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PROCEEDINGS OF THE SECTIONS
AND INSTITUTE NOTICE

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EDITED BY
ALFRED N. GOLDSMITH, Ph.D.

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PROCEEDINGS OF THE SECTIONS OF THE INSTITUTE

WASHINGTON SECTION

A meeting of the Washington Section of The Institute of Radio Engineers was held at the Commercial Club in Washington on the evening of Saturday, March 7, 1917. The dinner was in honor of the accession of Brigadier-General George O. Squier, Chairman of the Washington Section, to the office of Chief Signal Officer of the U. S. Army. The meeting was largely attended. Congratulatory telegrams to General Squier were received from President Pupin of the Institute and Professor Goldsmith.

BOSTON SECTION

A meeting of the Boston Section of the Institute was held at the Cruft High Tension Laboratory, Harvard University, on the evening of Thursday, January 18, 1917. Mr. H. B. Lawther presented a paper entitled "Resistance and Capacity of Condensers at Frequencies from 30 to 10,000,000 Cycles per Second." This was followed by a description, from Dr. E. L. Chaffee, of an absolute method of calibrating wave meters. The description was accompanied by an experimental demonstration.

On the evening of Wednesday, February 21, 1917, a meeting of the Boston Section was held at the Cruft High Tension Laboratory. Dr. David L. Webster presented a paper on "X-Rays and Crystal Structure."

SEATTLE SECTION

A meeting of the Seattle Section of the Institute was held at Denny Hall, University of Washington, Seattle on the evening of January 6, 1917, Chairman Robert H. Marriott presiding. A paper on "The Measurement of Radio Telegraphic Signals with the Oscillating Audion" by Dr. Louis W. Austin was presented. The attendance was sixteen.

On the evening of February 9, 1917, a meeting of the Seattle Section was held at the Y. M. C. A. in Seattle, Mr. R. H. Marriott presiding. The attendance was eighteen. Certain national radio matters and the financial affairs of the Section were discussed.

SAN FRANCISCO SECTION

A meeting of the San Francisco Section of the Institute was held at the Engineers' Club in San Francisco on the evening of January 16, 1917, Mr. W. W. Hanscom presiding. The attendance was forty-six. A paper by Mr. E. T. Cunningham on "Historical Sketch and Some Theories of Vacuum Detectors" was read, and discussed by Messrs. Roos, Hanscom, and Burglund. A paper on "The Manufacture of Vacuum Detectors" was then read by Mr. O. B. Moorhead, and discussed by Messrs. Hanscom, Cookson, Cunningham, and Greaves. A third paper on "The Characteristic Temperature Curves of Vacuum Detectors" was presented by Mr. Haraden Pratt, and discussed by Mr. Burglund and others. Previous to the technical meeting, a Section Dinner was held in the club rooms, and was attended by fourteen. Members of the Engineers' Club and of the Telephone Company were invited to the meeting.

On the evening of February 20, 1917, a meeting of the San Francisco Section was held at the Engineers' Club, Mr. W. W. Hanscom presiding. The attendance was thirty. A paper on "Engineering Precautions in Radio Installations" by Mr. Robert H. Marriott was presented. It was discussed by Messrs. W. W. Hanscom and T. M. Stevens. A formal discussion on the paper together with further data was then presented by Mr. Ellery W. Stone, and this was discussed by Messrs. V. Ford Greaves, Secretary of the Section, O. C. Roos, and W. W. Hanscom. Thereafter Mr. E. W. Stone was appointed Chairman of the Social and Entertainment Committee, and Mr. O. C. Roos was appointed a member of this committee.

On the evening of March 20, 1917, a meeting of the San Francisco Section was held at the Engineers' Club, Mr. W. W. Hanscom presiding. The attendance was forty-two. Mr. L. F. Fuller presented an abstract and discussion of Professor P. O. Pedersen's paper on "The Poulsen Arc and Its Theory." The discussion was carried on by Messrs. Hanscom, Stone, Sprado, Roos, and Pratt. This was followed by a discussion of a bill then pending relative to radio regulation. A Committee on Papers, consisting of Mr. Haraden Pratt was appointed, Mr. Pratt to serve with the Executive Committee. The Membership Committee was appointed as follows: Mr. H. W. Dickow, Chairman, Messrs. H. Berringer, and H. D. Hayes. The Committee on Modern Practice was constituted as follows: Mr. A. A. Isbell, Chairman, Messrs. T. M. Stevens, and O. B. Moorhead.

The Institute of Radio Engineers announces with regret the death of

Mr. Francis P. Miller

(Experimenter and Radio Operator, of Los Angeles, California, and associated with the Institute)

UNITED STATES RADIO DEVELOPMENT*

By

ROBERT H. MARRIOTT, B.Sc.

(PAST PRESIDENT OF THE INSTITUTE OF RADIO ENGINEERS, EXPERT RADIO AIDE, U. S. N.)

Before taking up the radio development of the United States as a whole, some of the more notable instances of Pacific Coast development will be cited. The Pacific Coast is particularly noteworthy for early construction *combined* with *lasting* construction.

The first *permanent* COMMERCIAL PUBLIC SERVICE radio station in the United States, using U. S. built apparatus, was constructed at Avalon, Santa Catalina Island, California in the spring of 1902.

At the same time this station became the first *permanent* station in the United States to adopt exclusively the telephone method of reception.

The first *permanent* radio trans-oceanic service from United States soil was established between California, near San Francisco, and Honolulu in 1912. Also these were the first stations permanently to use the constant amplitude type of transmitters.

The first PERMANENT, COMMERCIAL, OVERLAND, PUBLIC SERVICE, RADIO STATIONS using CONSTANT AMPLITUDE transmitters in the United States were established by the Federal Telegraph Company, between San Francisco and Los Angeles in 1911.

At an early date the Army constructed stations at Nome and St. Michaels, which, from 1904 on, became known for the comparative reliability with which they rendered radio service between these points.

We may now take up radio development in the United States as a whole. In numerical results given in this paper, only

* A paper delivered before a joint meeting of the American Institute of Electrical Engineers and The Institute of Radio Engineers at the Panama Pacific Convention, San Francisco, September 17, 1915. This paper is based on Government records as found by the writer, and on the writer's notes and recollection. The records and notes are too voluminous to include in a paper of this kind; for example, about 3,000 sheets were used to classify and enumerate the radio transmitters.

Government stations and stations established for commercial purposes have been included because it was found that the number of experimental stations, their date of use and the apparatus used, was indefinite, extremely complicated, and required lengthy explanation.

Considering Chart 1 marked United States "Wireless" Telegraph Development (transmitters):

This chart shows the total number of transmitters and the total number of each class of transmitters for each year from 1899 to 1915, together with manufacturers of these transmitters and operating organizations.

PLAIN ANTENNA TRANSMITTERS (P. A. Class) shown in black includes the type of transmitters wherein the antenna was connected to one side and the ground to the other side of the spark gap of an induction coil.

TUNED COUPLED CIRCUIT TRANSMITTERS (C. T. Class) shown in heavy diagonal lines, includes, for example, the transmitters where an antenna in series with an inductance was tuned to the same frequency, and inductively coupled to a circuit containing a plain spark gap in series with an inductance and leyden jars. United Wireless Telegraph Company transmitters were commonly of this type.

IMPULSE EXCITATION TRANSMITTERS (I. E. Class) shown in lighter diagonal lines, includes, for example, the quenched gap type of apparatus. The Telefunken Company transmitters were commonly of this type.

CONSTANT AMPLITUDE TRANSMITTERS (C. A. Class) shown in white, includes transmitters which produce constant amplitude alternating current in the antenna. Federal Telegraph Company arc transmitters, and radio frequency alternators are included under this class.

With the exception of the number of stations equipped with the different classes of transmitters and the names of Companies, the points in this chart are contained in a general way in Chart 2 and its discussion.

CURVE *R* at the top is intended to indicate the approximate maximum distances used for public or government service each year from 1899 to 1915 referred to the numerals at the left reading from 0 to 4,000 and marked "Range in Miles." (1 mile = 1.6 km.)

CURVES *T*, *S*, *L*, *V*, and *G* are intended to indicate the number of stations each year from 1899 to 1915 referred to the

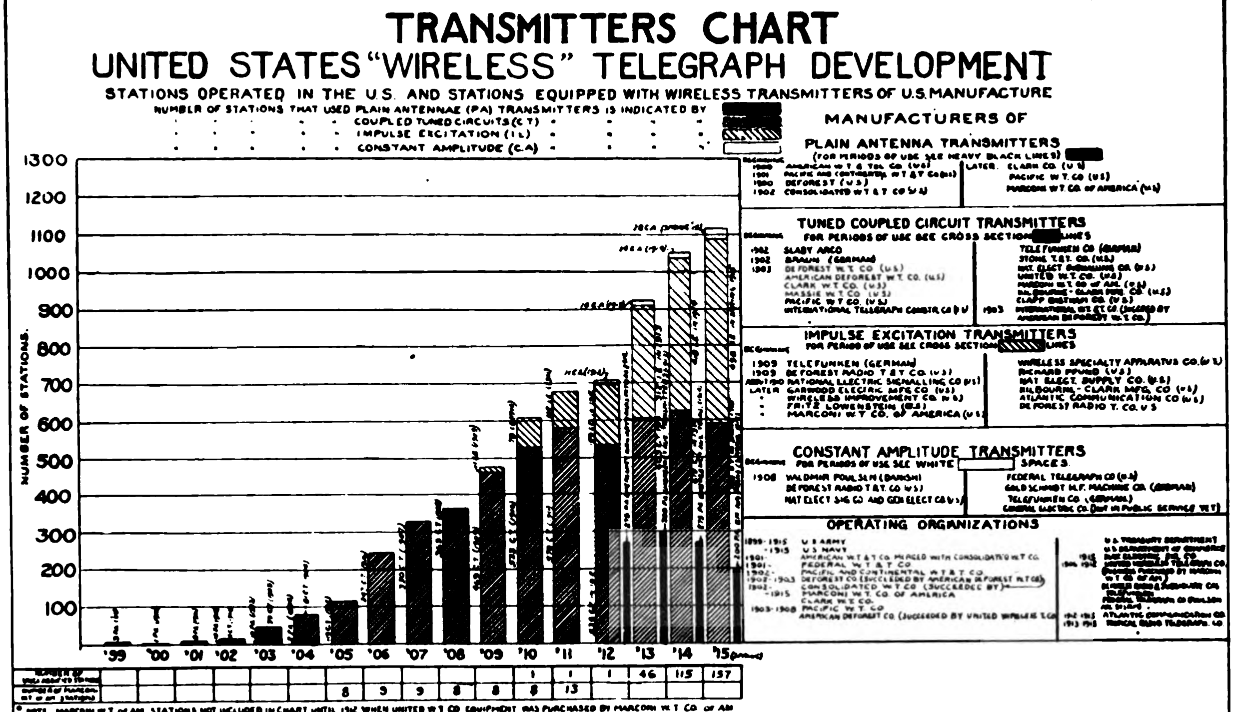
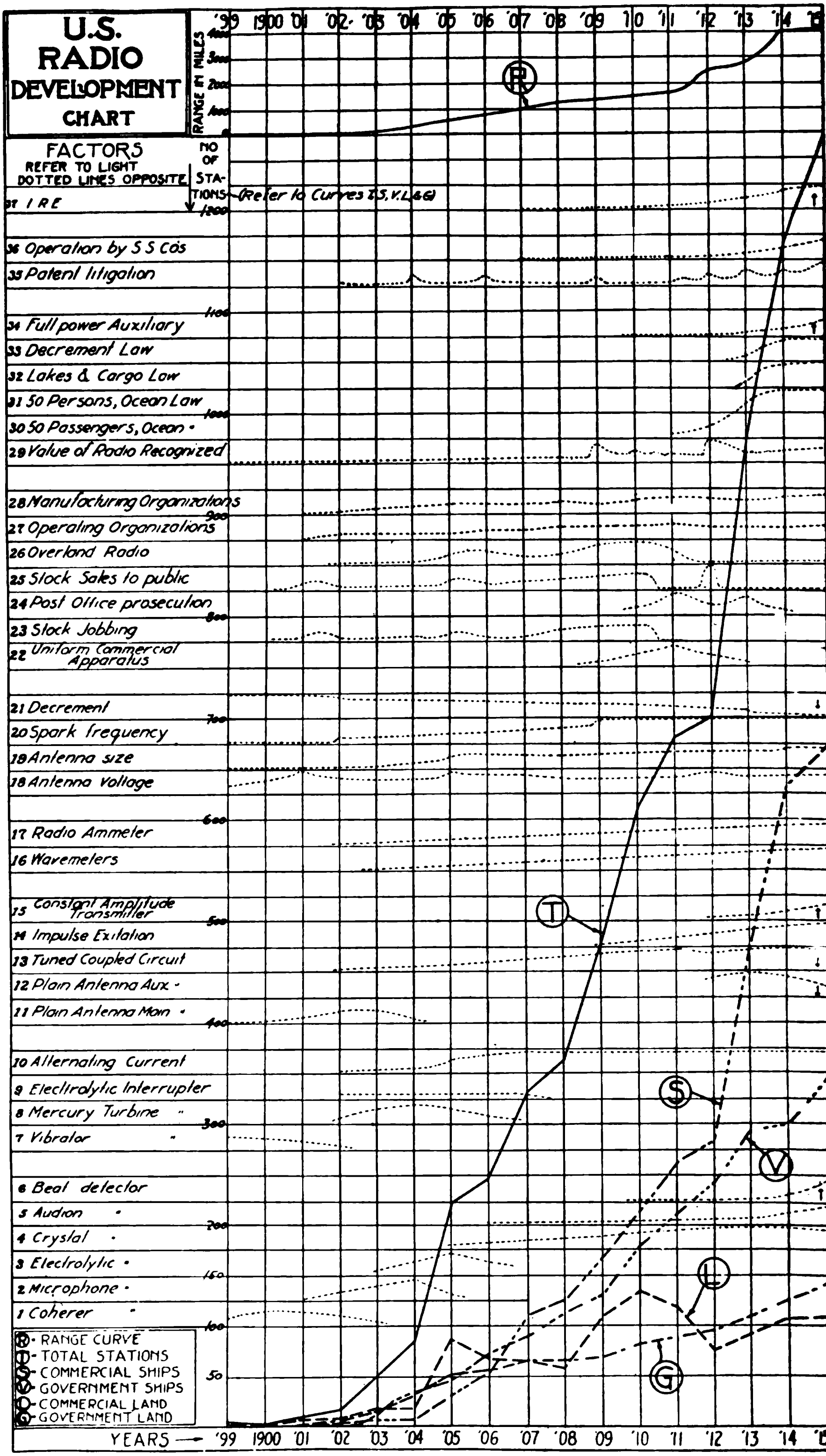

TRANSMITTERS CHART
UNITED STATES "WIRELESS" TELEGRAPH DEVELOPMENT
STATIONS OPERATED IN THE U.S. AND STATIONS EQUIPPED WITH WIRELESS TRANSMITTERS OF U.S. MANUFACTURE
NUMBER OF STATIONS THAT USED PLAIN ANTENNAE (PA) TRANSMITTERS IS INDICATED BY
COUPLED TUNED CIRCUITS (C.T.)
IMPULSE EXCITATION (I.E.)
CONSTANT AMPLITUDE (C.A.)
NUMBER OF STATIONS
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
'99
'00
'01
'02
'03
'04
'05
'06
'07
'08
'09
'10
'11
'12
'13
'14
'15
MANUFACTURERS OF
PLAIN ANTENNA TRANSMITTERS
TUNED COUPLED CIRCUIT TRANSMITTERS
IMPULSE EXCITATION TRANSMITTERS
CONSTANT AMPLITUDE TRANSMITTERS
OPERATING ORGANIZATIONS

CHART 1



United States Radio Development Chart 2

Numerals at the top and bottom of this chart indicate years numerals at the left reading from 0 to 1,200 and under the heading "Number of Stations."

These curves, particularly in latter years, lag somewhat because it frequently happened that the existence of stations was not recorded or was unknown to the writer until the following calendar year. Data for 1915 was brought up to about June 1.

Curve *T*—Total number of radio stations in the United States. (Government and commercial)

Curve *S*—Number of commercial ship stations

Curve *L*— " " " land "

Curve *V*— " " Government ship "

Curve *G*— " " " land "

Under the heading of "Factors" at the left on chart 2 is a list of subjects, numbered on the extreme left. The lighter dotted curves extending across the chart in the single narrow spaces opposite these subjects are intended to indicate approximately the rising, falling, peaks, and depression in the history of these subjects or factors.

1. Coherer. This form of detector was used in the Navy stations in 1899. Apparently coherers of English Marconi Company and Navy make were used. Owing to its insensitiveness and uncertainty of action, the coherer was almost entirely discarded in the United States by 1903 as, indicated by the light dotted line opposite "Coherer" on the Chart. Changing from the coherer was one of the greatest steps, not only by virtue of increased sensitiveness and reliability, but by leading to detectors more capable of utilizing long wave trains thereby making it easier to construct more powerful transmitters.

2. Microphone. This is intended to include the class of detectors which superseded and took the place of the coherer. As a rule, they consisted of a contact between steel and carbon, or steel and aluminum; however, the detectors as used at Avalon and Whites Point, California, consisted of the contact between steel and an oxide of iron (and thus may have had more of the qualities of the crystal detectors). The microphone was abandoned largely because of its lack of stability.

The arrival of the microphone marks the arrival of the lasting telephone method of reception, a revolutionary and comparatively large step in radio advancement.

3. ELECTROLYTIC. This detector succeeded, and took the place of the microphone. At its best it was very sensitive but atmospherics destroyed its extreme sensitiveness and the acid used in it damaged other things. A court decision tending to give Mr. Fessenden and his associates a patent monopoly on this form of detector apparently hastened its disapproval and disappearance.

4. CRYSTAL. This detector succeeded and took the place of the electrolytic partly because it was cheaper and more stable and partly because the United Wireless Telegraph Company, the commercial company having the greatest number of stations at that time, controlled the use of the carborundum detector.

Also, the Government became active in the use of silicon and perikon (zincite and chalcopyrite). Galena and various combinations with zincite came into use. These crystal detectors have been used in greater number than any other since about 1907.

5. AUDION. This form of detector was used to some extent as early as 1906, but apparently in very small numbers until about 1912 when the amateurs became active in its use, and within the last year or more it has been used to some extent by the Government.

The TIKKER detector, not shown in the Chart, was mainly used in 1912 and 1913 for receiving constant amplitude waves.

6. BEAT detector. This form of detector consists, in part, of a radio frequency, constant amplitude generator supplying a radio frequency differing from the frequency of the incoming, constant amplitude signals by such an amount as will produce audible beats. This appeared some time ago, to a very limited extent, in what was called the "heterodyne," wherein an arc produced the local radio frequency.

Within the last year or more, detectors, of which the audion is one type, have been arranged to act as detectors and local generators. This comparatively simple form of beat detector is taking the place of the tikker and increasing in number with the increase in use of constant amplitude transmitters.

The pliotron and other detectors and oscillators are increasing in numbers with the audion, particularly for beat reception.

These successive detectors, and the telephone method of reception, together with the subsequent improvements in telephone receivers and tuner circuits, have obviously contributed to radio service and to the rise of the range curve *R*, shown at the top of the chart.

All of the detector steps were markedly useful in radio development, but those recent steps of which the audion and pliotron are types (with their three-fold abilities, as detectors, generators and amplifiers), stand out as particularly useful. And the possibility of tuning to group frequency adds encouragement to the thought of better selectivity for the future.

7. The Vibrator Interrupter used first as a means of breaking the primary current in the induction coil, because of its unreliability, small current carrying capacity, and slow operation was abandoned quite early by most United States users; the chief exception being the American Marconi Company, which brought it back into use in considerable quantity in 1912 in connection with the auxiliary 10-inch coil supplied by them and indicated under Factor 12. However, it has again been condemned and is passing out.

8. The Mercury Turbine Interrupter replaced the vibrator to some extent. This interrupter was capable of giving a much higher interruption rate per second and to some extent was more reliable; however, the mercury required frequent cleaning and was somewhat expensive and injurious.

At the Avalon and Whites Point, California Stations, in 1902, rotating commutators were used. These were more reliable and gave higher interruption frequency than the vibrator.

9. The Electrolytic Interrupter came with the mercury turbine interrupter, as a part of German made apparatus, supplied to the U. S. Navy in 1902. It, too, produced higher interruption frequency, but varied in action and became less satisfactory as its temperature increased and the acid used was injurious.

10. Early in 1903, Dr. de Forest brought an *alternating current generator and transformer* to the Navy Department at Annapolis. This was the beginning of the marked advancement in power and reliability at the transmitter. And the alternating current has lasted up to the present time.

The mercury turbine and electrolytic helped to increase the range and service, while the alternating current contributed to a greater and more lasting extent.

11. The Plain Antenna Transmitter was used by the United States Navy as early as 1899 at the Atlantic Highlands near New York and on vessels. At this time, it appeared with the vibrator interrupter and coherer detector.

12. The Plain Antenna Transmitter as an auxiliary was brought back by the American Marconi Company in 1912. The plain antenna transmitter was the characteristic transmitter of Marconi Companies.

13. The Tuned Coupled-Circuit Transmitters made by the Slaby-Arco Company of Germany were used by the United States Navy at Annapolis and on vessels in the Fall of 1902. Tuned coupled circuit transmitters later became the characteristic transmitters of the de Forest and United Wireless Telegraph Companies.

14. The Impulse Excitation Transmitters made by the Telefunken Company of Germany and by Dr. Seibt of Germany (then with the de Forest Radio Telephone and Telegraph Company) were put in use almost simultaneously in 1909. The Telefunken transmitters were used shortly thereafter by the Navy and Army. Later the quenched gap transmitters became known as the characteristic transmitter of the Telefunken Company.

15. Constant Amplitude Transmitters of the arc type were used in commercial radio Service in 1912, and have become known as the characteristic transmitters of the Federal Telegraph Company. The Goldschmidt alternator type came into service at Tuckerton in 1914, and the frequency-changing transformer type came into service at Sayville in 1915.

Before 1912, constant amplitude generators were built and experimented with in an endeavor to obtain serviceable machines, and for calibrating purposes.

The Radio Telephone has been experimented with in varying amount since about 1907, but up to the middle of this year it apparently has never been sufficiently marked in its usefulness to remain in Government or commercial use. Apparently the main reasons have been: 1: inability to construct a telephone transmitter (e. g. microphone) which would reliably modulate sufficient energy; and 2: difficulty in obtaining constant amplitude current at short wave lengths or satisfactory spark frequency above audibility. The pliotron and similar devices may serve in solving these difficulties.

The word "radio" came into marked use in place of "wireless" in 1907, and was officially adopted by The Institute of Radio Engineers in 1911 and shortly thereafter by the United States Government.

16. Wave Meters of German make were used by the Navy Department early in 1903, and stations were adjusted to prescribed wave lengths with increasing accuracy up to the present. Also, Navy records made about that time or shortly after show resonance curves. The wave meter was used in the United Wireless Company in 1907 and increased in use, until in 1910, practically all the United Wireless (the then largest commercial company) stations were adjusted by using the wavemeter.

17. Radio Ammeters came with the German apparatus to Annapolis in 1902 and the Navy has used such ammeters in increasing numbers since that time. Commercial organizations were slower to adopt these however. Within the last two years radio ammeters have been used in noticeably increasing numbers in commercial stations.

18. Antenna Voltage increased from time to time up to the insulation limits as attempts were made, with different transmitters, to increase the power. The point of breakdown was quickly reached with the plain antenna transmitters, and this was one of the several objectionable features of the plain antenna transmitter. It may be that the insulation broke down more quickly with this type of transmitter because the antenna potential to ground remained high (before the spark discharge took place) for a greater length of time than where coupled circuits were used. For example, assuming that a coupled transmitter produced only alternating currents in the antenna and the potential rose from zero to a maximum and returned to zero again in one millionth of a second, while with the induction coil connected in the plain antenna circuit, the potential possibly increased from zero to a greater maximum for about one-tenth of a second before the discharge took place, the antenna insulation was subjected to higher potential for longer intervals.

19. Antenna Size. At first the vertical dimension of the

antenna was increased because it was recognized quite early that the sending range increased with the height of the antenna.

Later it was recognized that more power could be put in an antenna without breaking down the insulation by adding horizontal wires to the vertical antenna, and more power meant greater range.

Still later the antenna size was also increased to obtain natural periods more nearly equal to the longer transmitting wave lengths desired. An exception was the recent (since 1912) decrease in horizontal length of some shipboard antenna, to bring down the natural period so that the legal requirements for 300 meter waves could be met, as prescribed by the International Radio Conference.

In each step of development of the transmitter the size of the antenna was as a rule increased.

The plain vertical antenna grew from less than 100 feet (30 m.) to over 100 feet in height.

With the tuned coupled circuits at land stations in 1905, the height increased to over 200 feet (60 m.), and the horizontal dimensions were increased by fanning the wires and by increasing the number of masts. On shipboard, wider spreaders and more wires were used, increasing the capacity and *decreasing* the *resistance.*

With the impulse exitation transmitters, the height on land increased to 400 feet (120 m.) or more and the spread became greater; for example, in 1912, Sayville with its antenna, about 500 feet high and covering an area of about 4,000,000 square feet. With the constant amplitude transmitter came still larger antennas, for example, Tuckerton in 1914, with its antenna 850 feet (250 m.) high and covering an area of about 7,000,000 square feet.

An increase in height of about 10 to 1 occurred between 1899 and 1915, and a large increase in area with consequent capacity increase of about 25 to 1.

For future high power stations, right of ways may be obtained along roads or waterways and long antenna erected on high towers in one or more directions from the transmitter.

The single vertical wire antenna probably gave rise to the term "open circuit" while its use as plain antenna helped to stamp radio frequency circuits as "oscillating circuits." Apparently the term "open circuit" is passing with increased horizontal dimensions of antenna as also is "oscillating" with the advent of constant amplitude transmitters.

20. Spark Frequency increased from about 30 to 1,000 sparks per second during the period from 1899 to 1909. At Catalina, in 1902, about 70 sparks per second were used. In 1903, the 60 cycle alternating current brought the spark frequency to 120 or more per second. By 1905, apparently, spark frequencies as high as 500 per second were used. In 1909, spark frequencies of 1,000 per second and higher were used, particularly with quenched gap transmitters.

21. Decrement. The decrements of the alternating currents in the antenna have materially decreased since 1899.

Apparently, with practically all the steps in radio development tending to produce longer ranges and greater continuity of radio service, the effective power radiated increased with, and largely because of, the decrease in decrement. Or, probably, it may be said that the trend of transmitter development has been to increase the power and the size of the antenna and to produce single, radio frequency, constant amplitude (zero decrement) alternating current in the antenna.

22. Uniform Commercial Apparatus. The era of standardization from the standpoint of having apparatus of fixed type was between about 1908 and 1912, with the peak equipment consisted of a power switchboard, motor generator of uniformity in apparatus at about 1910. The uniform (delivering 60 cycle A. C. and about 1 K. W.), open core transformer, rack with 12 jars, muffled open gap in a helix (direct coupled), two coil direct-coupled tuner, carborundum receiver, telephones, and flat top antenna (loop connected). This uniformity kept down first cost and maintenance, but it prevented material improvement, because improvement meant violation of uniformity and consequent raising of maintenance cost and because other vessels would want the same improvement thus resulting in the scrapping of apparatus without indication of sufficient compensation.

23. Stock Jobbing. The exaggeration of radio matters in connection with the sale of "wireless" stocks of doubtful or practically no value was, as a rule, more or less associated with the operating commercial radio companies, from 1900 to 1911. As early as 1901, one company circulated printed matter and letters emphasizing the increase in telephone and telegraph stations and the great increase in selling price of telephone stocks and implying that the radio telegraph and telephone were ready to take the place of wire telegraph

and telephone. This company and subsidiary companies sold or attempted to sell stock. The same general process with amplifications continued to 1911 being promoted by several groups of people and under many names.

This stock jobbing influenced radio development in many ways; and whether or not this method was good, bad, or avoidable it certainly was an effective factor.

To sell stock required the showing of assets and activity. Patents and stations were considered as assets and activity. A patent was usually cheaper than a station which probably accounts for many radio patents.

Stations which were unprofitable from the standpoint of tolls or rental were established and maintained for and by the sale of stock.

Many steamship companies apparently only equipped their vessels with radio some years ago because it cost them little or nothing. By virtue of stock jobbing, the ocean-going public received more radio service and protection some years ago than it probably would have otherwise received, and the science and art were developed thereby. In the main, the general public paid the expenses without return of dividends or principle. It will be noted that curve *L* (land stations) drops at the beginning of the discontinuance of stock jobbing in 1910 and for similar reason the commercial ship stations, curve *S* changed direction in 1912.

Since 1911, the laws requiring and regulating radio have probably been the chief factors in fixing the number of ship and shore stations.

24. POST OFFICE PROSECUTION. This result of stock jobbing reached its most active stage in 1910 and 1911, or about ten years after the stock jobbing started. About ten men were sent to the penitentiary and two or more were fined. These were later-day stock jobbers, the earlier stock jobbers had been out of radio long enough to be forgotten or to be protected by the statute of limitations before the continued and growing complaint from the public became effective. While the charges and convictions were specified under several counts and certain specific instances were brought up for proof, it possibly may be summed up by saying these men were punished for getting money from widows and poor people by flagrant misrepresentation about radio thru the United States mails.

25. STOCK SALES to the public by stock jobbing methods were largely stopped in 1910 and 1911 by the Post Office prosecution; but, oddly enough, probably the greatest sale of radio stocks in the United States history occurred in 1912, when apparently about $6,000,000 changed hands in the sale of Marconi Wireless Telegraph Company of America stocks. The Marconi Company had raised its capitalization for taking over the United Wireless Company. Marconi stock was put on the market following the publicity attached to the Post Office prosecution and then the Titanic sank, further emphasizing radio. The result was old Marconi stocks went up in price from about $12 to $360 per share on the curb market and the new issue was sold.

Apparently some of the results of this new sale of stock to the public were to produce high power stations for trans-oceanic work, increase patent litigation, raise rentals to steamship companies, cause steamship companies to own and operate radio equipments, with some development of steamship apparatus by the Marconi Company.

26. OVERLAND RADIO was attempted in competition with the wire lines at one time or another in a majority of the states of the United States. In many cases the gross receipts were not sufficient to pay for the coal used in heating the stations. A large percentage of these stations were said to have been erected for stock jobbing purposes.

As a rule the overland stations were unable to handle business satisfactorily during the season of summer atmospheric disturbances, and the stations interfered with each other. In addition to this, they were competing with minor portions of two or three long established wire lines that were equipped to render service to nearly any point in the United States and to a great many points thruout the world, and the public was in the habit of using the wire lines. The result was practically universal abandonment of overland radio stations.

27. OPERATING ORGANIZATIONS have apparently varied from about 5 in 1902 to 10 at the present time, marked in earlier days by small short-lived companies, later by larger longer-lived companies with the more recent addition of operation by steamship companies.

28. MANUFACTURING ORGANIZATIONS. For a time, manufacturing companies were usually operating companies, but with the continued demand of the Navy and Army for

radio apparatus of U. S. manufacture and for improved apparatus, companies other than operating companies were formed to manufacture, and to meet this demand.

29. VALUE OF RADIO RECOGNIZED. In the earlier history except when convinced by a stock salesman, the public as a whole apparently regarded radio as more or less of a scientific toy which had possibilities but was not particularly useful; and because of stock jobbing, radio people, as a class, bore a somewhat bad reputation, both as to morals and ability.

The sinking of the "Republic" and the use of radio caused the public to recognize that it was of value, and its subsequent use (as, for example, on the S. S. "Ohio," and lastly, with the "Titanic") made such an impression that Congress passed laws requiring and controlling radio.

It may be said that from 1899 to 1911, the period characterized by stock jobbing, was the ERA OF DEVELOPMENT OF DEMAND FOR RADIO SERVICE, and with the coming of the Radio Laws and the stopping of stock jobbing in 1911 began the ERA OF FIXED MINIMUM DEMAND FOR RADIO SERVICE.

30. 50 PASSENGER, OCEAN LAW.

The first law passed, which became effective in July, 1911, required *ocean-going* vessels carrying *passengers* and carrying 50 or more persons, including passengers and crew, for a distance of 200 miles from United States ports to have a radio operator and apparatus capable of working 100 miles (160 km.). Additional stations principally on ships, were required, which offset somewhat the decrease in stations due to the closing of stock jobbing stations.

50 PERSONS LAW

In October, 1912, a revised law became effective for 50 persons which added one more operator and an emergency auxiliary source of power for the radio transmitter on ocean-going passenger ships; and later in 1913 on cargo and passenger carrying ships on the Great Lakes and on ocean cargo ships.

As will be noted in curve *S*, by the time all of these laws became effective the number of ship stations was approximately twice that of 1911 when the first law began to be effective.

In addition, these laws covering vessels carrying 50 persons required two licensed operators and an auxiliary source of power which increased the number of operators on commercial ships to about four times that of 1911 and brought in the plain antenna auxiliary set and later the full power auxiliary set.

The licensing of the operators by examinations raised the technical training of the operators as a class.

The requirement for continual service and operative apparatus has improved the apparatus and provided far better radio protection for occasions of distress on vessels.

33. The Decrement Law, or portion of the law, effective in 1912 with regulations, was made to prevent interference and for that reason required certain wave lengths and licenses for various classes of stations, all of which stations were required to use a decrement of less than 0.2.

34. Full Power Auxiliary. This is an auxiliary source of power capable of furnishing sufficient power to operate the main radio transmitter for four hours or more. Two such installations were made early in 1911 by the United Wireless on the Lamport and Holt line. When the law requiring auxiliary sources of power went into effect, ten inch induction coils with small storage battery were put on by the Marconi Company, thereby providing less power for distress purposes than was provided for ordinary business. In 1913, the United Fruit Company installed large Edison storage batteries to furnish full power for their main transmitters and for emergency deck lights, and since then other steamship companies have been making somewhat similar installations.

35. Patent Litigation. In August, 1902, the Marconi Wireless Telegraph Company of America brought suit against the de Forest Wireless Telegraph Company on the Marconi reissue patent number 11,913. Nearly three years later, in April, 1905, Judge Townsend held that claims 3 and 5 of the Marconi patent were infringed and granted an injunction and accounting on those claims, but said that claim 1 was too broad and claims 8, 10, and 24 were not infringed. However, in April, 1905, the de Forest Wireless Telegraph Company was a company of the past, and the decision practically only served to make others wary of claims 3 and 5. So that, altho the Marconi Company sued the American de Forest Wireless Telegraph Company in March, 1906 on claim 3 of this patent, the American de Forest Wireless Telegraph Company was using the loop antenna, and Judge Townsend rendered a decision in April, 1907, holding that the showing

made did not warrant the granting of an injunction. The chief result of this litigation which started in 1902 and ended in 1907, was the loop antenna, excepting, of course, that a considerable sum of money was probably expended. Taking into account all the radio litigation up to the present, probably the main features have been the expenditure of money and the time between the starting of the case and the final decision. This litigation effected the development of radio in a number of ways.

Beginning with 1902, one or more suits have been before the courts each year.

The decision in favor of the Marconi Company, plaintiffs, in 1905 resulted in the loop antenna which was successfully defended later.

The decision in favor of Fessenden and his associates, plaintiffs, in 1906 on the electrolytic detector, helped bring crystal detectors into use.

The decision in favor of the Marconi Company, plaintiff, in 1914, against the National Electric Signaling Company, and the National Electric Signaling Company suits against the Marconi Company apparently brought about the working agreement between these companies.

Seven suits filed in 1914 were the greatest number filed in one year.

Of approximately 27 suits filed from 1902 to the present time, apparently only seven have shown permanent status in favor of the plaintiff.

Of these, two were rendered ineffective by the defendant subsequently using other apparatus, two produced a working agreement, one was in connection with the selling out of the defendant, and the other two partially restricted two companies but are still being fought.

About eight suits are pending trial or decision.

Apparently United States radio patent litigation has been unprofitable for both the defendants and plaintiffs.

The time elapsed between filing the suit and the decision has varied from one month to four years and averaged about one and one half years.

36. Operation By Steamship Companies. That is, wherein the steamship companies rent or buy their apparatus, handle the traffic accounts, control their operators the same as the other members of their crews, etc. Among the first to do this was the United Fruit Company. Recently this

method of operation has increased quite rapidly, particularly on the Pacific Coast.

In the early days the stock jobbing operating companies rented the operators, apparatus, and traffic service for from $62.50 per month *down* to *nothing* per month. The steamship companies were not required to have it, and they were *not responsible* for it. Then, to the steamship company it was largely a *cheap* novelty which might be useful.

But with the departure of the low rent stock jobbing method, and the coming of some patent decisions and combinations in attempted patent monopoly, and the enforcement of radio laws, conditions have changed. Now, to the steamship company, it is more expensive and usually it is a *necessity* and a *responsibility*.

It has become a matter of question whether the steamship company cannot operate radio as cheaply as to rent its operation, and since it is now a *necessity* and a *responsibility*, the natural question is, why should not radio apparatus be in the same business system as other parts of the ship's equipment, the operator the same as any other member of the crew, and the traffic accounts the same as other traffic pertaining to ships? The result is that additional lines own and control the radio on their vessels.

37. THE INSTITUTE OF RADIO ENGINEERS. The Institute of Radio Engineers, formed by the combining of the Society of Wireless Telegraph Engineers and the Wireless Institute, was developed in the former organizations, principally by the persistent efforts of a few individuals. Practically, its early development was mainly characterized by the persistence of a few persons in meeting, reading, and discussing radio papers, regardless of attendance. Later, gradually, and still later, more rapidly, others became interested and active until now The Institute of Radio Engineers is an international, influential, educational organization, occupying a class by itself, and is worthy of classification as an effective factor in radio development.*

SUMMARY: The history of radio development in the United States is considered in great detail. Transmitters, detectors, antennas, a number of detailed parts of radio apparatus, and various branches of radio communication are classified, and their progress studied. Such topics as standardization, financial procedure, litigation, radio laws, and their consequences are treated fully.

* In this connection, it is a pleasure to inform the readers of the PROCEEDINGS that it is largely thru the loyal and continued efforts of Mr. Marriott that the originally very restricted membership of the Institute now runs into the thousands.—EDITOR.

DISCUSSION

Lloyd Espenchied: Mr. Marriott's paper is the story of the development of a new communication art, from the time of its inception, thru a varied probationary career up to a period in which it has become established upon a substantial service basis.

The value of the paper is considerably enhanced by the data given and by the manner in which it is graphically presented. This not only adds to its usefulness as an historical reference, but also injects an element of engineering importance, by showing up existing trends in the art and thereby enabling, by imaginary extrapolations of the curves, some insight to be had into the future.

As regards the trend in the technique of the art, the author's first chart illustrating the history of the development of transmitters, indicates clearly the tendency toward types giving a more and more frequent renewal of the antenna energy, i. e., toward the constant amplitude type of transmitter. The most intermittent type of transmitter (plain antenna) is already declining in numbers, while the next most intermittent type (ordinary coupled tuned circuit type) seems to have reached its growth and to have about started upon its decline. The impulse excitation type of transmitter representing the third step toward the constant amplitude type has taken up practically all of the growth of the more recent years and seems still to be growing. Altho the growth of the constant amplitude type has been slow up to the present, nevertheless from the trend indicated in the chart, and from our knowledge of its desirable transmission characteristics, we would be led to expect henceforth a more rapid growth in the number of such transmitters, in time accompanied by an actual decrease in the number of stations of other types.

Somewhat analogous trends are shown in the history of detector developments, starting as it does with the intermittently operated coherer, which accompanied the most intermittent type of transmitter, and coming down to the vacuum-tube-beat type of detector, co-operating with transmitters of the constant amplitude type.

Turning now to the curves of chart 2 showing the growth in the application of the radio art, we naturally wonder as to whether, for instance, the total number of stations will continue to grow at the same rate as in the past or whether it is approaching the "saturation" point. Curve *T*, giving the total number of radio stations in the United States, shows a rapid rise for the last six or seven years. This curve is made up in greater part by ship stations, and the recent growth in such stations is very largely due to legislative enactment compelling their adoption. This has resulted in the rapid discounting of a growth which probably would have occurred naturally, tho more slowly, by the gradual recognition of the value of radio to the maritime world. Hence there is some question as to whether, in so far as it is due to ship stations, curve *T* may not soon fall off to a growth coincident with that of the maritime field itself. However, as regards total growth in an art as young as is radio, one should not lose sight of the possibility of enlargements in its sphere of economic utility brought about by scientific or technical advances either in it or in other arts as, for instance, that of aerial navigation.

February 15, 1917.

ON THE USE OF CONSTANT POTENTIAL GENERATORS FOR CHARGING RADIO TELEGRAPHIC CONDENSERS AND THE NEW RADIO TELEGRAPHIC INSTALLATIONS OF THE POSTAL AND TELEGRAPH DEPARTMENT OF FRANCE*

By

Leon Bouthillon

(Engineer in Charge of the Radio Telegraphic Service of the Postal and Telegraph Department of France)

Numerous experimenters have attempted to use constant electromotive forces for charging the condensers used in radio telegraphy. Even if we neglect the field of sustained waves, such as are produced by the arc (of Poulsen, de Forest, Blondel, etc.), by the method of Galletti, or by the method of Marconi, and restrict ourselves to spark radio telegraphy, we find that there have been numerous attempts to use constant electromotive forces. Limiting ourselves to the principal instances, we recall at once that Marconi employed in his stations at Clifden and Glace Bay sets of 6,000 cells of storage battery. This battery was charged by means of direct current generators. When it was used alone, the voltage was from 11,000 to 12,000; but when the battery was used in parallel with the generator, the potential difference could be raised to 15,000 volts. The discharger consisted of a disc on the periphery of which were a number of regularly spaced projections, which disc rotated between two smooth electrodes. The arrangement of the circuits is shown in Figure 1.† In collaboration with Captain Brenot, Blondel carried on a series of experiments directed toward radio telephony at the Eiffel Tower. He used a direct current machine with considerable inductance in the charging circuit of the condenser, and a stationary spark gap.

Von Lepel introduced a system whereby the musical note was obtained thru the effect produced by an auxiliary circuit consisting of inductance and capacity connected in parallel with the

* Received by the Institute, March 19, 1916. Translated from the French by the Editor.

† See "Proc. Royal Institution," June 2, 1911.

gap, as indicated in Figure 2. In this figure, *S* is the key, *G*, *G* the choke coils, *H* an inductance, *F* a condenser, *A* the gap, and *C*, *D* the radio frequency coupler. (See "Electrical Engineering," September 15, 1911, page 591). Related to this system are the experiments in multiplex radio telegraphy carried on by the Compagnie Générale de Radiotélégraphie, wherein circuits indicated in Figure 3 were used. (See G. E. Petit and L. Bouthillon, "La Telegraphie sans Fil," 3rd edition, page 69. Delagrave, Paris.)

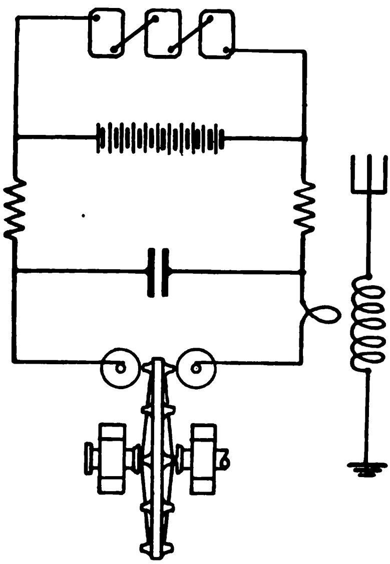


FIGURE 1—Marconi High Direct Voltage Transmitter

The present paper will show why, when faced with the task of developing a type of radio telegraphic station for the Postal and Telegraph Department of France, I also have chosen to use constant electromotive forces for charging the condensers; and also how, by selecting the best features of the systems of Marconi and Blondel, I have formed a combination which is an advance on each of them.

I shall begin by studying completely the functioning of a charging circuit connected to a source of constant electromotive force and of a discharge circuit containing a gap. I shall then discuss the relative value of the various types of generators and indicate the criteria of their suitability in radio telegraphy.

In the third part of the paper, I shall indicate the principal characteristics of the system selected. In the fourth part of the paper, the choice of system will be justified by comparing its characteristics with those of the usual alternating current system.

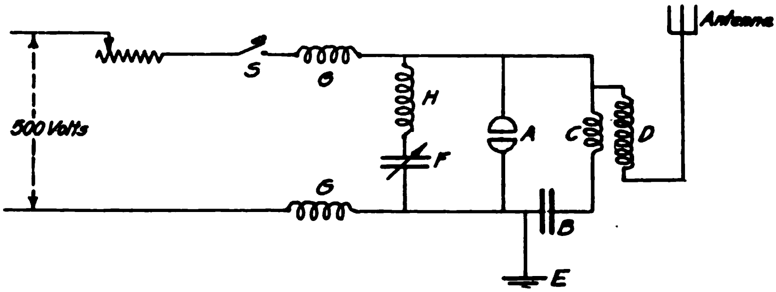


FIGURE 2—LEPEL CIRCUIT

PART I. THE CHARGING OF CONDENSERS BY CONSTANT ELECTROMOTIVE FORCES AND THEIR DISCHARGE IN OSCILLATORY CIRCUITS. PRODUCTION OF MUSICAL TONES.

1. *General Principles.* We are concerned, in all system of spark radio telegraphy, with the charging of condensers by a high potential generator and their subsequent discharge in an oscillatory circuit, the sequence of phenomena being repeated a certain number of times per second, which number determines the pitch of the characteristic signal note. This note is musical if the discharges recur sufficiently rapidly and regularly.

The arrangement to which we refer is shown in Figure 4. The charging circuit contains a constant potential generator S' of voltage E, an inductance L, a resistance R, a capacity C, and a discharger D in the oscillatory circuit. The sequence of effects depends on whether the gap D is rotary or stationary. In the latter case, a spark passes and the condenser is discharged each time the potential difference at its terminals reaches the constant value V, which value is determined by the break-down distance. In the former case, the spark passes at regular intervals separated by a time τ, which corresponds to the time between the passage of successive studs on the rotary electrode.

In both cases, we suppose that the duration of the spark is negligible compared to the charging time. We shall also suppose that the condenser is completely discharged at the termination of the spark. These assumptions are practically correct. In connection with the study of the action of this circuit the following theory is necessary.

2. *Theory of the Charging of a Condenser by a Constant Potential Generator.* In Figure 5, let the constants be as indicated.

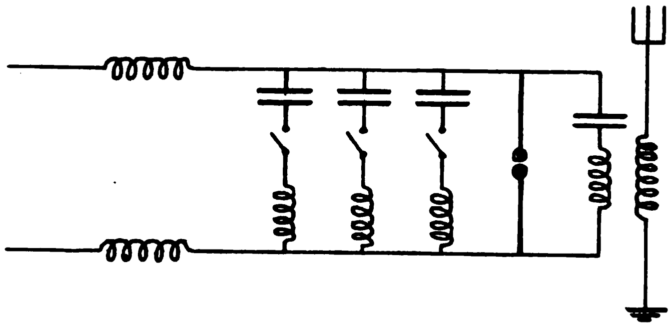


FIGURE 3—Multiplex Transmitter Compagnie Générale de Radiotélégraphie

Suppose that at time t, the current is i, the potential difference of the condenser terminals v, and the charge of the condenser q. The differential equation of the circuit is

$$L\frac{d^2 q}{d t^2} + R\frac{d q}{d t} + \frac{q}{C} = E \qquad (1)$$

This merely expresses the equality at all times of the E.M.F. E and the sum of the potential differences across L, R, and C. In addition, at all times,

$$v = \frac{q}{C} \quad \text{and} \quad i = \frac{d q}{d t} \qquad (2)$$

The condenser being supposed to be completely discharged when the spark ceases, the potential difference is zero at the beginning of the charge. Let i_o' be the corresponding current. The solution of (1) takes three different forms, according as the expression

$$\frac{1}{CL} - \frac{R^2}{4L^2}$$

is positive, negative, or zero. The only case which is interesting in practice (since it is the only case wherein an appreciable output can be obtained) occurs when the expression given above is positive. In this case, the current and potential difference at the condenser terminals are the following:

$$\left.\begin{aligned} i &= \frac{E}{L\omega}\varepsilon^{-at}\sin\omega t + i_o'\frac{\cos(\omega t+\phi)}{\cos\phi}\varepsilon^{-at} \\ &\qquad = i_o'\varepsilon^{-at}\frac{\sin(\omega t+\mu)}{\sin\mu} \\ v &= E\left[1-\varepsilon^{-at}\frac{\cos(\omega t-\phi)}{\cos\phi}\right] + L\omega i_o'\frac{\sin\omega t}{\cos^2\phi}\varepsilon^{-at} \\ &\qquad = E - i_o' L\omega\frac{\cos(\omega t+\mu-\phi)}{\sin\mu\cos\phi}\varepsilon^{-at} \end{aligned}\right\} \quad (7)$$

where we call,

$$a = \frac{R}{2L}, \qquad \omega = \sqrt{\frac{1}{CL} - \frac{R^2}{4L^2}},$$

$$\frac{a}{\omega} = \tan\phi, \qquad \frac{L\omega i_o'}{E - Lai_o'} = \tan\mu \quad (8)$$

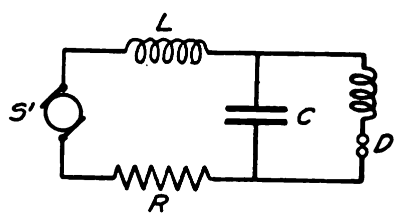


FIGURE 4—Charging Circuit and Discharge Circuit

Both current and potential difference are periodically damped. The period is $T = \frac{2\pi}{\omega}$ and the logarithmic decrement is $\delta = aT$. The potential difference, which was zero at the beginning of charge, is represented by a periodically damped oscillation curve, crossing the axis of co-ordinates E at regular intervals. It has its maxima when

$$\omega t = (2k+1)\pi - \mu, \quad (9)$$

and its minima when

$$\omega t = 2k\pi - \mu. \quad (10)$$

The location of the maxima and minima is given by

$$\frac{V}{E} = 1 \pm \frac{L\omega i_o'}{E\sin\mu}\varepsilon^{-at}. \quad (11)$$

The entire family of curves which show the values of the potential difference corresponding to different values of i_o' have a series of common points defined by the relations

$$\omega t = (2k+1)\pi$$
$$v = E\left(1+\varepsilon^{-a(2k+1)\pi}\right) \qquad (12)$$

and

$$\omega t = 2k\pi$$
$$v = E\left(1-\varepsilon^{-a.2k\pi}\right), \qquad (13)$$

these being the curves 1, 2, and 3 of Figure 6.

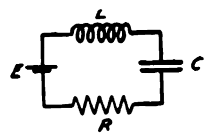


FIGURE 5—Charging Circuit

The current, which is i_o' at the beginning of the charge, is represented by a periodically damped curve, oscillating from one side to the other of the time axis, as shown in curves 1, 2, and 3 of Figure 7.

The zeros correspond to the maxima and minima of the difference of potential:

$$\omega t = k\pi - \mu \qquad (14)$$

These maxima and minima occur at times given by the formula

$$\omega t = (2k+1)\frac{\pi}{2} - \mu - \phi. \qquad (15)$$

Efficiency of the Charging Circuit. Let us suppose that the spark passes at the time when the potential difference at the condenser terminals is v. The energy available for the circuit at the condenser terminals is $\frac{1}{2} C v^2$. The energy expended in the charging circuit is $\int_o^t E\, i\, dt$. The efficiency is the ratio of these two quantities:

$$\gamma = \frac{\frac{1}{2} C v^2}{\int_o^t E\, i\, dt} = \frac{1}{2}\,\frac{v\, q}{E\int_o^t i\, dt} = \frac{1}{2}\frac{v\, q}{E\, q} = \frac{1}{2}\frac{v}{E}. \qquad (16)$$

In the case of aperiodic charging, the potential difference at the condenser terminals is always less than the electromotive force and the efficiency less than 0.5. Because of this low value of the efficiency, such a condition should be avoided in practice. In the case of "periodic charging," the potential difference is a damped period function, oscillating above and below the electromotive force E. Its maxima are given by

$$\omega t = (2k+1)\pi - \mu, \tag{17}$$

which maxima become smaller as k increases. (See the curves of Figure 6.)

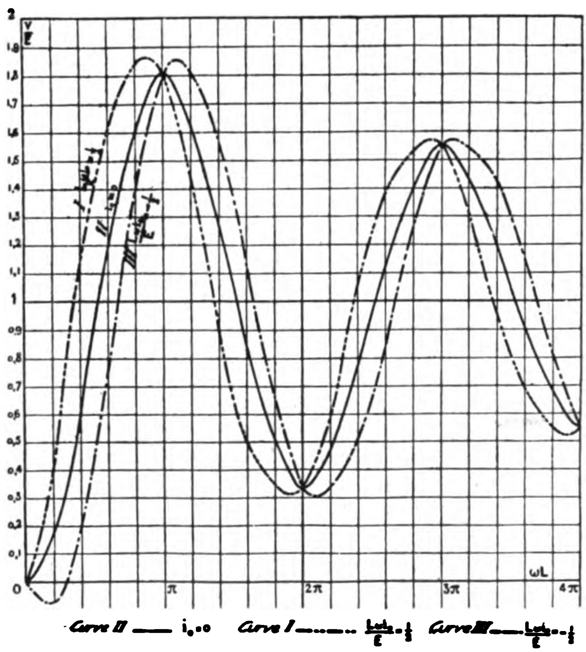


FIGURE 6—Variation of Condenser Terminal Voltage as Function of Charging Time $t \cdot (\delta = 0.4)$

3. *Study of the Production of Musical Tones: Characteristic Conditions.*

The charges and discharges will take place in such a way as to produce a musical note by the successive sparks if the two following conditions are met:

1. That the successive condenser discharges are regularly

spaced, at equal intervals, and consequently that successive charges require the same constant time.

2. That the voltage v and the current i are the same at the beginning of each charge. The voltage being zero, if the discharge is supposed to be complete at the time that the spark ceases, it is only necessary that the current i' shall have the same value i_o at the beginning of each charge. Since it is also assumed

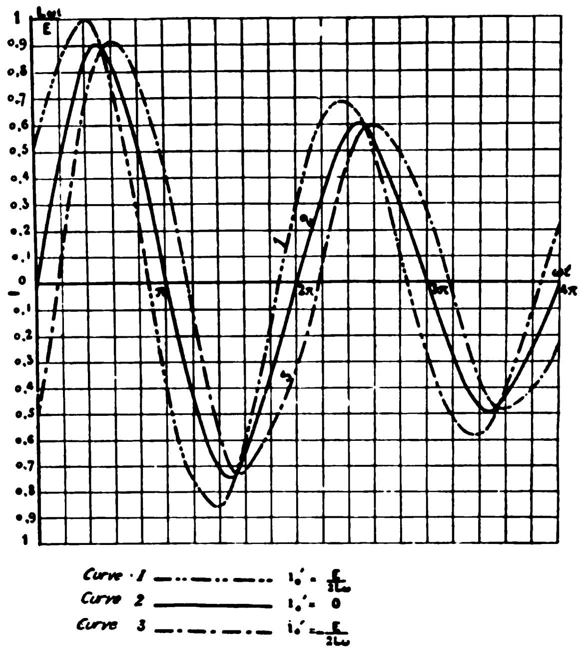


Figure 7—Condenser Charging by Constant E. M. F.
Current in Charging Circuit

that the time of discharge is negligible in comparison with that of charging, the current in the charging circuit must remain constant during the entire discharge, and the condition (2) above may be expressed as follows: The current at the end of the discharge must be equal to the initial current.

When applied to equations (7) and (8), these conditions lead to the following relating between the charging time τ and the current i_o for any spark.

$$i_o \left[1 - \varepsilon^{-a\tau} \frac{\cos(\omega\tau + \phi)}{\cos\phi} \right] = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin \omega\tau, \qquad (18)$$

We obtain also for the potential difference at the end of the charging period, under conditions of a musical note of frequency $\frac{1}{\tau}$,

$$V = E\left\{1 - \varepsilon^{-\alpha\tau}\frac{\cos(\omega\tau - \phi)}{\cos\phi} + \varepsilon^{-2\alpha\tau}\frac{\sin^2\omega\tau}{\cos^2\phi\left[1 - \varepsilon^{-\alpha\tau}\frac{\cos(\omega\tau + \phi)}{\cos\phi}\right]}\right\}$$

$$= \frac{E\left(1 - 2\,\varepsilon^{-\alpha\tau}\cos\omega t + \varepsilon^{-2\alpha\tau}\right)}{1 - \varepsilon^{-\alpha\tau}\frac{\cos(\omega\tau + \phi)}{\cos\phi}} \qquad (19)$$

Consequently, corresponding to each value of V, the sparking potential difference which is supposed to be held constant (as in the case of a stationary gap), there is a condition of musical tone production identified with the smallest value of τ given by equation (19) and by the value of i_o thereafter deduced from equation (18). So that, the value of V remaining constant, the current is i_o at the beginning of the first spark, and all sparks thereafter come at a regular interval τ thus giving rise to a musical tone.

In the same way, corresponding to each value τ of the time of charge, supposed to be held constant (case of the rotary gap), there is a production of a musical tone identified by the values of V and i_o. If the current at the beginning of the first spark is i_o, all later sparks will be produced by the same potential difference.

Sparking Potential and Efficiency.

The sparking potential and the efficiency which is proportional to it each vary with the frequency of the musical tone. Whenever the time of charge τ, which is also the period of the musical tone, is not zero, there are a series of maxima for values of τ corresponding to zero values of the derivative $\frac{dv}{d\tau}$.

$$\frac{dv}{d\tau} = \frac{E}{CL\omega} \cdot \frac{\sin\omega\tau \cdot \varepsilon^{-\alpha\tau}\left(1 - \varepsilon^{-2\alpha\tau}\right)}{\left[1 - \varepsilon^{-\alpha\tau}\frac{\cos(\omega\tau + \phi)}{\cos\phi}\right]^2} \qquad (20)$$

The maxima occur when

$$\omega\tau = (2k+1)\pi \quad \text{or} \quad \tau = \frac{(2k+1)T}{2} \qquad (21)$$

That is, the maxima occur when the time of charging is an odd multiple of the half period of the charging oscillation.

The minima occur when

$$\omega \tau = 2 k \pi \text{ or } \tau = k T, \tag{22}$$

that is, for values of the charging time which are multiples of the entire period of the charging oscillation.

The greatest of all the maxima is when

$$\tau = \frac{T}{2} \tag{23}$$

which is the case of a musical tone produced by one spark per half period. The current is then zero at the beginning and at the end of each charge, and the sparking potential is

$$V = E \left(1 + \varepsilon^{-\frac{\delta}{2}}\right) \tag{24}$$

and the efficiency is

$$\gamma = \frac{1 + \varepsilon^{-\frac{\delta}{2}}}{2} \tag{25}$$

These conditions then are those of maximum efficiency with a musical tone. The efficiency is greater the less the logarithmic decrement of the charging oscillation. When the decrement becomes zero, the efficiency is unity.

We shall successively study the variation of the maximum efficiency with the damping of the charging circuit and the variation of the efficiency when t changes slowly at values near $\frac{T}{2}$.

The following table gives the values of the maximum efficiency corresponding to various values of the decrement.

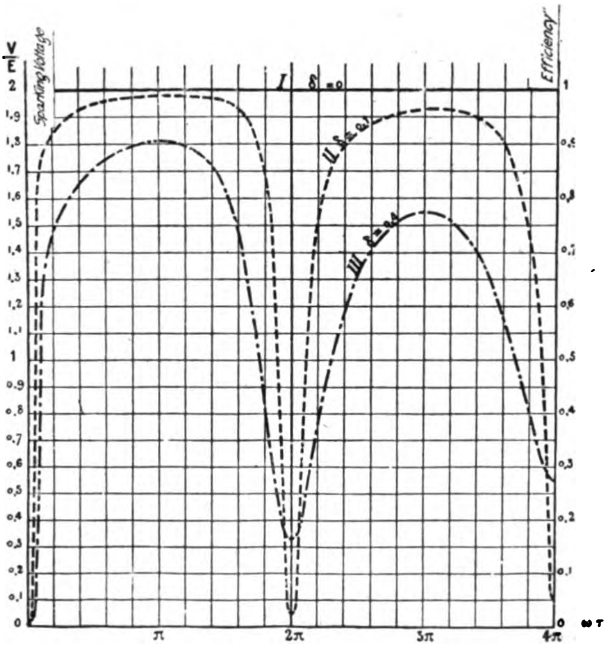
Decrement of Charging Circuit	Efficiency	Decrement of Charging Circuit	Efficiency
0.0	1.00	0.8	0.84
0.2	0.95	1.0	0.80
0.4	0.91	2.0	0.68
0.6	0.87		

The maximum efficiency is obtained at a spark frequency double that of the oscillations of the charge, i. e., one spark per half period. It is interesting to note how the efficiency changes when the spark frequency differs from this most desirable value $(\omega \tau = \pi)$.

If we assume $\frac{\alpha^2}{\omega^2}$ to be negligible compared to unity, the potential difference reduces to $V = 2 E$ and the efficiency to

$\gamma = 1$. In this case, the efficiency will always be equal to unity no matter what the period of the musical tone.

In practice, it is impossible to eliminate the resistance of the charging circuit; but the curve of sparking potential has the shape of curves I, II, and III of Figure 8 with large flat regions in the neighbourhood of the maxima. Consequently, considerable



Curve I ——— δ=0, Curve II - - - - δ=0.1, Curve III.—.—δ=0.4

FIGURE 8—Variation of Sparking Voltage and Efficiency as Function of Period τ of Musical Note

variations in the time of charging produce only slight changes in the efficiency. The less the decrement, the smaller are these changes and the nearer the maximum efficiency approaches unity.

The curves of Figure 8 show the variations of potential difference at the condenser terminals or of the efficiency as a function of the period τ of the musical tone for the three values of the logarithmic decrement, namely: $\delta = 0$, $\delta = 0.1$, and $\delta = 0.4$.

It can be seen that the spark frequency may be multiplied by 3 in the case where $\delta = 0.4$ (a value rarely exceeded in practice) and by 7 in the case where $\delta = 0.1$ without diminishing the efficiency by more than 10 per cent. This is an interesting characteristic of methods of charging continuous by sources of direct current.

Initial Current. The relation between τ the time of charge and the initial current i_o (which is also the current at the moment of discharge) is the following:

$$L \omega i_o = E \frac{\sin \omega\tau \ \varepsilon^{-a\tau}}{1 - \varepsilon^{-a\tau} \dfrac{\cos(\omega\tau + \phi)}{\cos \phi}}$$

For $\tau = 0$

$$L \omega i_o = \frac{E \omega}{a} \qquad i_o = \frac{E}{L a}$$

Thereafter i_o decreases, reaching zero when $\omega \tau = k \pi$.
It assumes the general shape of a damped periodic curve of period

$$T = \frac{2\pi}{\omega},$$

and passes thru a series of maxima and minima when

$$\varepsilon^{a\tau} = \frac{\cos(\omega \tau + \phi)}{\cos \phi},$$

which are represented in the curves of Figure 9.

If $a = 0$, that is, if the charging current is without damping, we have

$$L \omega i_o = E \cot g \frac{\omega \tau}{2}. \qquad (26)$$

In this case, i is zero when $\omega \tau = (2k+1)\pi$ and infinite when $\omega \tau = 2k\pi$ (curve 1 of Figure 9).

The current i_o assumes the value zero at points corresponding to the maximum sparking potential difference or maxima of the efficiency. The curves of Figure 9 show the variation of i_o as a function of τ for the three values, $\delta = 0$, $\delta = 0.1$, and $\delta = 0.4$. It will be seen that the larger the damping, the smaller i_o.

Potential Difference at the Condenser Terminals during the Charge.

During the charge, the potential difference is given by equation (7) above. The curve representing v is periodic and damped. If there is no sparking, it passes thru a series of maxima given by equation (11) above with the positive sign chosen in the second member, when

$$\omega t = (2k+1)\pi - \mu,$$

and thru a series of minima or negative maxima given by equation (11) above with the negative sign chosen in the second member when

$$\omega t = 2 k \pi - \mu \text{ (See the curves of Figure 6).}$$

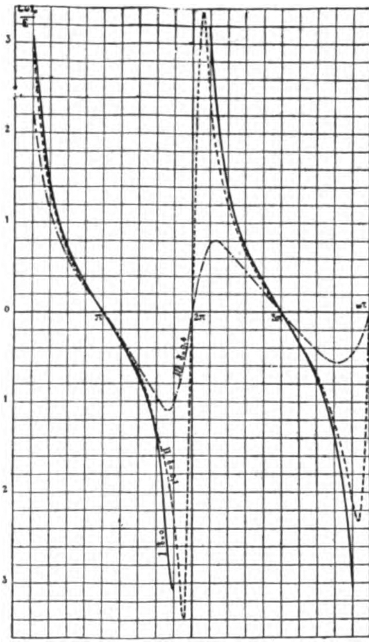


Figure 9—Variation of Initial Charging Current i_0 as Function of Period of Musical Note

If i_0 is positive, the first of all these maxima is always a positive one and the greatest of them all, having the value

$$V_1 = E\left(1 + \frac{L \omega i_o}{E \sin \mu} \varepsilon^{-a t_1}\right) \qquad (27)$$

where $\omega t_1 = \pi - \mu.$

If i_o is negative, the first of all the maxima is negative and equal to the expression just given except that the negative sign appears in the second member instead of the positive, and that t_1 is given by $\omega t_1 = -\mu.$

The second maximum is positive, and equal to the expression given in equation (27)

where $\omega t_1 = \pi - \mu.$

The greatest of the maxima is the first positive one, V_1. For certain values of i_o and small dampings, it reaches large values.

But this expression does not give the maximum potential difference attained during the entire charging process unless the time of charging τ (which is the period of the musical tone) is greater than half the period of the charging oscillation ($\omega\tau>\pi$). For in this case t_1 is smaller than τ, and the spark takes place before the maximum value is reached. If, on the other hand, the time of charging is less than half the period of the charging oscillation ($\omega\tau<\pi$), the spark takes place before the maximum potential difference is reached, and the greatest potential difference at the condenser terminals takes place at sparking.

Figure 10 shows the changes in the maximum potential difference at the condenser terminals during the charge as a function of the period τ of the musical note, and for three values of the damping decrement:

$$\delta=0, \quad \delta=0.1, \quad \text{and } \delta=0.4.$$

Whenever $\omega\tau$ is less than π, these curves are the same as those which give the sparking potential difference (Figure 9); and when τ is greater than the limiting value mentioned, the curves represent equation (27). It will be noticed that with $\delta=0.1$ and certain values of τ, the condenser terminal voltage is more than four times the generator electromotive force.

Potential Difference at the Inductance Terminals during the Charge.

During charging, the potential difference at the inductance terminals is

$$u=L\frac{di}{dt}=L\,\omega\,i_o\frac{\cos(\omega t+\mu+\phi)}{\sin\mu\cos\phi}\,\varepsilon^{-at}$$

which passes thru a series of maxima when

$$\omega t=2k\pi-\mu-2\phi$$

and minima when

$$\omega t=(2k+1)\pi-\mu-2\phi.$$

If i_o is positive, the first of these maxima is the greatest of all, and has the value

$$V_2=\frac{L\,\omega\,i_o}{\sin\mu}\,\varepsilon^{-at_2}$$

where $$\omega t_2=\pi-\mu-2\phi.$$

If i_o is negative, the first of all these maxima is the greatest, and positive, having the value

$$V_2'=\frac{L\,\omega\,i_o}{\sin\mu}\,\varepsilon^{-at_1}$$

where $$\omega t_2' = -\mu - 2\phi.$$

When the damping is not large, which is generally the case in practice, the values of V_1 and V_2' are quite close to the maximum condenser terminal, potential difference diminished by E.

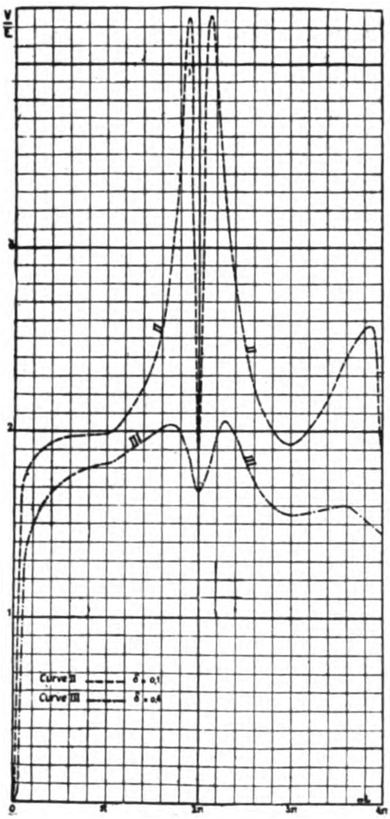


FIGURE 10—Variation of Maximum Voltage at Condenser Terminals during Charging as Function of Period of Musical Note

Difference of Potential at the Resistance Terminals during the Charge.

The value of this potential difference is

$$u = Ri = 2Lai \text{ or}$$

$$u = 2Lai_0\varepsilon^{-at}\frac{\sin(\omega t+\mu)}{\sin\mu}$$

Average Current in the Charging Circuit. The average current in the charging circuit (which is of interest, as we shall see later, since it is directly proportional to the power expended) is given by

$$i_{av} = \frac{1}{\tau}\int_o^\tau i\,d\,t = \frac{1}{\tau} C\,V = n\,C\,V$$

It is zero for $\tau = 0$, and increases as a function of τ, passing thru a maximum when

$$C\frac{d\,v}{d\,t} = i_{av}$$

and decreasing thereafter.

Energy Expended in the Charging Circuit.

The energy expended during a charge is

$$E\int_o^\tau i\,d\,t = E\,C\,V.$$

If the musical tone produced corresponds to n charges per second, the power expended is

$$W_d = n\,C\,E\,V = E\,i_{av}. \qquad (36)$$

It is proportional to the average current, and like it, passes thru a maximum when

$$i_{av} = C\frac{d\,v}{d\,t}.$$

Energy Available at the Condenser Terminals.

This is equal to

$$W_u = \frac{1}{2}n\,C\,V^2. \qquad (37)$$

It is zero when $t = 0$ and increases with t, reaching a maximum when

$$i_{av} = 2\,C\frac{d\,v}{d\,t}$$

and diminishing thereafter as t continues to increase.

Inception and Stability of Tone Phenomena:

We have seen that for each value of the sparking potential difference, V, supposed constant (which is the case for a stationary gap), there exists a musical spark determined by the values of τ and i_o. If the value of V is held constant, the current is i_o at the beginning of the first spark. All the successive sparks follow at regular intervals of time equal to the charging time, τ.

In the same way, to each value τ of the time of charge assumed constant (which is the case for a rotary gap), there is a musical spark determined by the values of V and i_o. If the current at the beginning of the first spark is i_o, all successive sparks will occur for the same difference of potential V.

It remains to be considered whether the tone phenomena are stable. That is, we must consider whether such musical functioning is re-established after the removal of a temporary disturbance which has caused irregularities, and whether the tone phenomena will occur no matter what the value of the initial charging current i_o'. There is, in fact, no certainty that otherwise the initial current can be regulated in such a way as to be equal to the value i_o which corresponds to a musical note.

From this point of view we shall study the phenomena which take place with each type of discharger.

Case of the Rotary Gap. The time of charging after each spark has the same value τ. Let i_o' be the current at the beginning of the first charge, i_1' that at the beginning of the second charge (which is equal to the current at the end of the first charge), i_2' that at the beginning of the third charge (and equal to that at the end of the second), and so on.

All charging times have the same value τ, the values of i_o', i_1', i_2' . . . i_n' are connected by the following relations, based onequation (7):

$$i_1' = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin \omega\tau + i_o' \frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}$$

$$i_2' = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin \omega\tau + i_1' \frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}$$

. . . .

$$i_n' = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin \omega\tau + i_{n-1}' \frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi} \qquad (38)$$

Let us multiply the first equation by

$$\left[\frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}\right]^{n-1},$$

the second by

$$\left[\frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}\right]^{n-2},$$

and so on, to the (n-1) st, and then add. The terms containing i_{n-1}', i_{n-2}' . . . i_1' disappear, and there remains

$$i_n' = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin \omega\tau \left[1 + \frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi} + \cdots + \left(\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right)^{n-1}\right] + i_o' \left(\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right)^n \quad (39)$$

The series in brackets equals

$$\frac{1 - \left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n}{1 - \frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}$$

so that we obtain for i_n'

$$i_n' = \frac{E}{L\omega} \sin\omega\tau \frac{1}{1 - \frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}} \left\{1 - \left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n\right\} + i_o' \left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n$$

or

$$i_n' = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin\omega\tau \frac{1}{1 - \frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}} \quad (40)$$

$$+ \left[\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}\right]^n \left\{i_o' - \frac{E}{L\omega}\varepsilon^{-a\tau}\sin\omega\tau \frac{1}{1 - \frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}\right\}$$

The initial current i_n' for the $(n+1)$st charge contains one constant term, and an additional term which is a function of n, this latter term becoming zero as n increases indefinitely, since

$$\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}$$

is less than 1 regardless of the value of τ.

If the current at the beginning of the first charge has the value

$$i_o' = \frac{E}{L\omega} \varepsilon^{-a\tau} \sin\omega\tau \frac{1}{1 - \frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}},$$

(that is, the value corresponding to i_o of tone phenomena) the additional term is zero, and the musical note is established after the first spark.

If the time of charge is such that

$$\cos(\omega\tau+\phi) = 0,$$

that is,

$$\omega\tau = (2k+1)\frac{\pi}{2} - \phi,$$

the additional term is still zero, and the tone phenomena are established at the end of the first charge no matter what value the current has at the beginning of that discharge.

In general, the term

$$\frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}$$

is not zero, but it is always smaller than unity and consequently the $(n+1)$st power thereof approaches zero as n increases indefinitely. After a certain number of discharges, which number will be smaller the larger the damping constant a, the additional term becomes negligible. The initial current will then be the same for each discharge, and the musical tone will persist. We find, as must naturally be the case, that the limiting value of i_n' then becomes i_o, which corresponds to musical phenomena having a charging time τ.

Consequently in the case of a rotary gap, tone phenomena are stable. They occur automatically regardless of the current value at the beginning of the first charge.

Case of Stationary Gap. When the spark gap is fixed, the spark always jumps, theoretically at least, when the potential difference reaches a certain definite value dependent on the bridged distance. Consequently, the discharge always takes place for the same voltage V.

Let $i_o'=i_o+\Delta i_o'$ be the initial current for the first charge, i_o being the current for tone phenomena corresponding to the potential difference V. Let $t_1=\tau+\Delta t_1$ (τ being the time of charging with tone phenomena). Then the time at which discharge occurs is a function of i_o' and is given by the equation

$$V=E\left(1-\frac{\varepsilon^{-at}\cos(\omega t-\phi)}{\cos\phi}\right)+\frac{L\omega i_o'}{\cos^2\phi}\sin\omega t\ \varepsilon^{-at}$$

or

$$V=E\left(1-\frac{\varepsilon^{-a(\tau+\Delta t_1)}\cos\left[\omega\tau+\Delta t_1-\phi\right]}{\cos\phi}\right)$$
$$+\frac{L\omega(i_o+\Delta i_o')}{\cos^2\phi}\sin\omega(\tau+\Delta t_1)\ \varepsilon^{-a(\tau+\Delta t_1)}$$

If Δt_1 and $\Delta i_o'$ are infinitesimal, this equation is equivalent to

$$\Delta t_1\left(\frac{\partial V}{\partial t}\right)_{t=\tau}+\Delta i_o'\left(\frac{\partial V}{\partial i_o'}\right)_{i_o'=i_o}=0, \qquad (41)$$

and determines Δt_1 as a function of $\Delta i_o'$.

The current, $i_1'=i_o+\Delta i_1'$ at the end of the first charge is given by the equation

$$i_1'=\frac{E}{L\omega}\varepsilon^{-at}\sin\omega t+\frac{i_o'}{\cos\phi}\cos(\omega t+\phi)\ \varepsilon^{-at}$$

If Δt_1 is infinitesimal, this equation becomes

$$\Delta i_1' = \Delta t_1 \left(\frac{\partial i_1'}{\partial t}\right)_{t=\tau} + \Delta i_o' \left(\frac{\partial i_1'}{\partial i_o'}\right)_{i_o'=i_o} \qquad (42)$$

The elimination of Δt_1 between the two equations (1) and (2) gives $\Delta i_1'$ as a function of $\Delta i_o'$.

$$\Delta i_1' = \Delta i_o' \left[\left(\frac{\partial i_1'}{\partial i_o'}\right)_{i_o'=i_o} - \left(\frac{\partial V}{\partial i_o'}\right)_{i_o'=i_o} \frac{\left(\frac{\partial i_1'}{\partial t}\right)_{t=\tau}}{\left(\frac{\partial V}{\partial t}\right)_{t=\tau}} \right]. \qquad (43)$$

We have here

$$\left(\frac{\partial i_1'}{\partial i_o'}\right)_{t=\tau} = \frac{1}{\cos\phi} \cos(\omega\tau+\phi)\,\varepsilon^{-a\tau} \qquad (44)$$

$$\left(\frac{\partial V}{\partial i_o'}\right)_{t=\tau} = \frac{L\omega}{\cos^2\phi} \sin\omega\tau\ \varepsilon^{-a\tau} \qquad (45)$$

$$\frac{\partial i_1'}{\partial t} = \frac{E}{L\omega}\varepsilon^{-at}(-a\sin\omega t+\omega\cos\omega t)$$

$$+\frac{i_o'}{\cos\phi}\varepsilon^{-at}[-a\cos(\omega t+\phi)-\omega\sin(\omega t+\phi)]$$

$$=\varepsilon^{-at}\frac{\sqrt{a^2+\omega^2}}{\omega}\left[\frac{E}{L}\cos(\omega t+\phi)-\frac{i_o'\,\omega}{\cos\phi}\sin(\omega t+2\phi)\right]$$

$$=\frac{\varepsilon^{-at}}{\cos\phi}\left[\frac{E}{L}\cos(\omega t+\phi)-\frac{i_o'\,\omega}{\cos\phi}\sin(\omega t+2\phi)\right].$$

For $t=\tau$, $i_o'=i_o$,

$$\left(\frac{\partial i_1'}{\partial t}\right)_{t=\tau} = \frac{\varepsilon^{-a\tau}}{\cos\phi}\left[\frac{E}{L}\cos(\omega t+\phi)-\frac{i_o\,\omega}{\cos\phi}\sin(\omega\tau+2\phi)\right]$$

and, substituting for i_o its value,

$$i_o = \frac{E}{L\omega}\,\frac{\varepsilon^{-a\tau}\sin\omega\tau}{1-\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}$$

and simplifying, after remembering that

$$\cos^2(\omega\tau+\phi)+\sin\omega\tau\,(\sin[\omega\tau+2\phi])=\cos^2\phi,$$

we have

$$\left(\frac{\partial i'}{\partial t}\right)_{t=\tau} = \frac{\varepsilon^{-a\tau}}{\cos\phi}\frac{E}{L}\,\frac{1}{1-\frac{\varepsilon^{-a\tau}\cos(\omega\tau+\phi)}{\cos\phi}}\left\{\cos(\omega\tau+\phi)-\varepsilon^{-a\tau}\cos\phi\right\} \qquad (46)$$

We know that

$$\left(\frac{\partial V}{\partial t}\right)_{t=\tau} = \frac{1}{C} i_o \qquad (47)$$

from the general formula

$$C \frac{\partial V}{\partial t} = i$$

$$\left(\frac{\partial V}{\partial t}\right)_{t=\tau} = \frac{E}{CL\omega} \frac{\varepsilon^{-a\tau} \sin \omega \tau}{1 - \frac{\varepsilon^{-a\tau} \cos(\omega\tau+\phi)}{\cos\phi}}$$

If we now substitute in equation (43) the values found for the various factors, we obtain finally

$$\Delta i_1' = \Delta i_o' \left[\frac{1}{\cos\phi} \cos(\omega\tau+\phi)\,\varepsilon^{-a\tau} - \frac{CL\omega^2}{\cos^3\phi} \sin\omega\tau \right.$$
$$\left. \varepsilon^{-a\tau} \frac{\cos(\omega\tau+\phi) - \varepsilon^{-a\tau}\cos\phi}{\varepsilon^{-a\tau}\sin\omega\tau}\right]$$

or, since

$$CL\omega^2 = \cos^2\phi,$$

$$\Delta i_1' = \Delta i_o' \left[\frac{1}{\cos\phi} \cos(\omega\tau+\phi)\,\varepsilon^{-a\tau} - \frac{1}{\cos\phi}\left\{\cos(\omega\tau+\phi) \right.\right.$$
$$\left.\left. - \varepsilon^{-a\tau}\cos\phi\right\}\right]\varepsilon^{-a\tau}$$

$$\Delta i_1' = \Delta i_o' \varepsilon^{-2a\tau} \qquad (48)$$

The current at the beginning of the second charge is

$$i_1' = i_o + \Delta i_1'$$

and in the same way for i_2', the current at the beginning of the third charge, i_3' at the beginning of the fourth charge, . . . i_n' at the beginning of the $(n+1)$st charge:

$$i_2' = i_o + \Delta i_2'$$

. . . . .

$$i_n' = i_o + \Delta i_n'.$$

We obtain successively

$$\left.\begin{aligned} \Delta i_1' &= \Delta i_o' \varepsilon^{-2a\tau} \\ \Delta i_2' &= \Delta i_1' \varepsilon^{-2a\tau} \\ &. \quad . \quad . \quad . \quad . \\ \Delta i_n' &= \Delta i_{n-1}' \varepsilon^{-2a\tau} \end{aligned}\right\} \qquad (49)$$

Eliminating the quantities $\Delta i_1'$, $\Delta i_2'$, . . . there remains

$$\Delta i_n' = \Delta i_o' \varepsilon^{-2na\tau}$$

Consequently, $\varepsilon^{-a\tau}$ being smaller than unity, the musical phenomena are stable.

The effect of a momentary disturbance ceases to be appreciable after a certain number of sparks. The greater the damping and the longer the charging time, the more marked the stability.

Special Case of Maximum Efficiency. We have seen that the efficiency is a maximum when the time of charge, which is equal to the period of the tone phenomena, is also equal to a half period of the oscillations of the charge $\omega \tau = \pi$.

Now the initial current is $i_o = 0$. The potential difference at the condenser terminals is

$$v = E\left(1 - \varepsilon^{-at} \frac{\cos(\omega t - \phi)}{\cos \phi}\right)$$

In this special case, the sparking potential difference is equal to the absolute maximum of condenser potential difference during charging

$$V = E\left(1 + \varepsilon^{-\frac{\delta}{2}}\right)$$

The current value during the charging

$$i = \frac{E}{L\omega} \varepsilon^{-at} \sin \omega t$$

The average current in the charging circuit

$$i_{av} = \frac{\omega C E}{\pi}\left(1 + \varepsilon^{-\frac{\delta}{2}}\right)$$

The effective current in the charging circuit

$$i_{eff} = E\sqrt{\frac{C\omega}{4\pi L a}(1 - \varepsilon^{-\delta})}$$

The potential difference at the inductance terminals during the charge

$$u = E\,\varepsilon^{-at} \frac{\cos(\omega t + \phi)}{\cos \phi}$$

This is a maximum and equal to

$$V_2 = E\,\varepsilon^{-a t_2}$$

when

$$\omega t_2 = \pi - 2\phi.$$

Energy dissipated in the charging circuit

$$W_d = n C E^2 \left(1 + \varepsilon^{-\frac{\delta}{2}}\right). \qquad \left(n = \frac{1}{\tau}\right).$$

Energy available at the condenser terminals

$$W_u = \frac{n C E^2}{2}\left(1+\varepsilon^{-\frac{\delta}{2}}\right)^2.$$

Efficiency

$$\gamma = \frac{1}{2}\frac{W_u}{W_d} = \frac{1+\varepsilon^{-\frac{\delta}{2}}}{2}$$

PART 2. CONDITIONS ARISING IN THE USE OF CONSTANT POTENTIAL GENERATORS FOR CHARGING CONDENSERS IN THE PRODUCTION OF RADIO FREQUENCIES.

In the case of radio telegraphy, we desire to obtain high efficiency for the case of oscillating charges and a low decrement in the charging circuit. Once the tone phenomena are taking place, the spark passes at regular intervals. After each spark the same initial conditions occur.

$$V=0 \quad \text{and} \quad i=i_o.$$

The best arrangement is that for which the time of charging is equal to a half-period of the free oscillation of the circuit (See Figure 11). In this Figure, the curves give the potential difference at the condenser terminals and the charging current.

The phènomena which occur are the following (shown in curves I and II of Figure 11):

Just before the extinction of the spark, the current and voltage at the condenser terminals are practically zero. Thereafter, the voltage increases continuously until time $\frac{T}{2}$, that of a half period of oscillating charge. At that time, the e. m. f. is approximately twice that of the generator.

The current starts at zero, increases to time $\frac{T}{4}$, then diminishes, and again comes to zero at time $\frac{T}{2}$.

If the discharger is so adjusted that the time between two sparks is equal to $\frac{T}{2}$ (which, as we have seen, corresponds to maximum efficiency), a spark will then pass, the condenser will be discharged, the spark will be extinguished, and the same series of phenomena will recur.

The oscillograms numbers 54, 12, 17, 18, 20, and 22 of Figure 12 give the current and voltages for the various cases.

Oscillogram 54—premature sparking. The condenser terminal potential difference (upper curve) increases as it leaves the origin. The current (lower curve) increases, reaches a maximum, and then decreases. Sparking occurs just before the maximum voltage is reached. The current still has an appreciable value at the moment of sparking.

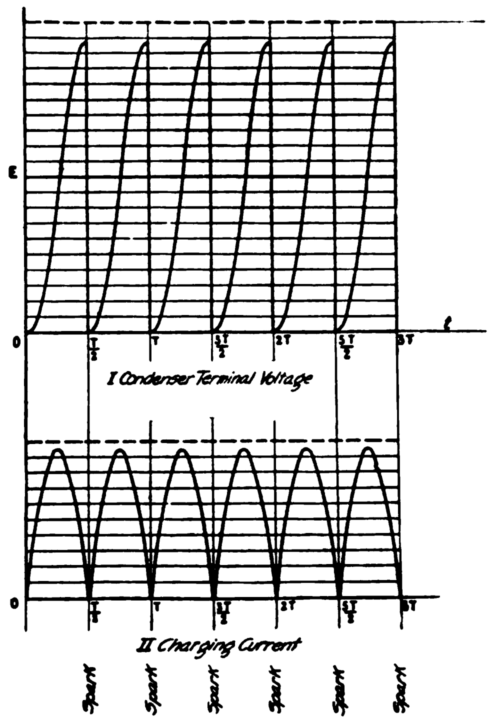


FIGURE 11—Successive Charges and Discharges of Condenser in Radio Transmitter. Charging by Constant E. M. F., Sparking at End of Each Half-Period of Charging Oscillation.

Oscillogram 12—Sparking at the maximum point, at the end of a half period of oscillation in the charging circuit. The voltage is a maximum at this time and the current zero.

Oscillograms 17, 18, 20—Slightly retarded sparking, on the falling branch of the condenser potential difference curve. The current at sparking is negative, and increasingly larger.

Oscillogram 22—Greatly retarded sparking, after two and a half periods of the charging oscillation.

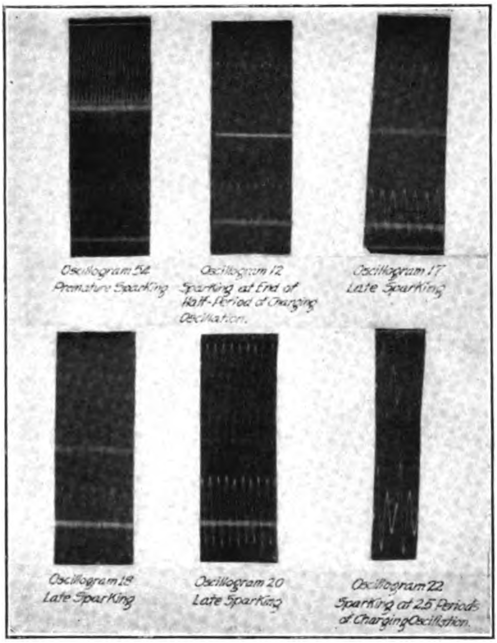


FIGURE 12—Oscillograms of Repeated Charging and Discharge of Condenser; Charging by a Direct Current Generator; Discharge in Oscillating Circuit with Rotary Gap. In all these oscillograms, the upper curve is the condenser terminal voltage; the lower curve the charging current

CHOICE OF THE CHARGING GENERATOR

We are here concerned with charging generators delivering voltages of the order of several tens of thousands of volts.

Use of Storage Battery Assemblies.

Until recent years, since high voltage generators had not been perfected to the point which has now been actually reached, the only solution which seemed available was the use of storage batteries. These were used by the Marconi Company at its Clifden station. The assembly of batteries at that station included 6,000 cells, and gave 12,000 volts.

The advantages of using storage batteries are the following: The e. m. f. is constant and is available at all times without the necessity of starting motors, the inductance is negligible, and consequently there is available a wide range of adjustment for obtaining different spark frequencies and different outputs with maximum efficiency.

The disadvantages seem to outweigh the advantages, and are the following: The inconvenience of a battery of several thousand cells is necessarily very marked, the difficulties of inspection and maintenance and repair are serious, insulation is troublesome to maintain in view of the high tensions and the presence of acid fumes which are continuously generated, and the cells, which even under the most favorable circumstances deliver only 70 per cent. of the energy which has been given them, have a poor efficiency. And, finally, the existence of the battery does not obviate the necessity of having high tension machines available, since they can be charged only by the use of a potential difference greater than their own on discharge.

All these disadvantages have prevented the spread of this system and made the plan of using high tension machines for charging condensers very attractive.

Direct Charging of Condensers by High Tension Direct Current Machines.

Until recent years, the highest voltages obtained by means of direct current machines was not greater than several thousand per machine. It was, consequently, useless to think of employing dynamos of such type for radio telegraphy. A system of energy transmission with direct current, developed by Mr. Thury, gave rise also to the problem of building high tension d. c. dynamos. The highest previously obtained voltage a few years before was not greater than 5,000. Next a voltage of 8,000 was reached, in the machines purchased by the Galletti Company from the Mechanical and Electrical Manufacturing Company (Compagnie de l'Industrie Electrique et Mécanique) at Geneva. A voltage of 10,000 was reached in a 10 kilowatt machine bought by the Department in 1913 for the radio telegraphic station at Ouessant and also in machines intended for use at the stations at Saintes-Mariès-de-la-Mer, Fort-de-l'Eau, Boulogne-sur Mer, and Bonifacio. Lately I have received several bids for the construction of machines delivering voltages of the order of 20,000. When we consider the difficulties which arise in the construction of such machines, we cannot but admit that their production marks a real advance in electrical engineering and manufacture.

It can therefore be asserted that no serious difficulty stands in the way of securing directly by direct current machines the high voltages necessary for radio telegraphy.

Requirements of Machines and Conditions of Use.

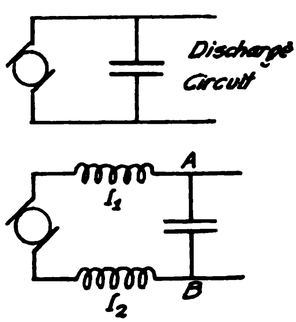
Experiments and tests in actual radio telegraphic service are aimed to determine the working conditions of the machines and the characteristics of the materials used.

1. At the moment of spark discharge, the potential is approximately double the charging e. m. f. The potential difference is never greater than twice the charging e. m. f. if a fixed gap is used, or if a rotary gap is employed of such type that the spark frequency is more than twice the frequency of the charging oscillation.

If the machine is connected directly to the terminals of the condenser, it must be so designed as to stand without danger a potential difference of twice the original e. m. f. However, to avoid this requirement, should it prove troublesome, it is merely necessary to insert in the charging circuit the inductances l_1, l_2 which must be insulated that they can stand sufficient potentials to protect the machine.

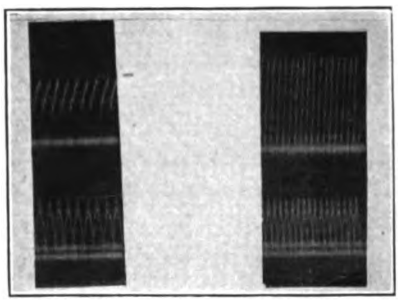
Oscillograms 75 and 76 show the potentials at the machine terminals and condenser terminals for a case where the inductance of the protecting chokes was about twice that of the machine.

2. During the condenser discharge, the two ends of the charging system, *A* and *B*, are at a radio frequency potential difference. There are therefore produced near points *A* and *B*, or in the machine if no choke coils are provided, stationary



Auxiliary Figures A and B

waves. These may become very dangerous, since the insulation may be punctured by the large potentials developed at nearby points of the same coil by the radio frequency standing wave. It is therefore prudent to insert in the charging circuit between the points A and B some type of damping arrangement such as extremely well insulated choke coils with iron cores so designed that the Foucault (eddy) currents in the sheets shall be negligible for the charging frequency but large for the discharge frequency, and capable of damping rapidly the radio frequency wave. Often sufficient protection is obtained by increasing the insulation of the first few turns of the choke coils L, L.



AUXILIARY FIGURE C

Oscillogram 75
Upper Curve: Potential Difference, Machine Terminals. Lower Curve: Current in Charging Circuit

Oscillogram 76
Potential Difference, Condenser Terminals. Current in Charging Circuit

3. If it is desired that the sparks really occur at the end of a half period of charging, the number of sparks per second is

$$n = \frac{2}{T}$$

and since

$$T = 2\pi\sqrt{LC},$$

the inductance of the charging circuit is finally determined by the expression

$$n = \frac{1}{\pi\sqrt{LC}},$$

$$L = \frac{1}{\pi^2 n^2 C}.$$

C and n are generally determined by conditions outside of the charging circuit. The inductance is therefore fixed. It is necessary that the inductance of the machine shall be at most equal to this value. In case choke coils are used for lowering the potential difference at the machine terminals, it is desirable to design them so as to leave a certain margin for adjustment. The limitation of the inductance of the machine imposed by the above expression is sometimes troublesome. In that case, one is forced to diminish the inductance by means of compensating windings.

4. The armature of these machines is traversed, not by a continuous current, but by a pulsating current of frequency equal to that of the number of sparks per second. It is therefore necessary to design the iron thereof sufficiently finely subdivided so as to avoid serious energy losses from Foucault currents.

5. Lastly, if a rotary gap is used, the speed of rotation and the number of points on the disc must be controlled and held constant, in such a way that the time between the passage of two points passed the fixed electrode must be constant and equal to a half period of the charging circuit, if maximum efficiency is desired.

Choice of Type of Discharger

We have seen that for both stationary and rotary gaps tone phenomena are stable, are self-establishing, and are re-established after a momentary disturbance of the system. The re-establishment occurs the more rapidly the higher the damping of the charging circuit.

In the case of the rotary discharger, the charging time τ is constant theoretically; and we have seen that corresponding to even marked variations in the charging time τ with tone phenomena there are only slight changes in the sparking potential. It follows that accidental variations in the speed of the discharger cause only slight and momentary disturbances of the musical note. Indeed it is easy to avoid such variations in speed by driving the discharger from a special motor. In addition, the rapidly rotating discharger acts as a fly wheel and naturally opposes changes in speed.

In the case of the stationary discharger, theoretically the sparking potential is constant. But in reality it varies from one spark to the next, because of alterations in the sparking surfaces, alterations in the ionisation of the intervening air, etc. These changes follow complex laws which cannot be determined.

And we have seen, further, that corresponding to very slight variations in the potential difference giving tone phenomena there are large variations in the charging time and therefore in the pitch of the note. It follows that, while stable tone phenomena correspond to each sparking potential, it will be more difficult to obtain a pure musical note with constant pitch and intensity with a stationary gap than with a rotary gap.

Continual variations in the sparking potential have an additional disadvantage. Let us suppose that the sparking distance has been regulated in such a way that it corresponds to the tone phenomena occurring with one discharge per half period; that is, for maximum efficiency and maximum potential. If, thru any cause, the sparking potential is increased, the charging potential no longer reaches its maximum value, the condenser becomes completely charged by damped oscillations to potential E without a spark occurring, and the system is open. The unforeseen and continuous variations in the sparking potential of a fixed discharger thus prevent the obtaining of tone phenomena with maximum efficiency. It would be always necessary to be content with somewhat less. This is a second disadvantage of stationary gaps as compared with rotary gaps.

It follows from the above statements that, if no other considerations intervene, it is theoretically preferable to employ rotary dischargers in preference to stationary ones.

The preceding statements suppose also that the spark frequency is not far from that corresponding to maximum efficiency. If the actual phenomena are those of a much higher frequency ($\omega \tau$ very small, or the rising part of the curves of Figure 8) the contrary would be true. For this case, variations in sparking voltage caused by irregularities in the action of the fixed gap, even if these variations were marked, would not produce more than slight disturbances in the period of the tone, and the fixed discharger is capable under such circumstances of functioning very steadily. It is probably this case which was used by Mr. Blondel in his tests of radio telephony with direct current dynamos and fixed gaps.

It should finally be stated that with the fixed discharger, the period of the tone phenomena is always less than half the natural period of oscillation of the charging circuit ($\omega \tau < \pi$) and the potential difference is never greater than twice the e. m. f. of the generator, whereas with a rotary discharger, the period of the musical tone may have any value whatever.

For certain values of this period ($\omega \tau > \pi$) and a small damping, the potentials may reach values much greater than twice the e. m. f. of the charging circuit. Consequently, a rotary discharger which is not properly regulated may be a dangerous arrangement in that the coils of the generator, the choke coils, and the charging condensers may be broken down by the excessive potentials, if the damping of the charging circuit is very small.

PART 3. THE PRODUCTION OF RADIO FREQUENCY ENERGY BY DIRECT CURRENT HIGH TENSION DYNAMOS AND ROTARY DISCHARGERS

The preceding discussion considers the operation of the Marconi system with storage batteries and rotary gaps; and it explains the good results obtained by Mr. Blondel with direct current machines, additional choke coils, and stationary gap. It also indicates how, being faced with the question of designing a type of station, we have chosen a definite combination of the previous elements, borrowing from each their best features and finally realising a step forward relative to each of them. In our stations, the condensers are charged by direct current, high voltage machines, with or without additional inductance or choke coils, and the discharge circuit includes a rotary gap.

Transmission cannot be accomplished by controlling the field circuit of the machine because of its large time constant. It is done by opening and closing the high voltage current where it leaves the generator. Because of the high tension, the switch or break is subdivided into several smaller portions, and the arc which tends to be formed is extinguished in the smaller stations by the air current from the rotary gap and in the larger stations by a separate blower.

Experiments have been made with system with powers reaching and exceeding 100 kilowatts, and charging voltages between 10,000 and 110,000 volts. These tests have demonstrated that between these limits, the use of the system presents no particular difficulty, and there is no reason why the same should not be the case for larger powers and still higher voltages.

The system has the following characteristics:

CHARACTERISTICS OF THE RADIO SYSTEM BASED ON HIGH VOLTAGE DIRECT CURRENT GENERATORS AND ROTARY DISCHARGERS

All necessary conditions being supposed fulfilled, we have obtained a system of the following characteristics:

1. The efficiency is equal to

$$\gamma = \frac{1 + \varepsilon^{-\frac{\delta}{2}}}{2}$$

(δ being the logarithmic decrement of the charging oscillation). In the observed cases, using the oscillograph on normal installations, it (the charging circuit efficiency) is often greater than 0.9. δ is given by

$$\delta = \frac{R}{2L} T$$

where R is the effective resistance of the charging circuit (including losses in the iron, the dielectric of the condenser, and ohmic resistance), and L is the inductance of the charging circuit. T is the period of the charging oscillation. I have given previously the values of γ corresponding to different values of δ.

2. The note is always perfectly musical, since the interval between two sparks is equal to that between the successive passage of two points on the rotating disc past the fixed electrodes, and since conditions are precisely the same for successive sparks.

The tone phenomena are stable, self establishing, and the effect of momentary disturbances quickly disappears.

3. The period of oscillation of the charge is independent of the speed of the machine. Consequently, changes in machine speed produce no irregularity.

4. Even marked irregularity in the speed of the discharger do not have any influence on the efficiency.

5. The discharger is completely independent of the generator and can be driven by a special motor.

6. It is very easy to vary the power of the station by placing in series a greater or less number of machines. I have already used this method repeatedly. The practical characteristics of a system of charging condensers for radio telegraphy are valuable ones, and a comparison of the method here described with that normally employed at the present time, whereby charging is done by alternating current, brings out the value of the former.

Comparison of Characteristics of Installations Employing Direct Current for Charging Condenser with Those Using Alternating Current

Case of Charging by Constant E. M. F.	Case of Charging by Alternating E. M. F.
1. Material in which commutator bars are imbedded and rotating parts at high tensions.	1. Structure is sturdy, all high tension equipment in the charging circuit is fixed and can be placed in oil.
2. The speed of rotation of the machines does not interfere with regulation of the circuits.	2. The speed of rotation of the alternator must be maintained rigorously constant, a speed change causing a discrepancy between the frequency of the charging circuit and that of the alternator.
3. No effect of this type limits the efficiency, which in practice markedly exceeds 90 per cent.	3. The permissible excess voltage must be kept so small that variations of alternator speed in the wrong direction do not cause serious disturbances. This limits the maximum efficiency of the system to a theoretical value of 85 per cent., and considerably less in practice.
4. Even a marked change in the speed of the rotary gap causes only slight diminution of efficiency.	4. Even a slight displacement of the rotary gap from its normal position causes a marked diminution in efficiency.
5. The musical tone obtained is completely pure and clear.	5. It is theoretically possible to obtain a perfectly pure musical tone. It is very difficult in practice to obtain an acceptably clear tone.
6. The placing in series of several high tension machines is simple, and provides an easy means of regulating the available power.	6. Placing several alternators of the high (audio) frequency used for spark production in parallel is quite a delicate task.

Conclusions

This paper has for its object an explanation of the considerations which have led the Radio Service of the French Postal and Telegraph Department to a system wherein a direct current source charges condensers which are in turn discharged by means of rotary gaps.

The investigation shows

1. The theory of the use of direct current in charging radio telegraphic condenser.

2. The possibility of using such direct current machines.

3. The conditions under which such machines can be used, and the useful formulas in connection therewith.

This work has had a further practical aspect in that it has called the attention of constructors to high tension dynamos. The highest voltages obtained up to several years ago were a few thousand volts per machine. It is now possible to build these up to 25,000 volts per machine, and even further. This has been one of the most interesting steps forward for several years in the field of direct current dynamos.

Paris, February 28, 1916.

Note.—Since the compilation of the present paper, the question of using sparks from constant high potential generators in radio telegraphy has been discussed by A. Blondel ("Lumière Electrique," April 15, 1916, page 49). Furthermore, the system described above has been further developed and experimented with on a considerable scale. A 50-kilowatt station, operating at 1,800 meters wave length, is being installed at Saintes-Maries-de-la-Mer (France). In this station the Technical Committee of the Department of Posts and Telegraphs, in accordance with an early suggestion by A. Blondel, has required a condenser bank placed across the terminals of a series of machines which form the source of high voltage. The addition of this condenser produces certain advantages which will be considered at an early date.

Paris, April 21, 1917.

SUMMARY: The charging of condensers by high voltage direct current generators is discussed theoretically and practically. The stationary and rotary gaps are compared as dischargers, and the evolution of the system used by the French Department of Posts and Telegraphs is given.