above, the following stations of the naval radio service are now opened for general commercial work between shore and ships:

Charleston, S. C.
St. Augustine, Fla.
Jupiter, Fla.
Pensacola, Fla.
Key West, Fla.
Guantanamo Bay, Cuba.
Colon, R. P.
Balboa, I. C. Z.
Tatoosh Island, Wash.
North Head, Wash.
Cape Blanco, Oreg.
Tutuila, Samoa.
Eureka, Cal.
Point Arguello, Cal.
San Diego, Cal.
Guam.
St. Paul, Pribilof Islands, Alaska.
San Juan, P. R.
St. George, Pribilof Islands, Alaska.
Unalga, Alaska.
Dutch Harbor, Alaska.
Kodiak, Alaska.
Cordova, Alaska.
Sitka, Alaska.

SHIP STATIONS OPENED TO COMMERCIAL BUSINESS

In addition to the above shore stations which were authorized to handle commercial business, all ships of the naval service are also available for the transaction of commercial business. This is for the benefit of officers and crews of such vessels and for their friends ashore, and all persons embarked on naval vessels have the same privileges as passengers on merchant vessels. This commercial business must not, of course, interfere with the transaction of necessary government business, and its regulation is a matter for the senior officer present in any organization to determine.

The opening of naval ship stations to commercial work has not only been a boon to the officers and crews of such vessels, whereby they can have intercommunication with their families or friends on shore, but in some instances has resulted in great convenience to the public at places where there are no shore radio stations or land lines or cables; as private citizens can file messages on board naval ships for further transmission. During recent troubles in Mexico, when land lines were interrupted, the only means of communication with certain points of the country was thru the radio stations of the United States ships in Mexican waters. Messages were received or delivered by boat and messengers or thru local ships, no ship charge is imposed on officers or crew of such ship; but the coast station charge and all forwarding charges are collected. Such messages to naval ships carry the ship's receiving charges in addition to the shore station and forwarding line charges.

POINT TO POINT WORK

It should be noted that the London Radiotelegraphic Convention under the provisions and requirements of which the Naval Radio Service is organized and conducted as far as its commercial work is concerned, deals only with regulations that relate to communication between shore and ships. No special regulations were made to cover communication by radio stations between fixed points on land, these being left to the managements of the separate governments concerned.

Several of the stations of the naval service are advantageously situated for communication with fixed radio stations of other governments, and mutual agreements have been made for the conduct of commercial business between such points. A notable example of this communication is between the naval stations at Jupiter, Fla., and Nassau, Bahamas, paralleling the cable between these two points. On interruption of this cable, the entire business which previously was handled by the cable was taken by the exchange of radiograms between these two points. The erection of a commercial station at Miami, Fla., made a division of this traffic desirable, as the naval radio service is not considered as a competitor of any commercial company.

Similar point to point work is done between the naval station at Colon and the station at Cartagena, United States of Colombia, by which long transmission by land lines thru unreliable offices is eliminated and the cost to the senders of messages considerably reduced. Colon also communicates with the land stations at Limon, Bocas, and Bluefields in Costa Rica and Panama, and eliminate a round-about transmission by land lines and cables.

In Alaska there are a good many points that can be reached by radio which have no connections with land lines or cables, and the commercial work between such stations is of considerable magnitude. The Naval Radio Service thru its stations at North Head, Wash., Sitka, and Cordova in Alaska practically parallels the cable system of the Washington-Alaska Military-Cable and Telegraph Company, and the rates to points in Alaska are such that it practically makes no difference to the senders of messages whether the cable is interrupted or not, as either service delivers messages at practically the same cost, transferring messages from one system to another as may be required. On this particular class of Alaskan business, both systems use the same system of counting and checking, and such messages carry the domestic (message) count thruout, whether wholly by radio or cable lines, or in part by them and the connecting land lines in the United States. On messages to ships at sea, however, the Naval Radio Service, the cable system and connecting land lines apply the cable count and charges.

Certain naval radio stations in Alaska communicate with a Russian station at Anadyr, and tests are being conducted between them and a Japanese station at Ochiishi. These systems of communication were developed primarily for the transmission of government messages, with special reference to Weather Bureau messages, tho such routes are open for the transaction of commercial business, and such messages have been so transmitted.

The unreliability of cable service to San Domingo necessitated some arrangement of communication by radio stations, and United States government messages are now delivered to officials in San Domingo or to ships in those waters thru the naval radio station at San Juan (Porto Rico), and the Dominican stations at La Romana and San Domingo. Similarly, Dominican government messages are transmitted to and from that country, and if occasion demands, these routes will be opened for commercial business.

The Naval station at Tutuila, Samoa, has no cable connection, but its radio station can communicate with the Suva radio station in the Fiji Islands where messages can be forwarded by cable. Commercial ships passing Samoa, as well as the inhabitants of Tutuila, make considerable use of this means of communication.

Ships passing Guam can transmit messages thru the naval radio station at that place for further transmission by radio to Yap*, or by cable at the sender's option.

RATES AND CHARGES

The London Radiotelegraphic Convention prescribes a maximum word charge applicable to all radiograms. For shore stations this is 60 centimes, or approximately 12 cents; and for ship stations 40 centimes, or approximately 8 cents. In the Convention, however, the United States abstained from all action with regard to rates, because the transmission of radiograms in this country is carried on wholly or in part by commercial or

*Transmission from the radio station at Yap has been interfered with because of the present European War. (Editor.)

private companies. However, no commercial company applies a higher word rate than allowed by the Convention, except certain shore stations engaged in long distance work.

The word rate fixed for naval stations must of necessity be based on that established by commercial companies operating in the same general locality. If naval radio service rates were higher, the service would not be of the same convenience to the public, and if lower, a state of competition would exist, which of course is undesirable. The word rates for all naval stations, except Alaskan stations, Guam, and Tutuila, for ship to shore work, is 6 cents per word, the excepted stations applying a 5-cent rate for local ship to shore work. Between North Head, Wash., and the Alaskan stations, for communication between ships and United States points, there is a flat word rate of 19 cents per word for ships beyond Cordova, and 9 cents per word for ships reached via Sitka. For local work between points in Alaska, a word rate of 5 cents is charged for radio service independent of the number of relays thru naval stations.

For point to point work the same rate of 6 cents per word applies, except in Alaska; and a special rate of 2 cents a word is allowed for press messages. This rate applies on all messages passing thru the stations in either direction.

Ships of the Navy apply a 4-cent word rate on all received commercial messages, making the radio tolls (shore and ship) thru a naval radio station 10 cents per word, with a minimum charge equal to that of a message consisting of ten words.

In general, commercial ships engaged in the North and South Atlantic trade apply a 4-cent word rate, while those engaged in trans-Atlantic trade apply an 8-cent word rate. Some coastwise vessels on the Pacific coast apply a 2-cent word rate, and it is these varying word rates applicable to ships which makes the accounting such an uncertainty, and which often result in over or under charges on radiograms addressed to ships at sea.

COUNTING OF WORDS

The cable count is used on all radiograms; that is, every word of the address, message, and signature is counted and paid for at a certain rate per word, tho every radiogram carries a minimum charge for its radio tolls which is equal to that of a ten-word radiogram. Where transmission is effected partly over cables, only the actual number of words is charged and paid for for this part of the transmission. The address must contain at least two words, one of which must be the coast station thru which the message is transmitted, but a signature is not necessary, and there is no limit to the number of words in a message.

RELAYING

Messages are entitled to be relayed under the following conditions:

(a) In case direct communication cannot be established between the station of origin and destination.

(b) In case the relaying is solely for the purpose of reaching the nearest coast station (for messages originating on a ship).

(c) In case the relaying ship or station is in a position to forward the message.

(d) In case the total number of relays does not exceed two. Messages originating on a ship may be relayed to another ship by means of:

(1) One or two ships.

(2) A coast station.

(3) Two coast stations and then connecting telegraph lines. Messages from shore may be relayed to a ship by another ship, but only in case the sender has specifically demanded such relay and the preamble contains instructions as to the number of relays, which must not exceed two.

In cases of relaying to a ship at sea, the coast station forwards the message by one or two relay ships and then notifies the office of origin what the amount of relay charges is, so that they may be collected from the sender. All relay charges must be prepaid as must all other charges on radiograms. There is but one charge per station allowed; that is, the reception and retransmission is made a single—not a double—charge. The naval radio service makes no charge for relaying messages, nor do certain of the commercial companies, notably the Marconi Wireless Telegraph Company and their affiliated companies.

SPECIAL CLASSES OF COMMERCIAL RADIOGRAMS

The ordinary radiogram between ship and shore carries the prefix "Radio," which is an indication of its strictly commercial character, and this is the ordinary type of prepaid message. In addition to this, special classes of commercial radiograms are authorized.

Classes of Messages	Designations
Radiograms with answer prepaid (on land lines "Reply Prepaid")	RP
Radiograms calling for repetition of message (on land lines "Repeat Back")	TC
Special delivery radiograms	EXPRESS
Radiograms to be delivered by mail	POST
Radiograms to be delivered by registered mail	PR
Multiple radiograms	TM . . x
Radiograms calling for acknowledgment of receipt	PCP (by mail) PC (by telegraph)
Acknowledgment of above	CR
Paid service notice	RADIO ST (prefix)
"Ocean Letters" or radiograms to be mailed by a ship at a port of call	POSTE (in address)

The addressee of a reply prepaid message (RP) is given a voucher equal in value to the amount prepaid for reply and which is good for six weeks. The receiver of a reply prepaid message is not bound to a reply to the sender of the original message, but may apply the value of his voucher to the payment of any message he wishes to send.

Radiograms calling for repetition of message are for the purpose of verification only. Messages carrying the word "TC" are repeated back by each station that handled it to the one before. An additional charge equal to one-fourth of the regular tolls is charged for such service. Special delivery radiograms are those which involve delivery beyond the limits of a telegraph office, which delivery is accomplished by telephone or messenger. Such messages are only accepted where the charge for special delivery is paid by the addressee and the special prefix is charged for as one word.

Radiograms to be delivered by mail are distinguished by the word "Post." When such a radiogram is received at a coast station, it is sent by mail to the addressee; or if the name of some other place follows the word "Post," it will be forwarded by land line to that place with the instruction "mail." It is then mailed from the telegraph office to which forwarded. In addition to the extra charge for the word "Post," there is an additional charge collected from the sender of 5 cents for postage; and if the expression " PR" is used instead of "Post," it signifies that the letter is to be forwarded by registered mail, which carries a collection from the sender of 15 cents instead of 5 cents.

By a multiple radiogram is meant one message addressed either by several persons, or to the same person at several addresses, in the same locality or in different localities served by the same telegraph office. Such messages contain the abbreviation "TM . . x" ("x" standing for the number of different addresses).

Radiograms calling for acknowledgment of receipt are limited to notification of the date and hour at which the coast station shall have transmitted the radiogram to the ship to which it was addressed. This notification is sent to the office of origin either by telegraph or mail, at the option of the sender of the message. The instruction to send acknowledgment of receipt is transmitted by the letters "PC," or the words "Acknowledgment Paid" as supplementary instructions at the end of the preamble, and also as the first item of the first address. The letters "PC" in the address are counted in the check charged for as one word. This calls for telegraphic acknowledgment by mail, and is charged for as one word. Should the expression "Acknowledgment Paid" be written on the blank, it shall be transmitted by the abbreviation.

If telegraphic acknowledgment is requested, the sender of the message is charged for a five-word telegram, by the same route. Mail acknowledgments are sent free. They are addressed to the telegraph office at which the message originated. Telegraphic acknowledgment is announced by service message containing the abbreviation "CR," followed by the name of the addressee, ship, the word "transmitted," and the hour and date.

Ocean letters are radiograms which may be transmitted by a coast station to a ship, or by a ship to another ship, to be forwarded by mail from a port of call of the ship receiving the radiogram. Such radiograms are not entitled to any relaying by radio. The address of such a radiogram shall embrace the following:

(1) The paid designation "Poste," or (if sent to a United States ship) "Mail," followed by the name of the port at which the message is to be mailed.

(2) Name and complete address of addressee.

(3) Name of station on shipboard by which the radiogram is to be mailed.

(4) When necessary, the name of the coast station.

The rate shall comprise, in addition to the radio and telegraph rates, the sum of 5 cents for postage.

ACCOUNTING

The system of accounting in vogue follows the requirements of Article XLII of the Service Regulations affixed to the International Convention of London, 1912. This article requires that the accounts regarding radio charges shall be drawn up by the radio managements to which the coastal stations are subject. Coastal and shipboard charges do not enter into the accounts provided for by the International Telegraph Regulations.

The primary requirements in the transmission of all radiograms is the prepayment of all charges from point of origin to point of destination, and no "collect" radiogram of any class is recognized. All telegraph, cable, and radio companies operating follow the same general system of accounting; which is, that the system on which a message originates becomes responsible for all the charges on said message, and that that system collects full tolls and thereupon pays to the next connecting line its tolls plus all tolls due forwarding lines. In turn, the second system handling the message pays the third connecting line its tolls and all tolls due systems following that system.

Altho the system on which the radiogram originates collects all tolls and is responsible for all charges beyond its system, the accounts are, in accordance with the Service Regulations, London Convention, drawn up by the radio management of the coast stations. This means that all the coast stations belonging to the Naval Radio Service which are opened to public general correspondence, draw up the accounts on all messages that pass thru them, either from shore to ship, or from ship to shore.

The required prepayment from shore to ship includes land line or cable charges from point of origin to the coast station (or a message may be filed locally at a coast station, in which the above charges do not appear), the coast station charge, and the ship station charge. If the message originates on ship and is destined to a shore point, the charges to be applied and paid on board ship are the ship's charge, the coast station charge, and the land line or cable charges to destination. If destined to be delivered locally at the coast station, there may be no forwarding charges. Thus on a message from an inland point to a ship at sea, the administration of the coast station charges the forwarding land line company which handed the message to it with its own station charge plus the ship station charge, and on collection hands to the administration controlling the ship installation, the amount due it, retaining its own charge. Similarly on messages from sea the administration of the coast station thru which the message passed charges the company controlling the ship installation with the shore station charge plus all forwarding charges due to land line or cable companies. On collection of these charges, the administration of the coast station turns over to the forwarding company its proportion of the charges and retains its own.

The general principle followed is that the coast station debits the company that handed the message to it, whether from ship or shore, with its own and all forwarding charges, and credits the proper companies with all charges beyond it. Thus in case a shore station has no direct physical connection with a land telegraph or cable line, but is connected by means of a telephone line, the administration of the coast station does its accounting with the company controlling the telephone line and turns over all forwarding charges to it, and this company in turn accounts with any further forwarding company, unless both telephone and telegraph lines are controlled by the same company.

Most naval coast stations in the continental limits of the country have direct connection with either Western Union Company telegraph lines or Postal Company telegraph lines and some have both. In some instances there is but a telephone line connection, as at Cape Blanco, Ore., where accounting is done with the Coos Bay Home Telephone Company. At Tatoosh, the connecting telegraph line is controlled by the Weather Bureau which involves accounting with that bureau. Several naval coast stations that are open to commercial business are on outlying possessions, as at Guantanamo Bay, San Juan, Colon, Darien, Balboa, Guam and stations in Alaska. These are connected to land lines in the countries in which they are situated; some of them foreign as in the case of Guantanamo thru Cuba, and the Canal Zone stations thru the Republic of Panama. All are connected with other points by cables which thru their connections may reach all parts of the world.

SUMMARY: The work done by the United States Government in connection with radio telegraphy is historically traced, and the practical control of government radio service by the Navy Department is described. The division of duties in this field is between the Bureau of Steam Engineering, which is in charge of engineering and technical details, and the Superintendent of Naval Radio Service, who controls the administrative and operating features. The transmission of time signals, weather reports, hydrographic information, and

ship messages from the naval shore stations is considered. The commercial work of the naval radio stations, both shore stations and ship stations, is discussed. This is followed by a description of shore point-to-point work. Certain traffic matters are then handled, such as: rates and charges, the counting of words, relaying of messages, special classes of commercial radiograms, and methods of accounting for tolls.

DISCUSSION

Edward J. Nally: I have read Captain Bullard's paper on "Naval Radio Service" very carefully and with great interest. I think it is a text-book on the subject, and one in which the subject is most thoroly and lucidly handled. In fact, I think it is a historic document.

Alfred N. Goldsmith: Captain Bullard's description of the work of the United States Government in the radio field will doubtless be an interesting revelation to those who have been accustomed to regard that field as in large part monopolized by commercial companies. It will be seen that the government has organized a highly efficient service of its own, quite apart from military necessity. The scope of that service, particularly in Alaska, is practically as complete as that of any of the operating companies. It is a subject for careful consideration as to what will be the ultimate outcome of this incursion of the government into the field of public communication.

A DIRECT-READING DECREMETER AND WAVE METER[1]

By

FREDERICK A. KOLSTER

INTRODUCTION

The laws of the United States governing radio communication specify, among other things, that at all stations the logarithmic decrement per complete oscillation in the wave trains emitted by the transmitter shall not exceed two-tenths, except when sending distress signals or messages relating thereto.

The importance of the regulation lies in the fact that when persistent oscillations of single frequency are emitted from a radio transmitting station much more selective receiving apparatus may be employed with advantage at receiving stations, permitting sharp tuning with consequent minimizing of interference caused by stations other than those with which communication is desired.

When full advantage is taken of the rapid scientific and technical progress which has been made in the methods of transmission of electromagnetic waves it is not at all difficult to comply with this requirement. In fact, it is practicable as well as desirable to keep well within this limiting value of two-tenths.

The purpose of this paper is to describe a new direct-reading instrument for measuring the logarithmic decrement and wave length, especially designed about two years ago for the radio inspection service of the Bureau of Navigation, Department of Commerce, and since adopted by the War and Navy Departments.

GENERAL THEORY

It is supposed that in the primary of two coupled circuits there exist damped electrical oscillations of decrement δ_1, the natural decrement of the primary. The natural decrement of the secondary circuit is δ_2. When the secondary circuit is tuned

[1] Delivered before The Institute of Radio Engineers, Washington Section, February 5, 1914. This article is based on a publication in the Bulletin of the Bureau of Standards, Vol. 11 (Scientific Paper Number 235).

so that maximum current is induced in it by the primary, it is assumed that its capacity is C_r and the current in it I_r. If the secondary capacity is altered to a new value, C, the current will drop to a value I. Bjerknes has shown that the sum of primary and secondary decrements is given by the equation:

$$\delta_1 + \delta_2 = \pi \frac{C_r - C}{C} \sqrt{\frac{I^2}{I_r^2 - I^2}}$$

The conditions under which this formula may be applied with sufficient accuracy are,

1. That $\delta_1 + \delta_2$ be small as compared with 2π.
2. That $\frac{C_r - C}{C}$ be small as compared with unity.
3. That the degree of coupling between the circuits be small.

Let us assume that it is desired to determine the logarithmic decrement of the oscillations in the aerial circuit of a radio transmitter as shown in Figure 1. A circuit containing inductance

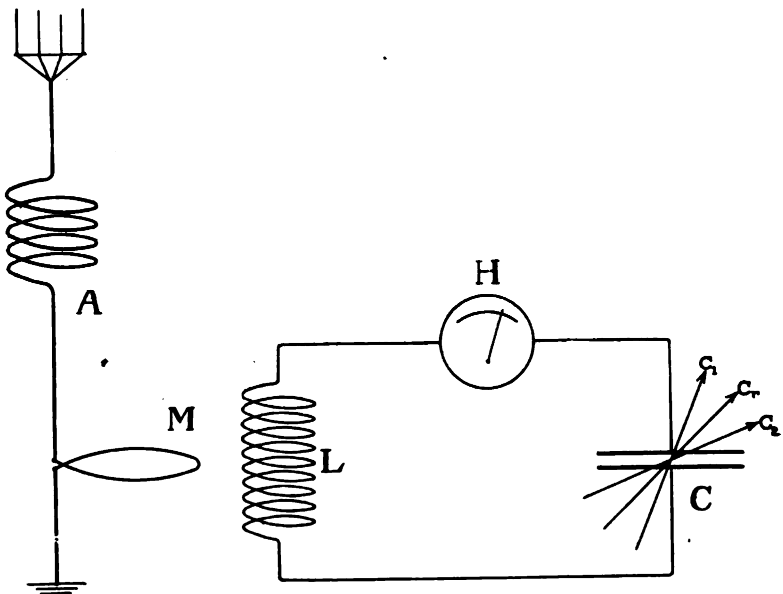


FIGURE I—Decremeter Circuit Coupled Loosely to the Antenna Circuit of a Transmitter

L, a calibrated variable condenser C, and a sensitive low resistance hot-wire instrument H, is very loosely coupled to the aerial or antenna circuit A. Readings of the hot-wire instrument

H, which are proportional to the square of the current in the circuit, are taken for several values of capacity C on both sides of the resonant value C_r. Plotting these readings against capacity, a resonance curve such as Figure 2 is obtained, and from one of the following formulas,[2] the sum of the logarithmic decrements δ_1 and δ_2 may be obtained.

$$\delta_1 + \delta_2 = \pi \frac{C_r - C_1}{C_1} \sqrt{\frac{I^2}{I_r^2 - I^2}}$$

$$\delta_1 + \delta_2 = \pi \frac{C_2 - C_r}{C_2} \sqrt{\frac{I^2}{I_r^2 - I^2}}$$

$$\delta_1 + \delta_2 = \pi \frac{C_2 - C_1}{C_2 + C_1} \sqrt{\frac{I^2}{I_r^2 - I^2}}$$

If the decrement δ_2 of the measuring circuit has been previously determined, the decrement δ_1 of the aerial circuit under test is at once obtained.

Altho the measurement of the logarithmic decrement as outlined above appears to be comparatively simple, nevertheless, to obtain reasonably consistent and accurate results, the observations must be taken with considerable care, the resonance curve must be plotted on a large scale, and calculations must be made from several points on the curve. In fact, it is only with laboratory conveniences that satisfactory measurements can be obtained.

The instrument, which it is the purpose of this paper to describe, was designed for the purpose of facilitating the work involved in making measurements of decrement and yet permitting as great accuracy as can be expected in the ordinary laboratory method. These requirements are particularly desirable for the purposes of the inspection service of the Bureau of Navigation in the enforcement of the radio communication laws. The inspection of a radio station on board ship, for example, has to be done quickly and in many cases under very unfavorable circumstances.

In Figure 2, a typical resonance curve is shown, and the task of obtaining the logarithmic decrement by the ordinary method is indicated. Identical results are obtained in a very much shorter time by means of the direct reading instrument.

[2] In practice it is found permissible to make the change in capacity from C_r to C_1 such that I^2 becomes $\frac{1}{2}I_r^2$, thus making the expression under the radical sign equal to unity.

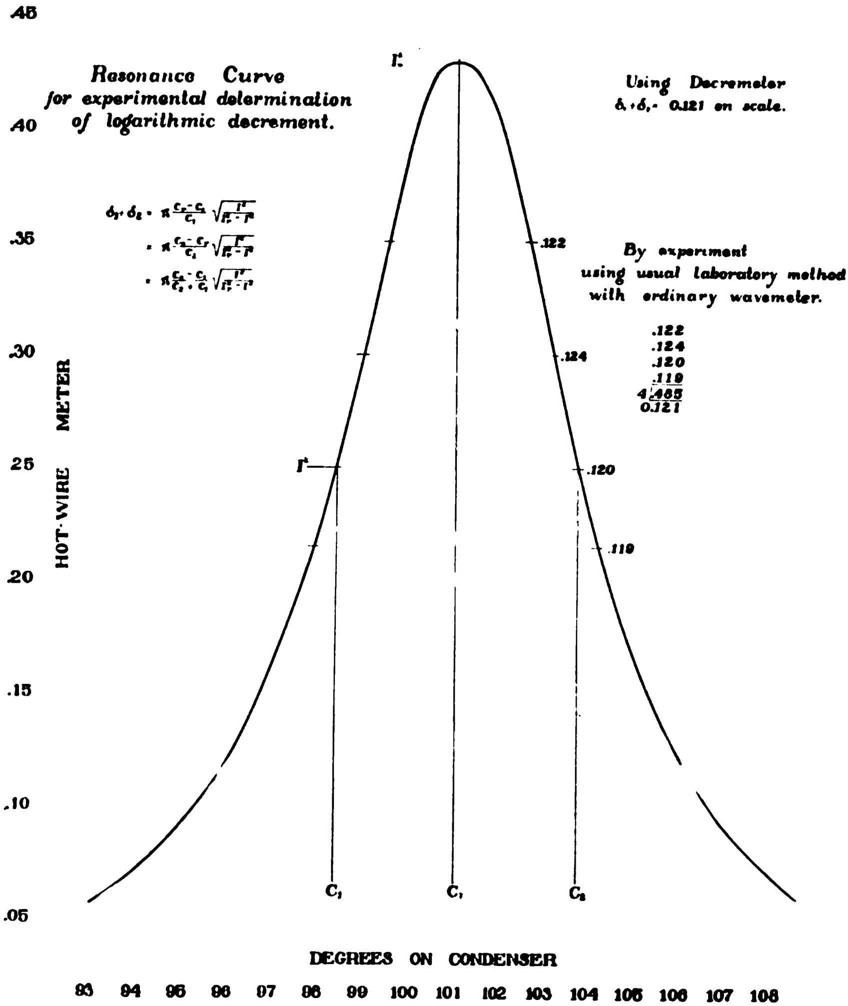


FIGURE 2—Resonance Curve for Experimental Determination of Logarithmic Decrement

THEORY OF THE INSTRUMENT

The shape of the moving plates or surfaces of the ordinary variable condenser in common use is such that for equal angular displacements of these surfaces from the position of minimum capacity to that of maximum capacity, an approximately straight line variation of capacity is obtained. It is evident, therefore, that for any given displacement of the plates, the percentage change of capacity, $\frac{\Delta C}{C}$ will not be equal to that obtained for an equal displacement of the plates at any other point.

In order to make it possible to attach to a variable condenser a single predetermined scale giving values of logarithmic decrement corresponding to various percentage changes of capacity thruout the range of capacity of the condenser as defined by the Bjerknes formula,

$$\delta_1 + \delta_2 = \pi \frac{C_r - C}{C}, \text{ for } I^2 = \tfrac{1}{2} I_r^2,$$

the capacity variation with equal displacements of the moving plates must be such that for any given displacement of the plates, taken at any point from the original position of the plates to their final position,

$$\frac{C_r - C}{C} = \frac{\Delta C}{C} = \text{a constant.}$$

The problem, therefore, of constructing a direct reading instrument for decrement measurements is largely that of determining the proper shape for the plates or surfaces of the condenser to produce a variable capacity such that for any given displacement the value of $\frac{\Delta C}{C}$ will be constant thruout the range of motion of the moving surfaces.

In other words, for a displacement of ΔX, Figure 3,

$$\frac{C_2 - C_1}{C_1} = \frac{C_3 - C_2}{C_2} = \frac{C_4 - C_3}{C_3} = \ldots\ldots \frac{C_n - C_{n-1}}{C_{n-1}}$$

but if, $$\frac{C_2 - C_1}{C_1} = \frac{C_3 - C_2}{C_2}$$

then $$C_2^2 = C_1 C_3, \text{ or } C_2 = \sqrt{C_1 C_3}$$

similarly, $$C_3 = \sqrt{C_2 C_4}$$

or, $$C_n = \sqrt{C_{n-1} C_{n+1}}$$

It is seen, therefore, that the capacity of the variable condenser must vary in accordance with the law of geometric progression, and it is now easy to formulate the equation giving the connection between the value of capacity and the position

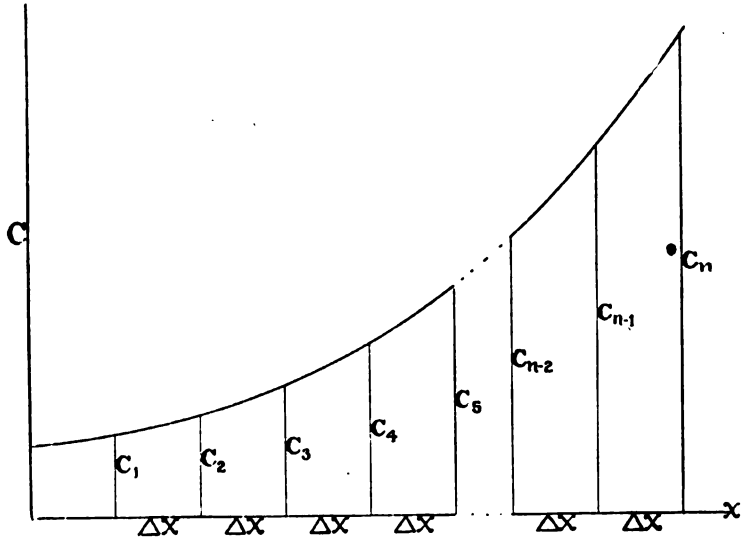


FIGURE 3—Capacity Varying in Accordance with the Law of Geometric Progression

of the moving plates, for since the curve of capacity must obey the law of geometric progression, we have the following, Figure 4.

$$
\begin{array}{rll}
\text{at } x = o \text{ let} & C_o = aK^o = a & \\
\text{then at } x = 1 & C_1 = aK^1 & \\
x = 2 & C_2 = aK^2 & \\
x = 3 & C_3 = aK^3 & \\
\vdots & \vdots & \\
x = n^n & C_n = aK^n, &
\end{array}
$$

or, in general,

$$C = aK^x \qquad (1)$$

This is equivalent to equation (1) derived above.[1]

[1] This law might have been deduced more directly as follows: The fundamental requirement of the condenser may be written:

$$\frac{dC}{C} = ndx \qquad (2)$$

$$\therefore \log C = nx + h$$

and

$$C = \varepsilon^{nx+h} = \alpha\varepsilon^{nx}$$

For the case of a rotary condenser where θ is the displacement angle in degrees

$$C = a\,\varepsilon^{m\theta} \qquad (3)$$

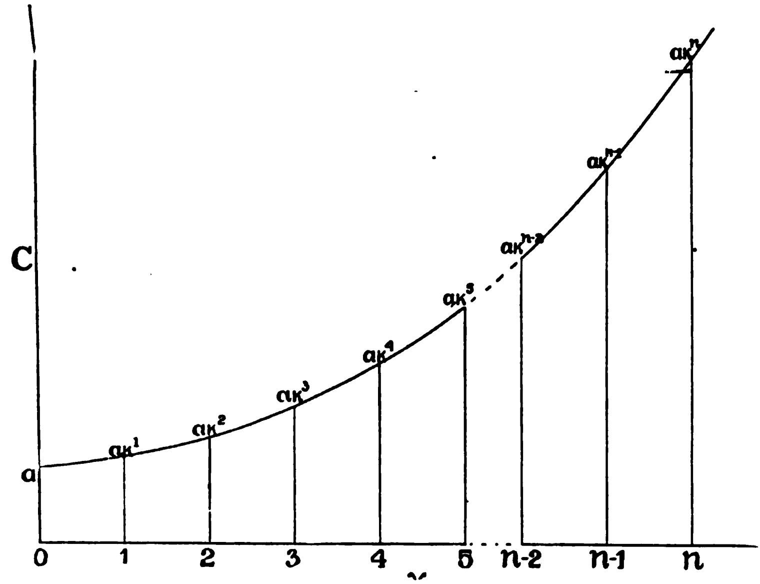


FIGURE 4—Geometric Progression

DESIGN OF CONDENSER

Since the capacity of a condenser is directly proportional to the active area of the movable surface, neglecting edge effects we may write,

$$A = b\,\varepsilon^{m\theta}$$

A being the area of the active surface of the moving plate, and θ the angle of displacement.

If we now consider Figure 5, the actual shape of the moving plate can be determined.

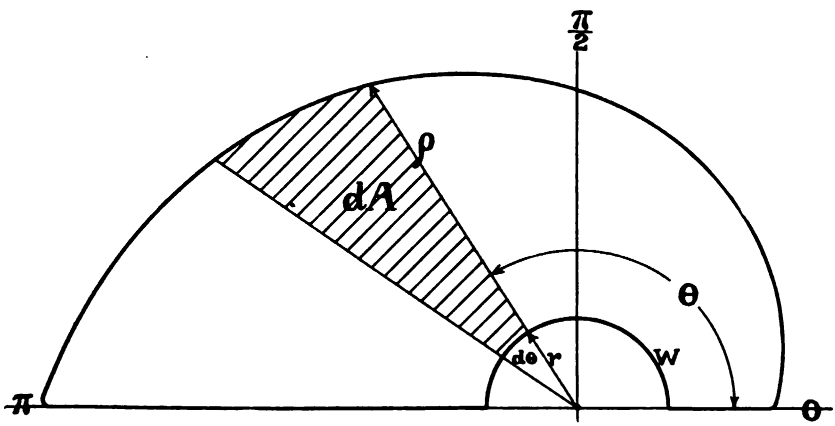


FIGURE 5—Shape of Rotary Plate of Condenser

By analogy with equation (2)

$$\frac{dA}{A} = m\,d\theta$$

or,
$$dA = b\,m\,\varepsilon^{m\theta}\,d\theta$$

but,
$$dA = \frac{1}{2}\left(\rho^2 - r^2\right)d\theta$$

ρ being the distance from the center O to the enveloping curve of the plate, or the radius vector, and r being the radius of the small circular space occupied by the separating washers between the plates.

Then
$$\frac{1}{2}\rho^2 - \frac{1}{2}r^2 = b\,m\,\varepsilon^{m\theta}$$

and
$$\rho = \sqrt{2\,b\,m\,\varepsilon^{m\theta} + r^2}$$

b and m are constants which determine the minimum and maximum values of capacity of the condenser to be used, and having chosen these constants to suit our particular requirements, we can immediately determine the size and shape of our plates and construct a condenser, the capacity of which will vary in accordance with the law of geometric progression.

In Figure 6 are shown the stationary and rotary plates of the condenser. The stationary plates are made semicircular for convenience.

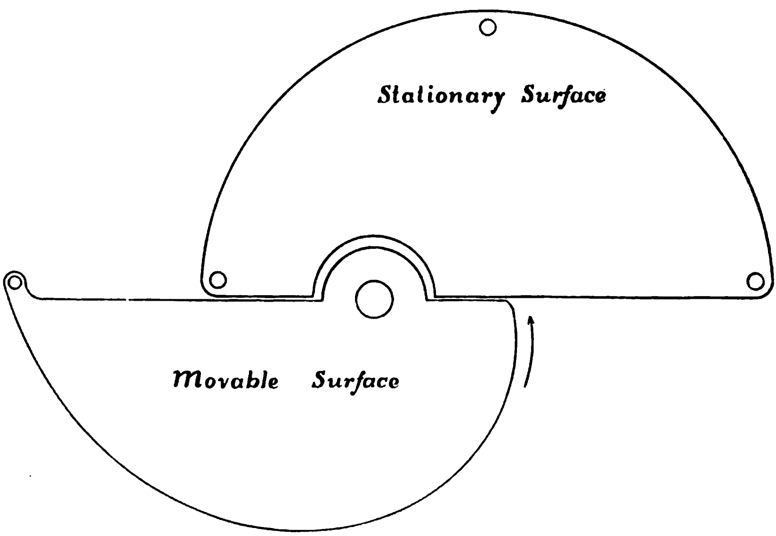


FIGURE 6—Stationary Surface, Movable Surface

Equations (1) and (3) are identical and we may write

$$K^x = \varepsilon^{m\theta}$$

or

$$x \log K = m\theta$$

therefore

$$m = \frac{x \log K}{\theta}$$

If we assume that when

$$x = 1, \ \theta = 180^\circ$$

then

$$x = \frac{\theta}{180}$$

and

$$m = \frac{\log K}{180}$$

therefore,

$$C = a\,\varepsilon^{\frac{\log K}{180}\theta}$$

for

$$\theta = o, \ C_o = a$$

for $\theta = 180^\circ$ $\qquad C_{180} = a\,K$

hence, the ratio between maximum and minimum capacity will be

$$\frac{C_{180}}{C_o} = K$$

In order to obtain the ratio K which has been chosen to suit our particular requirements, a fixed condenser is connected in parallel with the rotary condenser. The capacity of this fixed condenser is determined experimentally.

A rotary condenser constructed in accordance with the theory just given, with a fixed capacity connected in parallel with it, so chosen as to give the desired ratio between the maximum and minimum capacity of the combined condensers, will give a calibration curve in exact agreement with theoretical values.

DETERMINATION OF DECREMENT SCALE

It has been shown that since the capacity of the condenser to be used in the instrument varies in accordance with the law of geometric progression, the term $\frac{C_r - C}{C}$ in the formula,

$$\delta_1 + \delta_2 = \pi \frac{C_r - C}{C}\sqrt{\frac{I^2}{I_r^2 - I^2}} = \pi \frac{C_r - C}{C}$$

when

$$I^2 = \frac{1}{2} I_r^2$$

will remain constant for any given angular displacement of the rotary plates thruout the range of motion from 0° to 180°.

In order, therefore, to predetermine a scale which can be attached to the rotary condenser and which will indicate directly the value of $\delta_1 + \delta_2$ for various displacements of the rotary plates, the following calculations are made.

$$\text{Case I: } \delta_1 + \delta_2 = \pi \frac{C_r - C_1}{C_1}$$

where C_r is the value of capacity at resonance and C_1 is a smaller capacity of such a value that the current squared is reduced to one-half of its value at complete resonance.

Since C_r is proportional to $\varepsilon^{m\theta_r}$ and C_1 is proportional to $\varepsilon^{m\theta_1}$, we may write

$$\delta_1 + \delta_2 = \pi \frac{\varepsilon^{m\theta_r} - \varepsilon^{m\theta_1}}{\varepsilon^{m\theta_1}} = \pi\left(\varepsilon^{m(\theta_r - \theta_1)} - 1\right).$$

Let $\qquad \delta = \delta_1 + \delta_2$ for convenience,

then, $$\varepsilon^{m(\theta_r - \theta_1)} = \frac{\delta}{\pi} + 1 = \frac{\delta + \pi}{\pi}$$

and $$\theta_r - \theta_1 = \frac{1}{m} \log \frac{\delta + \pi}{\pi}$$

The displacement angle $\Delta\theta = \theta_r - \theta_1$ may therefore be immediately calculated for various values of $\delta = \delta_1 + \delta_2$. m is as before a constant dependent upon the ratio of maximum to minimum capacity of the condenser and is equal to $\frac{\log K}{180}$, where K represents this ratio.

$$\text{Case II: } \delta_1 + \delta_2 = \pi \frac{C_2 - C_r}{C_2}$$

where C_r is again the value of capacity at complete resonance and C_2 is a larger capacity of such a value that the current squared is reduced to one-half of the value at complete resonance.

Since C_2 is proportional to $\varepsilon^{m\theta_2}$ and C_r is proportional to $\varepsilon^{m\theta_r}$

$$\delta = \delta_1 + \delta_2 = \pi \frac{\varepsilon^{m\theta_2} - \varepsilon^{m\theta_r}}{\varepsilon^{m\theta_2}} = \pi\left(1 - \frac{\varepsilon^{m\theta_r}}{\varepsilon^{m\theta_2}}\right)$$

then $$\varepsilon^{m(\theta_2 - \theta_r)} = \frac{\pi}{\pi - \delta}$$

and $$\theta_2 - \theta_r = \frac{1}{m} \log \frac{\pi}{\pi - \delta}$$

and again, the displacement angle $\Delta\theta = \theta_2 - \theta_r$ may be readily calculated for various values of $\delta = \delta_1 + \delta_2$.

For the particular case in question, the following angles and corresponding decrements as calculated are tabulated:

$\delta_1 + \delta_2$	Case I. Reducing capacity from resonance: $\theta_r - \theta_1$	Case II. Increasing capacity from resonance: $\theta_2 - \theta_r$
0.05	1°.292	1°.313
0.10	2 .564	2 .650
0.15	3 .821	4 .008
0.20	5 .055	5 .389
0.25	6 .272	6 .793
0.30	7 .472	8 .222

It should be emphasized that the formula

$$\delta_1 + \delta_2 = \pi \frac{C_r - C}{C} \sqrt{\frac{I^2}{I^2_r - I^2}}$$

does not strictly apply in cases where $\delta_1 + \delta_2$ is great in comparison with 2π and $\frac{C_r - C}{C}$ is great in comparison with unity.

For $\delta_1 + \delta_2 = 0.2$ the formula may still be applied for practical purposes with reasonable accuracy. In the foregoing tabulation calculations have been made for $\delta_1 + \delta_2$ as high as 0.3, but the method and formula should preferably not be applied at values of $\delta_1 + \delta_2$ greater than 0.2.

It will be noted that the angles tabulated above are very small, and if the decrement scale were attached directly to the shaft of the condenser it would be extremely short and difficult to read.

In order to open out the scale, it is geared to the condenser shaft at a 6-to-1 ratio, as shown in Figure 7.

Furthermore, the decrement readings are taken in such a way as to simultaneously include both measurements as defined by cases I and II. The displacement angle is then the sum of the angles tabulated under these two cases.

$$\Delta\theta = \theta_2 - \theta_r + \theta_r - \theta_1 = \theta_2 - \theta_1$$

The value of this angle $\Delta\theta = \theta_2 - \theta_1$ could have been calculated directly from the formula

$$\delta_1 + \delta_2 = \pi \frac{C_2 - C_1}{C_2 + C_1}$$

for since C_2 is proportional to $\varepsilon^{m\theta_2}$ and C_1 is proportional to $\varepsilon^{m\theta_1}$, then carrying out the method used in cases I and II we get directly,

$$\theta_2 - \theta_1 = \frac{1}{m} \log \frac{\pi + \delta}{\pi - \delta}$$

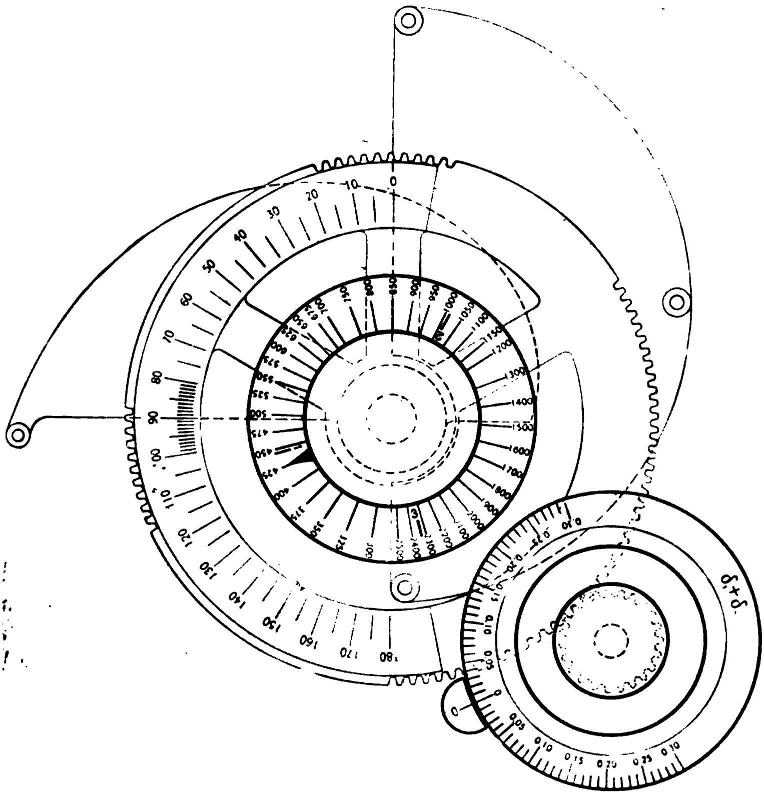


FIGURE 7—Variable Condenser, Showing Gears and Scales Mechanically Attached

The final graduations for the decrement scale are obtained by multiplying $\theta_2 - \theta_1$ by the gear ratio of 6, as in the following table:

$\delta_1 + \delta_2$	$\theta_2 - \theta_1$	$(\theta_2 - \theta_1) \times 6$
0.	0	0
0.05	2°.605	15°.63
0.10	5 .214	31 .28
0.15	7 .830	46 .98
0.20	10 .444	62 .70
0.25	13 .065	78 .39
0.30	15 .694	94 .20

The decrement scale is marked to the left and to the right of zero in accordance with this table.

Considering now Figure 8, the operation for measuring the logarithmic decrement is as follows:

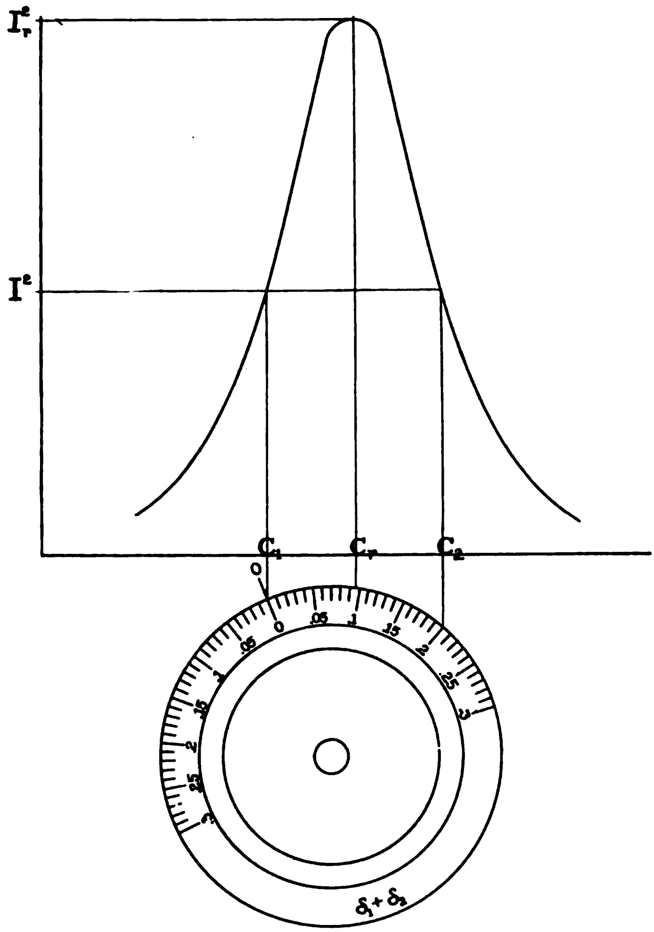


FIGURE 8—Diagram Showing Relation Between Decrement Scale and Resonance Curve

The rotary condenser is first set at the position of complete resonance as indicated by the maximum deflection of the sensitive hot-wire instrument, the scale readings of which are proportional to the current squared. This maximum deflection is now reduced to one-half its value by decreasing or increasing the capacity of the rotary condenser. The decrement scale, which may be rotated independently, is now set at zero, then clamped so that when the condenser is again varied it will rotate with it.

Starting at the zero setting with the hot-wire instrument reading one-half the maximum deflection, the condenser is varied continuously in one direction until the needle of the hot-wire instrument makes a complete excursion from one-half deflection to maximum deflection and back again to one-half deflection. The scale reading now opposite the index mark O is the value of $\delta_1 + \delta_2$, δ_1 being the decrement of the circuit under test and δ_2 the known decrement of the instrument.

It will be noted by referring to Figure 7, that it is desirable to make the zero setting of the decrement scale at the point of half deflection and also to take the final reading at the point of half deflection, because at these points the resonance curve is steep, and consequently the settings are sharply defined and easily made. In this connection it will be noted that the formula

$$\delta_1 + \delta_2 = \pi \frac{C_2 - C_1}{C_2 + C_1}$$

does not involve the resonant value of capacity C_r, but only those at the points of half deflection where the slope of the resonance curve is steep. This formula is therefore the most desirable one to use, and the decremeter is consequently operated in accordance with it.

In Figure 9 a schematic diagram of the circuit is shown. I is a single-turn coil which may be connected in the circuit under test, as, for example, the aerial circuit of a radio transmitter. The inductance of this single turn is, in the majority of practical cases, small as compared with the total inductance of the circuit under test, and therefore will not affect the tuning adjustment.

The coil L is the inductance of the decremeter circuit and is so arranged that the mutual inductance between it and coil I can be easily varied. It is very essential that the degree of coupling between the circuit under test and the decremeter circuit be small.

C_v is the variable condenser to which the decrement scale is attached thru gears. In parallel with C_v is a small condenser C_f which remains fixed in value after proper adjustment.

H represents the hot-wire instrument or indicating device, the scale of which is so marked that the readings are proportional to the square of the current passing thru it.

A crystal dector D is provided and the wave length of distant stations may be measured by using telephone receivers T.

By means of a switch, the buzzer circuit R B E may be connected to the instrument for calibration purposes.

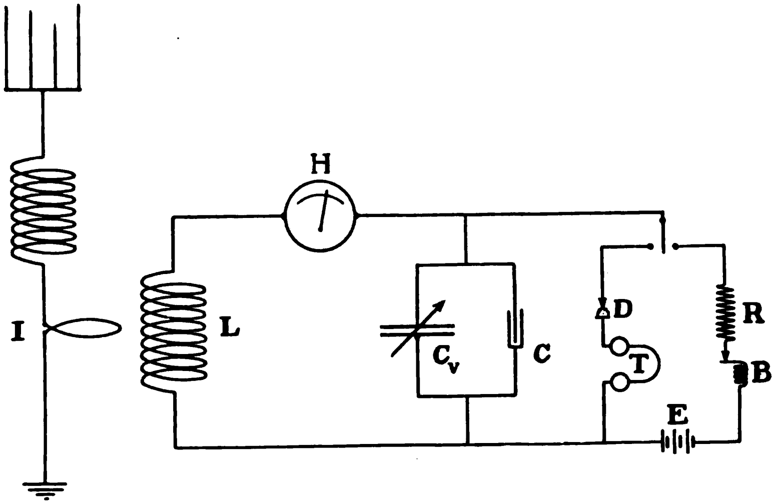


FIGURE 9—Diagram of Connections

Figure 10 shows a top view of the instrument in detail.

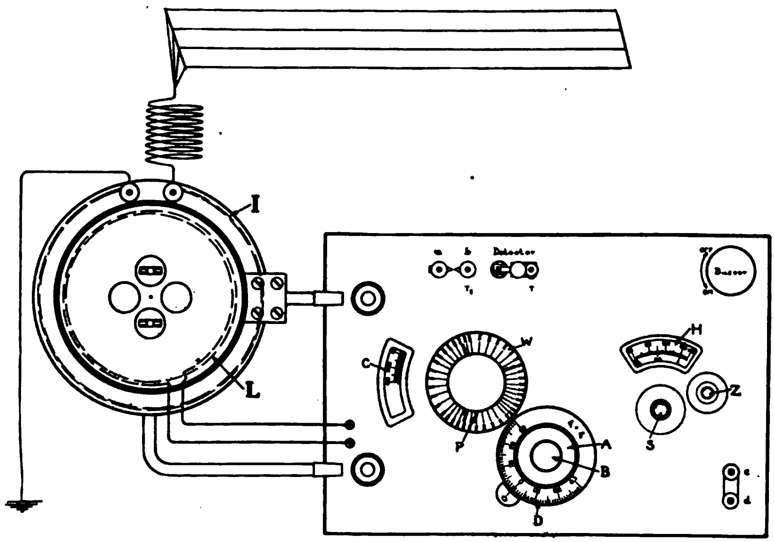


FIGURE 10—Top View of Decremeter

W = Wave length scale
C = Condenser scale in degrees
D = Decrement scale
H = Scale of hot wire instrument
A = Knob operating variable condenser
B = Clamping screw
S = Short circuit release
Z = Zero adjusting screw
a b = Terminals of condensers
c d = Terminals for series connection

EXPERIMENTAL DATA

In order to determine the accuracy of the instrument for measurement of $\delta_1 + \delta_2$ the following experiments were made:

Experiment 1.—The decremeter was used as an ordinary wave meter, loosely coupled to the secondary of a quenched spark transmitter. A resonance curve was obtained similar to that shown in Figure 2, and for several ratios $\frac{I_r^2}{I^2}$, $\delta_1 + \delta_2$ was calculated from the formula

$$\delta_1 + \delta_2 = 2\pi \frac{\lambda_2 - \lambda_1}{\lambda_2 + \lambda_1}\sqrt{\frac{I^2}{I_r^2 - I^2}}$$

and the following values obtained:

$\frac{I_r^2}{I_2}$	$\delta_1 + \delta_2$
1.180	0.0970
1.475	0.0893
1.735	0.0911
2.000	0.0903
Average	0.0919

A single measurement obtained by means of the decremeter used as a direct reading instrument gave at once a value of 0.091 for $\delta_1 + \delta_2$

A further check was obtained by calculating the required value of $\theta_2 - \theta_1$ for $\delta_1 + \delta_2 = 0.091$ from the formula

$$\theta_2 - \theta_1 = \frac{1}{m} \log \frac{\pi + \delta}{\pi - \delta} \text{ for } I^2 = \frac{1}{2} I_r^2$$

$\theta_2 - \theta_1 = 4°.75$ by calculation

$\theta_2 - \theta_1 = 4°.68$ as determined from the experimentally obtained resonance curve.

Experiment 2.—In this experiment the decremeter was again loosely coupled to the secondary circuit of a quenched spark transmitter and a direct measurement made of $\delta_1 + \delta_2$. A resistance, in the form of a short straight piece of about No. 40 manganin wire, was then inserted in the circuit of the instrument and a direct measurement made of $\delta_1 + \delta_2 + \Delta\delta_2$, $\Delta\delta_2$ being the additional decrement due to the inserted resistance.

The capacity of the condenser and the frequency of the oscillations being known, the value of the inserted resistance R was calculated from the formula

$$R = \frac{\Delta\delta_2}{\pi C \omega}$$

and the following results obtained.

TEST No. 1

$\delta_1+\delta_2$ read from decrement scale of instrument	$\delta_1+\delta_2+\Delta\delta_2$ read from decrement scale of instrument
0.132	0.168
0.130	0.169
0.130	0.163
0.131	0.172
0.130	0.167
Average = 0.131	Average = 0.168

$$\delta_1 + \delta_2 + \Delta\delta_2 = 0.168$$
$$\delta_1 + \delta_2 = 0.131$$
$$\therefore \quad \Delta\delta_2 \quad 0.037$$

Capacity of condenser at resonance = 334 $\mu.\mu.f.$

$$\omega = 2\pi n = 3.66 \times 10^6.$$

$$R = \frac{\Delta\delta_2}{\pi C\omega} = 9.63\Omega$$

By measurement on D. C. bridge,

$$R = 9.51\Omega$$

Another test was made at a different frequency and consequently with a different value of capacity.

TEST No. 2

$$\delta_1 + \delta_2 + \Delta\delta_2 = 0.155$$
$$\delta_1 + \delta_2 = 0.099$$
$$\Delta\delta_2 = 0.056$$

Capacity of condenser at resonance = 764 $\mu.\mu.f.$

$$\omega = 2\pi n = 2.47 \times 10^6$$

$$R = \frac{\Delta\delta_2}{\pi C\omega} = 9.45^{\Omega}$$

Value of R measured on D. C. bridge = 9.51.

Test No. 1: $R = 9.63^{\Omega}$
Test No. 2: $R = 9.45^{\Omega}$
Average = 9.54^{Ω}

Experiment 3.—In this case resistance was inserted in the secondary circuit of the transmitter and the value of this resistance calculated in the same manner as in experiment 2.

TEST No. 1

$$\delta_1 + \Delta\delta_1 + \delta_2 = 0.141$$
$$\delta_1 \qquad + \delta_2 = 0.089$$
$$\Delta\delta_1 \qquad = 0.052$$

Capacity of condenser at resonance = 3900 $\mu.\mu.f.$

$$\omega = 2\pi n = 3.35 \times 10^6$$

$$R = \frac{\Delta\delta_1}{\pi C\omega} = 1.27^{\Omega}$$

Value of R measured on D. C. bridge = 1.242^{Ω}

TEST No. 2

$$\delta_1 + \Delta\delta_1 + \delta_2 = 0.111$$
$$\delta_1 + \qquad \delta_2 = 0.074$$
$$\Delta\delta_1 \qquad = 0.037$$

Capacity of condenser at resonance = 3900 $\mu.\mu.f.$

$$\omega = 2.43 \times 10^6$$

$$R = \frac{\Delta\delta_1}{\pi C\omega} = 1.24^{\Omega}$$

Test No. 1: $R = 1.27^{\Omega}$
Test No. 2: $R = 1.24^{\Omega}$
Average = 1.255^{Ω}

DETERMINATION OF WAVE-LENGTH SCALE

Since the capacity of the variable condenser in the instrument varies according to a definitely known law, it is possible to attach to this condenser a predetermined scale indicating wave lengths directly. The graduations of the wave length scale are determined by calculation in the following manner:

It has been shown that the capacity of the condenser may be expressed as $C = \alpha\varepsilon^{m\theta}$.

The wave length λ is proportional to $\sqrt{C}$

therefore, λ is proportional to $\sqrt{\varepsilon^{m\theta}}$

or λ is proportional to $\varepsilon^{\frac{m\theta}{2}} = \varepsilon^{n\theta}$

where $n = \frac{m}{2}$

Now let λ_1 be any wave length within the range of the instrument, and λ_2 any other wave length desired, then

$$\frac{\lambda_2}{\lambda_1} = \frac{\varepsilon^{n\theta_2}}{\varepsilon^{n\theta_1}} = \varepsilon^{n(\theta_2 - \theta_1)}$$

and
$$\log \frac{\lambda_2}{\lambda_1} = n(\theta_2 - \theta_1)$$

or
$$\theta_2 - \theta_1 = \frac{1}{n} \log \frac{\lambda_2}{\lambda_1} = \frac{2}{m} \log \frac{\lambda_2}{\lambda_1}$$

therefore
$$\theta_2 = \theta_1 \pm \frac{2}{m} \log \frac{\lambda_2}{\lambda_1}$$

For the purpose of determining the graduations for the scale, λ_1 may be any wave length, as, for example, 300 meters. Furthermore, θ_1 may be taken as zero, for convenience, then

$$\theta_2 = \pm \frac{2}{m} \log \frac{\lambda_2}{300}$$

From this equation θ_2 may be calculated for any wave length λ_2.

The scale is arranged so that it can rotate about the shaft of the variable condenser independently but remains stationary when the condenser is rotated. A pointer is attached to the shaft of the condenser and travels over the scale as the condenser rotates.

In order to cover a wide range of wave lengths, several coils are supplied with the instrument, each coil covering a part of the range. It is necessary, therefore, to adjust the position of the wave length scale to correspond with the particular coil in circuit. Red marks on the wave length scale indicate the maximum wave length obtainable with the coils 1, 2, and 3, respectively. The position of these red marks is determined experimentally.

THE MEASUREMENT OF WAVE LENGTH

The variable condenser is first set at 180°, the wave length scale is then adjusted so that the red mark on the scale corresponding to the coil in circuit is directly under the pointer attached to the condenser shaft. The wave length scale remains in this position and, as the condenser is varied, the pointer travels over the scale, indicating the wave length when resonance is obtained, as shown by the maximum reading of the hot-wire instrument needle.

When the instrument is used as a receiver with detector and telephones, or as a transmitter using the buzzer, the wave length scale does not strictly apply for the wave length range below the 90° position of the condenser. In these cases it is necessary to refer to calibration curves for the small correction.

The instrument may be used in an interesting manner for receiving audible signals from a source of undamped oscillations, such as an arc circuit or a high frequency alternator. To accomplish this, oscillations are set up in the wave meter circuit by means of the buzzer and the telephone receivers are connected to the detector at T and to the binding post a instead of b (see Figure 10). Under these conditions, when undamped oscillations are induced in the circuit, a heterodyne effect is produced and the wave meter becomes a comparatively sensitive receiver of undamped oscillations. Very weak harmonics existing in arc circuits may be readily measured by using the instrument in this manner.

DETERMINATION OF THE DECREMENT OF THE INSTRUMENT

To obtain the logarithmic decrement, δ_1 of the circuit under test, it is necessary to know δ_2, the decrement of the instrument, in order that it may be subtracted from the scale reading which is $\delta_1 + \delta_2$.

An ideal method for determining δ_2 would be to charge the condenser of the instrument at a given potential and allow it to discharge thru the circuit, first without inserted resistance and then with a known resistance inserted in the circuit, noting in each case the reading of the hot-wire instrument.

The energy in the circuit in both cases would then be equal and,

$$I_1^2 R = I_2^2 \ (R + \Delta R)$$

where R is the resistance of the circuit and ΔR is the resistance inserted. Then,

$$R = \Delta R \frac{I_2^2}{I_1^2 - I_2^2}$$

where I_2^2 and I_1^2 represent, respectively, the readings of the hot-wire instrument with and without inserted resistance, these readings being proportional to the square of the current flowing in the circuit.

If the inductance L or capacity C of the circuit are known, δ_2 is then determined for any value of ω, since,

$$\delta_2 = \pi R C \omega = \pi \frac{R}{L\omega}$$

A method used in practice which approaches this ideal case very closely is as follows:

Energy is supplied to the instrument by means of impact excitation, in which case nearly free oscillations exist in the circuit of the instrument. These oscillations, therefore, have a frequency and damping determined by the constants of the circuit. To determine the resistance of the circuit, readings of the hot-wire instrument are taken with and without inserted resistance. The energy in the circuit, however, would not in practice be strictly equal in the two cases and

$$I_1^2 R = K I_2^2 (R + \Delta R)$$

or

$$R = \Delta R \frac{K I_2^2}{I_1^2 - K I_2^2}$$

It has been shown in previous works[1] on this subject that

$$K = 1 + \frac{\Delta\delta}{\delta_1 + \delta_2}$$

where δ_1 is the decrement of the exciting circuit, δ_2 the decrement of the instrument circuit, and $\Delta\delta$ the additional decrement due to the insertion of a small resistance ΔR.

It is seen that for the case of impact excitation where δ_1 is very large as compared to $\Delta\delta$, K will be very nearly unity and for practical purposes we may write

$$R = \Delta R \frac{I_2^2}{I_1^2 - I_2^2} = \Delta R \frac{1}{\frac{I_1^2}{I_2^2} - 1}$$

Where it is desired to make ΔR, the inserted resistance equal to R, the resistance of the instrument circuit, which corresponds to making $\Delta\delta$ equal to δ_2, then for the case of impact excitation,

$$\frac{I_1^2}{I_2^2} = 2$$

On the other hand, if $\delta_1 = 0$ as in the case of undamped oscillations,

$$K = 2 \text{ and } \frac{I_1^2}{I_2^2} = 4$$

In general, therefore, when it is desired to make the inserted

[1] Lehrbuch der Drahtlosen Telegraphic. Zenneck, 1913, p. 142.

resistance ΔR equal to the resistance of the instrument R, the amount by which I_1^2 must be reduced or the ratio of $\frac{I_1^2}{I_2^2}$ depends upon the ratio of δ_1 to δ_2, for when $\Delta\delta = \delta_2$

$$K = 1 + \frac{\delta_2}{\delta_1 + \delta_2} = 1 + \frac{1}{\frac{\delta_1}{\delta_2} + 1}$$

and for $\delta_1 = 0, K = 2 \text{ and } \frac{I_1^2}{I_2^2} = 4$

$$\delta_1 = \infty, \ K = 1 \text{ and } \frac{I_1^2}{I_2^2} = 2$$

For intermediate values of $\frac{\delta_1}{\delta_2}$ between 0 and ∞, K will vary from 2 to 1 and the ratio $\frac{I_1^2}{I_2^2}$ correspondingly from 4 to 2.

The most direct and simple method, however, for obtaining δ_2 is to excite the instrument by means of undamped oscillations. Then

$$\delta_2 = \pi \frac{C_2 - C_1}{C_2 + C_1} \sqrt{\frac{I^2}{I_r^2 - I^2}}$$

as shown in the earlier part of this paper.

If suitable means for producing undamped oscillation are not available the method of impact excitation is very satisfactory, provided that δ_1 is very large as compared with $\Delta\delta$.

The curves in Figure 11 give the values of δ_2 for coils 1, 2, and 3, at various settings of the variable condenser. These values were obtained by the method of impact excitation.

On curve 3 are shown values of δ_2 obtained by using undamped oscillations from a Poulsen arc as a source of excitation.

In Figure 12, the assembled decremeter is shown, with the cover of the carrying case turned back. As will be seen, the coupling and decremeter coils and their supports are mounted for transportation in the cover. The function of the other parts shown is made clear by reference to the key of Figure 10. Figure 13 is a photograph of the interior of the instrument. To the right is the special variable condenser, and to the left the variable condenser which is set once for all in the initial calibration of the instrument. This latter condenser is of the rectangular sliding interwoven plate type.

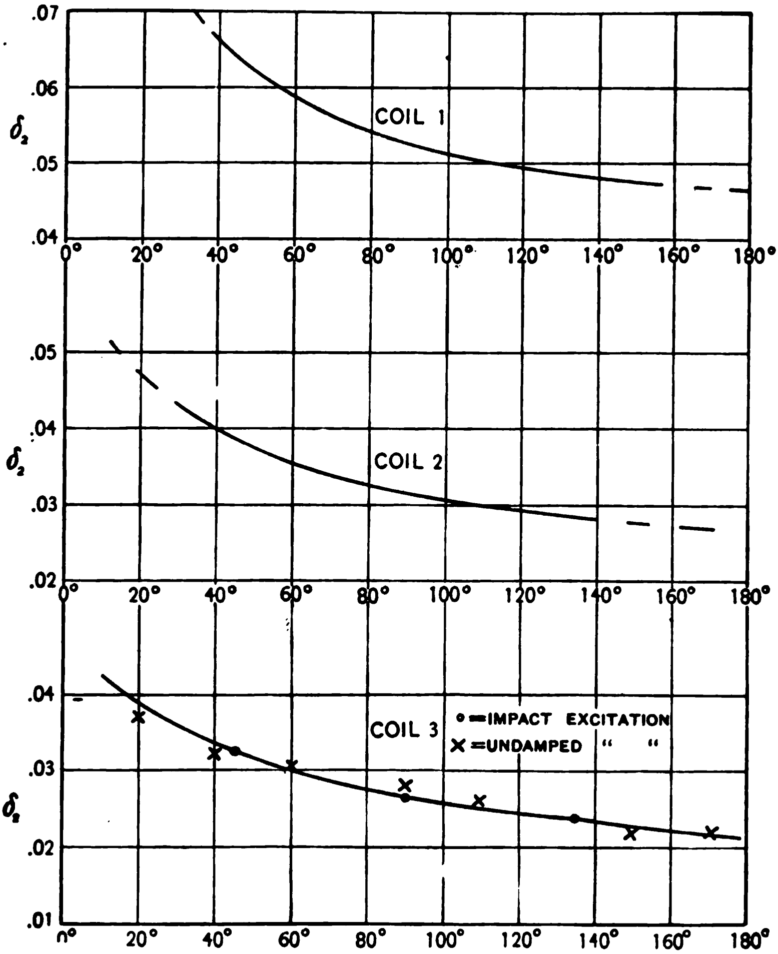


FIGURE 11—Decrement of Instrument

SUMMARY: A new type of direct-reading decremeter and wave meter is described. It is based on the Bjerknes method, but much simplifies the measurement and increases the accuracy thereof. The variable condenser of this wave meter is of a special type, the movable plates being cut to an appropriate outline. By placing a fixed capacity in parallel with this variable condenser, which fixed capacity is adjusted once for all in each instrument, a standard and predetermined calibration curve can be used with all instruments. The design and construction of the apparatus is given in detail, and a number of measurements with it are considered critically. Several methods of determining the decrement of the instrument itself are shown. The instrument can also be used as an exciting circuit of known wave length and decrement. An interesting example of heterodyne reception of sustained oscillations with this instrument is described.

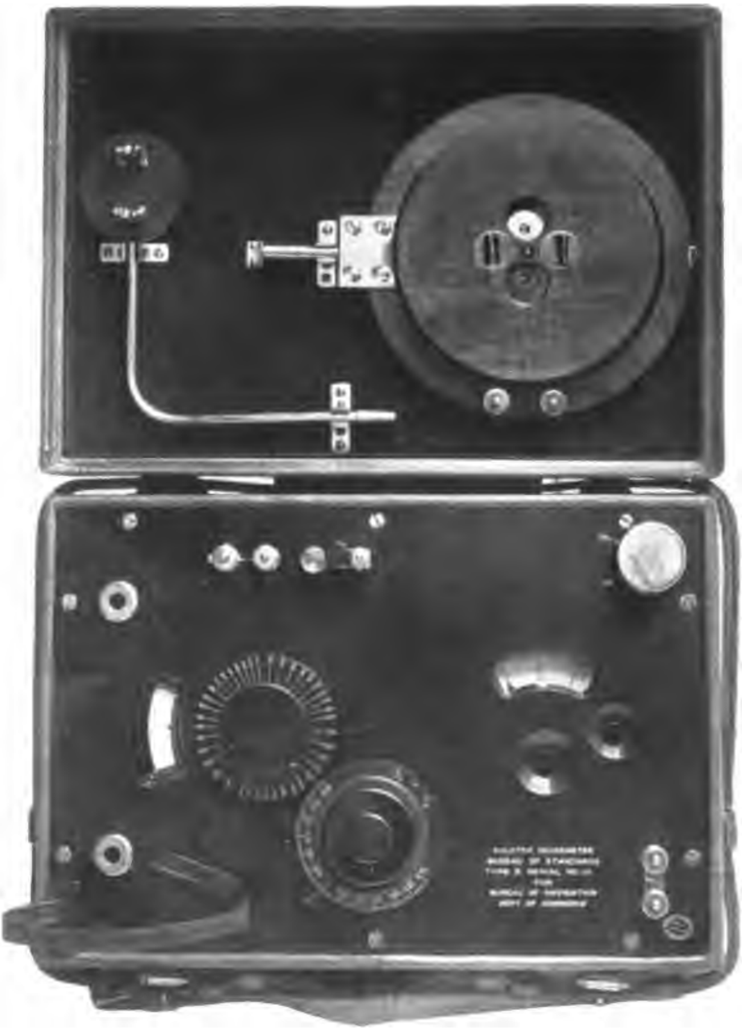


FIGURE 12—Decremeter Mounted in Leather Carrying Case

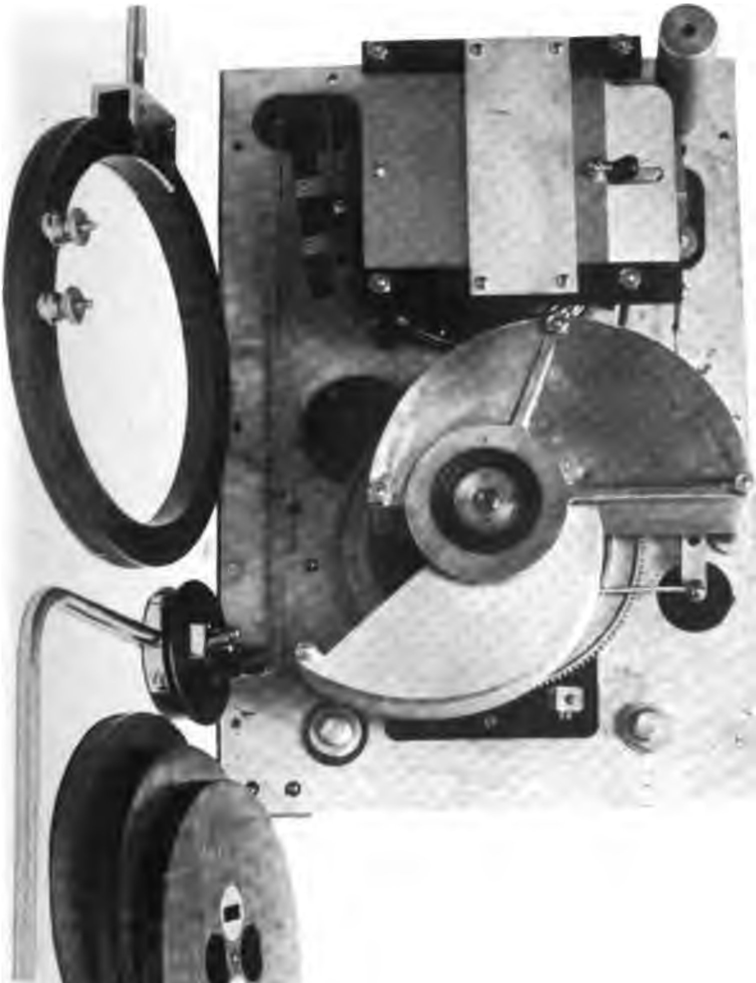


FIGURE 13—Interior View of Decremeter Showing Condensers

RADIO FREQUENCY CHANGERS*

By

Alfred N. Goldsmith

For a considerable number of years after its inception, the development of radio transmission was bound up practically completely with the generation of radio frequency currents by means of the discharge of a condenser in an oscillatory circuit which contained a spark gap discharger. The use of a section of an ionised gas in an oscillatory circuit has never completely satisfied those members of the radio engineering fraternity who are most imbued with the older and more usual methods of generating various types of alternating currents. To them the employment of a spark (which is a never failing source of thermal energy dissipation) has seemed an uncertain method, and they have always believed that the deterioration, uncertainty, and impairment of efficiency of such apparatus did not compensate for its simplicity and comparative inexpensiveness. We shall not here attempt to decide the relative merits of the spark methods of generating radio frequency currents and the newer alternator-frequency changer methods. Such an attempt would be necessary futile, since only time, patient development of the frequency changers, and detailed experiments under widely varied conditions could definitely settle the question. We shall merely confine ourselves to a description of the various types of apparatus whereby the frequency of an alternating current may be directly increased without the use of the usual gap discharger.

Furthermore, we are completely unconcerned here with the difficult and delicate questions of historical precedence of invention. Unfortunately there can be but little doubt that the courts will be required to adjudicate the property rights of the various inventors in this as in so many other cases. It is only to be hoped that the deterrent influence of such patent litigation on the genuine scientific and commercial development of the frequency changers will be slighter than is usual. We shall

* Delivered before The Institute of Radio Engineers, New York, October 7, 1914; and before the Boston Section, December 3, 1914.

attach the names of certain investigators to definite pieces of apparatus as an indication that the investigators in question have clearly described and claimed such apparatus in open publications.

The first method we shall consider is dependent on electrostatic induction and involves the use of moving parts. It was first described by Petersen.† The principle of the machine is illustrated in Figure 1. As will be seen, the terminals of a

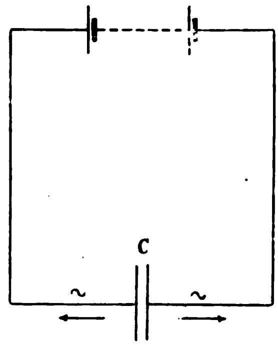


FIGURE 1

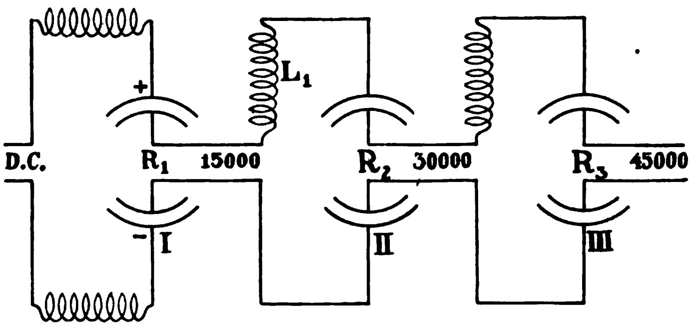


FIGURE 2

battery are connected to the plates of the condenser C. The capacity of the condenser C may be cyclically varied; either by altering the separation of its plates or by altering the dielectric constant of the medium between them. If either of these expedients is adopted, current will flow into the condenser and out of it cyclically, and by appropriate means, alternating current energy can be obtained from the arrangement. It involves

† Petersen, German Patent Number 2578.

a simple type of transformation of mechanical energy into alternating electric energy.

The type of machine just described produces the fundamental frequency which is increased by the method shown in Figure 2. At A we have a high voltage source, e. g., a storage battery of many cells. Its terminals are connected thru large inductances to the field plates of generator I. Within the strong electric field thus produced, two sets of insulated plates rotate. Alternating differences of potential appear at the terminals of the rotating armature plates. By properly constructing the machine, with due regard to the necessary limits of tensile strength of the materials used, it may be possible to secure a fundamental frequency of 15,000 cycles per second. The terminals of the armature of generator I are connected thru the carefully adjusted inductance L_1 with the field plates of the second machine, which is a frequency changer. The inductance L_1 is so chosen that the circuit in which it is placed is resonant to the frequency n_1 of generator 1; which may be, say, 15,000. In the electric field of machine II (the first frequency changer) there rotate the armature plates, and their speed of rotation is chosen so that they revolve synchronously with the electric field in which they move There will then appear at their terminals an alternating potential of frequency 2 n_1. The reason for this is the following. Let F_m be the maximum field intensity in a vertical direction between the field plates. At any time t the field intensity will be

$$F = F_m \sin \omega t$$

where

$$\omega = 2 \pi n_1.$$

Suppose that the armature plates have rotated thru an angle θ from the position shown in the diagram. Then, if m is a constant, the instantaneous difference of potential **e** between the armature plates is

$$e = m F_m \sin \omega t \cos w t$$

where

$$w t = \theta$$

If, now, we rotate the armature synchronously, so that

$$w = \omega$$

we have

$$e = \frac{m}{2} F_m \sin 2 \omega t$$

It is thus clear that we are producing an electromotive force of double frequency. Physically this corresponds to the fact that the alternating electric field which is due to the field plates may be regarded as the sum of two rotating electric fields, revolving synchronously in opposite directions. If now the armature also rotated synchronously, it will be stationary relative to one of the rotating component fields and will rotate with twice synchronous speed relative to the other component rotating field. The first of these rotating fields will therefore produce in the armature no alternating potential differences, whereas the second will produce an alternating potential difference of twice the fundamental frequency. This principle should be remembered, since it is also extensively applied in radio frequency changers dependent on electromagnetic induction. As an example of an important machine wherein this method of frequency doubling is employed, the Goldschmidt alternator may be mentioned.

It is therefore evident that in the first frequency changer, an alternating potential difference having a frequency of 30,000 cycles per second will be produced. The process of frequency doubling may be increased thru any desired number of steps; tho, in general with a consequent diminution in over-all efficiency of the system. It is also noteworthy that, by somewhat the same artifice as will be later described in connection with the Goldschmidt alternator, all the frequency transforming processes just described may be caused to take place in a single machine.

As has been stated, each of the circuits consisting of a pair of armature plates, a tuning inductance, and a pair of field plates of the next frequency changer, must be tuned to resonance to the appropriate frequency. The resonance condition, which is readily fulfilled, is that

$$\omega^2 L C = 1$$

where ω is the angular velocity (2π times the frequency), and L and C are the total inductance and capacity of the circuit in question. The final circuit comprises the armature of the last frequency changer, a tuning inductance, and the capacity comprised by antenna and ground.

It is as yet too early to decide even vaguely the probable commercial value of this type of machinery. It must be admitted that the electrostatic machine herein described can be built so as to have the utmost simplicity. To avoid losses thru high voltage brush discharges, the entire machinery might be enclosed in compressed air, as has in fact already been done for the normal types of electrostatic generators. A marked increase in efficiency was thereby produced.

Still considering rotary machinery we pass to those frequency changers based on electromagnetic induction. One of the simplest of these is that one worked out independently by E. Arnold and D. Korda in 1893. The circuit diagram is shown in Figure 3.

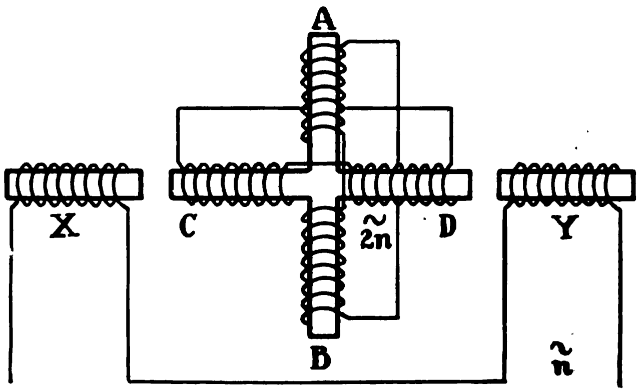


FIGURE 3

In this diagram X and Y are two field coils thru which a single phase alternating current passes. As a matter of practical construction a great number of arrangements of such a field can be employed; for example, a Gramme ring connected to the alternator at two opposite points of its circumference. There will be produced, then, between the coils X and Y a stationary alternating field. The two coils A B and C D, which are mutually perpendicular, rotate in this field. In the figure each of these coils is shown as short-circuited, but instead their terminals may be connected to a slip ring. If now the two coils mentioned rotate at synchronous speed, it can be shown that there will be induced in each of them, electromotive forces of double frequency. The proof of this is quite similar to that already given for the case of the electrostatic generator. Two alternating currents differing in phase by 90 degrees can be obtained from the two rotating coils, and the magnitude of these currents can be brought to a maximum by appropriate tuning thru inserted condensers in the circuits connected to the rotating coils. It can be shown further that the sum of the torques for an entire revolution is zero if the coils are rotating in phase with the field of the field magnets.

If we desire to draw energy from this device, that is, to use it as a generator, the rotating coils must lead the field of the coils

X and Y. The process of frequency doubling herein described may be carried thru any number of stages.

The arrangement described may be modified, as Korda has shown, by using stationary armature coils and rotating field coils. A number of ingenious modifications of this method are possible whereby direct current field excitation can be employed and also two phase alternating current excitation. In this latter case, it is possible to produce currents of double frequency but of cyclically varying amplitude; and such a method may well be applicable for tone production in radio frequency generators.

Korda has worked out a very ingenious method whereby the frequency of an alternating current may be directly tripled. In Figure 4 is shown the arrangement previously described with an additional coil E F. The field of the two coils A B and C D compound to a single field having an angular velocity of rotation which is twice that of the coils; that is, twice synchronous speed. If now this field were to rotate in the same direction as the coils rotate, its absolute angular velocity in space would be three times synchronous speed, and if this could be accomplished, there would be induced by it, in the stationary coil E F, a current of three times the fundamental frequency. Unfortunately, in the arrangement shown, the field of the rotating coil rotates in the opposite direction to the coils, and therefore induces in the stationary coil E F a current of the fundamental frequency.

In order to cause this rotating field to have the same direction of rotation as the coils themselves it is necessary to displace the alternating current in one of these coils by 180 degrees in phase. This can be done readily enough in the arrangement shown in Figure 5. Coils 2 and 4, which are mounted parallel to each other on the same shaft, are wound in the same direction and connected as shown. Coils 1 and 3 are mounted parallel to each other on the same shaft, wound in opposite directions, and then connected. Coils 1 and 2 correspond respectively to coils A B and C D of Figure 4. It will be seen that inasmuch as the current in coil 3 has been displaced 180 degrees thru the use of the reversing connection, the field of coils 3 and 4 combined will rotate at twice synchronous speed relative to these coils and in the same direction as that of their rotation. There will therefore be induced in coils 5 and 6 a current of triple frequency. The device described is directly applicable to multipolar machines and it is easily seen that a rapid multiplication of frequency can be produced by its use. It is further advantageous in that no brushes or slip rings are employed.

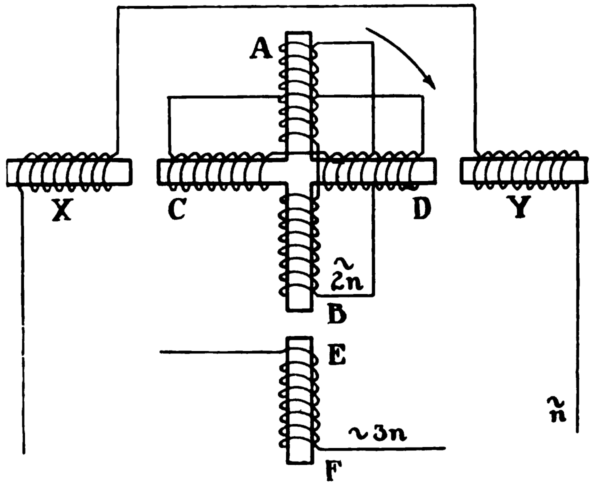


FIGURE 4

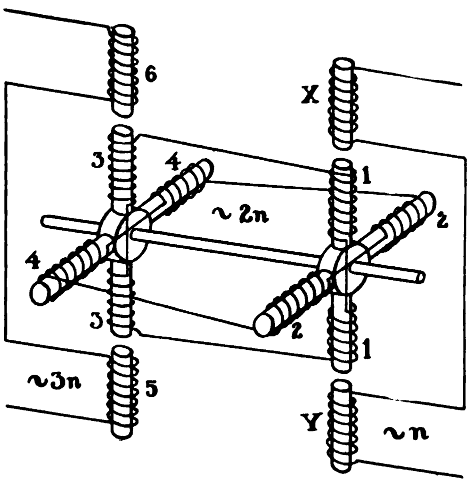


FIGURE 5

A further method based on electromagnetic induction and employing moving parts was described by Cohen in the "Electrical World" in 1908. It was proposed to place a number of alternating current generators on the same shaft, as shown in Figure 6. The field of the first generator was excited by direct current. The armature of each generator was connected thru an appropriate tuning condenser to the field magnets of the next. The device shown is perfectly analogous to Petersen's method previously

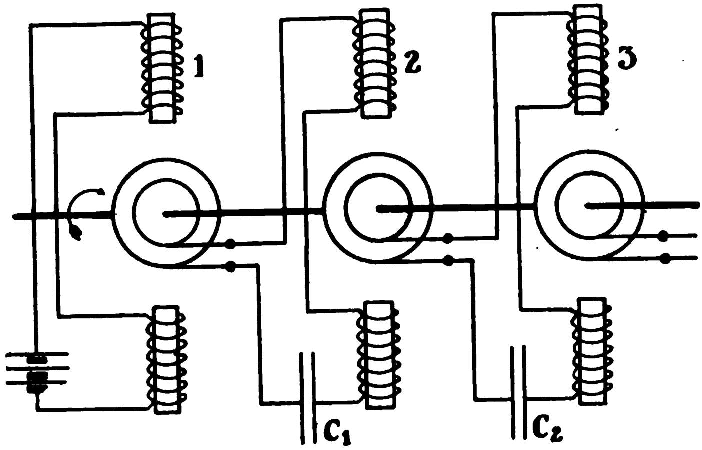


FIGURE 6

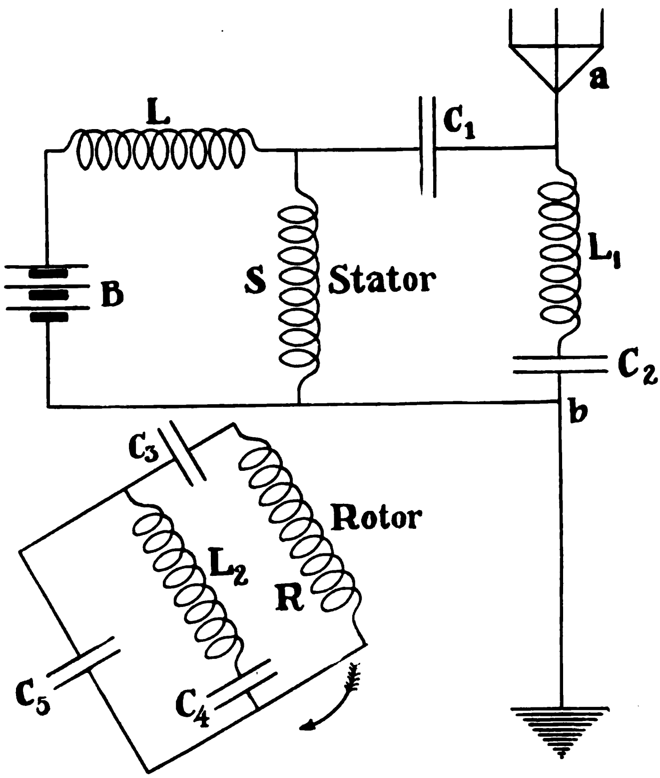


FIGURE 7

described. As in that former case, there will be a doubling of frequency in each step. The alternators used in any process of this sort must be particularly adapted to their purpose. A minimum of iron should be used, particularly when working at the higher frequencies. Such iron as is used should have a small hysteresis constant and should be very finely laminated. It may further be stated that the armature reaction in each of the frequency changers will require correction of the values of the tuning condenser of the field magnet circuit of that frequency changer, this correction being different for each different output. The varying permeability of the iron coils employed will introduce a certain error in the tuning, and somewhat diminish the over-all efficiency.

It remained for Dr. R. Goldschmidt to work out the method described in German patent Number 208,206, wherein all the changes of frequency performed by separate machines in the previous method take place in a single machine. It is not necessary for me to describe this method in detail. A full description of it is found in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, Volume 2, Number 1, page 69, et seq. The method is diagrammatically illustrated in Figure 7. Herein the battery B supplied the current necessary to excite the field magnet S of the stator. L is a large inductance intended to prevent the flow of alternating currents thru the battery circuit. In the field of the stator S is a rotor which is short circuited for the fundamental frequency by means of the capacities C_3 and C_4 and the inductance L_2. It is to be noted that R and C_3 alone would be in resonance to the fundamental frequency, as also would L_2 and C_4. The complete circuit $RC_3L_2C_4$ therefore contains approximately twice the inductance and half the capacity of either RC_3 or L_2C_4. Its period is therefore the same as that of either of these, and even if L_2C_4 were to be short-circuited, the rotor would still be resonant to the fundamental frequency. A perfectly similar arrangement is adopted for the stator by the use of the circuit S C_1 L_1 C_2, except that the circuit in question is tuned to twice the fundamental frequency. It will be seen that as the rotor revolves in the field of the stator, powerful currents of the fundamental frequency will flow thru it. The great magnitude of these currents is due to the fact that the rotor is itself part of a circuit resonant to the fundamental frequency. If we consider the field of the rotor, we may regard it as resolved into two component fields of constant and equal magnitude, rotating in opposite directions relative to the rotor.

Their absolute angular velocity relative to the stator will therefore be zero and twice synchronous speed respectively. There will therefore be induced in the stator electromotive forces of twice the fundamental frequency (and zero frequency); and since a circuit resonant to the double frequency is provided, powerful currents will flow thru the stator. These alternating currents of double frequency will induce in the rotor electromotive forces of frequencies 3n and n, where n is the fundamental frequency. By means of the condenser C_5, a path resonant to the frequency 3n is provided in the rotor. By properly choosing the constants of the various rotor circuits, the current of frequency n mentioned first can be made very nearly to neutralize the second current of frequency n which we have mentioned. The reason for this is that these currents may be brought to nearly complete opposition in phase, and equal amplitude. There will be left then in the rotor a powerful current of triple frequency. Its field may be resolved into two equal and constant revolving fields, rotating in opposite directions, with absolute angular velocities twice and four times the fundamental angular velocity. There will therefore be induced in the stator, currents of frequency 2n and 4n. Of these the current of frequency 2n will nearly completely neutralize the former current of frequency 2n in the stator, which was mentioned above. The outstanding current of frequency 4n, in the diagram of Figure 7, is shown as flowing into the capacity and inductance formed by the antenna a and the ground b.

In practice, very finely laminated iron of high quality, worked far below the saturation value of flux density, is used in these machines. The air gap between rotor and stator is kept as small as possible, and in some cases special methods of cooling the machine are employed. In order to prevent the radiation by the antenna of some of the lower frequencies, it is desirable to keep the coupling between the various oscillatory circuits at moderate values. Too large a coupling also tends to distribute the energy absorption in the circuits of lower frequency instead of concentrating it in the circuit of highest frequency.

In 1913, Leon Bouthillon described an ingenious type of generator, intermediate in type between a rotary converter and an alternator. It depends on the following principle. If, in any circuit, there are a number of alternating electromotive forces of any wave form, and each of these is equally displaced in phase relative to the preceding, under certain conditions the resultant electromotive force has a much greater frequency than any of the component forces and a very appreciable amplitude. Analytically and more exactly expressed: if there are m such electromotive forces, each of frequency n, and the phase displacement of each relative to the preceding is $\frac{2\pi G}{m}$, where G is a whole number, the resulting electromotive force has a frequency $\frac{m}{V}n$, where V is the greatest common divisor of G and m. The amplitude of the resulting potential difference is the product of m and the amplitude of the $\frac{m}{V}$th term of the Fourier's series expressing the original electromotive forces.

To carry out this idea, we need only use an alternator having Y poles in the field, with the armature rotating U times per second. Then

$$n = \frac{UY}{2}.$$

If the armature has m conductors, the phase displacement of the electromotive force in each relative to the preceding will be $\frac{\pi Y}{m}$. Bouthillon has calculated that a machine could be built with the following characteristics: peripheral velocity of rotor = 196 meters per second, outer diameter of pole supports = 156 centimeters, 40 revolutions per second, 2,401 (=49 x 49) turns on rotor, 49 pairs of poles, final frequency 96,040 cycles, corresponding to a wave length of 3,124 meters, rotor of solid steel, output 100 kilowatts. Such a machine, he states, could be built in any good electrical factory.

The desired overtones in the component electromotive forces are exaggerated by properly shaping the pole pieces, and by coupling suitable resonant circuits. The machines should be suitable for producing musical tones by the use of alternating current excitation, and are also applicable to the field of radio telephony.

We pass now to frequency transformers without moving parts. In the following we shall consider only such methods as deliver appreciable amounts of energy at a reasonable efficiency. The first we shall consider is the method described by Kruh (in American patent No. 787,193 of 1905). The somewhat complicated wiring diagram of the complete arrangement is shown in Figure 8. At the bottom of the figure is the mercury arc rectifier on which the whole arrangement is dependent. It has two

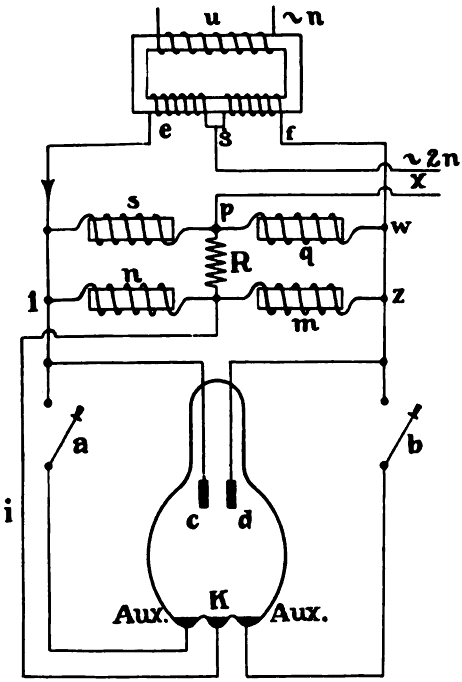


FIGURE 8

anodes c and d, one cathode K, and two auxiliary anodes for starting the arc. To ignite the arc the rectifier is tipped in one direction or the other, while the auxiliary lighting circuits are closed thru the switches a, b. So soon as the current flow is established, the switches are opened, automatically or otherwise, and the normal operation of the arc between K and c, d begins. The two coils e, g and g, f are the halves of the secondary of a transformer, the primary u of which is supplied with a current of the fundamental frequency n. The four coils q, s, m, and n, are inductances, the connecting points of which are joined thru the small resistance R. Between the points g and p can be drawn a current of double frequency. The explanation of the phenomena follows.

If, at any given time e is the positive end of the secondary of the transformer, current will flow thru the anode c to the cathode K and thence to the point p where the current will pass thru two alternative paths. One of these paths is to the double frequency circuit and the remaining portion of the current, after passing thru the inductance q assists in magnetizing the core of the transformer. There is also stored in the core of the inductance q a certain amount of energy, and this energy storage continues until the peak of the positive path of the alternating current wave is reached. Thereafter, in accordance with Lenz's law the coil q tends to keep the current flowing in the positive direction. This discharge current of the choke coil q also has the choice of two paths. It may pass to the cathode K by means of the anode d and thence return to the point p thru the circuit i. Another portion thereof will flow thru the section f, g of the transformer secondary into the double frequency circuit and thence back to p.

It is to be noted that while the current amplitude was increasing, the current flow in the double frequency circuit was *away* from p, but that during the second half of the positive portion of the alternating current wave (that is, during the decrease of current amplitude) the direction of current flow in the double frequency circuit was *toward* the point p. Evidently then, during a half cycle of the primary current there is produced in the double frequency circuit a complete cycle of current changes. It is evident, therefore, that the device is a frequency changer. The function of the extra choke coils m and n is easily understood. The losses in the core of the inductance q during the time that its core is being magnetized are necessarily greater than during the time of its de-magnetization. A disymmetry in the double frequency current would be thereby produced, and this disymmetry is minimized by the use of the extra inductances m and n and the resistance R. The current thru the inductances s and q is thereby made larger than the arc current. The resistance R also prevents the arc current passing into the double frequency circuit thru the conductors l and z and then thru i. A nearly uniform alternating double frequency current is thus produced. Inasmuch as it has been shown that mercury arc rectifiers can be operated at a good efficiency even at radio frequencies, it would seem that the method of Kruh might be applicable in radio work.

We pass to the methods of frequency change involving the use of the electrolytic cell rectifiers. If we study the behavior of an electrolytic cell employing a solution of alum as the electrolyte and carbon and aluminum as the electrodes, we discover that it permits the passage thru it of current only in one direction, namely, from the aluminum to the carbon. In Figure 9 is shown an application of such a cell to a frequency changer. V_1 and V_2 are two such electrolytic cells; and S_1 and S_2 are the

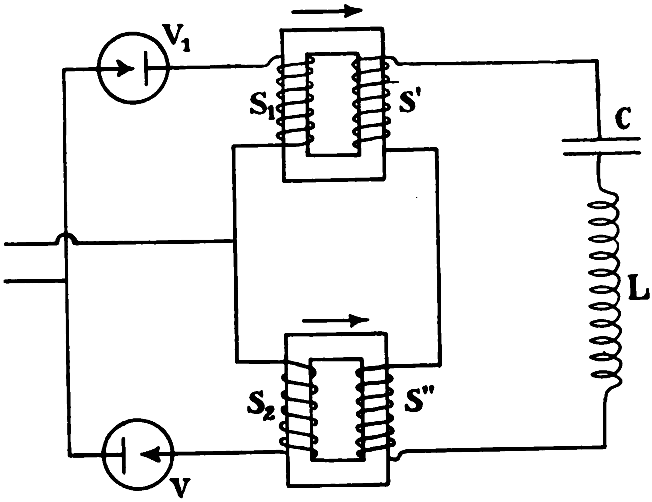


Figure 9

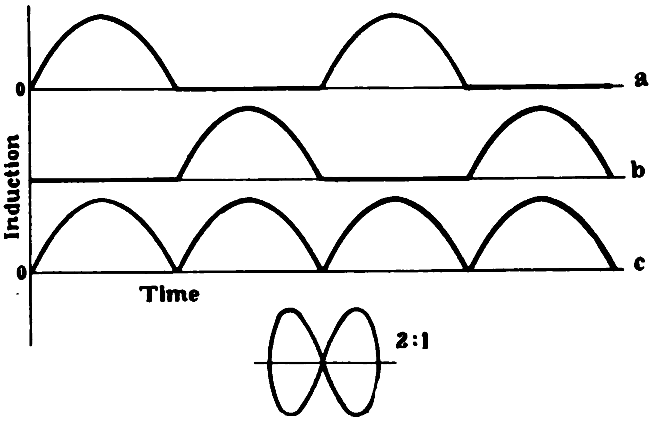


Figure 10

primaries of two transformers of which S′ and S″ are the secondaries. It will be noticed that V_1 and V_2 are connected with opposite polarity in their respective circuits, and that in consequence current can flow thru S_1 only in one direction and thru S_2 in the opposite direction. Furthermore, coil S_1 is wound in the opposite direction to coil S_2. On the other hand, S′ and S″ are wound in the same direction. In Figure 10, curve a shows the current passing thru S_1, and the consequent magnetic flux thru the corresponding transformer core. Curve b shows similarly the induction in the core of the second transformer.

The total magnetic induction for both transformers is shown in curve c. It will be seen that during the time of a single alternation of the supply current there are two maxima and two minima of the magnetic induction in the transformer cores. It is therefore clear that there will be produced in the circuit containing the two secondaries a current of double frequency altho the wave form of this current will be noticeably distorted in view of the non-sinusoidal character of the magnetic induction.

If it is desired to draw any appreciable amount of energy from the frequency changer, the inductance L and the capacity C are connected in series with the two secondaries, thereby bringing that circuit to resonance with the double frequency. Zenneck has done a considerable amount of valuable work along these lines and has found these cells to be usable at radio frequencies. However, the passage thru them of considerable energy is attended with certain difficulties based on excessive heating and deterioration of the electrodes. Using a cell having lead and aluminum electrodes in a 5 per cent solution of ammonium phosphate, Zenneck has demonstrated the production of the double frequency in an admirably clear way by the Lissajous figures. A Braun tube oscillograph was employed. Near the cathode stream were placed two mutually perpendicular coils, one of which was connected to the primary circuit of the frequency transformer and the other to the secondary circuit thereof. The familiar Lissajous "figure of eight," which signifies a ratio of frequencies of two to one, immediately appeared on the screen (Figure 10).

Among the other circuit arrangements suggested by Zenneck are those shown in Figures 11 and 12. In Figure 11 only a single transformer is used, and in spite of the interaction between S_1 and S_2 in that case, a double frequency secondary current is obtained. In Figure 12 a transformer with but a single winding on both primary and secondary is employed. The current path during a half cycle in this case is thru the path V_2 S_1 V_3. During the second path of the cycle the current path is V_1 S_1 V_4.

Continuing the consideration of frequency changes without moving parts, we come to a method for tripling the frequency directly by taking advantage of certain characteristics of an ordinary alternating current arc. It is well known that the potential difference at the terminals of an alternating current arc may have the form shown in Figure 13. So greatly deformed a wave form naturally suggests the existence of strong upper harmonics. It is in fact found that if we decompose this curve

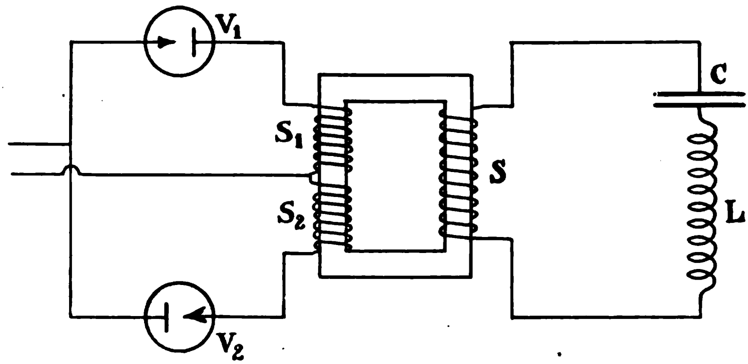


FIGURE 11

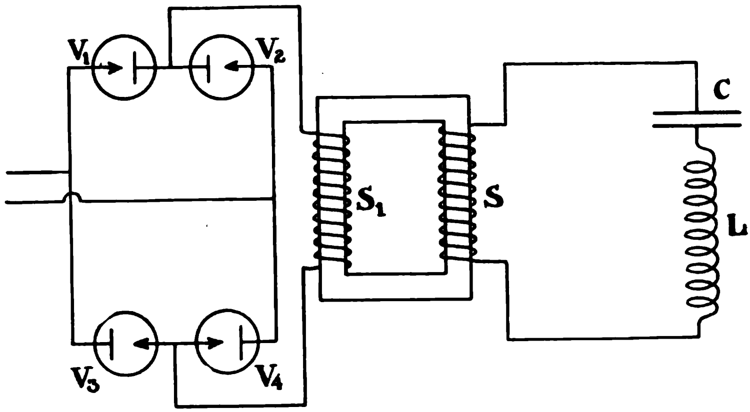


FIGURE 12

into component waves of the fundamental and other frequencies, the third harmonic is very prominent. In Figure 14, curve *a* represents fairly accurately the potential difference at the terminals of the arc. Curve *b* shows one of its components; namely, that of the fundamental frequency. Curve *c* shows the component of triple frequency; in fact, curve *a* is merely the sum of curves *b* and *c*. A circuit arrangement which can be employed to advantage under these conditions is given in Figure 15. The circuit L C is tuned to the triple frequency, and the inductances D prevent to a certain extent the triple frequency current from getting back to the alternator. The arrangement shown further permits obtaining the fifth, seventh, ninth and so on, frequencies, provided the circuit L C is tuned to the appropriate frequency. In fact, Rukop and Zenneck have done considerable work for the case where the frequency

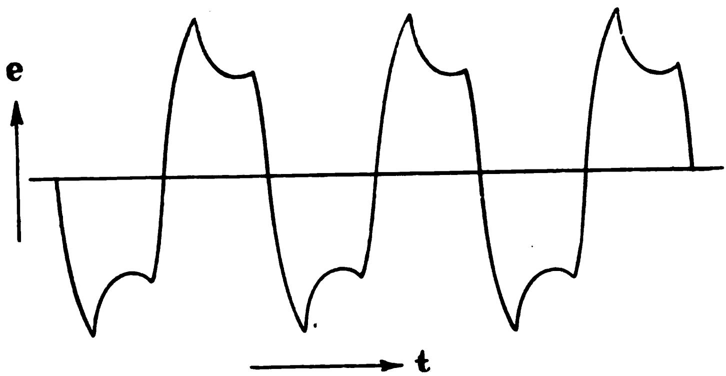


Figure 13

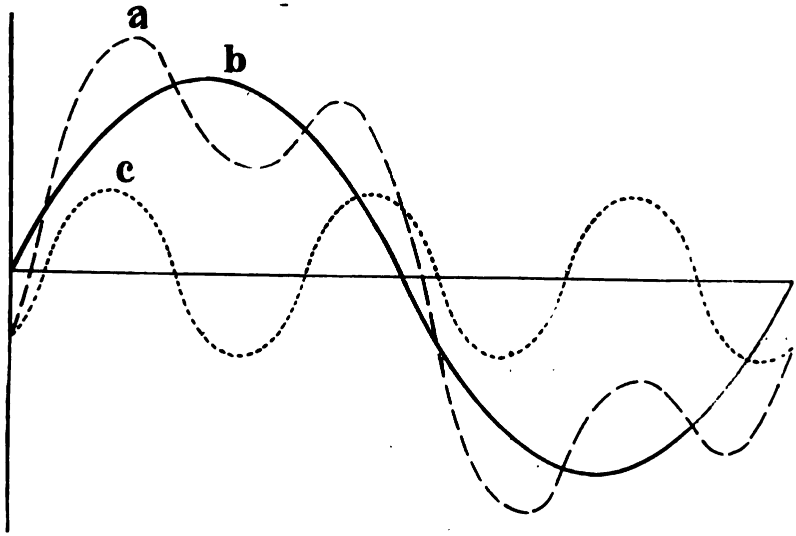


Figure 14

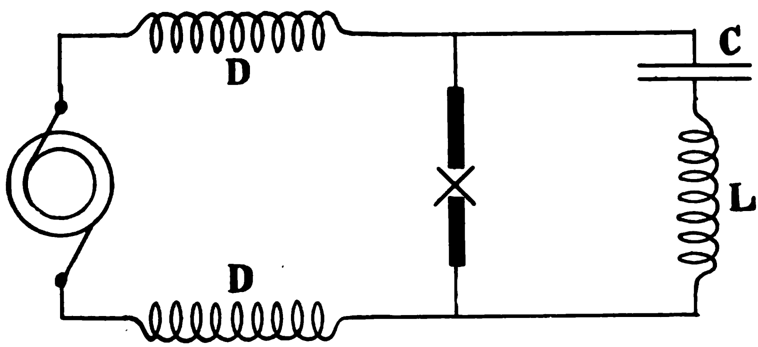


Figure 15

of the circuit L C was 300 times the fundamental frequency. For details of this investigation, the reader is referred to their article in "Annalen der Physik," 1914, Volume 44, page 97.

We consider now the extremely important cases wherein stationary frequency changers are employed, their operation being dependent on electromagnetic induction and the peculiar properties of iron. In Figure 16, is shown a typical B-H (magnet-

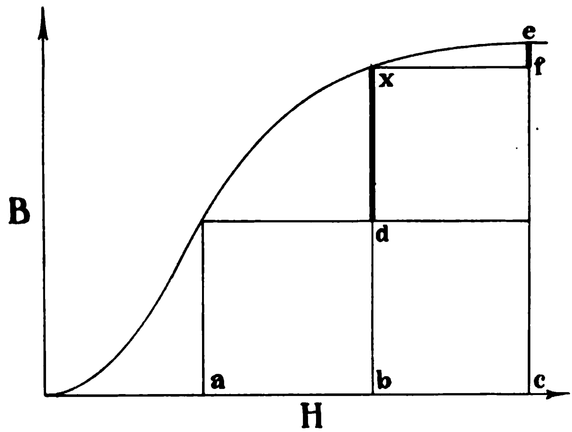


FIGURE 16

izing force-induction) curve for iron. Let us suppose that the magnetization of the iron has been brought to the point x. If now, by means of a superposed alternating magnetizing force, equal increments and decrements be added to the magnetizing force, the magnetic induction will increase during the positive half of the cycle by the small amount e f. On the other hand, during the negative half of the cycle, the induction will diminish by the considerably larger amount x d. The explanation of this phenomena is to be found in the well known magnetic saturation qualities of iron. In other words, a marked deformation from a sinusoidal variation of magnetic induction will occur when nearly saturated iron cores are employed. Such a deformation always leads to the production of upper harmonics, and it is upon this principle that the entire series of frequency changers employing iron is based.

A modification of the method just mentioned, and one of a highly ingenious sort, has been devised by Dr. R. Goldschmidt. It will be remembered that Rutherford first showed that remanent magnetism in iron could be destroyed by an alternating current field of high frequency. Furthermore, the hysteresis loop of iron for a magnetic cycle is much diminished in area if the iron is at the same time placed in a weak high frequency field.

Consequently it follows that if a piece of iron be magnetized longitudinally by a direct current field and transversely by an alternating current field, any slow variations in the direct current field will show only small hysteresis effect. A rough physical explanation of this phenomena is given by the consideration that the transverse magnetization keeps the elementary magnets of the iron in a mobile condition and thereby permits the longitudinal field to control them accurately and instantaneously. The large "static friction" between them is replaced by a much smaller "dynamic friction." Furthermore, if a direct current transverse field be employed, the effective permeability of the iron for the longitudinal magnetization will be diminished, and the hysteresis loop therefor will be changed in slope. We have here the interesting situation that two mutually perpendicular coils may react on each other thru the influence of the medium between them, and in spite of their apparent zero mutual inductance.

The arrangement used by Goldschmidt is given in Figure 17.

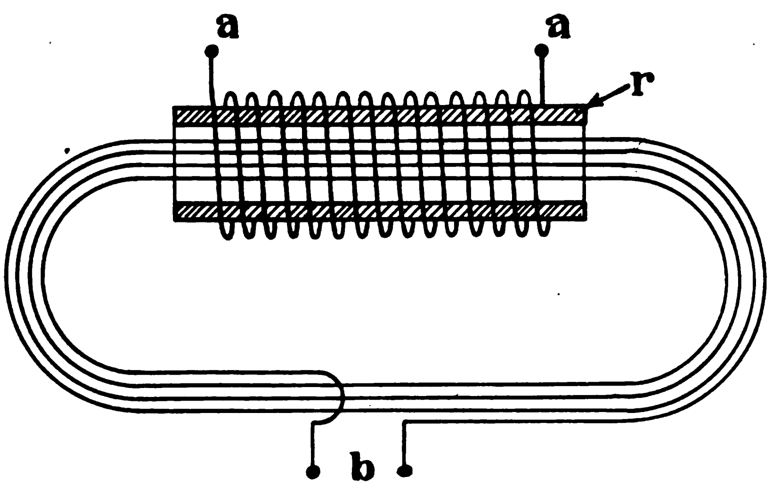


FIGURE 17

The iron tube r is magnetized longitudinally (axially) by means of the coil *a* and is magnetized transversely by means of the coil *b*. If the longitudinal magnetization is produced by direct current and the transverse magnetization by alternating current, both the positive and the negative maxima of the alternating transverse field will cause minima in the strength of the longitudinal field. These variations in the longitudinal field have, therefore, a frequency which is twice that of the alternating current supplied to the transverse field.

If now we connect across the terminals of coil *a* a condenser, whereby coil *a* and the condenser are resonant to the double frequency, and if we simultaneously place in the large choke coils direct current supply lines to the coil *a* to prevent alternating current getting back to the direct current source, we shall be able to draw considerable amounts of double frequency energy from the terminals of coil *a*.

By a further artifice we may carry the process of frequency transformation forward any desired number of steps. If we have a direct current as well as an alternating current flowing in the transverse magnetizing coil *b*, the double frequency current in coil *a* will produce a quadruple frequency current in coil *b*. The next step will give us a current of eight times the fundamental frequency in coil *a*, and the process may be continued thru any desired number of steps. Any of the upper frequencies may be brought to resonance and energy absorbed at that frequency by appropriate tuning. The limitations of the process as to energy output are based on the small amount of iron which is available in any arrangement of this sort and the consequent over-loading thereof.

The method next described was shown by Epstein in 1902 (German patent 149,761) and has since been worked out and amplified in detail by Joly in 1910, and by Vallauri in 1911. The circuit arrangement employed is shown in Figure 18. As will be seen, an alternating current source A sends its current thru the primary P_1, P_2 of two transformers. These primaries may be either connected in series or in parallel. They are wound oppositely. A direct current source B supplies two auxiliary coils M_1, M_2, which coils are wound on the transformer cores. These direct current coils are also wound oppositely. The secondaries of the transformers S_1 S_2 are wound in the same direction and connected as shown.

The operation of this device is as follows: The direct current magnetization of each of the transformer cores is such that it is working at the knee of the magnetization curve. If we consider Figure 19, curve a, we shall have a representation of the varying magnetic flux or induction in one of the transformers. The dotted horizontal line represents the constant direct current induction, the full line represents the resulting induction. It

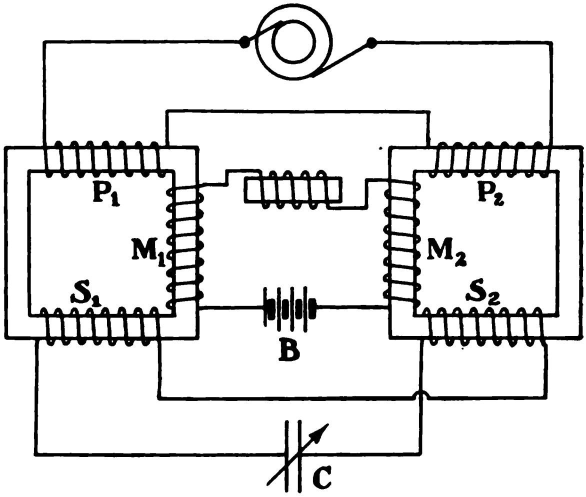


FIGURE 18

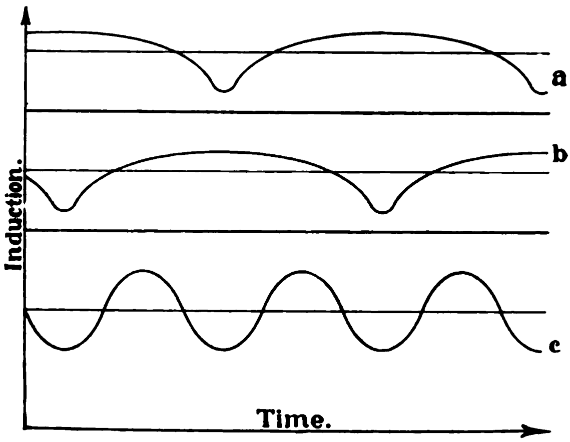


FIGURE 19

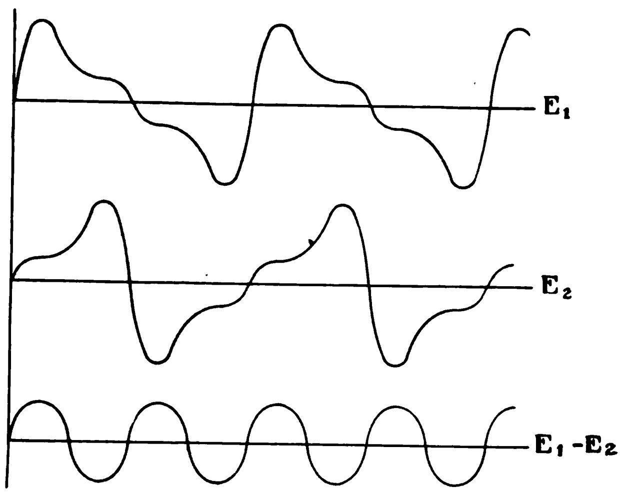


FIGURE 20

will be seen that when the positive half of the alternating current cycle is taking place, there is only a small increase in the magnetic induction, whereas when the negative half cycle is taking place, there is a large diminution in the induction. It will be noticed that the direct current coils and the alternating current coils on the two transformers are wound so that during the positive half cycle they assist each other on one transformer and oppose each other on the other. From this it follows that the induction in the second transformer is given by curve b, which lags practically 180 degrees behind curve a. The resulting total induction is given by curve c, and is seen to have a double frequency. In Figure 20, oscilligrams of the phenomena mentioned are shown. The voltage at the terminals at one of the transformers is given by E_1; that at the terminals of the other transformer by E_2, and there is also shown the resultant voltage, namely E_1-E_2. This latter is seen to be of double frequency.

A simplified modification of the circuits shown is given by Vallauri, and is illustrated in Figure 21. It will be seen that

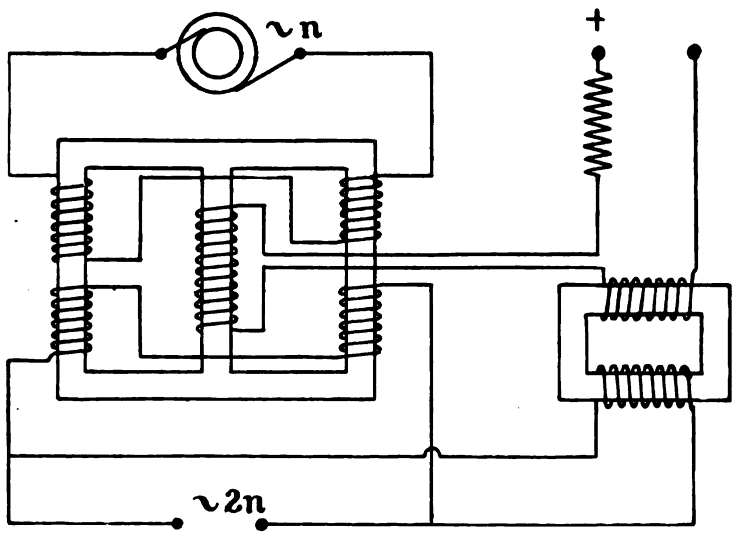


FIGURE 21

only a single transformer is used, and that a special small auxiliary transformer T is employed, whereby the double frequency alternating current which is induced in the direct current circuit is neutralized and suppressed. All the arrangements described are readily adaptable to use with two phase and polyphase currents. ...ting data is given by the inventor. Using a 0.5

kilowatt transformer without tuning capacity, and with fairly large leakage, an efficiency of 0.75 was obtained. It was possible to increase this efficiency still further by making the alteration in flux density considerably larger than in the usual transformer. In all frequency changers of this type, the secondary voltage leads the primary current considerably, and the device works at a low power factor; say under 0.5.

Joly has described a method for directly tripling the frequency, using iron core transformers. It depends upon the following principles. If we send an alternating current thru the primary of a transformer, and arrange that at the maximum current point of the cycle the iron core shall still be working far below saturation, the induction curve will be a peaked curve such as is shown in curve c of Figure 22. On the other hand if we work the iron at saturation value for the maximum current point of the cycle, we shall obtain a very flat-topped induction curve as shown by curve b of the same figure. If two such primaries, of the classes mentioned, are connected in series in opposite directions on two transformers, as shown by S_1 S_2 of Figure 23, the resulting secondary electromotive force will be of triple frequency. This is clearly seen from curve d in Figure 22, which curve represents the difference of the two induction curves in the separate transformer. It will be noted that the secondaries, S' and S'', are wound with appropriate numbers of turns, so as to compensate for the inequalities in the number of turns of S_1 and S_2. Furthermore the secondary circuit is carefully tuned to the triple frequency. Needless to say a very rapid multiplication of frequency can be obtained by this method. For example, the frequency can be raised 81 times in only 4 steps. In the foregoing, the author has utilized among many other sources, discussions on the subject of radio frequency generation and multiplication by Professor B. Glatzel and Dr. F. Kock.

It is our belief that the most fruitful results in the field of radio telephony may well be obtainable by the use of one or the other of the frequency changers which have been herein described. One of the difficulties in practical long distance radio telephony, and it is a very serious difficulty, is the control or modulation to speech form of the outgoing energy by an ordinary microphone transmitter. Up to the present time, it has not been possible to replace the ordinary transmitter by any simple and at the same time reliable device. We are therefore driven to use some method of trigger control whereby small changes in the resistance of the microphone transmitter, such as are caused by

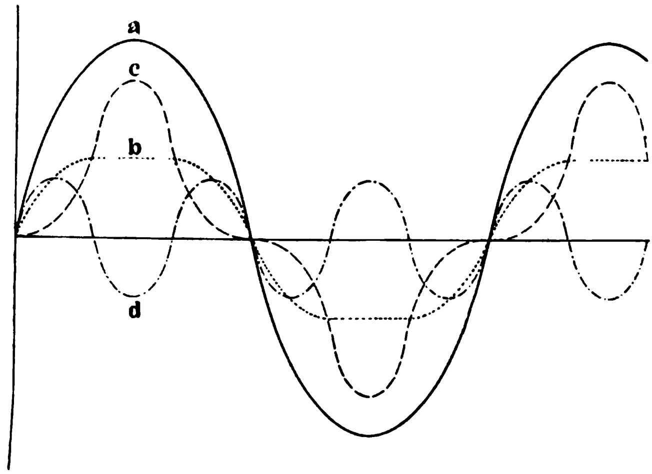


FIGURE 22

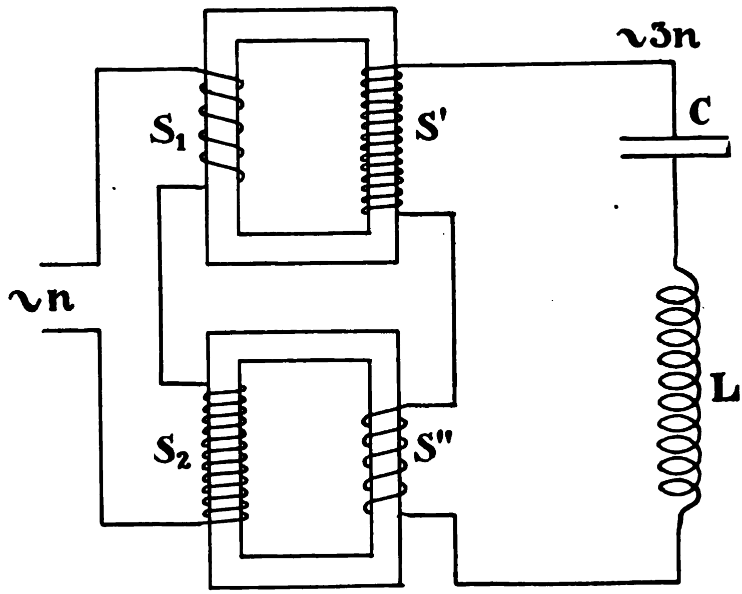


FIGURE 23

speech, will produce proportionate but highly magnified changes in the amount of radiated energy. The various frequency changers described lend themselves admirably to different forms of trigger control of output. For example, many of them are very sensitive to a small change in tuning in one of the intermediate steps. If, therefore, we shunt one of the tuning condensers in the iron core type of frequency changer by either one or more microphones, we are given a ready means of controlling the output to a certain extent. Still another possibility is given in some of these types of transformers just described if we cause the microphone to vary the direct current magnetization which brings the iron cores to the saturation point. Since the proper operation of the Joly frequency transformer is largely dependent on an accurate adjustment of the core magnetization, it is clear that microphone control thereof should be successful in practice. The Telefunken Company, which has widely experimented with the Joly transformer, has attained considerable success in radio telephony by some of the above means.

It seems to the writer that the apparent trend of high power radio design is in the direction of the moderately high or even radio frequency alternator, employed in conjunction with one or more of the frequency changers. So far as radio telephony is concerned, this direction of development should be highly favorable to success.

SUMMARY: Starting with the principle that a coil (or capacity) rotating in a single phase alternating magnetic (or electric) field, may be regarded as producing a magnetic (or electric) field rotating with double frequency, a number of frequency doublers and multipliers of magnetic and electric nature are described. Under this heading, the reflection or Goldschmidt alternator is considered. A typical mercury arc frequency doubler is treated. The use of electrolytic rectifier cells in increasing frequency is discussed, and a number of useful arrangements of this type shown. Frequency multiplication by the use of the arc is also handled. A detailed description of a number of frequency changers depending on the nature of the magnetising force-induction curve of iron follows. The application of the results to the field of radio telephony, and the possibility of adequate trigger control of the outgoing energy by ordinary microphones is considered.

DISCUSSION

NEW YORK SECTION

John Stone Stone: There is no doubt as to the importance of the frequency changer, and it is particularly pleasing to know that Dr. Goldsmith regards some of the stationary frequency changers as promising, because on shipboard, where the vast majority of radio sets are going to be for many years to come, the high speed dynamotors are bound to be excluded for mechanical reasons.

There is one further type of frequency changer to which reference may be made. A friend of mine in Boston (Mr. Sewall Cabot) has worked out a synchronous pole changer which, in connection with the discharge of a condenser, is capable of converting direct to sinusoidal alternating current and alternating to direct current. This principle has been patented for use in X-ray work, but may well be applicable to the radio field as well.

Guy Hill: There seems to me to be one serious drawback to the methods of frequency transformation described; namely, the inability to change wave length quickly (and continuously, if need be). Of course, this would not make much difference for long range stations working on fixed wave lengths, but it is of great importance in military work, particularly in time of war. Until some such method can be devised for the frequency changers, the rapid changing of wave length possible with the arc transmitter as developed by the Federal Telegraph Company will make this system more valuable than any of the frequency changing systems described.

John Stone Stone: Some of us are inclined to believe that ability to change frequency rapidly is of importance in commercial working thru serious interference as well as for military purposes. Furthermore, the only practical secrecy systems known at present depend on a rapid switch control of wave length, such as would prevent the enemy from following the messages.

Guy Hill: I have heard, however, that it is possible, using the Goldschmidt system, to build apparatus which will permit rapid change of wave length.

H. E. Hallborg: In connection with the study of frequency changers, the interesting question arises whether it is necessary to use them at all in connection with very long distance transmission from large stations. The frequency multiplying devices described have all, I believe, an initial frequency of say 10,000 cycles per second. This, however, is not far from the operating frequency of the New Brunswick, N. J., station. Since successful transmission across the Atlantic has been accomplished from New Brunswick at a frequency of 19,000 cycles, it seems that the source of initial power described could be quite efficiently applied to an aerial of the size of the one at New Brunswick without the necessity of further increasing the frequency. This brings up the open question; how low may the frequency of a transmitter be for successful long distance communication?

Alfred N. Goldsmith: In favor of the use of low frequencies for radiation are the facts that the original alternator may be of low frequency and therefore standard and inexpensive; and that if a frequency changer is still employed, less steps in the transformation are necessary. The over-all efficiency is therefore fairly high, and the machinery comparatively simple. On the other hand, a much larger antenna, ground, and tuning system are necessary. If land is expensive, the use of an extremely long antenna is sometimes prohibited on the score of cost. It will be seen that the most advantageous frequency of radiation is a fairly complex function of

(a) Cost of land;
(b) Cost of towers, and wires for antenna and ground;
(c) Cost of erection of large antennas and placing of grounds;
(d) Cost of alternators (as dependent on frequency);
(e) Cost of frequency transformers (as dependent on number of stages of transformation);
(f) Over-all efficiency of complete set (taking into account the cost of fuel, the cost of operation, freedom from interference by static at various frequencies, and the absorption in transmission at various frequencies);
(g) Rate of depreciation of such antennas, ground, alternators, and frequency transformers as required at various frequencies.

In fact, even the current state of the money market, and the terms on which loans may be secured will exert a considerable influence on the type of machinery chosen and the proper frequency therefor.

Lester L. Israel: It is of interest to note that heating of the iron core of the frequency transformer has been resorted to in the search for higher efficiencies. Hans Boas of Berlin has recently patented (D. R. P., Number 268,161) a method for frequency transformation above 1,000 cycles along the lines of the saturated iron core transformer described in the paper.

The interesting feature is that iron heated to about the critical temperature is used for the core. At this temperature, the permeability is large for small values of the magnetomotive force ($\mu = 12{,}000$ for $H = 0.15$), and diminishes sharply for higher values ($\mu = 1{,}000$ for $H = 9$). Consequently a flat-topped magnetic curve suitable for frequency transformation is obtained. Since the specific resistance of the iron is greatly increased, eddy currents are diminished. Hysteresis losses decrease from 3,660 ergs per cc. at 24° C. to 120 ergs per cc. at 764.5° C.

It is held that high efficiencies of transformation are thus obtained.

William Dubilier: In the paper which has been presented this evening, there have been shown some widely different forms of frequency changers, all to be used at radio frequencies. I would like to add that a large amount of research work has been going on for some time to produce currents of audio frequency directly from direct current. In a machine that I constructed to obtain these musical frequencies from direct current, a vibrating or revolving member was employed for breaking the direct current source; but so connected with an auxiliary oscillating circuit, that altho it opens the circuit, it does not actually interrupt the current. The method used has been fully described in the "London Electrician" of December 12 and 19, 1913, and the "Revue de Radiotelegraphie et Radiotelephonie" (T. S. F.) of April and May, 1914.

It was interesting to note from these experiments that the mechanical motion can be controlled by simply varying the capacity or inductance of a controlling circuit. That is to say, the mechanical interrupter can be forced to come to the same frequency as that of the oscillating circuit. If the proper inductance is inserted in the primary circuit, and the proper capacity in the oscillating circuit, there will be a time when the discharges of the condenser in the negative direction will entirely neutralize the primary current; and at this point there will be no current flowing in the primary of the transformer. The oscillator or interrupter will then be released without any arcing or sparking. On the other hand, when the condenser charges in the same direction as the primary current, the energy thru the transformer becomes the sum of the primary and condenser currents, thus giving the wave a higher amplitude.

By means of this method, I have been able to build an apparatus for producing a uni-directional pulsating current with a sine wave, and at a frequency of 1,000 cycles per second using direct current.

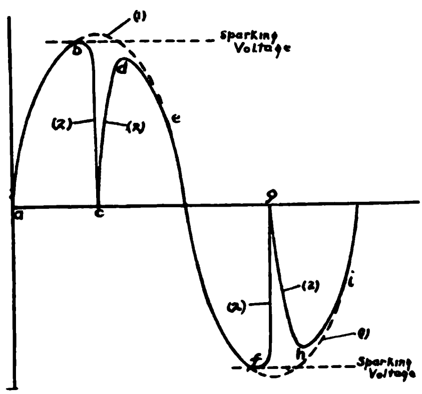
I have made experiments using this method of tuning the oscillating circuit to a mechanical interrupter and have obtained radio frequencies. It is possible to transform a direct current into an alternating current of radio frequency with a high efficiency by means of a revolving commutator whose segments were about one-thirty second of an inch wide, the space between the segments having the same valûe. This commutator is made of a single wheel, all the segments being connected together. The brush consists of a needle point. A number of these points may be used to increase the total surface of contact. By rapidly revolving this commutator, which is about one foot (30 centimeters) in diameter, and not more than one-eighth of an inch (3 millimeters) wide on the outer surface of the commutator, a frequency of about 50,000 cycles per second and even more can be obtained. A proper capacity and inductance was shunted across this interrupter, the natural frequency of their circuits being equal to the working frequency of interruption. This apparatus would be found suitable for use on board ships.

Austen Curtis: Some time ago, in connection with the design of head receivers for radio telegraphy, I had occasion to make some measurements on the coils of a Marconi magnetic detector in an impedance bridge at audible frequencies; and discovered that if a current of frequency n is sent thru one of the coils, a current of frequency 2n makes its appearance while the band is moving, and disappears when the band is stopped. For each value of impressed current there is a certain speed of the band which gives the maximum strength of the harmonic. When the break in the band passes thru the coil, the harmonic disappears momentarily, but if one magnet only is used with its poles opposed to the band on either side of the coil, no harmonic is produced except for the instant when the break in the band passes thru the coil. Large changes in the distances of the magnets from the band cause little difference in the strength of the harmonic, but a sudden movement of the magnets in any direction causes a transient increase in the strength of the harmonics.

It is generally known that effects quite similar to those described are noted with the detector in radio telegraphic reception; the changes in signal strength corresponding to the changes in strength of the harmonic produced when the impressed current is of audible frequency. It therefore seems probable that both groups of effects are caused by the same property ol the magnetic detector.

The impressed currents of audible frequency used in the measurements during which the above effects were noted, were of the order of 0.5 milliampere.

Fritz Lowenstein: The paper on "Radio Frequency Changers" brings to my mind a phenomenon of which I have made use in the design of transformers for radio operation.



Considering a quenched gap outfit, and referring to the accompanying figure in which curve (1) represents the impressed condenser voltage without sparking; it will be seen that curve (2) represents the condenser voltage with sparking. With no spark gap, curves (1) and (2) would coincide. When the condenser is robbed of its charge, however, by a spark gap as in radio operation, the condenser voltage takes the form shown in curve (2). From a to b (1) and (2) coincide. At b the gap breaks down, amounting to a short circuit; and curve (2) drops to zero as indicated at c. The condenser voltage then rises again to d, but not sufficiently to cause resparking. It again coincides with curve (1) at e, and again drops at f, to g, and so on.

From c to g the condenser voltage goes thru a complete cycle, whereas the generator voltage goes thru a half cycle. The spark gap as used in radio operation might therefore be termed a "frequency changer."

John H. Morecroft: I congratulate the Institute upon having had such an able presentation of the development of generating apparatus for continuous waves; and think it fortunate that at this time such a paper has been presented, because the continuous wave generators are by all means the most important pieces of generating apparatus for the radio engineers to investigate and develop. In my opinion the large stations using spark apparatus will surely be changed over to continuous wave stations in the course of the next year or two. This remark is based upon the results of experiments which have been carried out in the radio laboratory of Columbia University during the past two years, which experiments have shown the great possibilities, in range and selectivity, of continuous wave transmission, when received by a suitable scheme.

I question very much the claims which many inventors make for their apparatus and further question the explanation of the operation of some of the pieces of apparatus which the speaker of the evening offers; I understand, of course, that the explanations offered are those of the inventor and not necessarily the ideas of the speaker, who probably questions some of them himself.

When one teaches a subject it is necessary to do more than read a patent claim; it is necessary to ask oneself if the inventor, himself, knew how his apparatus was operating. It is from this standpoint that I have been studying radio telegraphy for the past two years and have used the oscillograph actually to find out how some of the apparatus functions. Instead of using very high frequency current and the Braun tube oscillograph, we have used the General Electric oscillograph and low frequency currents; the phenomena investigated all occur in the same way at 60 cycles as they do at 100,000 cycles. I hope to be able to present some of the more interesting oscillograms at some future meeting of the Institute.

John Stone Stone: I feel it safe to say that to-day there is no branch of the electrical art in which research work and theoretical work are so far ahead of practice as in the radio field. There is no comparison between the apparatus supplied to commercial users and that which is known to exist in laboratories, and is described in published books and in patents.

I wish to state further that the art is far from being in as empirical a state as we are led to believe by some of the speakers of this evening. Our knowledge of radio engineering is extremely exact, and I believe that time will show that most of the explanations of phenomena which have been given are absolutely correct.

Robert H. Marriott: The condition which Mr. Stone mentions relative to the inferiority of commercially used apparatus compared to laboratory apparatus is caused by the objectionable way in which the radio business was conducted in its early days.

In those days the then existent companies sold stock; and in order to raise the value of the stock which was being sold, placed the price of their apparatus at far below actual cost so that the purchaser of the stock would imagine that a large business was being done. This has given rise to difficult conditions to-day, when the purchaser of modern apparatus must be trained to pay an appropriate and suitable price for it.

Another objectionable feature of radio commercial work in the past was the extremely large salary paid to publicity men as compared to those paid to the engineer. It would be difficult to expect to obtain good apparatus from engineers who are shamefully underpaid, particularly when they know that the publicity end of their enterprise is, if anything, very considerably overpaid.

It is necessary that in the future the radio engineers should get proper compensation for good work.

Alfred N. Goldsmith: As far as the explanations of the phenomena given by me this evening are concerned, it is my opinion that most of them are correct. It may be that detailed points in the operation of some of the apparatus have not been clearly understood by the inventors and patentees, but only much research work can make this clear.

I would call attention to the necessity for much caution in applying the principle that phenomena at radio frequency are necessarily identical with those at audio frequencies. It is true that if we know accurately the law of variation of these phenomena with frequency, we may by rational processes predict radio frequency phenomena. This seems to me, however, to be begging the question; because, before we can obtain this law of variation, we must investigate the phenomena of radio frequencies as well as at audio frequencies. I refer specifically to such phenomena as arc and spark conduction.

A. E. Kennelly: Dr. Goldsmith's paper collects, in an interesting way, a number of proposed methods of frequency multiplication. Broadly speaking, these may be divided into two classes, namely—machines, and induction apparatus. The former employ rotating parts; while the latter do not. The machines, as described in the paper, may be either electric or magnetic and an interesting parallelism runs between these two types, one depending on variations in electric flux, the other on variations in magnetic flux. In both cases the method of operation may be readily conceived of by the concept of a single alternating field being substituted by a pair of oppositely and synchronously revolving fields of half strength. There has also been suggested another type of single-phase machine* in which a high-frequency harmonic is carefully nurtured and augmented with multiplication and resonance while the fundamental frequency is suppressed by cancellation.

The types of induction-apparatus mentioned are particularly interesting on account of their mechanical simplicity. They may be regarded as harmonic-nurseries. Iron cores are electromagnetically excited in such a manner as to set up powerful harmonic alternating-current ripples. These higher-frequency harmonics are then carefully nursed and amplified for delivery to the antenna. In alternating-current power transmission and distribution, such harmonics are regarded as objectionable visitors, and efforts are made to exclude them or at least to minimize their influence. In radio engineering, however, these ordinarily unbidden visitors are specially invited and encouraged The actions here considered depend upon their presence.

As a mere matter of nomenclature, it would seem to be unfortunate if the name "frequency-changer" should continue to be applied to the devices described in the paper; for the reason that this name has for years been applied to a class of machines in which alternating-current power of one frequency is converted into alternating-current power of either a higher or lower frequency, as for example, when a synchronous motor operated from a 50-cycle system is directly coupled to an alternator of half the number of poles, supplying a 25-cycle system. Such machines are also known as frequency converters. In radio engineering, the corresponding devices raise the frequency from a lower to a higher value, and there does not seem to be

*Science Abstracts (Engineering), Vol. XVI, p. 558, 1913, No. 1162, Bouthillon, Lumiere—Elect., Sept. 13, 1913.

any need for a device to operate inversely from a higher to a lower frequency. On this account, it would seem desirable to name these radio devices "frequency-raisers" or "frequency-multipliers," either of which would be a distinctive term free from possible ambiguity or misapplication to the ordinary "frequency changers" or "frequency converters."

Alfred N. Goldsmith: I have preferred to employ the term "frequency changer" for the devices described rather than "frequency raiser." My reasons for this are that many of these devices are usable interchangeably either for increasing *or diminishing* the frequency, and that some of them have actually been used in radio reception to convert the received energy into energy of a *lower* and audio frequency. Some confusion might therefore be caused by invariably applying the term "frequency raiser."

Melville Eastham: As regards the use of compressed air in electrostatic alternators, as suggested by Dr. Goldsmith, such radio frequency alternators have a very high electrical efficiency in theory, and would seem to have great possibilities if a design could be worked out which would give a reasonably large output from a machine of ordinary size. The electrical losses, being practically confined to dielectric losses, might be made extremely small; but the losses due to air friction would probably be very high. The use of compressed air would greatly increase these losses, and it would seem preferable to work in a vacuum, since the same or a higher dielectric strength could be thus obtained with much smaller air resistance. Alternators of this type, used by Tesla about 1890 and by Fessenden about twelve years later, have a number of advantages; such as the possible generation of pure sine wave currents, extremely simple construction, and high theoretical efficiency. It is to be hoped that more development work will be done on the electrostatic alternator, as it would be a valuable piece of apparatus at least for very high frequency bridge tests and similar work, even with the small outputs which it seems possible to secure from such an alternator at present.

Sewall Cabot: The use of a vacuum in an electrostatic alternator seems to me to be objectionable because of the necessity of securing extremely low pressures. Unless an extremely low pressure is reached, the air is more conducting than at ordinary pressures. The pressure which would probably be needed would be of the order of one millionth of an atmosphere, and it would be extremely difficult to obtain or maintain so low a pressure because of the liberation of occluded gases from the generator. It would probably be necessary to use metal parts made, for example, of tungsten from which it would be possible to remove all the air. But even then, the difficulty would be very serious.

As regards the Goldschmidt alternator or any other generator of frequencies of the order of 50,000 cycles, described in Dr. Goldsmith's paper, employing iron in the paths of magnetic flux, I do not see how the efficiencies can ever become comparable to those obtained in low frequency machinery; since the losses must increase at some greater ratio than the first power of the frequency, other conditions remaining the same.

It would be of interest to have some data regarding the Goldschmidt alternator losses, so that we might compare it with other forms of generators.

Such data might consist of the output in K. V. A., watts lost in windings of the alternator, in windings of the component resonant circuits, in iron laminations, in dielectric hysteresis of the condensers, in friction and windage, etc. If we also had data regarding the masses of iron and copper referred to, we could then make an intelligent comparison of efficiency and cost of generation with this machine with that using other forms of generators concerning which there is available data.

I regard the electrostatic alternator as a promising piece of apparatus; but the mechanical construction, because of the necessity for high speed and careful insulation, would be very difficult.

In this connection, I should like to call attention to a somewhat analagous device of mine described in United States letters patent, 1,081,090, December 9, 1913, and 1,112,435 of October 6, 1914.

The apparatus in question essentially consists of two condensers and two inductances, together with a contact making device. One condenser and inductance form a resonant circuit which is tuned to the desired frequency. The second condenser is charged by a source of high potential direct current. The contact making device is timed to make one contact per cycle, the contact having a duration of only a fraction of a cycle.

The contact making device connects the first mentioned condenser with the second mentioned condenser in series thru an inductance of such value as to make the duration of the contact equal to the time of a half cycle of oscillation of the circuit comprising the two condensers in series, the contact maker, and the inductance in series with it.

This results in the transfer of electrical energy from the condenser charged by direct current to the oscillating circuit condenser, in the form of free half oscillations, provided there has been a dissipation of energy in the oscillation circuit during the cycle.

The advantage of using a natural half oscillation to accomplish this transfer of energy is that the current starts at zero and rises to a maximum at the middle of the duration of the contact, and falls to zero just as the contact is breaking; which phenomena permits of sparkless interruption as the contact opens.

The contact device might consist of two toothed wheels rotating at very high velocities in opposite directions, so mounted that the teeth pass as close as possible to each other without engaging.

Melville Eastham: The electrostatic alternator might possibly be built in such a way as to act like a Gaede molecular pump as well as an alternator, and so to remove any gases as rapidly as they appear. The losses in the pump would be very slight since no large volume of air was being removed.

As regards the efficiency of the Goldschmidt alternator, its inventor has claimed up to 80 per cent under certain conditions. Up to date, the largest current obtained by any radio set of which I am aware, is above 200 amperes and is found in the antenna of the Hanover and Tuckerton stations.

Emil E. Mayer: (by letter to the Editor): As regards the efficiency of the large Goldschmidt alternator at Tuckerton, it is possible to give the following figures. Working with an antenna of about 6 ohms resistance, an antenna current of 140 amperes is obtained with an input (direct current) of 990 amperes at 218 volts. The direct current input is, therefore, 217 kilowatts, the radio frequency output 117 kilowatts, and the efficiency 54 per cent. This efficiency is that obtained while sending a continuous dash. While sending messages with the same radiation at a speed of about 15 to 18 words per minute, the input decreases to 690 amperes at 222 volts, equalling 153 kilowatts. The efficiency therefore becomes 76.5 per cent. It is to be understood that it is this latter efficiency which is of real importance in the determination of the actual energy used for transmission. The same machine working on the same antenna with an antenna current of 120 amperes gives about 115 kilowatts during transmission; so that for that energy the efficiency would be of about the same order as before.

Herman A. Affel: The iron losses in radio frequency alternators are probably much lower than might be expected because the volume of iron employed can be rapidly reduced as the frequency is raised.

Sewall Cabot: It may well be that the efficiency of the Goldschmidt alternator is due in large part to the suppression of all the lower frequency fields by the neutralizing effect of the field in opposite phase but at the same frequency. (This is described in PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, Volume II, Number 1, page 71—EDITOR.)