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ON THE NATURE AND ELIMINATION OF STRAYS*

AN INVESTIGATION UNDER THE AUSPICES OF THE DUTCH EAST INDIAN DEPARTMENT OF TELEGRAPHS

BY

CORNELIS J. DE GROOT, SC.D., E.E., M.E.

(ENGINEER OF THE DEPARTMENT OF TELEGRAPHS, DUTCH EAST INDIES)

PART 1. RADIO VS. CABLE COMMUNICATION IN THE TROPICS

One of the most troublesome phenomena met with in connection with long distance radio communication, where the signals are usually faint and of variable intensity, is atmospheric disturbances or strays. These interfere seriously with radio communication during the summer in temperate climates. Their magnitude increases to an overwhelming extent in the tropics, especially during those seasons when the sun attains its maximum altitude.

In the tropics, and at such times of the year, it is a task of the utmost difficulty for a radio engineer to establish and maintain communication. Particularly unfavorable under these conditions is the comparison between the cost of upkeep and operating reliability for radio communication and submarine cable communication.

The difficult undertaking of establishing radio communication on a regular basis in a tropical climate was voluntarily accepted by the Department of Telegraphs of the Dutch East Indies. Tho it cannot yet be said that a completely successful solution has been obtained of the problem of substituting the proposed radio service for submarine cable communication the incidental investigations have been of much interest. Systematic researches have been carried on which have resulted in the accumulation of a great quantity of valuable material dealing with such radio phenomena as the propagation of electromagnetic waves and the origin, propagation, nature, and elimination of strays.

It is this last information concerning strays which will constitute the main subject of this paper.

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*Received by the Editor, October 15, 1916. Presented before The Institute of Radio Engineers, New York, December 6, 1917.

It may be a matter of astonishment that so unfavorable a region as the tropics was chosen in attempting to substitute radio communication for submarine cables; particularly when one considers that under much more favorable conditions as to strays, and cost of up-keep, the problem has not yet been successfully solved. It must be admitted, however, that special circumstances dictated the choice of radio service, assuming the feasibility of such communication.

These circumstances are the following:

(a) The East Indian Archipelago consists of a great number of islands separated by straits and seas, of enormous depth, 12,000 feet (3,700 meters) being quite common. In this region, earthquakes and similar disturbances of the sea bottom are frequent, and the coast line rises steeply.

Such conditions are not favorable for submarine cable work. Repairs are very difficult and sometimes impossible at such great depths, and in every case a first class cable repair steamer, with extraordinarily heavy hoisting apparatus, would be necessary. Especially is this the case in the much deeper waters of the eastern part of the archipelago. The existing cable steamer does not meet the above requirements; and since the communication was most urgently required, and since the establishing of communication in the eastern part of the Indies would have involved the purchasing of a second and larger cable steamer, an extension of the cable system was regarded as undesirable. The great extent of the archipelago, this being nearly 3,000 miles (5,000 km.) in length, would have necessitated keeping two cable steamers, at least, in commission at all times. The great frequency of earthquakes and sea disturbances of similar character would have resulted in frequent, and possibly simultaneous, breakdowns of the cable service with the result that the widely separated parts of the archipelago might have been out of communication for very long periods of time.

(b) As an additional advantage, radio stations afford the possibility of maintaining communication with ships at sea. Tho the traffic is not sufficiently extensive to justify the erection of radio stations for this purpose exclusively, especially as violent storms and fogs at sea are unknown in this part of the world, it still remains an additional advantage of the radio chain as compared to submarine cables. It is clear that navigation is facilitated by free communication to ships.

The advantages of a radio chain as regards ship communication are obvious from a naval standpoint, and were most readily realized at the beginning of the present war. It would have been almost impossible for the small squadron of Dutch men-of-war to maintain neutrality as perfectly as it did, had all points now connected by radio been dependent entirely upon submarine cable service.

(c) Another reason for embarking in the enterprise of estabishing reliable radio service in this tropical region was the apparent slightness of the risk, at least at the inception of the undertaking. The well-known Telefunken Company of Berlin entered into a contract with the Dutch Government to erect the chain of stations at a very moderate price and with full guarantee of continuous correspondence at the stated speed of twenty-four words per minute during all twenty-four hours of the day and every day of the year. The only exception to this guarantee was during such times as strays would have reached an intensity which would have become a menace to the apparatus and operators or such times as those during which an ordinary overhead telegraph land line would have been equally crippled. It appeared, however, after some years of systematic tests, that the conditions guaranteed in the above contract could not possibly be fulfilled and that even under much less strict requirements, a radiated energy of some six to eight times as large as that actually furnished was necessary to maintain anything like trustworthy communication during unfavorable parts of the year. By trustworthy communication is meant service comparable to that obtained with normal hand sending on submarine cables.

The Telefunken Company is only partially to be blamed for the poor results obtained since, at the time of the original contract, no one had the slightest idea as to the difficulties which were encountered in the tropics. My opinion in this direction is confirmed by the equally poor results obtained by other radio contractors in India at about the same time.

As a matter of fact, during the three most favorable months of the year, which corresponds roughly or most nearly with European conditions, the communication was entirely in accordance with the agreement.

At the time the contract was drawn up, the cost of erection, maintenance, and repair of submarine cables, was well known by long years of experience. The cost of erecting radio stations of the proposed magnitude could also be approximated closely. In consequence, the comparison between radio communication and the cables seemed a reasonably favorable one, and competition between them not impossible.

Altho the apparent risk was not great, it must be appreciated that this enterprise indicated much energy and a broad-minded attitude on the part of the Dutch Colonial Telegraph Service. In facing this pioneer work, the Service undertook the first systematic investigation in connection with radio in the tropics. Tho success was not reached in every direction, much valuable material was obtained on the basis of which completely successful radio communication could be based in the future. In addition, from a scientific point of view, fascinating phenomena were encountered; thus casting much light over the laws governing the propagation of electromagnetic waves as well as on the nature and elimination of strays.

All of these advantages more than compensated for the disappointment incidental to the insufficient communication between the stations as erected; and, as a matter of fact, the stations have more than paid for themselves by the strategic value they have been shown to possess during the present war.

On the other hand, the necessity of enlarging these stations so as to radiate six to eight times their present energy was entirely unfavorable to the financial comparison instituted between radio and submarine communication and in a direction prejudicial to the radio service. The original apparent equality of first cost was dependent upon a curious circumstance. Normally, the radio service would have been obviously much the less expensive but a strict clause in the original contract required the Government to erect the stations on expensive reservations at great distances from existing towns, with accompanying high rates of transportation for materials, the building of new roads, special accommodations and houses for the staff, and huge initial expense in connection with the purchase and destruction of trees and vegetation on the sites of the stations. It is therefore not astonishing that the original calculations comparing radio and cable communication, showed substantially equality, and that the choice between the two was solely one of convenience.

Personally, I am convinced that with more up-to-date radio apparatus and with freedom in choosing suitable sites, independently of the contractor's wishes, radio communication will always be preferable to submarine cable communication under certain definite conditions. Such conditions are the following:

Wherever the traffic is of such nature as to permit an interruption of communication at the most of two hours per day (in consequence of thunder storms and entirely excessive strays) the radio service will be preferable.

For distances of more than 600 miles (1,000 km.) the cost of radio communication may, even in the tropics, be easily made less than that of cable service. In addition, the reliability and speed, as expressed in terms of words handled per day, may be made superior to that of normal cable service. Furthermore, radio telegraphy has the advantage of communication with ships.

Investigations which were carried on showed that the requirements of the contractors as to station sites were not necessary, and that the stations might easily have been erected in much more convenient and inexpensive locations. Needless to say, this knowledge is of great future use.

Radio service has great military and political possibilities. It has the great advantage that repairs are always local in nature. Spare parts, or even duplicate sets, could be kept in every station and skilled engineers or operators provided. Under these conditions, communication could hardly be interfered with by any ordinary disturbances, being subject only to extremely severe earthquakes, which are indeed a source of interruption to any type of communication.

In this regard, particularly, radio service compares very favorably with the submarine cables for in the latter case the breakdowns may cause a cessation of communication for several weeks.

PART 2. OPERATING CONDITIONS IN THE TROPICS

Tho the results of the comparison between the two competing systems of communication are interesting, the systematic research work concerning the propagation of the radiated energy and the nature of strays are more absorbing to the scientific worker.

Of this research work, only that portion directly concerned with strays will be summarized in this paper.

As an introduction to the conditions under which observations were carried out, a short description of the stations and their geographical location as well as some photographs thereof, are given. In Figure 1 is shown a map of the East Indian Archipelago on which are indicated clearly the stations under consideration. These are:

Landangan, 7° 40′ south, 114° east, and situated in the eastern part of the main island. From this island as a center,

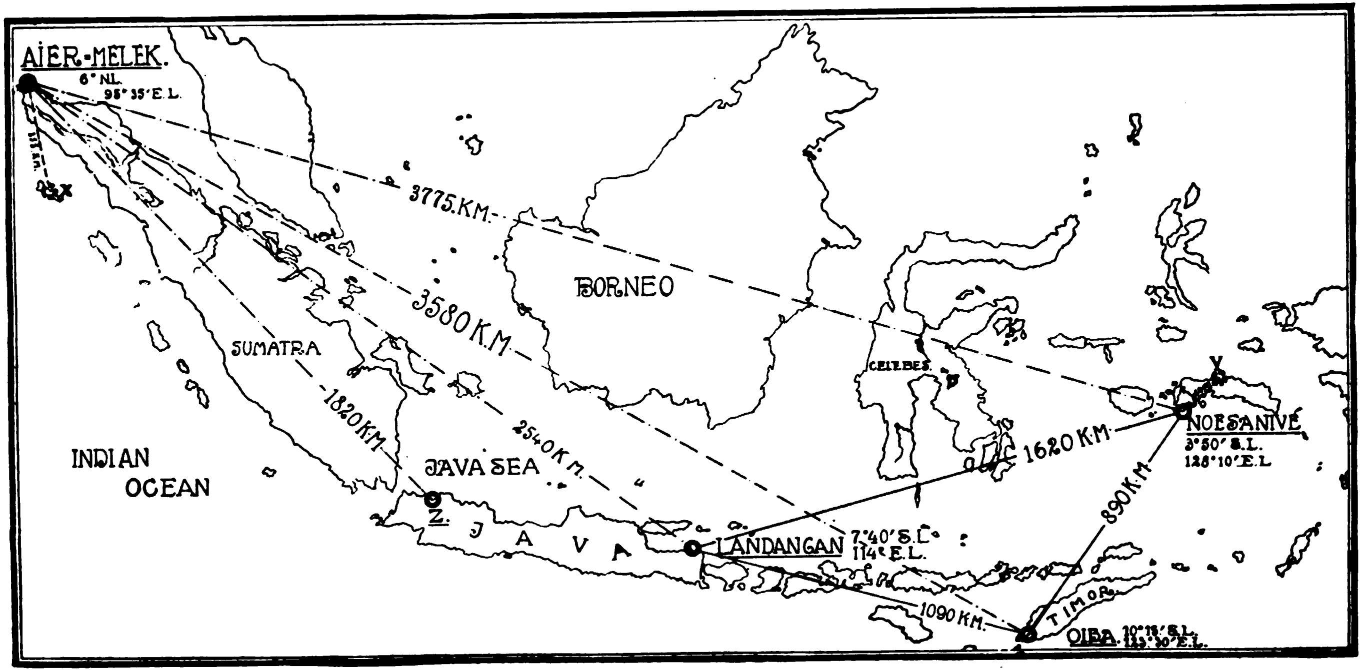

FIGURE 1—Location of Stations in Dutch East Indies

India is governed and the two other stations are merely secondary governmental centers, so that the main object of this communication is in governmental service.

Oiba, 10° 15′ south, 123° 30′ east, and near Timor, one of the secondary centers of government.

Noesanivé, 3° 50′ south, 128° 10′ east, and situated on the island of Ambon, also a secondary center of government.

The contractor had agreed to furnish continuous communication between Landangan and Oiba, 680 miles (1,090 km.), and from Oiba to Noesanivé, 555 miles (890 km.). The tests, however, were extended so as to include the unguaranteed direct communication between Landangan and Noesanivé, 1,010 miles (or 1,620 km.).

All three stations were of the same design and output and differed only slightly to conform to local conditions.

As the design is the well-known commercial Telefunken musical, quenched spark set, no detailed description will be given here. It is sufficient to note that all the stations were of the so-called 5 T.K. standard type, (this being 5 K.W. in the antenna). The prime mover was a 28 H.P. Deutz gasoline engine, starting on compressed air, and with belt drive to a 10 K.W., 500 cycle generator and exciter. The generator fed the closed core 220-to-12,500 volt transformer, which charged a group of Leyden jars. These discharged approximately 1,000 times per second thru an air-cooled, Wien, silver surface, spark gap, composed of 14 gaps connected in series. Since the generator system is worked near resonance, a high pitched note is produced in the receiving set.

The antenna and closed circuits were coupled closely and directly, and any one of four pre-determined waves could be readily radiated. These were a 600 meter wave for ship-to-shore work, and 1,200, 1,600, and 2,300 meter waves for long distance work. The 1,600 meter wave turned out to be the most desirable for direct communication between the three main stations, especially during the day time. At night, the 600 meter wave, which was not desirable during the day, was approximately as good as the 1,600 meter wave. At night, the 1,200 meter wave was slightly better than either the 600 or 1,600 meter waves. From the point of view of simplicity, the 1,600 meter wave was practically always used, with the exception of special tests intended to determine the relation between the working conditions when using different wave lengths. These latter tests showed, however, that the 1,200 meter wave length which was most efficiently radiated, was superior during the night time, whereas in the day, the combined effect of the better radiation at short waves and the better propagation of the longer waves, resulted in a most efficient wave length which changed with distance as well as with the hour of the day. On the average, this optimum wave length was about 1,600 meters for the 890 kilometer (530 mile) distance of transmission, and from 1,800 to 1,900 meters for the 1,090 kilometer (650 mile) connection.

The contractor, who was authorized to pick out the wave length at which the tests were to take place, decided after preliminary tests with wave lengths up to 3,500 meters, that the 1,600 meter wave should be the working wave thruout the day and night.

The 600 meter wave was radiated by a fan shaped, six-wire antenna in connection with an earth of radially spreading galvanized iron wires. The longer waves were radiated from a four wire umbrella, or rather ("X") shaped, antenna in connection with a counterpoise ground made of twelve wires of copper-plated steel.

These arrangements proved best for all three stations so far as maximum effective radiation at the different wave lengths was concerned.

Both antennas and the counterpoise (which was elevated to the average height of 60 meters (20 feet)), were supported by a center, steel lattice tower, 85 meters (280 feet) in height. This tower is of the well-known triangular cross section type, much used by the Telefunken Company, and stands on a ball-and-socket joint, being stayed by two guy sets each of three solid rod stays, each stay terminating in a concrete anchor block. These stays were made up of sections of rods three meters (10 feet) long and three centimeters (1.2 inches) in diameter. The approximate stress on each stay was 19 tons (17,000 kg.). In this way, the towers were held in vertical position tho the support was flexible.

In two of the three stations, both stays and towers were insulated from each other and from the earth by glass plate insulators, but at the Noesanivé station, frequent earthquakes made it necessary to avoid this construction and the tower and stays were all directly connected to each other.

Measurements based on my method[1] of measuring radiation resistance and dissipative resistance showed clearly that this

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[1] "Jahrbuch der drahtlosen Telegraphie, etc.," volume 8, part 2, pages 109-121.

earthed tower construction produced a slight diminution in the radiation resistance as well as a small increase in the dissipative resistance. There resulted a slight decrease of the total antenna resistance as well as of the efficiency of the antenna as a radiator. The effects described were measured only for the 1,600 meter wave.

The practical result was that the Noesanivé station proved slightly inferior for transmission and slightly superior for reception as compared with the two other stations. The relative superiority and inferiority were, however, quite slight, and in no way comparable to the advantages resulting from greater security against earthquakes. An additional feature of the construction of the Noesanivé tower was that it was anchored to its base in such a manner as permitted play in the ball-and-socket base joint but prevented the tower from jumping out of its support in the case of serious earthquakes. As an additional precaution against snapping of the main stays, each stay was paralleled by a second auxiliary stay connected between the same end points. The auxiliary stays were made so as to have more sag than the main stays and consequently would come into operation only after the main stay had broken. These auxiliary stays are shown in Figure 3.

The area of all the stations was 220 meters (720 feet) by 440 meters (1,440 feet), the tower being at the center of the rectangular area. Four additional masts only 16 meters (52 feet) high were provided at the corners to permit the four antenna wires to be held. These four small masts also supported eight of the counterpoise wires. Four seven-meter (23 foot) poles supported the remaining four counterpoise wires. The fundamental wave length of the large antenna is about 1,100 meters and the capacity at 1,600 meters wave length was about 0.00266 microfarad. The corresponding figures for the smaller antennas were 450 meters wave length, and 0.00156 microfarad capacity. There was measured in the antenna an output of about 4 K.W. for the 600 meter wave and 5 to 7 K.W. for the longer waves.

Transmission is accomplished in the usual way by a hand key which operates a quick-acting magnetic relay key in the transformer low tension circuit.

Earth arresters are provided as well as an appropriate form of switch for changing from sending to receiving.

For reception, the normal Telefunken, crystal detector receiving set was provided, consisting of an antenna tuning circuit and aperiodic secondary system coupled magnetically and closely thereto. The secondary system contained the crystal rectifier and the telephone. The coupling employed in practice gave the loudest telephone response; that is, the coupling was the so-called most "economical" one, whereby one-half of the antenna energy is converted into useful energy in the detector. The maximum possible energy conversion is thus achieved.

While this method gives the greatest signal strength, and therefore the longest transmission range, it is of doubtful value when considering the elimination of interfering signals or strays the antenna damping being doubled as compared to that of the unloaded antenna. The selectivity is therefore diminished, and the detector circuit is too closely coupled to the antenna circuit and takes up or responds to the transferred and forced vibrations, such as strays in the antenna. During the greater part of the year, however, communicating signals were so weak that no usual method of reception was possible with the apparatus as installed. A loosely coupled intermediate circuit was available, and was sometimes used at night to diminish the intensity of strays; since, in this case, signals were sufficiently loud to permit the weakening which always occurred with this arrangement.

Whereas *transmission* with the large antenna and *counterpoise ground* were found best for all four wave lengths; in *reception* the best results were obtained using a *conductive* ground, the relative advantage in reception being as much as 50 per cent. as compared with the counterpoise ground.

The detectors were silicon crystals and no special means were provided to avoid the enormous strays existing in these parts of the world.

A group of illustrations give a clear idea as to the nature of the stations. In Figure 2 is shown the exterior of the Landangan (or Siteobondo) station. The tower was 280 feet (85 meters) high. In Figure 3 are shown the station buildings. Starting at the left, there are visible the machinery room, repair shop, a long gallery which prevented the noise of the machinery room from interfering with the receiving operators, the operating room, the inspector's quarters, and an auxiliary building. In Figure 4, the base of the 60 meter (200 foot) tower at Landangan is shown. The ball-and-socket base construction, triangular cross section of the tower, insulators, internal ladder, and radiating ground wires are all clearly visible. The machinery room at Landangan is shown in Figure 5, the belting from the gasoline engine in the rear and the generator in the front, being depicted as well. In Figure 6 is illustrated, in greater detail, the generator at Landangan.

The operating room at Landangan is shown in Figure 7.

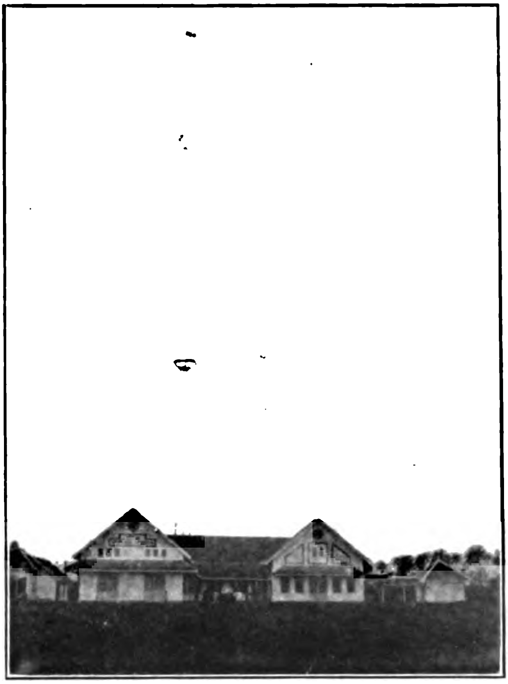

FIGURE 2—Landangan (near Siteobondo), 85 m. (280 foot) Tower, Insulated

At the left is seen the operating table with its usual Telefunken receiver, while to the right are shown the high tension panels and frames of the transmitter. The middle panel supports the antenna and coupling inductances and the shortening condensers, while the right hand panel supports the spark gap, primary circuit inductance, and primary capacity. Back of this panel is seen the high tension audio frequency transformer, and between the panels is visible the antenna ammeter. The transmitter at Noesanivé is shown in greater detail in Figure 8, wherein the means of changing wave length readily by the insertion of moveable plugs is clear. The system of ventilating the spark gap by a blower, placed beneath, as well as other details are shown.

In addition to the tests carried on between the three stations already mentioned, some tests were made in connection with the following:

(a) The station at Aer-Melek, 6° north and 95° 35′ east, working as a shore station on a 600 meter wave. This station is of the same design but only half the power of the three former stations.

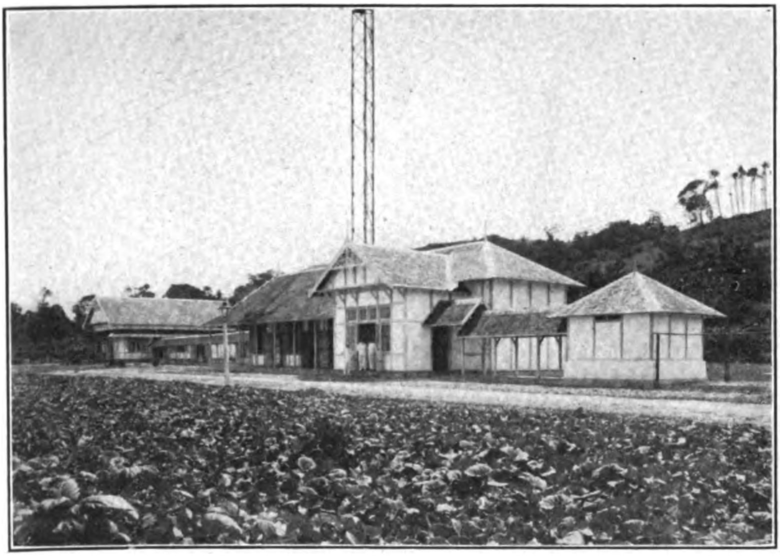

FIGURE 3—Station Buildings
Starting at left—Machinery Room, Shop, Gallery (40 m., or 130 feet) Long, Operating Room, Inspector's Quarters, Gallery, Conveniences

(b) Men-of-war at the points marked *X* and *Y* on Figure 1. The output of these stations was about equal to that mentioned under (a).

(c) A small old-fashioned station at Batavia (*Z* on Figure 1).

Following this general description of the chain of stations, we shall consider one of the subjects technically investigated; namely,

PART 3. CLASSIFICATION AND ELIMINATION OF STRAYS

As is generally known in radio practice, these atmospheric disturbances produce in the operator's telephones a hissing, crackling, and rattling noise, and are not due to other stations or electric power plants in the neighborhood, but are propagated thru the ether and therefore received in the same way as the signals originating at other points.

The origin of strays, in many cases, is quite obvious but in other cases almost untraceable. Even before the invention of radio telegraphy, many types of strays were known, especially on long over-head telephone and telegraph lines in mountainous tropical regions, but the interference produced in these cases was by no means so great as in radio communication.

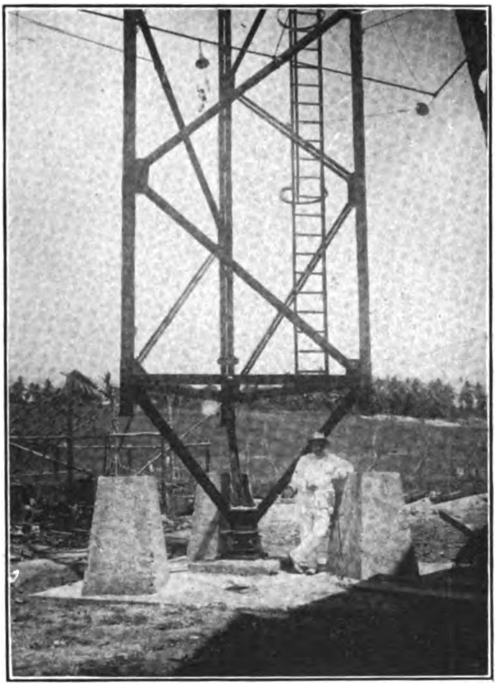

FIGURE 4—Base of 60 m. (200 foot) Tower at Sabang (Showing Ground Wires)

As a general rule, it may be stated that strays are at their worst during the night time and in the tropics, and that their intensity and character is a function of the time of day and of the season of the year.

The worst trouble from strays is experienced, generally speaking, during those months when the sun's altitude is greatest and consequently the poor periods of communication do not occur simultaneously over the entire earth. During my own tests, it was found that in the tropics, the most unfavorable time was that of the west monsoon (or trade wind) which lags somewhat behind the time of greatest altitude of the sun.

A very unfavorable circumstance connected with radio communication in these parts of the world is that the periods of maximum strays coincide with those of marked fading and diminution of signal strength during the day time. At some of the receiving stations, this diminution brought the signals down to inaudibility.

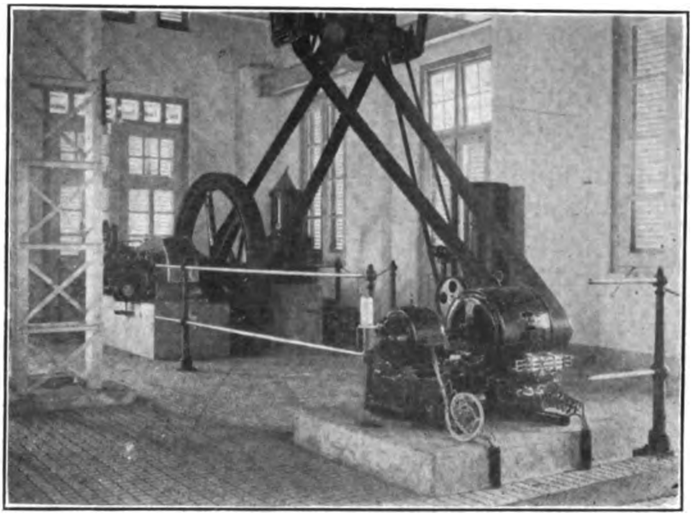

FIGURE 5—Machinery Room at Landangan (Siteobondo)

The result of this unfortunate combination was that during the very worst months, signals were much too weak to drown out the strays of maximum loudness and on some occasions not a single word could be received during the day time.

A fortunate circumstance connected with these days of poor transmission was, however, that the night disturbances were not much worse than those during the afternoon, and on the other hand, for the wave lengths used, the night signals in these parts of the world increased to at least 1,000 times audibility, thereby becoming more than 30 times as strong as the best signals during the day time. It therefore became possible at night to get the delayed messages thru, working at very slow speeds and repeating messages, sometimes, as many as six times. Thus, by extraordinary stress on the operators, no message was delayed for more than forty-eight hours.

The above statement of conditions shows most clearly how unfavorable a field for radio communication are the tropics; and that for the existing stations, at least, communication of the same order of reliability as that existing on submarine cables, could not be expected.

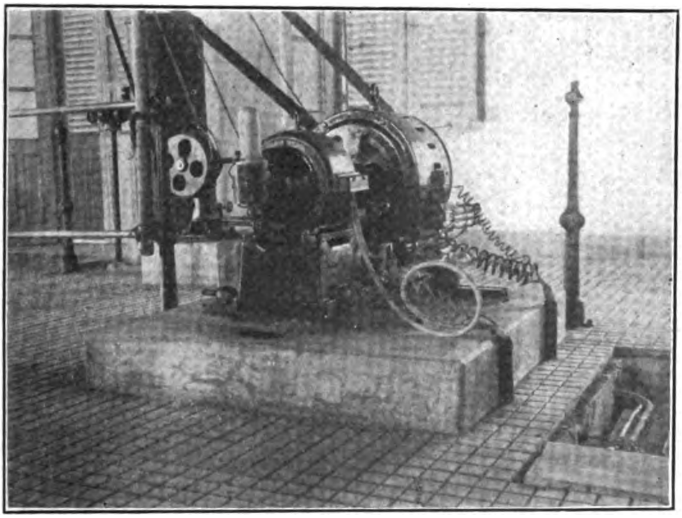

FIGURE 6—Generator at Landangan (Siteobondo)

It should be pointed out, however, that during the favorable seasons of the year, the stations worked satisfactorily and that the same reliability and speed as that obtained on submarine cables was then available.

For measurements made, during more than a year, of the variation in signal strength and from numerous estimates of the strength of the atmospheric disturbances, it was found that during the most unfavorable times approximately six to eight times as large an output was necessary, as compared with the favorable season, for suitable communication. It was further found that, even with this increased power, there were a couple of hours each day which would have to be abandoned for working because of the impossibility of eliminating the very worst strays and thunder storms.

Since the fading of signals during the day time is a very unfavorable circumstance in the tropics, it is obvious that in these parts of the world especially, successful competition with submarine cables is dependent upon the development of means of overcoming strays. On the other hand, the invention of such means is possible only when a clear understanding exists of the mechanism of their production. The doubtful success of most of the inventions in this direction must be attributed to the ignorance of the inventors of the fact that several classes of atmospheric disturbances exist. Generally their inventions are aimed at only one of these classes. The results were unsatisfactory in all cases since the other types of strays remain harmful. Furthermore, most of the means employed to reduce strays do not even completely cut off the one type of strays against which they were supposed to be devised.

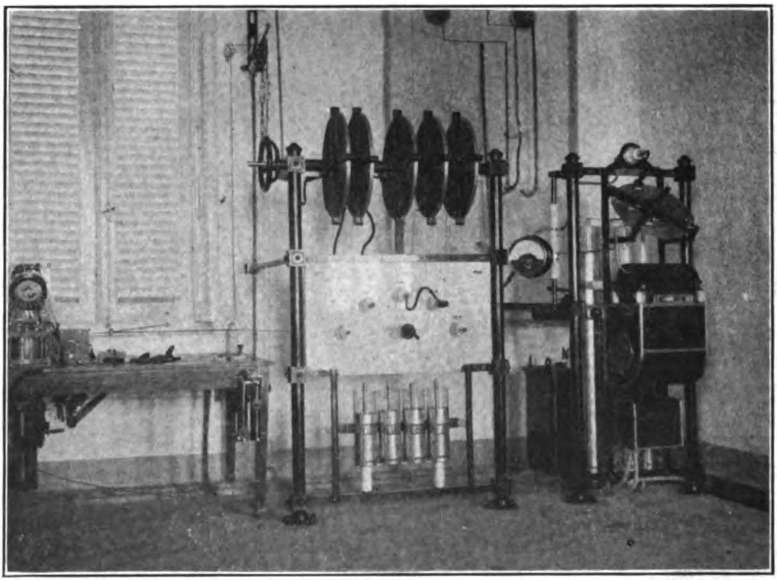

FIGURE 7—Operating Room at Landangan (Siteobondo)

As a matter of fact, systematic observations were necessary, and these observations were arranged to classify stray disturbances as follows:

(a) According to the trouble they gave and the interference which they caused with communication; (specifically as to loudness and frequency of recurrence).

(b) According to their apparent difference in quality or electrical characteristics, so as to enable a determination of their source.

(c) Detailed tests were then made to separate the different classes as indicated under heading (b).

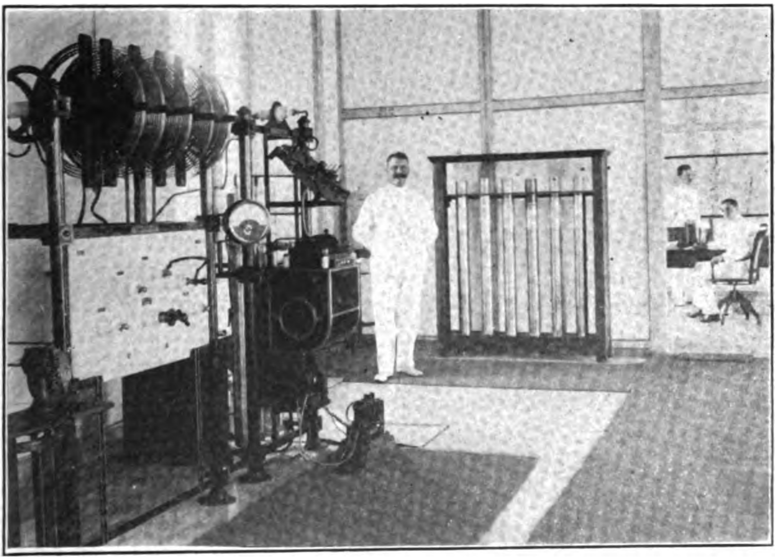

FIGURE 8—Transmitter at Noesanivé

A. OBSERVATIONS ON THE LOUDNESS, AND FREQUENCY OF RECURRENCE OF STRAYS

The quantities in question were estimated by the operators, usually twice every hour, and in accordance with a scale of values stated below. At the same time the cloudiness of the neighborhood around the station, temperature, humidity, air pressure, wind direction, and strength of wind were stated, so as to give some indication of the dependence of atmospheric disturbances on all the factors stated above. It will be noted that the scale of value is a practical communication scale and is intended to be of value in connection with actual working. The scale of values follows:

0. *No Disturbance* (This case *never* occurred).

1. *Weak Strays.* These were of such intensity as not to interfere to any extent with musical spark signals (1,000 sparks per second), corresponding to a loudness of 100 ohms shunted across a telephone of 1000 ohms resistance. Such an audibility is generally referred to as "ten times audibility." *This loudness of signal is referred to hereafter as the standard signal.*

2. *Medium Strays.* These, tho troublesome to some extent when the standard signal was being received, and forcing the operator to have occasional words repeated, still permitted communication.

3. *Strong Strays.* While these strays permitted the carrying on of communication with much trouble, at slow speeds, and with frequent repetition (while working with the standard signal), they did not entirely stop communication.

4. *Heavy (or very heavy) Strays.* These made communication quite impossible with the standard signal but permitted working with very strong signals (between 500 and 1,000 times audibility).

5. *Overwhelming Strays and Thunder Storms.* These naturally made communication quite impossible even with the strongest signals which could be produced in practice. This case was almost never experienced, except during one or two hours of the very worst days during the most unfavorable part of the year.

After very many observations, it can be stated that the following signal strengths are desired when 1,000 sparks per second are employed at the transmitter and an ordinary speed of transmission of twelve words per minute.

Class 1: Signals of 10 times audibility (100 ohms shunt in parallel with 1,000 ohms telephone).

Class 2: Signals of 20 to 30 times audibility.

Class 3: Signals of 60 times audibility.

Class 4: Signals of 250 to 500 times audibility.

Since class 4 is often required during the bad season and since class 1 is the class which is encountered during the good season, it is quite apparent that during the unfavorable season the radiated energy of the station must be at least six to eight times as large as during the favorable season, especially since the absorption and variation in strength of the signals is more marked during these unfavorable parts of the year.

In addition to the classification of strays which is given, in strength from 0 to 5, these atmospherics were registered, from time to time (when they were very loud), on a tape by means of an ordinary Kelvin syphon recorder of the submarine cable type.

A record of this kind is shown in Figure 9 which gives an excellent picture of strays of classes 2 and 3. These types of strays are present every afternoon in the tropics on an average and extend over the whole year. Their limits of strength are between 1 and 4.

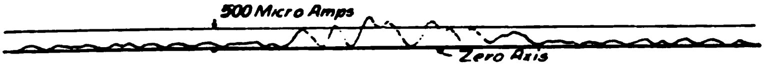

Figure 9—Tape Record of Medium and Strong Strays Taken with Syphon Recorder

The coil of the syphon recorder was of some 200 ohms resistance and was connected to that point in the receiving apparatus where the telephone receivers were normally placed. Since the impedance of the syphon recorder coil was not very suitable in view of the much higher resistance of the silicon detector employed, and since the receiving apparatus was not very sensitive, very strong impulses only could be recorded in this way. This may be easily seen when it is stated that the straight line at a distance of about 2 millimeters from the zero line of the recorder was made by the syphon with a continuous uni-directional current of 500 microamperes was passing thru the instrument, corresponding to an e.m.f. of 0.1 volt at the terminals. It is quite clear on observing the tape that on the average afternoon of the year, atmospheric disturbances will cause the detector to generate e.m.f.'s of several volts.

Strays of the worst class handled (that is, ranging between classes 4 and 4.5), forced the syphon to run off the tape and must have produced rectified detector currents of the order of some 3,000 microamperes.

If it be recalled that the standard signal of ten times audibility produced only 0.15 microamperes in the recorder coil, and that a signal of 500 times audibility (which could be received thru almost all strays) produced only 7 microamperes; it is a matter of extreme astonishment that signals can be read thru strays as readily as is the case. The superiority of the musical signal is obvious since it is picked up thru noises giving direct currents in the coils of the recorder or telephone receiver as much as 400 or 500 times the current corresponding to the signal itself.

As a matter of fact, these very strong atmospheric disturbances will result in a loss of some words. It is clear, however, that a signal which pierces all strays and is 500 times audibility, gives a deflection on the tape of only 0.02 mm. (0.008 inch) and therefore is not detectable. On the other hand, the continuous crackling atmospherics of small amplitude in Figure 9, which would not cause the loss of any signals, still represented strays 20 times and more as strong as signals of 500 times audibility. This again brings out clearly the superiority of musical signals.

The tape, on the other hand, records the average atmospheric disturbance during the afternoon in the tropics, and shows clearly how difficult radio communication is under these circumstances. We may take as the basis of comparison, that a signal of 500 times audibility gives an unreadable deflection of 0.02 mm. (0.008 inch) while the actual strays give deflections of the order of millimeters.

B. Classification of Strays as to Electrical Nature and Source

The *strength* and *frequency* of *recurrence* of strays were the most important factors from the point of view of the designer, since they determined the necessary signal strength at the receiver and therefore the output of the transmitting station. Of course, the variation of received signal strength and the speed of transmission must be considered.

The *source* of strays and the mode of their propagation is of the most *scientific* value, altho such knowledge also assists the designer in devising improvements for rendering strays harmless and therefore permitting the maintenance of service with smaller station outputs. In order to procure this necessary knowledge, the operators were ordered to note the typical features of disturbances which were received, in order that a possible classification thereof, relative to origin, might be considered. In this way we succeeded in getting three distinct types of atmospherics.

Type 1: *Loud and sudden clicks* occurring in more or less widely separated groups. When these are not mixed with other disturbances, they do not interfere seriously with communication. They cause the heavy dominating groups of Figure 9. Generally, they will result in a loss of a single word in a message for each of the widely separated groups, and they were shown to *originate in nearby or distant lightning discharges.*

Type 2: *A constant hissing noise* in the telephone receivers giving the impression of a softly-falling rain or of the noise of water running thru tubes. This type occurs only occasionally when there are dark, low-lying electrically charged clouds near the receiving antenna.

This type was studied in great detail by one of my collaborators, Lieutenant H. G. Holtzappel of the Royal Dutch Navy, and now Engineer of the Dutch Indian Telegraph Service. These strays proved to be intermittent, unidirectional currents in the antenna. A direct current galvanometer switched into the antenna without any rectifier showed a deflection corresponding to these strays.

The hissing noise in the telephones as well as the fact that the condenser in series with the galvanometer altered but did not stop the deflection, proved, however, that we had to deal here not with ordinary direct current but with uni-directional impulses. The ordinary course of events with this type of strays was the following: The galvanometer gave an increasing deflection for about one-quarter hour, and a maximum of some 0.3 milliampere effective current was reached. Thereafter, the deflection decreased for another quarter hour and strays became normal again.

At the same time, incoming signals had the opposite tendency to become weaker and weaker, and after one-quarter hour they began to increase until the normal signal strength was again obtained at the close of the disturbance.

Lieutenant Holtzappel attributed the fading away of the signals to the alteration of the antenna constants by the passing clouds. We should rather suggest (or possibly add thereto) the alteration of signal strength caused by overload of the detector and consequent diminution of sensitiveness of the detector. The antenna current produced by these strays is rather strong, as has been stated, and the hissing sound produced in the telephones shows that a large amount of energy is being transferred to the detector.

As disturbances of the type are rather rare and last for only a short period, they did not interfere seriously with communication and are rather of *scientific* than of engineering interest.

I would suggest that these disturbances are due to physical contact of the antenna with charged particles or to an invisible brush discharge of the antenna toward the low-lying, highly charged clouds. The fact that the current induced in the antenna grows and diminishes synchronously with the arrival and departure of the clouds hints at the correctness of the latter solution.

Type 3: This type produces a *continuous rattling noise* in the telephone something like the tumbling down of a brick wall. Such strays are *always present.* Their strength is a function of the period of the year and they are most troublesome in the afternoon and night. They are not well known during the day time in temperate climates, as in Europe, but are always present in the tropics.

Since these disturbances are of a continuous character, they are the most troublesome to handle; and, in fact, frequently suppress communication entirely. Often during the period of the west trade wind or monsoon, they are accompanied by heavy thunder storms, these latter causing disturbances of type 1, tho this is not the general rule for all seasons of the year. As a matter of fact, the maxima of types 1 and 3 do not coincide at the same portions of the year.

Both types 1 and 3 do not affect to any noticeable extent the loudness of the signal, as do strays of type 2. The signals are merely actually overwhelmed by the superior loudness of the strays.

So far as these disturbances were known in Europe, they were largely attributed to distant tropical thunder storms.[2] Dr. Eccles' well known theory is based on this assumption. It will be proven further on that Dr. Eccles' theory does not cover strays of type 3 since these have been shown to be aperiodic. In contrast, strays of type 1 have been shown to have only a very limited range, especially during the day time.

On the other hand, M. Dieckmann[3] has already pointed out that other disturbances may possibly be produced by sudden alterations of the potential distribution in air levels near the earth. It was therefore thought of interest to investigate to what extent the three types of strays were different in nature and source, in order that they might be separated electrically.

C. TESTS FOR THE SEPARATION OF DIFFERENT TYPES OF STRAYS

The means of investigation in this direction were given by Dieckmann himself in that he recommended the use of an aperiodic shielding cage around the antenna. If this cage is

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[2] Dr. Eccles' paper, September 4 and 11, 1912, before the "British Association," and "Jahrbuch der drahtlosen Telegraphie, etc.," volume 7, part 2, page 203.

[3] M. Dieckmann, "Luftfahrt und Wissenschaft," part 1, 1912.

suitably designed it will permit signals and such periodic disturbances as those of type 1 to pass thru, and reach the antenna; and they will be received almost unweakened. On the other hand, aperiodic variations in the static field around the earth and other aperiodic disturbances would not reach the detector, the antenna being screened from the earth field by the Dieckmann cage.

As such a cage is not easily built around extensive antennas, a special antenna was built for this purpose, consisting of phosphor bronze wire of 1.5 mm. (0.06 inch) diameter, surrounded by a vertical cage. The length of both the wire and this cage was 30 meters (100 feet).

The cage consisted of four vertical hemp ropes placed parallel to the antenna wire and at equal distances from it. The four ropes were linked together every 50 centimeters (20 inches) by horizontal square loops of galvanized iron wire, making a large cage, the section of which measured 50 centimeters by 50 centimeters (20 by 20 inches).

As these squares of wire were all placed perpendicular to the antenna wire, they could not interfere seriously with the reception; but could only increase the effective antenna capacity.

All sixty of these squares were connected aperiodically to each other and to the earth by a thin high resistance manganin wire. Afterward it proved possible to connect them by a copper wire and to connect the entire system to the earth from this wire thru the high resistance without spoiling the results. The best solution remains, however, to have resistance coils inserted in the down leads, so that practically no part of the cage can swing electrically.

Since the antenna under test was supported by a mast from which other antennas were also suspended, these antennas and all other parts of the masts and stays that could be set into electrical vibration had to be grounded thru high resistances.

This precaution is very necessary to make the cage function effectively; since otherwise aperiodic strays would cause the above systems to vibrate by shock excitation in their fundamental frequencies and the electromagnetic waves produced by them would pass thru the cage and reach the test antenna. In this way, strays would be propagated thru the cage and received.

Other investigators have not found the Dieckmann cage of any use and I can attribute their failure only to lack of the proceeding precautions.

After the precautions mentioned were carried into practice, however, we found Dieckmann's statements as to the usefulness of the electrostatic shielding cage to be strictly confirmed, inasmuch as a certain aperiodic type of strays was quite suppressed thereby. The result of comparative tests was that on afternoons when distant lightning showed in the sky, loud clicks produced by atmospherics of type 1 were received regardless of whether the cage and surrounding oscillators were aperiodically earthed or not.

While observing these distant lightning flashes, almost every click or group of clicks in the receiver coincided with a distant flash, thus proving that the lightning type of atmospherics (Eccles' type) cannot be cut off by the Dieckmann cage and for this reason must be of periodic character as heretofore supposed.

It should be noted that the strength of signals received when using the Dieckmann cage was not appreciably reduced.

On the other hand, at night time, after thunder storms and rain in the afternoon (the neighborhood being then quite free from lightning disturbances), rattling strays that could still be heard as long as the cage and neighbouring oscillators were insulated, would be completely cut off as soon as all these conductors were aperiodically grounded.

This proved that this particular type of strays (of type 3) was not of periodic character but must have been of the aperiodic type found by Dieckmann.

The type 2 disturbances did not happen to occur during these comparative tests, but since their natural source is known, as before stated, it is easily seen that the Dieckmann cage must eliminate them.

The only type not cut off by the cage seems to be type 1, or the lightning type of strays.

We shall next prove that these strays of type 1 are by no means the general type they were supposed to be by Dr. Eccles. Thereafter, it will be clear that strays of type 3 are the most *important* and *main type* of strays.

PROOF THAT THE LIGHTNING TYPE OF STRAYS IS NOT THE MOST GENERAL TYPE (AS SUPPOSED BY DR. ECCLES)

and

THAT THE DIFFERENCE BETWEEN DAY AND NIGHT STRAYS IS NOT DUE TO DIFFERENCES OF ABSORPTION BETWEEN THE LIGHTNING CENTER AND THE RECEIVING STATION

(a) The continuously present strays of rattling character, without much space between the different groups, faint in the morning, stronger in the afternoon and at least equally strong or even stronger at night, do not originate in distant lightning at all. This is clearly shown by the above-mentioned tests with the Dieckmann cage. These strays were easily screened off, whereas strays originating in lightning passed thru.

(b) The Eccles' theory presupposes a long range for strays originating in lightning, and especially during the night time because of the lack of absorption in the intervening medium. This supposition must be doubted. At our three stations, we frequently had to ground one of the receiving antennas because of dangerous and violent thunder storms in its immediate neighborhood. On the other hand, at the same time both of our other stations were continuing their communication without noticing any trace of extraordinary strays.

As the stations are only between 890 and 1610 kilometers (550 and 940 miles) apart, and thunder storms at one station did not produce noticeable disturbances at our other stations, there is no way of understanding how strays originating in thunder storms could reach temperate zone countries, (e.g., in Europe) at least ten times as far away and produce serious disturbances there. As a second proof of the short range of disturbances produced by thunder storms, it will be remembered that on nights following afternoons during which a thunder storm occurred with heavy rain fall, no strays originating in thunder storms were received. This was known by the fact that during such nights, the strays could be cut off by the Dieckmann cage.

Since the strays produced by the above-mentioned thunder storms were clearly local in character, it was obvious that distant thunder storms do not produce appreciable disturbances.

(c) Dr. Eccles takes the tropics as the origin of thunder storms. This being supposed to be their origin, there could be no large difference between strays during the day and during the night, the source being at all times comparatively near at hand.

Tho this point of view is partially supported by the fact that there are some times of the year when strays are almost as loud in the afternoon as during the night, still there is always enough difference, even in the worst months (and especially in those months during which strays in the day time are not strong), to make it certain that the tropics are not the center of strays originating in thunder storms.

The tropical regions cannot be a center of lightning storms and resulting strays for the reasons mentioned; and, in addition, they can not be at a great distance from a long range center, since, in the latter case, strays at our different stations, tho of different loudness, should always occur at the same moment. This is positively shown not to be the case by experiments; tho the same average daily and annual laws of intensity variation are found. The same definite noise or burst of strays is not heard at the same moment by the different stations.

As our stations are not in the supposed center of stray origin and since they are also obviously not outside of this center, the stray center of Eccles can not exist. There are, of course, centers of wave propagation in the neighbourhood of thunder storms but the range of these strays is certainly less than 900 km. (550 miles).

Consequently the stray phenomena observed in Europe can not simply be explained on the basis of the assumption of a tropical thunder storm center and subsequent variations in the strength of strays caused by changes in propagation thru the intervening ether. It is clear, then, that the most generally present type of strays, namely, those of type 3, must be generated in some other way than that suggested by Eccles, that is, by tropical thunder storms. And the simultaneous existence of the different types of strays may account for the failure of the many arrangements attempted to eliminate strays.

Marconi's original "X-stopper," which operated on the assumption of a definite frequency of the incoming strays, could only reduce strays of type 1, but was not effective in practice because it failed to eliminate strays of types 2 and 3.

The Dieckmann cage could only eliminate strays of type 2 and 3 but could not prevent strays of the first type from reaching the detector.

Since the investigators were not aware of the different existing types of strays, both of the devices were rejected as being non-operative.

Every means, such as loose coupling in the receiver and simultaneous detuning of the intermediate circuit and also Marconi's balanced detectors (which helped for all types of strays to a certain degree) was based only on the principle of weakening of strays to a greater extent than the signals, and therefore could attain only partial success. The Marconi balanced crystal receiver is shown in Figure 10. Later in this paper, I shall describe a device of my own employing only a single detector but giving similar results to those which Marconi obtained, but with two detectors. I shall describe also several other devices, the principal one of which might be expected to be completely successful.

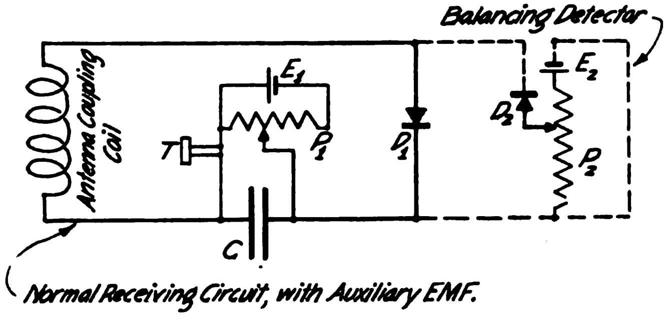

Figure 10—Marconi Balanced Crystal Receiver

As to the existing devices, *with the exception of the last-mentioned one*, none proved as effective as the musical character of the transmitting note; which, as stated, enabled the high selectivity of the ear to pick out signals thru strays of from 100 to 500 times as great intensity.

Before proceeding to the last portion of this paper, an explanation of my own as to the origin and propagation of the dominant type of strays (those of type 3) which are not covered by Dr. Eccles' theory, will be given. I shall first describe several arrangements which I devised to eliminate strays and interferences from other stations.

(a) The first device is similar in action to Marconi's balancing detector, but needs only one detector. It is effective against very heavy strays, but especially against interfering stations. The arrangement consists in applying to a carborundum-steel detector, an additional constant e.m.f. in the reverse direction from that generally used. The diagram of connections is shown in Figure 11, and will be seen to be the same as that of the Marconi balancing scheme with the exception of the omission of the second crystal. The e.m.f. E_1 is reversed so that the direct current flows in that direction for which the crystal shows the smallest conductivity. As is generally known, this weakens the reception to something like 50 per cent. of the available rectified current as against the optimum rectification obtained by applying the e.m.f. in the right direction. Still, reception is many times stronger than when using the detector without any additional applied e.m.f.

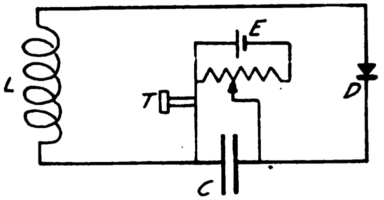

FIGURE 11—Stray Reducing Circuit Operating with Reversed Auxiliary E.M.F.

On the other hand, the reverse applied steady e.m.f. changes the characteristics of the detector as Figure 12 shows. The result is that weak signals are received much more loudly in proportion and absolutely than stronger ones; and that for a certain strength of signal and the corresponding applied e.m.f., there is no rectified current at all and therefore no reception.

I was easily able to make the loud signals from a steamer in the neighborhood of one of our stations inaudible by applying a suitable e.m.f. in the reverse direction. At the same time, signals 100 times weaker were being received from a distant station. As regards strays, the device operates in the same way as the balancing detector scheme; that is, there is only one strength of strays which can be made completely inaudible. Stronger strays are weakened and signals are similarly weakened, suppression depending upon their intensity. The device is therefore much more useful for the elimination of powerful interference from stations of constant loudness; and particularly so since these can be cut out with increasing ease, the louder they are. On the other hand, the device is only very partially successful against strays, which is also the case with Marconi's device. To explain the operation of the device I shall consider

Figure 12. This represents the well-known direct current characteristic of the carborundum-steel detector. As is generally known, the best working conditions are obtained at the bend *B* of the positive part of the curve, say for an additional applied e.m.f. of $+V$ volts. The best value of *V* depends to some extent, on the strength of the incoming signals.

If we apply instead of the positive e.m.f. $+V$, a negative e.m.f. $-V$, we see that the additional alternating e.m.f. $2A1$, will give no response whatever, since the areas of $A2b$ and of $A1a$ are equal and opposite in sign. A loud signal, therefore, gives *no response*, altho a weak signal does. For instance, a signal of one-third the former amplitude, $a'AO$, will give the response corresponding to the resulting negative area $Aa'b'$.

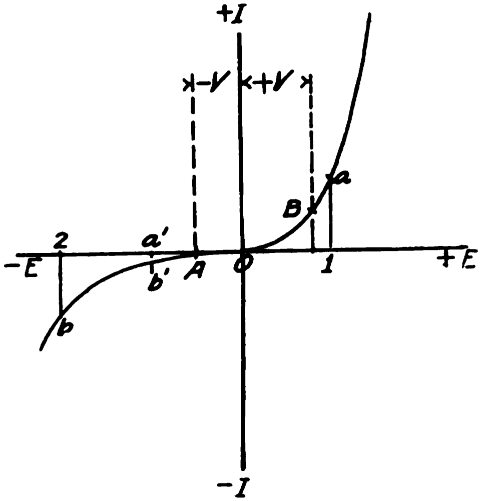

FIGURE 12—Characteristic of a Carborundum-Steel Detector

We see that we have no reception of strong signals but at the same time a perfect reception of weak signals. We can cut out very powerful interfering stations in this way. It is clear from Figure 12, that the stronger the interfering signal is, the higher the negative voltage which must be applied to cut out interference perfectly. Since on the other hand the loudness of the signals for which reception is intended, depends largely on the value of the applied negative e.m.f., the best working conditions are obtained for the value of $-V$ between 0 and 2. The arrangement works best for the *very strong* *interfering signals* which are compensated for by this large negative voltage. The arrangement is thereby best suited to long distance stations, situated near harbors or other centers of heavy traffic, and consequent interference.

The effectiveness of the arrangement against strays is quite clear since Figure 12 shows that the weaker the signal, the smaller the response, proportionately speaking. For strong signals the response becomes zero. While for excessively strong signals the response begins again, the rectified current is in the opposite direction to the applied constant e.m.f.

(b) Another arrangement was tried, which was effective only against interfering stations to some extent, but did not weaken incoming signals at all. Tho the arrangement is of no use against strays, it is briefly described here since it is useful in many cases.

The Landangan station, when receiving from Oiba on the 1,600 meter wave and working on the large antenna, was always interfered with by ship stations in the harbor of Panaroekan, 15 km., (9 miles) distant, and Soerabaie, 180 km., (110 miles distant) on the 600 meter wave. This interference was overcome in some tests by tuning a small antenna (which is referred to in the description of the stations) to the interfering 600 meter waves. As soon as this was accomplished, the interference was practically eliminated especially when resistance was introduced in the smaller antenna so as to make the damping of both antennas the same. This tuning was very sharp; and the success of the arrangement was not due to a screening action since the two antennas were not in the same line with the interfering station. The action must be due to compensation of the incoming interfering signals in the main antenna by re-radiated energy from the compensation antenna.

(c) The third arrangement, which was tried, was in the direction of the elimination of strays, and its diagram is given in Figure 13.

Two receiving antennas, L_1, L_2 of the same shape and dimensions, were installed near enough together (10 or 20 meters or thirty to sixty feet apart), to make them respond in the same way to strays. (For the aperiodic disturbances, this distance could be easily increased, but for periodic disturbances, the distance of separation must be small compared to the wave length of the strays, in order to get the induced e.m.f.'s in phase.) On the other hand, the antennas must be placed sufficiently far apart so that signals set up in the one which is made aperiodic (L_2) shall not cause currents in the tuned antenna (L_1).

One of the antennas, L_1, is tuned to the incoming signal and coupled to the detector circuit D_1 in the ordinary way. The detector D_1 will rectify signals as well as strays and send the rectified current into the telephone; or, as in the case of the drawing, into the differential transformer T_r. The antenna L_2 is tuned either to the same, or preferably a longer wave length, thus making it less sensitive to the signals and more sensitive to the long wave strays. The detector D_2 is switched directly into this antenna, thus making it aperiodic or nearly so. This arrangement makes it almost impossible to receive any distant signal on the antenna L_2, but loud signals on wave lengths different from those to which L_1 is tuned and strays give a response that is nearly as loud as can be obtained on the tuned antenna L_1.

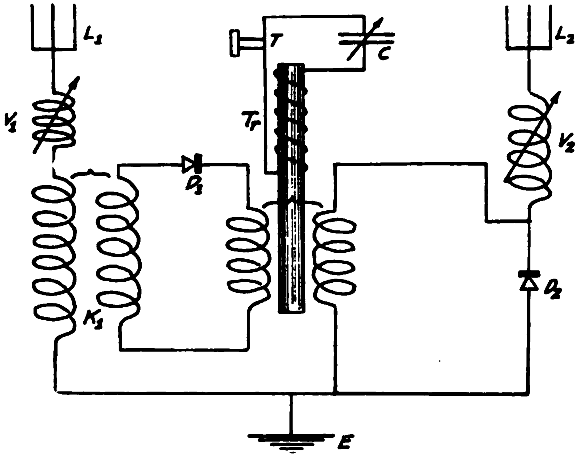

FIGURE 13—Compensation of Periodic Strays at Audio Frequencies

The rectified current is sent to the same telephone mentioned before; or, as in the case shown in the drawing, to the differential transformer T_r. However, this second current from the aperiodic antenna, L_1, is arranged to act in the opposite direction from that of D_1. The telephone T is either connected in series with D_1 and D_2; or, as in the drawing, in a third winding of the differential transformer and in series with the condenser C to permit tuning to the spark frequency. Since D_2 does not respond to distant signals, there will be heard in the telephones the signals from D_1 only, whereas the strays rectified by D_1 and D_2 tend to compensate. By varying the coupling K, this compensation can be made complete.

This device will only permit complete compensation of strays of different loudness when the characteristics of both detectors D_1 and D_2 are similar. This is easily accomplished by using carborundum crystals with the best applied e.m.f. As soon as this is applied, the characteristic for rectified currents as plotted against incoming alternating current is almost a straight line. This scheme was tried in practice but since the two equal antennas were not available, compensation could be obtained only for rather weak couplings, K, with a consequent loss of signal strength. The results were encouraging enough, however, to warrant repeating the trials on a larger scale, and with proper apparatus. The results of these more elaborate and confirmatory tests, will be published in the PROCEEDINGS within a short time. I am entirely convinced that this compensation device, combined with the Dieckmann cage around the antenna to cut off aperiodic strays, solves the problem of the elimination of strays. It will be seen that the same principle of compensation just described for the rectified or audio frequency currents is available too for the radio frequency currents. However, the currents to be compensated for in this case must be of the same frequency, decrement, and phase, thus introducing difficulties not encountered with audio frequency compensation. For audio frequency compensation, it is sufficient that both rectified currents should be equal in frequency. Radio frequency compensation requires two antennas tuned to the same wave length and close together, and having the same decrement. Consequently, in this case, the use of an aperiodic compensating antenna is not possible.

In order to get compensation at radio frequency, two antennas of the same size and wave length must be used, one of which is more sensitive to incoming signals than the other and both of which must be equally sensitive to strays. This could be done by having a directive aerial pointed toward the receiving station, and either a directive antenna in the minimum receiving position relative to the sending station or a non-directive antenna for compensation. In both cases, a great loss of signal strength will be involved, since the compensating antenna will not only compensate strays but also the incoming signals to at least a large extent. I therefore prefer compensation of the rectified audio frequency current rather than radio frequency compensation.

Part 4. The Author's Suggestions Relative to the Origin and Propagation of Type 3 Strays

Since the theory of Dr. Eccles' does not hold good for this type of strays, I attempted to suggest another solution. To begin with, it is necessary to consider the curves of daily and monthly variation of strays. In Figure 14 are given the curves of daily variation, averaged over every month of the year, for all strays received during the daytime at the Landangan (Siteobondo) station. The year during which the observations were made began in June, 1913 and ended in June, 1914. The averages for these two years (that of June, 1914 being dotted) agreed very well.

The strays indicated by the letters "*Ls*" are plotted vertically in accordance with their scale of values from 0 to 5 as given in Part 3 of this paper. The average value for every hour of the day (in true solar time of the place under consideration) is the heavily drawn black line. The dashed lines indicate the limiting (that is: the highest and lowest) values observed during the hour in question.

We see that altho the average line could be drawn for the daily variation, the individual values during the same hour on different days in the months may be widely divergent on both sides of the average. It is clear also that morning and afternoon curves are symmetrical only for those months of the year during which the altitude of the sun is a minimum (that is: June, July and August). Symmetrical curves of this type are common for European stations.

These months of maximum sun's altitude covered the period of the latest trade wind (or east monsoon); and we shall call the daily variation curves during these months, the "east monsoon characteristic." We shall indicate this type of characteristic by the sign ◡, meaning that during these months, strays slowly fall from the sunrise point $\underline{o}$ to noon and then slowly rises until sunset $\bar{o}$. It will be seen that the characteristic for the month of August is already changing into a second type of characteristic, and that a change is also occurring during the month of May. It is only during these months that the stations fully fulfill their contract.

As the altitude of the sun increases, it will be noticed that the characteristics continually change, not so much in the morning but chiefly in the afternoon. The characteristic then becomes of the general shape indicated by its sign _⌒ as found in the characteristics during the months of September, October,

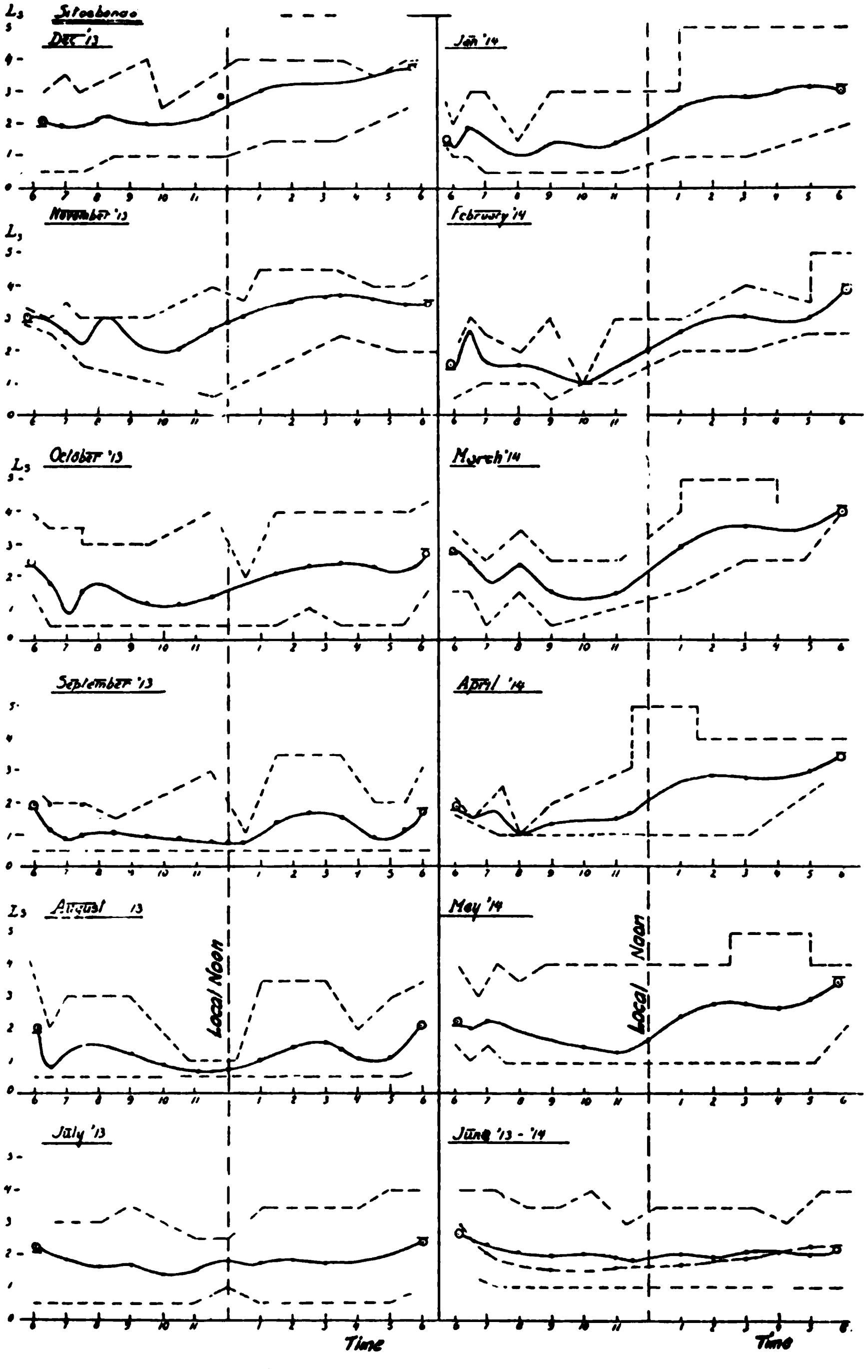

FIGURE 14—Daily and Monthly Variation of Strays

March, April, and May. As has been stated August is of an intermediate form. This characteristic we shall call the "intermediate period characteristic." It is found during stormy periods when neither of the two types of trade wind dominates. On the average, communication is possible in the morning during these months, but during the afternoon contractual requirements could not be met.

With the latitude of the sun still increasing and the west trade wind (the west monsoon) becoming permanent, the characteristic takes the form indicated by its sign ∽, with high values in the morning during the months of November, December, January, and February. During some days in this period, no communication can be handled, since the signals also fade in intensity as do the strays in the morning.

We shall study hereafter, the meaning of the signs employed in these characteristics.

Figure 15 gives the average daily variation over the whole year, with night observations included. It must be admitted, however, that the dashed portion of the night curve is to be critically considered, since not many observations were available

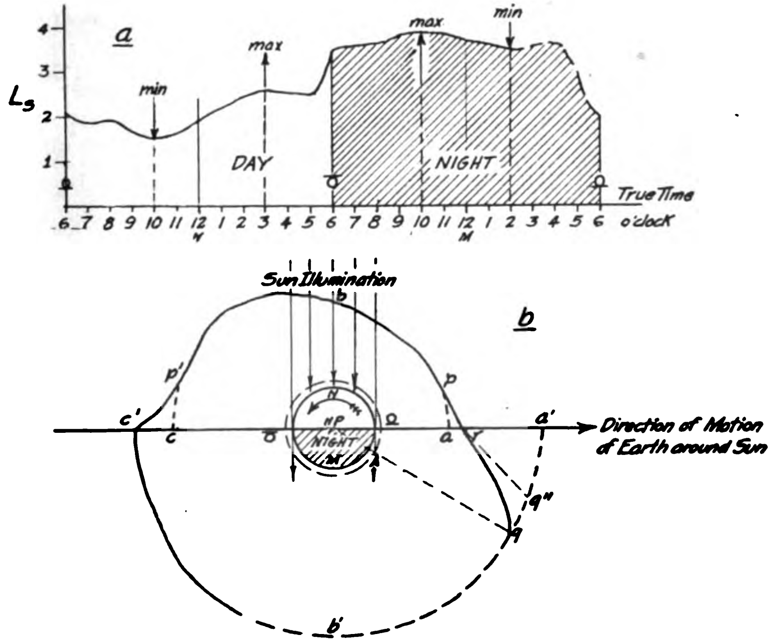

Figure 15—Average Daily Variations of Strays Thruout the Year during such times, the stations being generally closed during that part of the night. We see that the average day of the year gives a high value during the night time for the stray intensity; (namely, class 4; that is, requiring a signal strength of 250 to 500 times audibility for satisfactory communication). About two hours before sunrise, the strays began to weaken until at 10 o'clock in the morning, the minimum is reached. Then the strays increase until three in the afternoon, remain almost constant until an hour before sunset, after which they rise sharply to the night value.

It is easily seen that there is enough difference between day conditions (and especially morning conditions) and night conditions to enable us to conclude that if the theory of Eccles were correct, our stations on the average, are not situated near the thunder storm center. On the other hand, it would seem that in the afternoon, we were rather near such a center, the difference between average afternoon and night observations being only small. This already indicates that the phenomena are not governed by so simple a supposition as that of Eccles. In Figure 15 there is also shown the same curve of daily variation of stray intensity thruout the year plotted in polar co-ordinates around the circular cross section of the earth. The direction of the impinging sun beams and the direction of rotation of the earth around the sun are given.

We see that the polar diagram shows two curious half-oval curves of different sizes for the day and night observations (*abc* and *a'b'c'*) symmetrically arranged relative to the direction of motion of the earth around the sun and connected by the steep lines (*pq* and *p' q'*), these steep portions occurring near sunrise and sunset.

It is quite clear that the night phenomena are the symmetrical repetition of the day phenomena; and that the reason for the difference between night and day must be found, in all probability, in the medium between the point of origin of the strays and the receiver which is under the influence of the radiation of the sun. We find this same influence, in a much more pronounced form, in the propagation of the electromagnetic waves of the radio transmitter; and I proved elsewhere that the difference must be due to ionization of the air layers up to a height of some 200 km. (125 miles).

In this connection, it is interesting to note from the polar diagram of Figure 15 that the diminution of strays at the point *A* begins long before the time of sunrise at the place in question.

That is, as soon as the layers in the atmosphere above the place are touched by sunlight, the change begins.

This indicates that the source of strays is not (as Eccles supposes) in the lower layers of the atmosphere, since the difference between night and day would, in that case, begin only as soon as the lower layers between the source and receiver are reached by sunlight. The assumption of the source of the strays in the higher layers of the atmosphere is therefore logical, and under these conditions, the difference between day and night strays is natural and to be expected.

Another interesting fact in connection with the shape of the polar curve of Figure 15 is that the strength of strays is not a function of the direction of the impinging *sunbeams* but that the curves are symmetrical relative to times determined definitely by the movement of the earth around the sun. This furnishes a hint as to the manner in which the higher layers of the atmosphere may become the source of disturbances.

In its course around the sun the earth frequently is struck by cosmic particles which give rise to disturbances in the electric conditions of the upper layers of the atmosphere. It is clear that the disturbances must be different on different parts of the layer; and this difference between collisions in front of the earth and those in back of the earth (as referred to the earth's motion) would give rise to the oval form of the diagrams.

These oval curves would be easily explicable if we assume as the source of strays an atmospheric layer of considerable height which is disturbed by the irregular bombardment of cosmic particles of dust or is disturbed in any other plausible fashion. Tho the theory of cosmic bombardment of upper layers appears to me to be the most plausible origin of strays of type 3, particularly since such a source of strays would explain also the cause of daily variation in the strength of the earth's magnetic field, nevertheless, we are not sufficiently well informed concerning the upper layers of the atmosphere to be able at this moment to give a definite proof of my assumption.

If, therefore, I base my explanations of the strays of type 3 on the above mentioned proposition, it is rather because it seems to me quite a plausible explanation than because it can be absolutely proven to be the truth. If this high layer is the source of strays of type 3, it is quite clear that not only the point directly over the station (that is, the zenith) can be the source of strays; but that in every case, the changes in electric conditions in the circular segment of this layer the center of which is the zenith of the station will contribute to the strays observed at the station under consideration. The nearer the point of disturbance to the station zenith, the more pronounced will be the disturbance.

It is, of course, of some interest both practically and scientifically to note the approximate radius of the segment above mentioned, since this will give us an indication of the range of strays of type 3 and of the limiting possibility of distance at which strays of type 3 may be heard simultaneously in different stations.

Of course, the type of receiver used alters this effective stray radius, and it is well known that with very sensitive receivers, not only the *loudness* of the strays increases but also that the *number* of strays received every minute also increases, thus showing that in the latter case, we detect more distant stray centers.

For the detector and receiving set used for the observations in the Indies, which receiver has been briefly described in Part 2 of this paper, the average range of strays of type 3 can not be definitely determined.

On examining the oval curves of Figure 15, it can be clearly noted that the average diminution of the night strays into the day strays (as averaged over the entire year) is complete only at the point p; that is, one hour after sunrise at the receiving station. Similarly the increase of day strays to night strays begins as early as p'; that is, one hour before sunset at the station under consideration. This shows clearly that the illumination by sunlight of places one hour distant from the station in question causes a limiting effect, which is just detectable by means of the resulting change in strays at the receiving station, if receivers are used of the type described. The range of these centers of stray origin, or the radius of the segment mentioned, is therefore the distance of rotation of the earth in one hour; that is to say, $1/24 \times 40{,}000$ km., or 1,670 km. (1,000 miles). In other words, stations with receivers of the type employed at our station and separated by a distance of 3,340 km. (2,000 miles) might expect to detect some strays of type 3 at the same moment; but in this case the strays would be faint to the limit of audibility. On the other hand, if the stations are 1,670 km. (1,000 miles) apart, and the stray originates just above one of the stations, this station will detect it very loudly and the other station will detect it as just audible.

This is the reason why during tests intended to study simultaneous strays at different stations, the stations must be quite close to each other in order to detect simultaneously and continuously the same strays at the same time, as the researches carried out by Dr. Eccles showed.

Under these conditions, each station hears the most powerful groups of strays. The conclusion drawn from these results has been used erroneously to prove Dr. Eccles' theory of the lightning origin of strays. Since, however, strays of type 3 were dominant and since the range of strays from lightning is not very large, the method of simultaneous station observations will yield only slight results.

In the light of my theory concerning type 3 strays, loud groups of such strays mean that the point at which strays are originating in the upper layers of the atmosphere is near both stations; that is, at a distance considerably less than 1,670 km. (1,000 miles). Furthermore, simultaneously heard loud signals indicated, in addition, that the source of strays was not very far from the point half-way between the stations. It is quite clear that these conditions are only fulfilled for stations not more than at the most about several hundred km. (or miles) apart. The extreme limit is estimated by me as approximately 1,000 km. (600 miles). Also all other centers of type 3 strays around the stations will produce responses in both stations which undoubtedly occur simultaneously but will be so different in strength, because of the difference in distance, that these stray interruptions will never give the impression of simultaneity. Lastly, the apparent similarity of strays at the two stations will be still further spoiled by the reception at each station of strays which are inaudible at the other.

The correctness of the previous reasoning is strictly confirmed by the fact that, tho Figure 15 shows a range of the strays at 1,670 km. (1,000 miles) during the day time, no simultaneous strays could be observed at our three stations which were only between 890 km. (550 miles) and 1,610 km. (970 miles) apart; and this was the case even at night.

On the other hand, tho not simultaneously occurring, the *average* daily curve of strays was not much different for the different stations. This was to be expected from my theory, the different stations being sufficiently near together to be under practically the same average influence of the layer above them, and this small part of the total layer is struck by a nearly constant number of cosmic particles.

All of these effects agree with the theory here given and militate against the correctness of the theory of the lightning origin of strays, as do also the demonstrations with the Dieckmann cage. On the other hand, it is possible from the consideration of the point q of Figure 15, where the diminution of night strays to day strays begins, to approximate the *height* of the *disturbed layer.*

The diminution from night strays to day strays begins as soon as a point of the upper layer some 15° sunward (that is, to the east) of the station under consideration is reached by sun beams. We must also remember that this distance of 15°, which equals one hour of earth rotation, was found to hold during the day time (at points p and p'). The distance between the station and the most distant perceptible centers of strays at night is larger since the propagation of strays is then better. We are at a loss, however, to determine what value shall be taken for the better transmission at night; consequently we shall assume a minimum distance; that is, 15°, and equal to that during the day. We shall see that by so doing, the layer height as calculated will be too large.

From Figure 15, we note that the decrease of strays begins about 2.5 or 2 hours before sunrise. The exact moment is not quite certain because, between these times, the dashed portion of the curve is not absolutely trustworthy. From these figures, and taking a more frequent radius of the stray circle to be one hour or 15°, we find that the first sun beam, after touching the earth (see beam A of Figure 15) reaches the upper layer at a point directly above the station, provided the station will have its sunrise 1.5 to one hour afterwards.

If in Figure 16, E is the earth, L the upper layer, A the zenith point of the station, a, which is reached by the first sun ray, then we can calculate the height h of the layer from the formula

$$h\,(2r+h)=R^2\,tan^2\,a,$$

and since H is small compared with $2R$

$$h=\frac{R}{2}\,tan^2\,a,$$

in which R is the radius of the earth. For $a=1$ to 1.5 hours $=15°$ to 22.5°, the height h is found to be between 225 km. (140 miles) and 540 km. (330 miles).

It is an interesting confirmation of this theory that in the neighborhood of the first value given (that is, between 180 and 200 km.) (110 and 120 miles), a layer of the type mentioned has been predicted by scientists in many fields. This layer, the *Heaviside* layer, is supposed to be a sharp frontier surface between the lower poorly conducting layers of the atmosphere and the highly conductive atmosphere above it. This layer is supposed to give rise to reflection phenomena in radio transmission at night, and is supposed also to be a seat of the cause of alteration in the earth's magnetism. This height has also been estimated to have the value stated from observations on the incandescence of meteors and also from the aurora borealis. On another occasion[4] I showed that phenomena in the night propagation of radio waves not only sustained this calculation but I showed also, from the "silent belts" in radio transmission at night, that the height of the layer was about 200 km. (125 miles). This value corresponds very well with the values of between 225 km. (140 miles) and 540 km. (330 miles) found for the height of the layer which produces strays of type 3. The excessively largely value of 540 km. (330 miles) can be easily explained by remembering, as before stated, that the radius of the segment of stray centers is not 1,670 km. (1,000 miles) as during the day, but much larger.

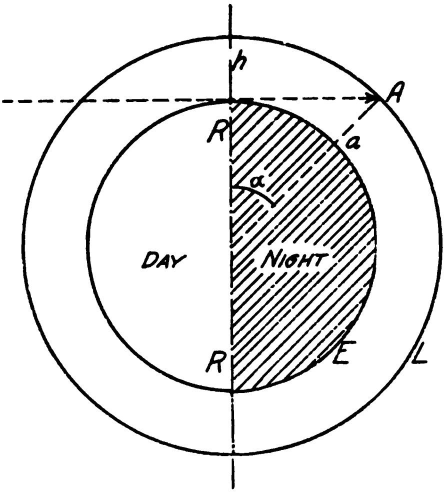

FIGURE 16—Location of Centers of Stray Origin

Taking the layer as being at the height of 180 km. (110 miles)

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[4] In a dissertation for the degree of Doctor of Science, May 18, 1916; and in "Jahrbuch der drahtlosen Telegraphie" (not yet published).

we get for the angle a in the equation above 13.5°, which is equivalent to the angle traversed in 54 minutes of time by the earth's rotation, so that the radius of strays at night time would be 2.5 (or 2) hours minus 54 minutes, that is, between 1 hour and 36 minutes and 1 hour and 6 minutes. This corresponds to an effective range of night strays of from 2,670 km. (1,640 miles) to 1,750 km. (1,080 miles), as against 1,670 km. (1,000 miles) during the day time.

This is quite possible, as shown in Figure 15, since the average loudness of strays at night is about 1.5 times that in the day time, so that there can be no objection to taking both the day- and night-stray-originating layers as existent and identical.

A further reason for these conclusions is the fact that the daily variation in strays, as given in Figure 14, is quite similar in character to the curves of variation of the earth's magnetism as I saw them published in the "Wireless World" (or "Marconigraph") some time ago, which latter variations are attributed to eddy currents in the Heaviside layer. By supposing this layer to be the "secondary" source of strays of type 3, we obtain a sufficient explanation for the daily changes in the strays, these variations being analogous to those of the earth's magnetism. On the other hand, the gradually altering form of the daily characteristic, as it changes in accordance with the symbols given, from ◡ thru _⌒ to ‿⁀, is easily explained if we regard the cosmic bombardment as occurring chiefly in the plane of the earth's orbit. It was found that the type of stray corresponding to the symbol ‿⁀ occurred whenever the angle between the sun's declination circle and the latitude circle of the station under consideration did not differ more than 10°. Similarly, the type _⌒ occurred for a difference in this angle of 10° to 20°; and when the difference exceeded 20°, the symbol was ◡. It is for this reason that strays in Europe are nearly constant over the entire day (strays from lightning sometimes excepted). In the case of the ◡ characteristic, the distance to the strong centers of cosmic bombardment is very large, and the strays are therefore weak. This is why strays of type 3 are so heavy in the tropics and so weak in Europe. At the poles we assume that they would be almost not noticeable. It remains to determine, however, in what way disturbances in the Heaviside layer produced strays in the antenna. This is not a difficult matter to explain, and the explanation will at the same time clear up the difference between the day and night strays of type 3.

The Heaviside layer is a conductor, as also is the earth. Between these two conductors, we have a layer between 180 km. (110 miles) and 250 km. (120 miles) thick, which is a non-homogeneous dielectric. This dielectric is fairly perfect during the night, as is indicated by the goodness of night communication; but it is rather an imperfect dielectric during the day, the conductivity changing with the height above the earth. This complex dielectric forms a large condenser almost free from losses during the day but rather imperfect at night. The cosmic bombardment by charged particles on the upper layer will be detectable thruout the dielectric; and this to a greater degree during the night than during the day. On the other hand, in the latter case, part of the effect is lost because of the imperfect character of the dielectric, and hence the difference between day and night conditions.

It must be remembered that the antenna is electrically connected to the earth (either conductively or capacitively), and that it will therefore be disturbed by all changes in the field or potential gradient of this condenser. Such changes depend upon the charge of the cosmic particles, or on other causes of excitation of the upper layer, as well as on the original charge of the condenser. This latter charge is the reason for the influence of the seasons on the strays, which point was not mentioned heretofor. It has already been stated that the light of the sun (and consequently the time of the year) influenced markedly the daily characteristic as expressed by the symbols ◡, ‗⌒, ∽.

In Figure 17, there are given the month by month characteristics for each of the three stations over a whole year, these being obtained from the average values at noon, over every month.

The times when the sun's altitude is 90° for the place under consideration are also given. We see that these occur twice a year for every station. Tho the symbol for every station is then ∽, we see, on the other hand that the points of *maximum strays* do not come at the same time but that there is a lag of as much as 1.5 months between 90° sun altitude and maximum strays.

We see that the maximum strays follow the monsoon or trade wind seasons of the year much more closely, the maxima always occurring at the time just between the west monsoon and the "intermediate period"; whereas the minimum always occurs during the east monsoon and close to the end of this season when it is passing into the intermediate period. The signs

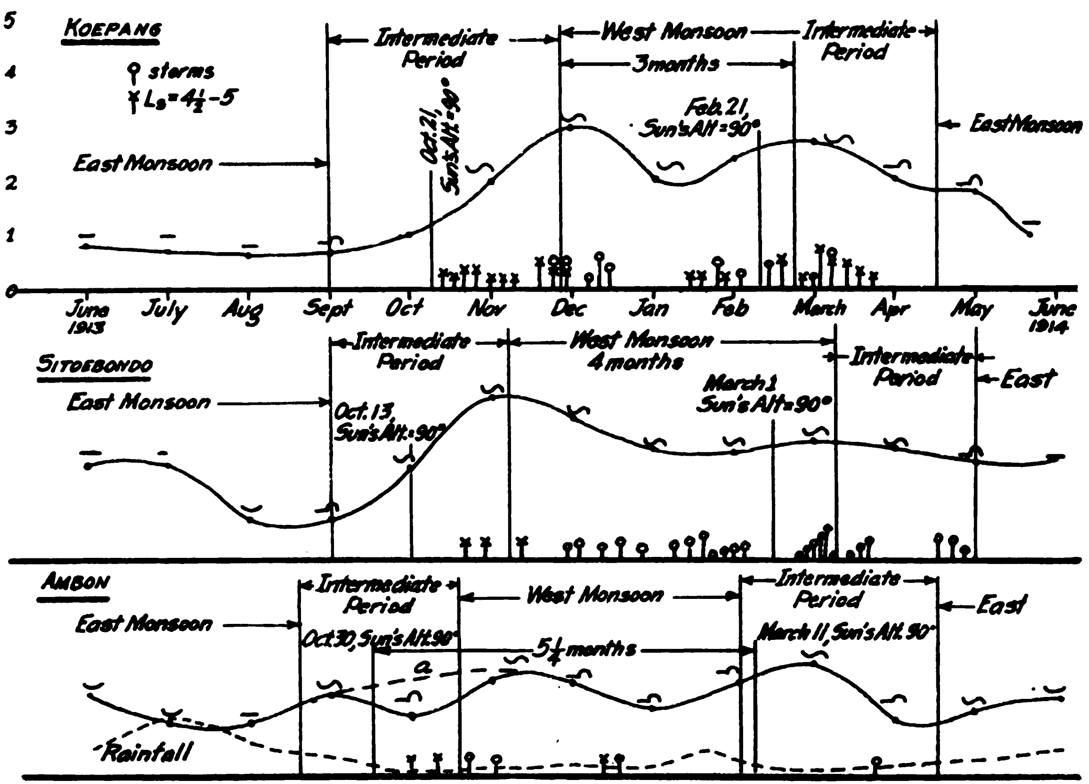

FIGURE 17—Yearly Variation of Strays

◡, ‿◠, ◡◠, correspond to the general aspect of the daily variation curve as taken from Figure 14 for the months to which they are assigned in Figure 17. In fact, the Director of the Meteorological Institute of Batavia assured me that the maxima of strays found by my observations correspond to the maximum increase in potential of the earth's field. Consequently, we have here located that original charge of the earth condenser which is the reason why, even tho disturbances of the upper layer do not alter with the sun's altitude, changes in the strength of their fields and consequently changes in strength of the strays produced must be dependent on the season.

In concluding this paper, I may state that inasmuch as type 3 strays do not originate in lightning, their maxima do not coincide with those of thunder storms either near the stations or distant from them.

In Figure 17, thunder storms and very heavy strays of the thunder storm type, were indicated by the symbols ⚲ and ϯ, the length of the vertical line giving the duration of the outburst of strays on a certain scale.

We see that for all three stations, the periods of thunder storm, ⚲, were preceded by heavy strays, ϯ, of type 1. These strays did not occur simultaneously at the three stations, which is the best proof that their range is short. For the station at Keopang (Oiba), it might be stated that strays of both classes occur almost simultaneously, tho the thunder storm, ⚲, occurred most nearly at the middle of the west monsoon period, where the type 3 strays have no maximum whatever.

For the Landangan (Siteobondo) station, the difference just mentioned is still more striking, and of the same type. For the Ambon (Noesanivé) station, it is even more evident that there is no connection between the two classes of strays. It is obvious that both are to be considered separately, and compensated for in different ways.

Other atmospheric conditions were shown not to have any influence on the strength of strays. Of course, thunder clouds coincided with strays of type 1 and low-lying rain clouds with type 2. In spite of the common belief, rainfall in itself has no influence on strays, at least so far as types 1 and 3 are concerned. This is clear from the curves for Ambon, in Figure 16, where are shown the strays and at the same time, the dotted rainfall curve.

SUMMARY: Following a general discussion of radio vs. submarine cable telegraphy, the work of the Radio Division of the Dutch East Indian Service is described.

A chain of stations installed for this Service are considered; their location, equipment, and operation being described in considerable detail. The failure of the original contractor to furnish stations covering the requisite distances (which would have required six to eight times the actual available power) is critically considered.

The choice of station location and certain details; e. g., precautions against earthquakes, are then treated.

A description of the origin and nature of strays and their classification is given; together with a number of methods for their elimination. In this connection, the Eccles' theory of a tropical thunder storm origin of all strays is disproven. There are described, in addition, some special methods of reducing strays, methods intended especially, however, for the elimination of undesired, powerful, and interfering signals.

Strays fall into three classes, the origin, character, and mode of elimination of which are as follows:

Type 1: Strays originating in nearby thunder storms, of short range, of periodic electrical character, audible as sudden and loud widely separated clicks, and eliminated by radio or audio frequency compensation circuits.

Type 2: Strays associated with low-lying rain clouds, of very short range, of intermittent uni-directional electric character, audible as a constant hissing sound, and eliminated by the Dieckmann electrostatic shielding cage.

Type 3: The most common or night strays, originating in cosmic bombardment of the Heaviside layer, of audible range of several hundred miles (with the receivers used), audible as a continuous rattling noise, and eliminated by the Dieckmann cage.

The daily and seasonal variation of strays is considered in great detail, and a number of interesting conclusions are drawn.

DISCUSSION

Roy A. Weagant: 1. Dr. de Groot's paper has certainly been of very great interest, yet there are many points contained in it which I am unable to accept. It seems to me fundamentally impossible that the shielding cage which he has used can work for the very simple reason that if you surround an antenna with a conducting structure of any kind, regardless of whether it is aperiodic or has a period of its own, it will have currents set up in it when acted upon by electromagnetic waves. Constructed as indicated by Dr. de Groot, this cage would have an extremely strong electromagnetic and electrostatic coupling to the antenna, consequently any currents set up in the shielding structure will induce currents in the antenna itself and I see no possibility of avoiding this result.

I might say in addition that my personal experience with arrangements of this kind have not produced any useful results.

The use of the balanced crystal or single crystal having current applied in the direction the opposite to the direction of rectification has some advantages. This has been quite fully developed by Mr. Round of the Marconi Company but its action is to limit the maximum response and thus save the operator from the disturbing effects of the loud crashes.

Dr. de Groot's scheme of using reverse potential on the crystal is really equivalent to selecting a crystal of the particular necessary characteristic and using the battery potential in the ordinary direction. This arrangement, however, can in no sense be considered a stray preventer.

Dr. de Groot also shows an arrangement of two antennas having the currents developed in the audio frequency circuit opposed. I am entirely unable to credit this arrangement with any successful results as I have tried it many times and, furthermore, a complete analysis of the actions involved, which is too lengthy for this discussion, does not indicate even theoretical possibilities. I do not quite see how insertion of a resistance in one of the antenna circuits referred to can be expected to secure the results stated since we know perfectly well that its effect would be to reduce both the stray and the signal in proportion, therefore when the audio frequency circuit attached to this antenna is opposed to the audio frequency circuit attached to the other antenna, the available energy from the stray will be of the same reduced order as the energy from the signal.

Dr. de Groot has stated that, when in the use of this arrangement the opposition took place in radio frequency circuits, accurate phase adjustment was necessary, but was not necessary when the audio frequency circuits were opposed to it. It seems to me obvious that in either sort of circuit where opposition effects are desired, correct phase adjustments are essential. The employment of circuits tuned to the group frequency of the incoming signal, as suggested in this paper, is an obvious fallacy to anyone who has made use of them. Such a tuned audio frequency circuit simply responds when struck by a stray impulse in its own period in the same way that a tuning fork vibrates from the blow of a hammer with the result that "musical" strays are produced. This is very much more disturbing and difficult to read thru than the response ordinarily heard from strays since it has the same note as the signal itself. Dr. de Groot's theory as to the source of that particular sort of strays which we have all recognized as being the most difficult to overcome is interesting but I am unable to reconcile it with the daily and seasonal variations in stray intensity which are commonly observed. It might, of course, be one of several contributary causes, but hardly the sole cause.

Another point which the paper makes is that these strays do not occur simultaneously at two or more stations of the author's system. This is rather a curious observation because of its disagreement with observations in this part of the world which have indicated to a considerable extent at least the simultaneous occurrence of stray discharges at widely separated points. For instance, it has been quite common to note that the same word or letter which was lost by a station in the British Isles from a transmitting station on the American continent was also lost at another station on this continent. There is, however, sufficient information available to indicate that in all probability both sorts of conditions obtain, the actual condition varying much with the location of the stations.

Alfred N. Goldsmith: The Dieckmann cage, as used by Dr. de Groot, is obviously a device of great utility in the elimination of strays. A further explanation of its action, supplementing that of the paper, is not amiss.

1. It is first necessary to consider the elementary action of the *Faraday cage*. It will be at once recalled that Faraday demonstrated conclusively that the electric field inside a closed conducting surface was absolutely zero. The experiment was the following. A cube of wood covered with tin foil, and about

6 feet (2 m.) on a side was built and mounted on insulators. The observer got inside the cube with the most delicate gold-leaf electroscope available. The tin foil was then connected to one terminal of a static machine, and charged until huge sparks brushed off all the edges and corners of the cube. Nevertheless, the electroscope did not indicate the faintest trace of any separation of the leaves, and evidently the cube acted as a *complete shield for all electric forces proceeding from charges on its surface.* The arrangement is shown in Figure 1.

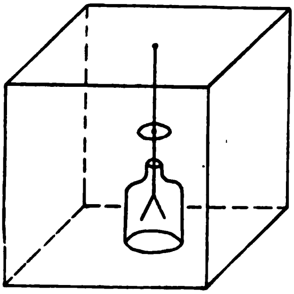

FIGURE 1—Faraday Shield

It is clear, therefore, that if such a cube surrounded an antenna the antenna would be entirely protected from all charges on the surface of the cube; and if this surface of the cube were grounded, charges passing over the surface of the ground or local distortions of the earth's electric field could not possibly affect the antenna electrostatically.

On the other hand, using this brutally simple shield, the antenna would be altogether too efficiently protected, inasmuch as it is well known that the electromagnetic waves of the incoming signals would be prevented from reaching the antenna by a solid metal sheet. So far, then, but little progress has been made; and we are forced to seek further expedients.

2. I quote now from Hertz's classic work on "Electric Waves" in connection with .the polarisation of short electromagnetic waves.

"From the mode in which our ray was produced we can have no doubt whatever that it (the radiated wave) consists of transverse vibrations and is plane-polarised in the optical sense." (The wave was produced by an ordinary linear Hertzian oscillator or doublet, the length of which lay on the focal line of a cylindrical metal mirror.) "We can also prove by experiment that this is the case. If the receiving mirror be rotated about the ray as axis until its focal line, and therefore the secondary conductor also, lies in a horizontal plane, the secondary sparks become more and more feeble, and when the two focal lines are at right angles, no sparks whatever are obtained even if the mirrors are moved close up to each other. The two mirrors behave like the polariser and analyser of a polarisation apparatus.

"I next had made an octagonal frame, 2 meters (6 feet) high and 2 meters broad; across this were stretched copper wires 1 mm. (0.04 inch) thick, the wires being parallel to each other and 3 cm. (1.2 inch) apart. If the two mirrors were now set up with their focal lines parallel, and the wire screen were interposed perpendicularly to the ray and so that the direction of the wires was perpendicular to the direction of the focal lines, the screen practically did not interfere at all with the secondary sparks (that is, with the passage thru it and subsequent reception of energy). But if the screen were set up in such a way that its wires were parallel to the focal lines, it stopped the ray completely . . .

". . . When the primary oscillator is in a vertical position the oscillations of the electric forces undoubtedly take place in the vertical plane thru the ray, and are absent in the horizontal plane . . ."

That is, Hertz demonstrates conclusively that a number of parallel wires (with separation considerably smaller than the wave length) entirely stop the passage of electromagnetic (plane polarised) waves whenever the wires are parallel to the electric force in the wave front, but *do not impede the passage of the waves at all when the wires stretch perpendicular to the electric force in the wave front.*

3. Coming now to Figure 2, it will immediately suggest itself to the skilled radio engineer that it is possible to effect an operative combination of the Faraday shield against changing electrostatic fields or movement of external charges with a Hertzian screen permitting the passage of electromagnetic waves. The combination is the elementary Dieckmann cage referred to, and is given in Figure 2 if we regard the faces as made up of horizontal wires connected together in such a way that they are all at ground potential and if these wires are also perpendicular to the electric force in the front of the advancing signal wave. This screen will therefore act as a perfect shield against charges or field alterations outside, since even if these charges are on its

own surface they can have no effect within. On the other hand, if the advancing electric field has the distinctive feature of a true electromagnetic wave, it can pass thru into the cage. This will be the case, since if X is the direction of transmission of the signal wave, E, the electric force will be vertically up or down.

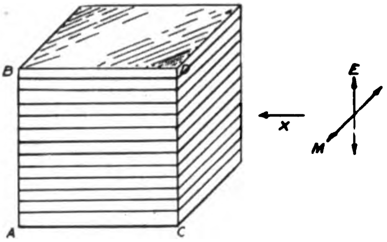

FIGURE 2—Hertzian Cage

To summarise, then, such a combined Faraday shield and Hertzian transmitting screen will *permit the passage of advancing signal waves* (or other true electromagnetic waves) while *absolutely shielding the interior from potential variations arising from moving charges* in the vicinity of the cage *or variations in the field of the earth.*

4. An objection would, however, be at once advanced against the elementary Dieckmann cage shown in Figure 2. The vertical edge wires, *AB*, *CD*, etc., which keep the entire sides at ground potential are parallel to the antenna within, and they would most certainly absorb a dangerously large portion of the incoming wave energy, being, in fact, themselves grounded antennas. This objection is satisfactorily met by Dieckmann thru the use of the arrangement shown in Figure 3. This is a side view of a shielded vertical antenna, the horizontal lines (with the short jumps in them) being representative of squares of wire around the antenna *A* and in a horizontal plane. These squares are kept at ground potential by means of the resistances *R* and the conductor *S*. These resistances in question keep the conductor *S* from periodicity, and the incoming waves can set up in it only feeble oscillations and consequently there will be but slight energy absorption therein. How feeble this absorption is will appear further in this discussion in connection with another aspect of the problem. We may say, then, that even the *grounding edge wires* can be arranged, *by insertion*

of more than the critical resistance, so that they *will absorb practically none of the incoming energy.*

5. One further possible objection to this system of shielding remains to be considered. Suppose that from some cause (which is so extreme as to be absurd and will never be encountered in practice) a variation was produced in the earth's field around the cage at radio frequency, say at $\lambda = 1{,}700$ meters or $\omega = 10^6$

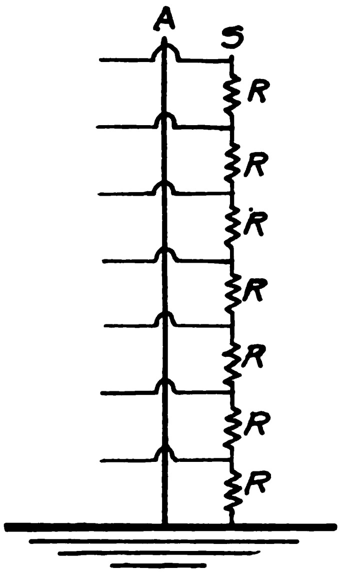

FIGURE 3—Dieckmann Shield. Side View

Suppose further that it corresponded to a potential difference between the top and the bottom of the grounding wires of 1 volt. Imagine further that the grounding wire resistance was 2,000 ohms and that of the antenna 10 ohms. We shall assume an antenna height of 30 meters (100 feet) and an average distance between the cage wires and the antenna of 30 cm. (1 foot). These strays will not affect the antenna directly, since their electrostatic field will merely cause currents to flow up and down the grounding wire without producing any electrostatic field variation within the cage, as indicated under (1) above.

We have taken the constants for this case as severely prejudicial to successful operation as could possibly be expected by bringing the grounding wire very near to the antenna itself.

We might expect, therefore, that the currents flowing up and down the grounding wire would magnetically induce similar currents in the antenna, thus permitting the excitation of the antenna by such variation of the earth's field.

A simple calculation will show, however, that the effect is negligible, even in this impossibly extreme case.

The mutual inductance between the two wires is 25 μh. If the 1 volt were applied to the antenna directly, since the antenna is resonant to the incoming frequency, we would have a current of 0.1 ampere flowing therein. In the grounding wire, also supposed resonant (tho aperiodically damped), there will actually flow 0.0005 ampere. This will induce in the neighboring antenna a current

$$i_2 = \frac{M \omega i_1}{R} = 0.00125 \text{ ampere.}$$

In other words, there is induced in the antenna approximately one one-hundredth the current and one ten-thousandth the energy which would be present were the antenna unshielded. Needless to say, in actual practice, this shielding effect would be vastly enhanced and the protection of the antenna by a Dieckmann cage of reasonably large dimensions would be practically perfect.

6. It remains then to explain the previous failure of experimenters in the radio field to eliminate strays. A brief consideration of Figure 4 and of Dr. de Groot's classification of strays clears up the question, as stated in the paper. Figure 4 shows the complete receiving system designed to eliminate strays. The two antennas A_1 and A_2 are each protected by a Dieckmann cage from strays of types 2 and 3, that is, those due to overhead rain clouds and cosmic bombardment of the Heaviside layer. Both these types of strays produce not periodic electromagnetic waves but extremely powerful increases in the potential gradient of the earth's field, but these are intermittent and unidirectional. As explained under (3) above, these disturbances will not reach the antennas. However, the strays of type 1, which are periodic electromagnetic waves originating in lightning storms, will pass thru. These will reach the antennas, but by means of the audio frequency compensation indicated, these periodic impulses can be balanced out leaving the signal still present.

It is important to remember that an essential feature of the system is to ground *aperiodically* all nearby conductors. Otherwise these will be set into vibration by variations in the earth's field and will radiate electromagnetic waves which will be of small damping and will get to the receiving antennas. The neglect of this precaution by all previous experimenters immediately renders criticism of this method by them on the basis of their experiments quite valueless since neighboring ungrounded or periodically grounded conductors would quite upset the proper operation of the system.

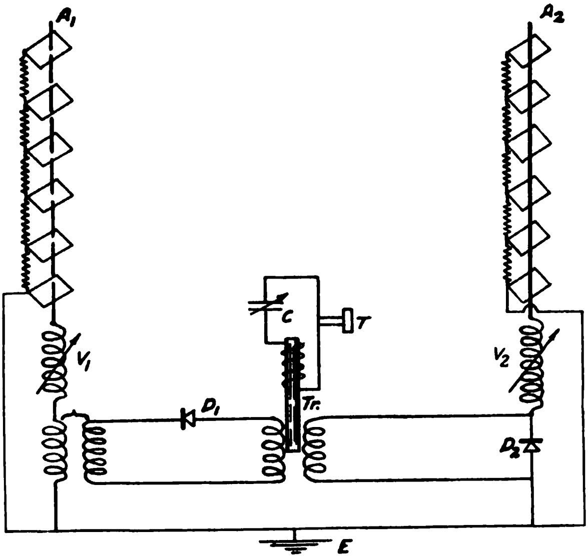

FIGURE 4—Complete de Groot Stray Eliminator, 1914

7. One further question should be considered. This is, why does one not use the audio frequency compensation method for all three types of strays instead of only for the periodic disturbances?

Light is thrown on this question by Figure 5. In the left hand side of the Figure, top curve, is shown an hypothetical sharp impulse lasting, say, 0.000,001 second (1 μs.). Its effect in the antenna A_2 which is aperiodic will last but little longer. On the other hand, its effect in the antenna A_1 will last for something like 150 μs. if the antenna A_1 is tuned to $\lambda = 1{,}000$ m. and has a decrement of $\delta = 0.1$. The magnetomotive force in the core of the differential transformer *Tr* will follow the curve labelled A_1—A_2 and will last 150 μs. It will therefore be responsible for a sharp click in the telephone receivers. No audio frequency compensation is therefore to be expected. If, however, the stray is of $\lambda = 10{,}000$ m. and of $\delta = 1.0$ (and large energy), it will last for approximately 180 μs. Its effect in the antenna A_2 will last approximately as long. Its effect in antenna A_1 will be not markedly different from that in A_2, and the differential magnetomotive force curve will be as indicated in A_1—A_2.

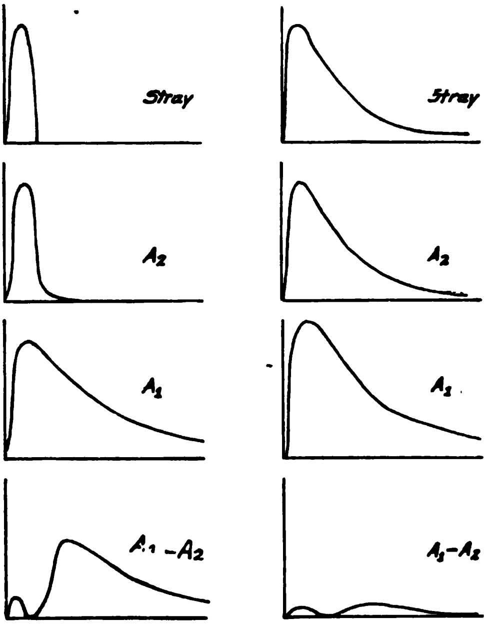

FIGURE 5—Envelope of Rectified Current

It will be noticed that the second magnetomotive force curve differs from the first in two respects: viz., that the maximum value is much less, and that the time rate of change thereof is much less. Consequently the resulting induced e.m.f. in the telephone circuit or secondary of the differential transformer will be extremely small in the second case as compared with that in the first.

It is probably some such considerations as these which have led Dr. de Groot to adopt audio frequency compensation only for reasonably periodic strays such as originate in lightning storms, and to eliminate sharp aperiodic strays by the shielding method. It is indeed fortunate that the latter type of strays have been found by experiment to be of the sort shown to be eliminable under heading (3) above.

Roy A. Weagant: Referring to the Faraday cage which Dr. Goldsmith has shown and which he states will be extremely effective in keeping both strays and the signal out of the antenna, I would state that obviously this cage is a simple vertical antenna and when acted upon by electromagnetic waves due either to strays or signal would have oscillatory currents flowing up and down it. This structure would have strong electromagnetic coupling with the antenna inside it and currents would of necessity set up in the antenna, so that both signal and stray would affect it.

4. Replying to Dr. Goldsmith again, I do not think it would make any difference whether this cage were aperiodic due to the insertion of high resistance or were capable of oscillating freely. If currents flow in it they will induce oscillating currents in the antenna itself.

5. Another point which apparently has not been covered in the papers which Dr. Goldsmith has referred to is the absorption of energy by the cage from the oscillating energy in the antenna. Assuming that the antenna has oscillating currents flowing in it, by reason of its coupling to the cage, energy would be extracted by the cage and probably to a very large extent.

6. There is another point which I would like to bring up and which none of the various explanations offered cover and which does not seem to be taken account of in the suggested methods of eliminating strays, viz., the very great increase of stray intensity as the wave length to which the receiving antenna is tuned is increased. I should be greatly pleased if anyone present could offer any explanation of this fact.

7. Is there any information indicating whether or not there is any peak in that effect.

8. The last statement of Dr. Goldsmith checks up with my own experience. There is a point in connection with Mr. Armstrong's reference to the heterodyne receiving method which I should like to amplify a little. Mr. Armstrong was a little modest in the way in which he stated the case. The heterodyne alone is not of any particular value in working thru strays. The really valuable thing is that method of using the heterodyne system which is embodied in Mr. Armstrong's invention of the regenerative circuits for the oscillating valve. The character-

istic of a vacuum valve when in the oscillating condition is such that its response to strong impulses is greatly reduced while its ability to amplify weak impulses is greatly increased. The result of this is that a valve in the oscillating condition may not give any louder response to a stray impulse than an ordinary crystal, while its response to a weak signal may be hundreds or even thousands of times greater.

Alexander E. Reoch: (by letter): I am not in the position to make any comment on Dr. de Groot's theory of the origin of strays, but the work he has done in determining the actual nature of the strays as received at the radio station is undoubtedly valuable.

As far as my information goes, the best method available for the elimination up to the present time is that recently patented by G. M. Wright of London, England, wherein the three-element valve is used with limited current-carrying capacity between the filament and the plate. The effect is that strays are reduced to the same strength as the signals. The balanced detector system also reduces the strength of strays to the strength of the signals, but in this case by opposing the audio frequency currents, whereas in the new arrangement the currents retain the radio frequency form, and can be further manipulated for increase of strength or reduction of damping so as to allow of further selection of signals from strays.

In the method suggested by Dr. de Groot for the elimination of periodic or Type 1 strays several difficulties arise. If the antennas are to be efficient as receivers, the distance between them will have to be very considerable or they will interact on one another, and the design of two antennas of the same size and wave length with different receptive properties as regards signals and both equally receptive to strays is by no means a simple matter. Assuming that in Figure 4, antenna 2 receives no energy from the signals (in which case there will be no opposing audio frequency current), half the energy which would ordinarily be available for the operation of the telephone from detector 1 will pass by means of the audio frequency transformer thru detector 2. This is a loss that has previously been encountered in efforts carried out along these lines to eliminate strays. It is quite serious, and unless special means are devised to prevent it, forms an objection of no small importance to this method.

The use of the Dieckmann cage seems to offer good promise, involving, however, some constructional difficulties.

The whole subject is one of extreme interest, and the difficulties encountered are by no means small. There seems to be little doubt that the nature of the strays will vary in different latitudes and with different climates. Whether their classification into Dr. de Groot's groups is possible at all parts of the world remains to be proved; and it seems more than likely that each locality will have its own peculiar type of strays requiring special treatment in each case.

Walter S. Lemmon: As regards the production of strays of the third class, by cosmic bombardment, would not the Heaviside layer shield the earth from such a disturbance, inasmuch as the Heaviside layer is a conducting surface completely surrounding the earth?

Alfred N. Goldsmith: We may assume that the actual burning up of the meteorites and the consequent production of strays takes place only when the meteor reaches denser (and therefore less conducting) layers of air than those in the Heaviside layer.

ADDITIONAL EXPERIMENTS WITH IMPULSE EXCITATION * †

By

Ellery W. Stone

(Assistant Radio Inspector, United States Department of Commerce)

In the June, 1916 issue of the Proceedings, the writer published a paper dealing with the design and operation of an impulse excitation transmitter. It is the purpose of this paper to set forth the results of some further experiments with this type of apparatus.

In the original paper, a hydrogen atmosphere gap of the modified Eastham-Peukert type, worked at considerably above atmospheric pressure, was described; and the various effects of gap speed, gap surface, and tone and antenna circuit absorption were set forth. In this paper, as in the last one, the term "impulse excitation" will be used to designate that form of shock excitation in which the antenna circuit is set into oscillation by a blow delivered from a rush of current in an adjacent aperiodic, or practically aperiodic, circuit as distinguished from the "beat" excitation of those quenched gap transmitters which make use of several current oscillations in the gap circuit before the antenna circuit is excited to free oscillation.

The writer has found it of assistance in the contemplation of impulse excitation to consider shock excitation in general to be divided into two regions of action, the one—impulse excitation, the other—"beat" excitation, using the definitions of these two terms given in the preceding paragraph. A transmitter which ordinarily might come in the one class, may, by the mere alteration of its spark gap, be placed in the other. That is to say, a gap circuit of high capacitance and low inductance, the action of which ordinarily places it in the "beat" excitation region, may be placed in the impulse region by the employment of one or more of a variety of artifices, and the reverse action may take place by the omission of the same.

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* Received by the Editor, September 1, 1916.

† See "Proceedings of The Institute of Radio Engineers," volume 4, number 3, page 233.

For instance, in the original paper, it was shown that when using the rotary quenched gap, with sectored surfaces, in air, impulse excitation could not be obtained. However, by the use of alcohol vapor at a pressure above atmospheric, this gap action could be brought well within the impulse region. The use of smooth gap surfaces brought it still further within this region and the use of a tone circuit shunted across the gap acted even more favorably. While the omission of any one of these aids to rapid damping of the current in the impulse circuit will still keep the action of the gap well within the impulse region, the use of all of them is desired.

HYDROGEN FIELD

With reference to the employment of the hydrogen atmosphere under pressure in the transmitter described in the original paper, the criticism has been made that too much time would elapse before the proper pressure could be built up, but this may be easily answered. In the first place, the use of the alcohol vapor is not essential to bring the gap action into the impulse region if smooth disks are used in the gap or if the tone circuit is used with either set of disks. But even when the sectored disks are used without the tone circuit, the pressure is built up within the gap just as rapidly as it is needed. Conductivity of the gaseous medium between the electrodes of any gap "is due mainly to the ions of the metallic vapor formed by the heating of the electrodes."[1] So long as the gap electrodes remain cool, and hence the surrounding medium, a high resistance, and therefore good quenching, will be maintained. Thus, at the start, when the gap is cold, the alcohol vapor under pressure is not needed to secure a high resistance. However, as soon as the enclosed gases begin to heat, the very heat which ordinarily would lower the resistance of the gap causes the increased pressure of the alcohol vapor, which raises the resistance.

That "the one action automatically compensates for the other," as stated in the original paper, has been repeatedly demonstrated. Using the sectored disks, the gap has been operated without the hydrogen vapor, causing the initial antenna current to drop rapidly 45 per cent. and more. The current drop is due to the fact that as the enclosed air heats, impulse excitation no longer takes place and the transmitter becomes merely a

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[1] From "Wireless Telegraphy," Zenneck-Seelig, page 98.

"beat" excitation, quenched spark transmitter, the gap and antenna circuits of which have widely different time periods. Upon admitting alcohol to the spark chamber, vaporization immediately takes place and sufficient pressure is made to cause the antenna current to return instantly to its normal value, indicating that impulse excitation is once more taking place.

COUPLING

The criticism was also made that the coupling between the impulse and antenna circuits in the transmitter previously described was not sufficiently close. Figure 5 of the original paper is herein reproduced as Figure 1. This illustration shows the inductive coupler. While the coupling between the two windings is close when considering the usual coupled circuits, it is in reality fairly loose for impulse operation, and the writer is grateful for this fact being called to his attention.

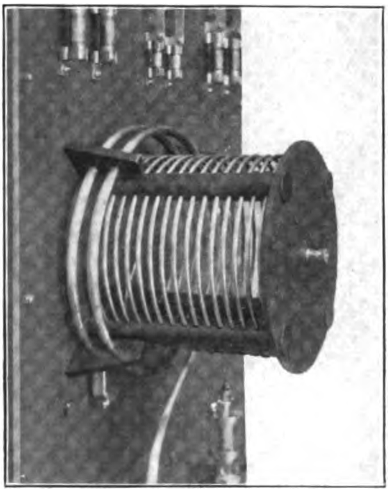

FIGURE 1

There are two methods by which the coupling between two circuits may be increased, one—purely mechanical, the other—electrical. The first is to increase the proximity of the two windings of the inductive coupler, the other is to make, as nearly as possible, all of the inductance in each circuit common to both. The latter limit would result in maximum coupling, but it is of course impossible to attain. The nearest approximation is to combine the usual antenna loading inductance with the antenna circuit winding of the inductive coupler, thus bringing all of the lumped inductance of the antenna circuit into the field of the impulse circuit. In addition, as much of the inductance in the impulse circuit as practicable should be designed so as to be effective in inducing energy in the antenna circuit winding of the coupler.

A reference to Figure 2, which shows the new coupler, will show how these two methods have been utilized. The impulse circuit winding of the coupler has been reduced to but one turn, and the condenser capacitance increased. In order to handle the momentarily high current amplitude, a special form of litzendraht has been made up, which is enclosed in a vulcanite tube for protection. The antenna circuit winding is wound spiral fashion on an insulating base and is arranged to swing directly into the single loop of the impulse circuit inductance.

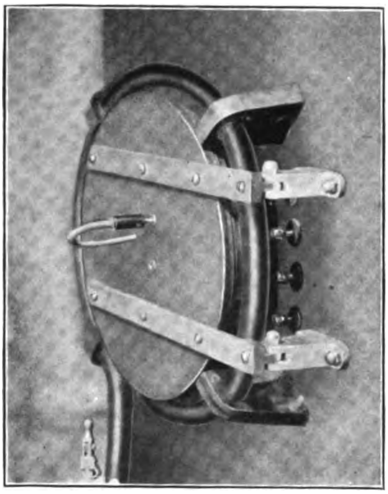

FIGURE 2

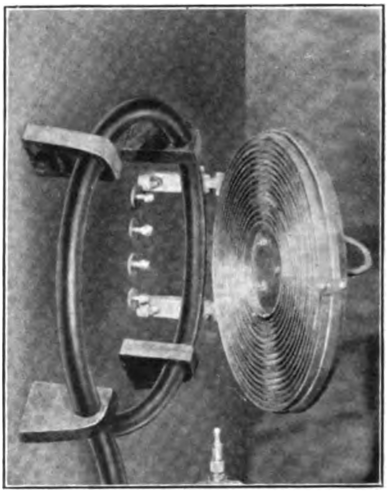

FIGURE 3

Figure 3 shows the antenna circuit winding swung back from its normal position in order to show the construction.

Due to the low potentials generated in the antenna circuit, the turns of the antenna circuit winding may be very closely spaced, thus securing enough inductance to obviate the necessity of loading inductance.

A plug with two sockets is shown, one for 600 meters, the other for 300 meters. The connections are such as to cut in a series condenser in the antenna circuit when the plug is inserted in the 300 meter socket.

The adoption of the new coupler resulted in a two-fold advantage, i. e., increased antenna current together with a lower antenna current decrement.

Figure 4 shows three resonance curves for various wave length settings of the antenna circuit with a fixed time period of the impulse circuit. Expressing this time period in terms of wave length, this was about 700 meters.

GAP LENGTH

The effect of gap length is of more than slight importance in the attainment of impulse excitation. Figures 5, 6, 7, 8 and 9 show resonance curves of the current in the antenna circuit for various gap separations, using the smooth disks. It should be borne in mind that, because of the construction of this particular type of gap, the actual spark length is twice the gap separation. The stationary disk is divided into two parts to which the terminals from the secondary of the step-up transformer are connected. The spark passes from one stationary electrode to the revolving disk and back from the disk to the other stationary electrode, thus making the total spark length twice the separation distance.

In each of these resonance curves, the logarithmic decrement given is the antenna current decrement; that is to say, the decrement as computed from the resonance curve minus the decrement of the measuring instrument.

From the curves, it will be seen that the best results are obtained when the gap length is as short as it is possible to make it. In actual practice, the revolving electrode is screwed up to the stationary one by means of the bearing shaft, which is threaded into the casing of the spark chamber, until the two touch. The bearing is then turned backward just enough to separate them from contact.

This is illustrative of one advantage of the revolving impulse discharger over the stationary one. To preserve such an exceedingly short distance with a stationary gap is somewhat difficult. The theory of the plane surface, short gap is that by providing large parallel surfaces, "wandering" of the spark may be effected, since as fast as the electrode is pitted, thus increasing

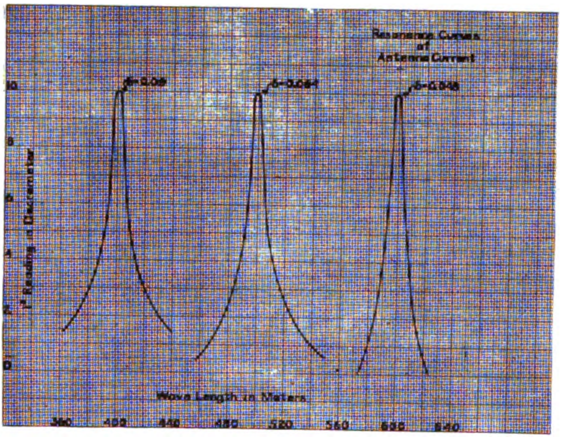

Figure 4

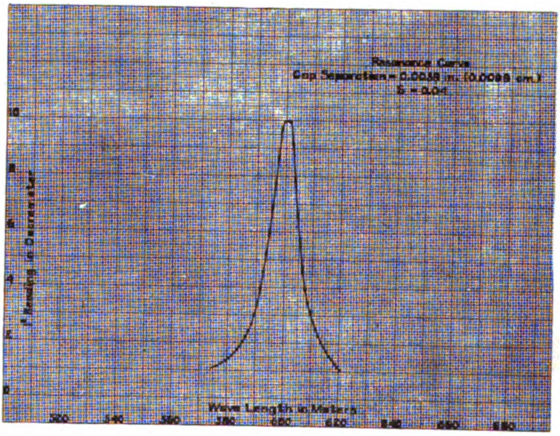

Figure 5

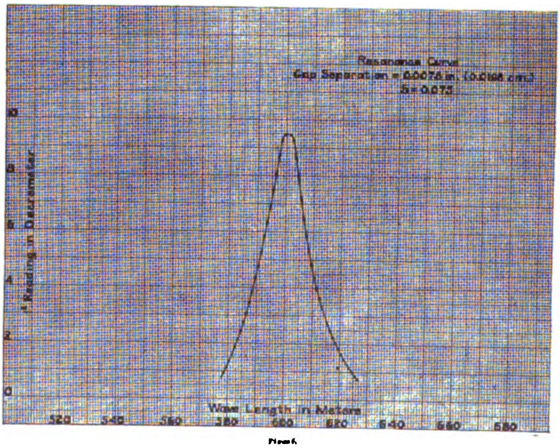

Figure 6

the gap length, the spark moves to a new and cooler position. This may work quite satisfactorily in ordinary quenched gap operation where the current amplitude in the gap circuit is not extremely high, but with impulse excitation and the consequent momentarily high current value encountered, burrs are very often formed on the gap surface. This prevents spark "wandering," and the action being cumulative, the gap soon becomes short-circuited.

With a revolving discharger, on the other hand, such effective "wandering" of the spark is obtained as to eliminate the formation of burrs and extremely low gap lengths may be employed without danger of fusion.

However, the use of a revolving discharger with a separation of the order of 0.004 inches (0.01 centimeter) necessarily entails extremely accurate lathe work. Roller bearings at each end of the bearing shaft and a system of facing up all surfaces have made the realization of such a short gap possible.

As set forth in the original paper, one of the chief requisites for high damping of the current in the impulse circuit is that the gap must rapidly regain its initial high resistance. That is to say, de-ionization of the gases between the gap electrodes must be effected as speedily as possible.

Zenneck discusses the various factors tending to bring about the de-ionization of spark gaps,[2] and concludes that such deionization is caused chiefly by the electric field between the gap surfaces and by absorption of the ions by the electrodes. It will be seen that the shorter the gap length, the more intense the electric field, and the more opportunities for absorption of ions by the gap disks.

The fact that a very short gap insures more rapid damping of the current in the impulse circuit than a longer one explains why better results were obtained with smooth instead of sectored gap disks as set forth in the original paper. The sectored gap, having projecting surfaces as in any rotary gap, causes the spark discharge to be drawn out, or the electrodes separated, as the projections pass each other, which is equivalent to using a gap of wider separation.

In taking the data for the curves in Figures 5, 6, 7, 8, and 9, the tone circuit was omitted for fear of puncturing the paper condenser in that circuit, due to raising the potential across the gap by the abnormal separation of the disks.

Figure 10 shows a curve of antenna current for the various

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[2] "Wireless Telegraphy," Zenneck-Seelig, page 97, *et seq.*

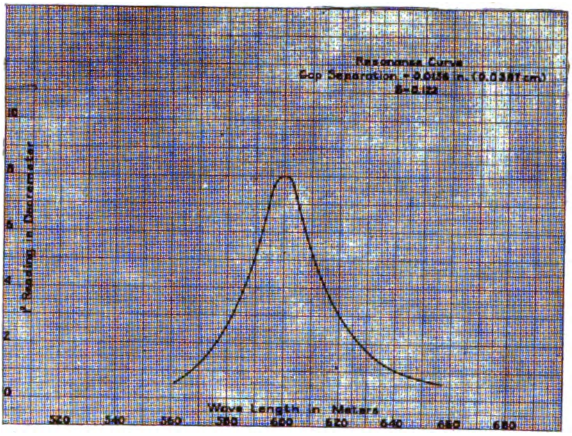

Figure 7

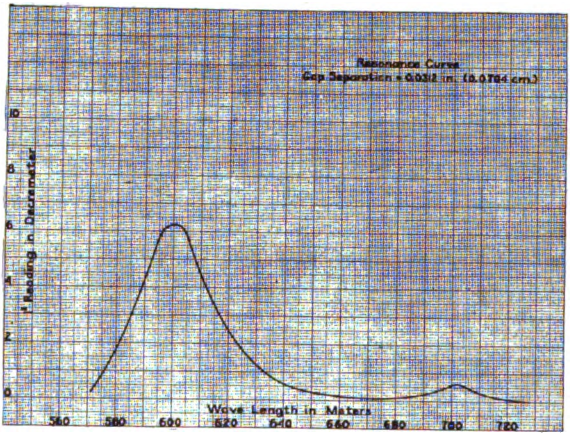

Figure 8

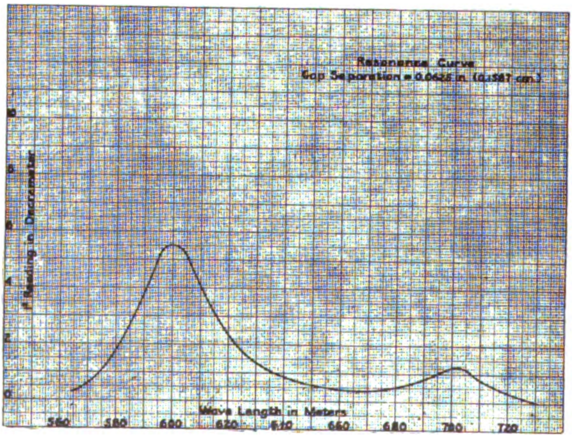

Figure 9

gap separations used in the preceding curves. It will be noted that while this current curve is a rising one with increased gap separation, the resonance curves in Figures 5, 6, 7, 8 and 9 successively decrease in amplitude. This is an excellent demonstration of the unreliability of aerial ammeter readings in damped wave transmission, at least, so far as the determination of effective energy for signalling purposes is concerned. Contrary to the action of the current indicating device in a decremeter, the aerial ammeter indicates the average integral effect of a large number of oscillations instead of the current amplitude at the oscillation frequency of the antenna circuit. Other things being equal, the higher the decrement of the antenna current, the greater the aerial ammeter reading—hardly a reliable method of measurement.[3]

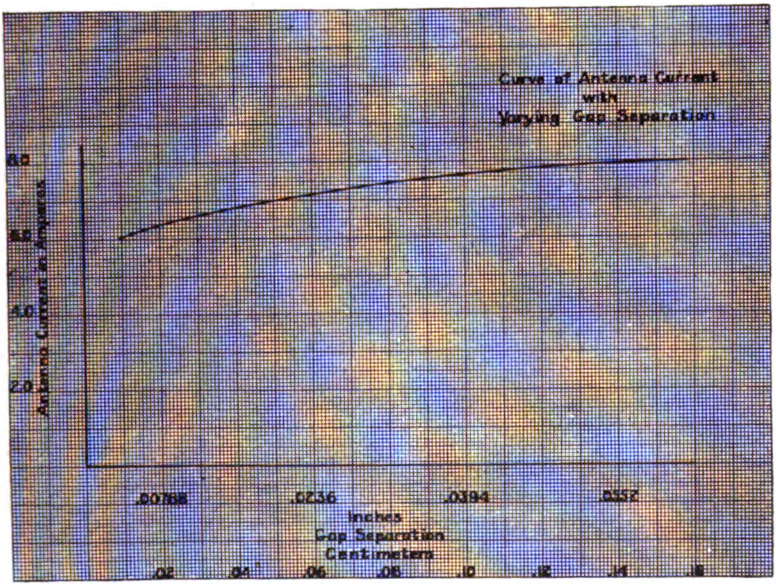

Figure 10

Tone Circuit

Figure 11 shows the schematic diagram of connections, the tone circuit being shunted across the impulse discharger. The condenser in the tone circuit is a paper one with fairly high

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[3] Cf. Discussion by J. Zenneck, "Proceedings of The Institute of Radio Engineers," volume 4, number 4, page 337.

capacitance. With this particular transmitter, signals are louder when received on crystal or audion (non-oscillating) detector when the tone circuit is used. However, because of the irregular impulse frequency and possible train interference in the antenna circuit, the note is not musical, altho possessing definite pitch. Mr. Eldridge Buckingham has found from experimentation with a Cutting and Washington gap on alternating current that, when using the tone circuit, the purest notes are obtained when the frequency of the tone circuit is some multiple of the supply frequency, or the group impulse frequency. This is in confirmation of one of the experiments described in the original paper in which the action of the tone circuit was noted when shunted across the sectored gap. "Certain speeds of the gap were found which tended to improve the tones greatly . . . . (These critical gap speeds were probably those which placed the impulse group frequency in resonance with the oscillation frequency, or a multiple thereof, of the tone circuit.)"

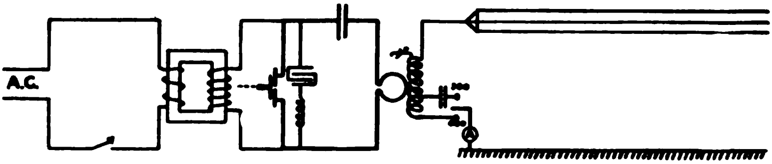

FIGURE 11

The use of a higher supply frequency would not tend greatly to improve the situation since it would not insure any more regularity of the impulse discharges. However, with a tone circuit adjusted to the same audio frequency as that of the supply current, say 500 cycles, favorable results should be obtained. Such an arrangement might seem unnecessary if it were not for the fact that the addition of the tone circuit secures greater telephonic response, altho with no actual increase of received energy, at the receiving end.

This is because, when omitting the tone circuit, the great number of partial discharges or impulses and their irregular spacing "tend to weaken rather than strengthen the effect upon the telephone diafram, as it may often not have time to return to its position of equilibrium and in any case is forced into extremely complex movements."[4] This is evidenced by the very

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[4] "Wireless Telegraphy," Zenneck-Seelig, page 198.

definite click heard in the receivers when the transmitter key is depressed and again when it is released.

This same lack of auditory response with crystal detector is encountered in arc operation. Here, the frequency is so high as to prevent the diafram from vibrating in its normal fashion, and it is simply pulled over toward the magnets and held there until the current flow ceases.

With the alternating current impulse excitation transmitter, the addition of the tone circuit, by the superimposition of its regular, audio frequency oscillations on the hissing impulse note, secures a more pronounced auditory effect.

The use of a sectored gap, properly milled, connected synchronously to the shaft of a 500 cycle generator, and with the voltage so adjusted as to give but one impulse per half cycle, has been suggested. This would undoubtedly produce a clear note without the use of a tone circuit. Whether the energy transfer between the impulse and antenna circuits would be as efficient with such a low impulse frequency might be questioned.

SUMMARY: After drawing a definite distinction between "impulse excitation" and "beat excitation," the writer considers broadly the conditions under which each of these is brought about.

In connection with a type of impulse excitation transmitter, there are considered the effect of a hydrogen atmosphere in the gap, the construction of the necessarily closely inductive coupler between spark gap circuit and antenna circuit, the effect of gap separation and "wandering" of the spark, and the effect of the tone circuit shunted around the gap.

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A STUDY OF HETERODYNE AMPLIFICATION BY THE ELECTRON RELAY*

By

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Part I

The purpose of this paper is to present the results of an experimental investigation of the heterodyne phenomena which occur in the oscillating state of the regenerative electron relay. The questions to be determined were first, the magnitude of the amplification produced by the presence of the local or auxiliary current, and second, the nature of this amplification and the factors which limit its extent.

In self-heterodyne circuits of the regenerative type there are, as the names indicate, two methods of amplification, and these occur simultaneously in the same circuit, each one operating in its own particular way and practically independently of the presence of the other to produce a total amplification proportional to the product of the two. On account of the rather involved nature of the various phenomena, the problem of separating the total amplification into its component parts by direct measurement is not simple and an indirect method is the easiest way out of the difficulty. In the light of our present knowledge concerning self-heterodyne circuits, there is no reason to believe that the magnitude of the heterodyne amplification obtained in these circuits should in any way differ from that obtained in an ordinary circuit with an external heterodyne. Hence by measuring the amplification produced in a simple audion circuit and then by measuring the total amplification produced when the same tube is provided with a regenerative circuit and used as a self-heterodyne, a general idea of the actual and relative magnifications of the two methods may be obtained.

This method of measurement was therefore adopted and the

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* Presented before The Institute of Radio Engineers, New York, October 4, 1916.

arrangement of apparatus was made according to the diagram of Figure 1. Referring now to this diagram, *M* represents the antenna circuit and *N* the closed circuit of an electron relay receiver which may be made regenerative by the opening of the switch *S*. The electron relay, which was of the audion type, was used as the detector and a condenser C_1 was included in the grid circuit in the ordinary way. On account of the high vacuum

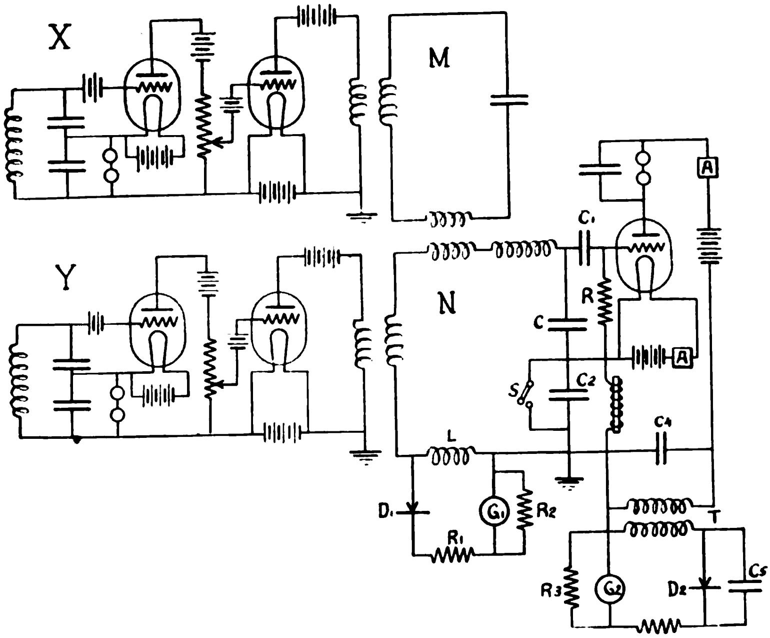

Figure 1

of the tube an auxiliary leak was required and a high resistance *R* was used between the grid and the negative terminal of the filament. The two systems *X* and *Y* represent the sources of signaling and local currents respectively. Each system consists of an oscillating electron relay arranged to excite a second relay, the input side of which was connected across a resistance located in the plate circuit of the oscillator. Energy is supplied to the receiver from the plate circuit of the second tube which acts purely as a repeater. This arrangement was adopted in order to prevent the amplification of the signaling current in circuit *N* by the regenerative action of the circuits of system *Y* which would occur with a direct coupling between the two. By using a one way repeater with the input side connected across a resistance in the plate circuit of the oscillator, this danger is avoided. The same arrangement was adopted in system X to prevent the relatively strong local current reacting in any way on the source of the signaling current. The relative amplitudes of the signaling and local radio frequency currents in the closed circuit were measured by means of a silicon rectifier D_1 and a galvanometer G_1. The combination was connected across a small inductance L one end of which was grounded. A shunt resistance R_2 across the galvanometer was used to vary its sensitiveness and a series resistance R_1 was used to compensate for changes in the total resistance due to adjustment of the shunt. The telephone current was measured in the manner described by Dr. Louis Austin* in a recent publication. A telephone transformer T separates the variable components of the plate current from its continuous component and a silicon rectifier D_2 and a galvanometer G_2 located in the secondary are therefore responsive only to changes in the plate current. To separate the audio from the radio frequencies, condensers C_4 and C_5 of 0.01 μf. each were connected across both the primary of the transformer and across the rectifier and as an additional precaution one end of the secondary of the transformer was grounded.

Both the silicon rectifier used for the measurement of the radio frequency and the silicon-arsenic rectifier which was used for the measurement of the audio frequency follow the square law in the lower part of their characteristics; that is, the rectified current is proportional to the square of the alternating current. The reading of the galvanometer G_1 is therefore proportional to the square of the radio frequency current in the circuit N. The reading of the galvanometer G_2 is proportional to the square of the audio frequency component of current in the plate circuit. The alternating current energy available for producing sound is likewise proportional to the square of the current and the reading of the galvanometer G_2 may therefore be taken as a direct measure of telephone signal strength.

In determining the amplification due to the heterodyne method a difficulty is encountered in continuous wave reception due to the fact that when the local current is not present there is no audible signal in the telephones. In order to obtain a tone a chopper must be used in some part of the receiving system. In the present investigation a chopper of the revolving commutator type was used in the antenna circuit and the square

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* In the "Proceedings of the Washington Academy of Sciences."

of the variable component of the telephone current taken as a standard of reference on which to base the relative strength of signal produced by the heterodyne.

The first series of measurements were for the purpose of comparing the signal strength obtained with a chopper and that given by the heterodyne when the local current was equal in amplitude to the signaling current. For convenience we may refer to this case as the "equal heterodyne," i. e., "equal other force." The conditions under which the comparison was made were the following: The signaling frequency was set at about 40,000 cycles and the frequency of the local current adjusted to a given beat tone approximately equal to the maximum frequency of interruption produced by the chopper. This was about 600 cycles per second. After a rough adjustment of the tuning and coupling of circuits *M* and *N*, the grid condenser C_2 and the auxiliary leak *R* were adjusted to give maximum response in the telephone. The values of capacity and resistance which gave this result were 0.0001 μf. and 2 megohms respectively. The time constant of the discharge of the grid condenser thru the leak is therefore about 0.0002 seconds. After this adjustment was completed, the local current was cut off and circuits *M* and *N* carefully adjusted until a maximum of current was obtained in circuit *N* as indicated by the maximum deflection of galvanometer G_1. These adjustments were held constant thruout all measurements in which the external heterodyne was used. The comparison was made over a wide range of signal strength and it was found that the equal heterodyne gave a signal which was from four to ten times as loud as that given by the chopper, the greatest advantage being on the weaker signals. The four fold amplification usually attributed to the equal heterodyne with respect to the chopper is fully realized but the ten-fold amplification was rather unexpected. The explanation is, however, a simple one, and will appear in the second part of the paper.

The second series of measurements were for the purpose of comparing the signal strength of the equal heterodyne and that obtained when the local current is increased to its critical value. This case may be referred to as the "optimum heterodyne." The results of these measurements are illustrated by the curve of Figure 2 which shows the relation between the amplification produced by the optimum heterodyne with respect to the equal heterodyne and the amplitude of the radio frequency signaling current. It is evident that the magnification varies over a very wide range and depends on some inverse power of the signaling current. On the strongest signals the response for the best adjustment of local current was only about one and a half times as great as that of the equal current; whereas, on the weakest signal, the response was increased fifty-five times and the shape of the curve indicated that this would be greatly bettered for still weaker signals. An amplification of several hundred appears quite probable. With the apparatus on hand, it was impossible to measure accurately a signal weaker than that on which the fifty-five fold amplification was obtained. The missing part of the curve presents an interesting field for further investigation with more sensitive measuring instruments. An idea of the strength of signal may be gathered from the fact that a shunted telephone test gave an audibility of about one hundred for the weakest signal on the curve. This measurement was made for the equal heterodyne and it is important to note that the method employed was to insert a second pair of telephones in series with the shunted pair and to take the square of

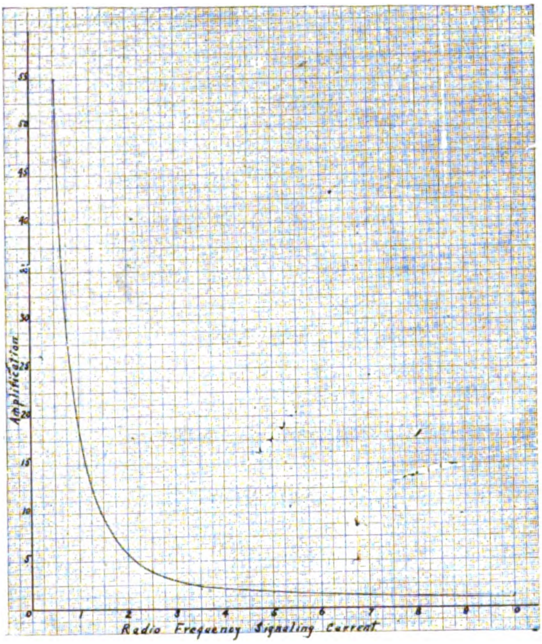

Figure 2

the expression $\frac{Z_T+R_s}{R_s}$ as the audibility. The justification of this procedure will be found in a contribution of L. Israel* which fully covers the present case.

The next series of measurements were for the purpose of determining the relation between the maximum signal strength obtainable with a simple electron relay with separate heterodyne and the signal obtainable when the same relay is supplied with a regenerative circuit and operated as a self-heterodyne. A large number of comparisons were made on a frequency of about 40,000 cycles. The results were extremely irregular due to the very critical nature of the adjustment of the self-heterodyne circuit but there was found to be an average amplification of about fifty times with respect to the signals produced by the external heterodyne. The delicacy of the adjustment may be gathered from the fact that even tho the tuning condenser of circuit *N* was provided with a handle a foot in length the slightest touch would frequently produce a change of 100 per cent. in the deflection of the galvanometer G_2. In addition to the arrangement of Figure 1, other forms of regenerative circuits were used, including the magnetic coupling and the particular form of static coupling illustrated in Figure 3 which has been termed in some quarters the "ultraudion connection." In spite of the claims by the patentee that it cannot be a regenerative circuit, and his explanation of the method of operation (which, by the way, involves perpetual motion),* this arrangement regenerates very effectively with a good bulb, and gives an amplification about fifty times greater than the simple connection with external heterodyne.

In summing up the total amplification obtained in the regenerative oscillating relay as compared to the signal obtained with the same relay in a simple circuit with a chopper, we find, taking average values, a multiplication of about five times by the equal heterodyne; a further magnification of at least twenty times by the optimum heterodyne, and lastly a fifty fold magnification by the operation of the regenerative circuit making a total of approximately 5,000. This figure has been checked by direct measurement and on weak signals even greater amplifications have been obtained.

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* "PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume 3, 1915, page 183. It should be noted, however, that as a high vacuum tube was used, changes in the resistance of the plate potential by adjustment of the shunt will not affect its sensitiveness. The sole object of the extra pair of telephones was to maintain constant the impedance of the plate circuit for the audio frequency current.

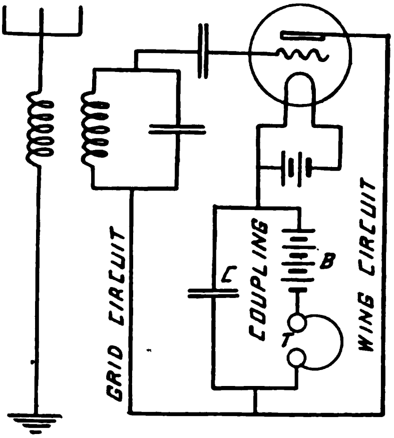

FIGURE 3

PART II.

THE NATURE OF THE HETERODYNE PHENOMENA

Several writers have treated the heterodyne phenomena mathematically,* but on account of various difficulties which arise, none of the treatments have been rigorous. When the special case of the current rectifier type has been considered it has been largely on a basis of physical reasoning. Without entering into details of the operations employed in getting at results, we may consider the conclusions arrived at by the various writers. They may be divided into two general classes, one of which supports the view that the amplification which may be obtained is, theoretically, unlimited, the practical limit being determined by the disturbances produced in the receiving system by the local frequency and the current carrying capacity of the detector. The second theory, which is that due to

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* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS," volume 4, 1916, page 266. Discussion on paper by Dr. L. W. Austin entitled "Experiments at U. S. Naval Radio Station, Darien." de Forest states "the circuit cannot be regenerative," and that the manner of operation is such that "a sudden change of potential impressed on the plate produces in turn a change in the potential impressed on the grid of such a character as to produce, in its turn, an opposite change of value of potential on the plate, etc. Thus the to-and-fro action is reciprocal and self-sustaining, etc." And all this self-sustaining to-and-fro action between grid and plate goes on (according to de Forest) *without any energy being supplied to the system!*

Also Hogan, "Proc. I. R. E.," July, 1913.
Cohen, "Proc. I. R. E.," July, 1913; June, 1915.
Liebowitz, "Proc. I. R. E.," June, 1915.
Latour, "Elect. World," April 24, 1915.

Liebowitz, states that the maximum true amplification due to the heterodyne is four; that this is obtained when the local current is equal in amplitude to the signaling current, and that any further increase in response which may be obtained by an increase in the local current is due to an improvement in the efficiency of the receiving apparatus and is governed by the usual limit in such cases, namely 100 per cent.

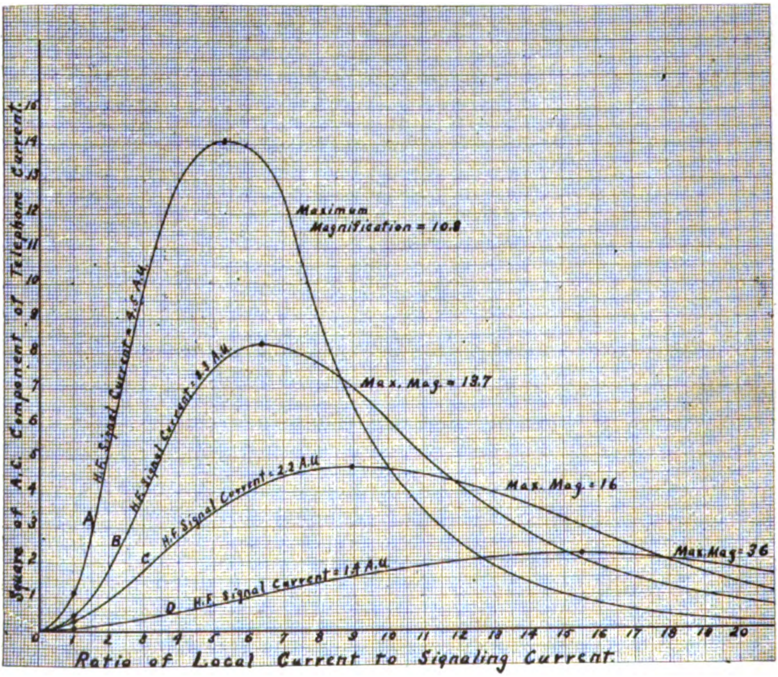

FIGURE 4

From an experimental standpoint, the key to the true nature of the phenomena would appear to lie in what may be termed the "heterodyne characteristic"; that is, the relation between telephone signal strength and the ratio of local to signaling current. A number of these characteristics for various values of signaling current were therefore obtained and the results are shown graphically in Figure 4. The ordinates of these curves represent the available energy in the telephones for producing a tone and the abscissa are in terms of the ratio of local to signaling current. It will be observed for all four values of signaling current that an increase in the ratio of the local to the signaling current beyond the one-to-one point produces a very rapid increase in telephone signal strength which continues up to a certain maximum value. The maximum is maintained for a limited range and then the curves fall off and gradually approach zero value. This is the typical heterodyne characteristic for the current rectifier and the explanation of the phenomena attending the rise and fall of these curves should definitely determine the nature of the amplification.

The rapid rise in the curve as the local current is increased beyond the one-to-one point will be found in the shape of the rectifying or valve characteristic of the relay. In relays of the audion type, this characteristic is the relation between the gird voltage with respect to the filament and the grid-to-filament current. The curve of Figure 5 shows this relation for the relay which was used in obtaining the curves of Figure 4. The grid current is the actual conduction current flowing between grid and filament, and it is on the amplitude of this current that the value of the cumulative charge in the grid condenser depends. The curve may be divided into two parts, the upper section of which is practically a straight line and the lower section of which

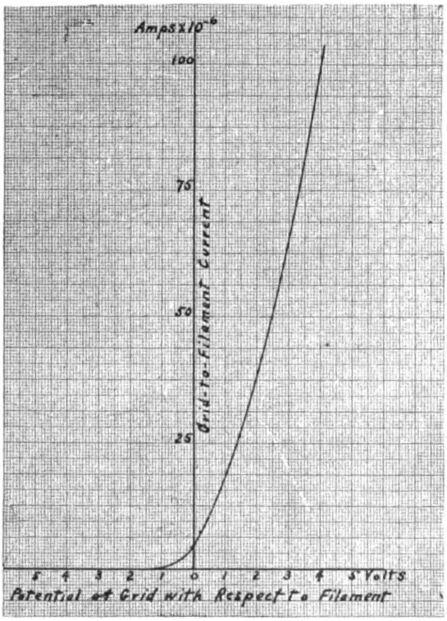

FIGURE 5

is curved in such a manner that the ordinate is proportional, approximately, to the square of the abscissa. On account of this curvature, a difference exists between the conditions of operation of the equal and optimum heterodyne. A graphical representation of these conditions is given by Figure 6. In case (*A*), which shows the equal heterodyne a local voltage of amplitude *V* is continuously applied and maintains a continuous

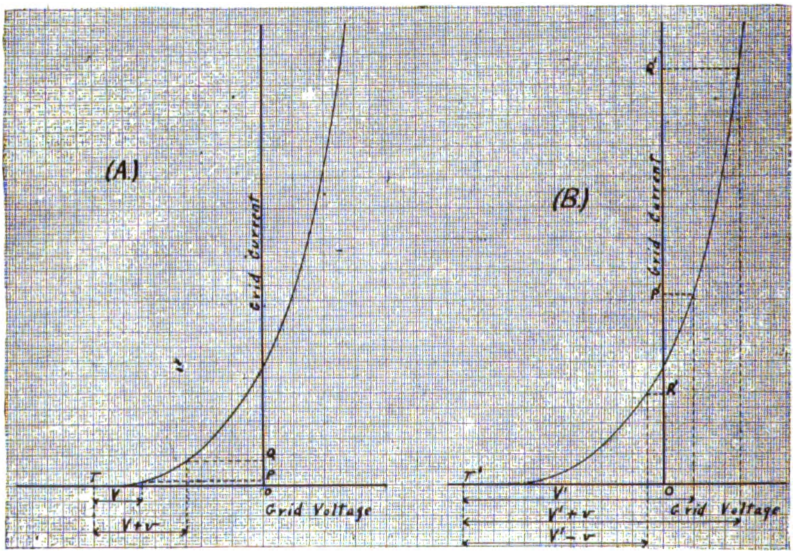

FIGURE 6

negative charge on the grid of some potential *T*. The value of the steady charging current is proportional to *O P*. When the signaling voltage *v* is superposed, we get, for the additive state a total voltage of $(V+v)$ and the charging current becomes proportional to *OQ*. For the opposing state the voltage $(V-v)$ is equal to zero and the charging current is consequently equal to zero. The total variation of the grid condenser charging current, and hence the variation in the average value in the average value of the grid potential, is between *O Q* and zero. The conditions of the optimum heterodyne are those illustrated by (*B*). A local E. M. F. of amplitude *V′* many times greater than the signaling voltage *v* continuously maintains the average value of the grid potential at some negative value *T′*. The steady value of charging current corresponding to *V′* is proportional to $O' P'$. When the signaling E. M. F. is superposed for the voltage (V^1+v) the charging current is given by $O' Q'$ and for $(V'-v)$ by $O' R'$. The total variation in charging current is therefore proportional to $(O' Q'-O' R')$ or to $R' Q'$ which is obviously very much greater than the variation $O Q$ in the charging current for the equal heterodyne.

It must be here stated that the foregoing analysis must not be taken too literally as to quantitative results. Tendencies only are represented and these are limited by certain factors which will now be taken into account. The most obvious limit to an ever-increasing amplification by increase of the local current even if the valve characteristic followed the square law thruout is the counter E. M. F. of the grid condenser. The variation of the average value of the potential difference across this condenser can clearly never exceed the variation in amplitude of the beat voltage across the tuning condenser to which the relay is connected. When the efficiency of rectification is poor, as it is on the lower part of the characteristic, the counter E. M. F. of the grid condenser is negligible in comparison with the resistance reaction of the value. As the efficiency of rectification is improved by means of the local frequency, the back E. M. F. of the condenser becomes the dominating reaction of the circuit and definitely limits the variation of the charging current. The phenomena are almost identical with the action of the electrostatic telephone and coincides exactly with the theory of Liebowitz. In the case of the electrostatic telephone, the increase in the efficiency as the local current is increased produces a greater amplitude of vibration of the diafram. This in turn produces an increase in the counter E. M. F. of the telephone which reduces the amplitude of the signaling current and consequently the variation in amplitude of the beat current. In the vacuum valve, the same increase in efficiency is obtained until the resulting increase in the counter E. M. F. of the part of the apparatus on which the work is being done (in this case, the grid condenser), definitely limits further amplification.

The fall of the curves of Figure 4 are apparently due to the overloading of the tube by the local current. The steady value of the grid condenser charge maintained by the local current gradually cuts down the plate current as the ratio of local to signaling current increases. This interferes with the relay action of the tube; and finally, when the plate current is reduced to zero, renders it entirely inoperative. This form of overloading may be compensated for in the manner shown in Figure 7 by means of an auxiliary battery in the grid circuit which makes it possible to maintain the plate current at its normal value. The effect of this auxiliary voltage in compensating for the grid charge is shown by the two curves of Figure 8. Curve A was taken with the arrangement of Figure 7 while curve B was taken in the same manner as the curves of Figure 4. The curves are self explanatory in this respect. It will be noted, however, that curve A, even when the effect of overloading of grid condenser is removed, eventually shows a tendency to fall off. This is undoubtedly due to another form of overloading, caused by the radio frequency variations of the grid potential overrunning the straight part of the grid potential-plate current characteristic and thereby interfering with the audio frequency repeating action. It is difficult to determine from the heterodyne characteristics of Figure 4 whether the peaks of the curves indicate a maximum of efficiency of rectification or the beginning of the overloading of the tube. The shape of the curves indicate the latter especially on the stronger signals, but it is in any case immaterial whether the limitation of apparatus or method predominates in present-day practice. It is entirely clear that outside of the four-fold amplification of the equal heterodyne, any further amplification by increase in the local current is purely a question of improvement in efficiency.

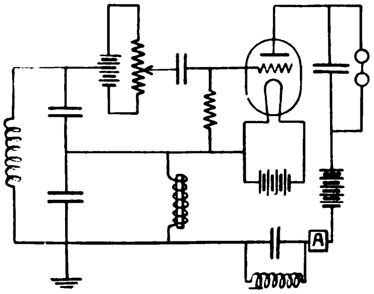

FIGURE 7

One of the remarkable features of the curves of Figure 4 is the very rapid increase in the telephone signal strength for a relatively small change in the local current. In the case of curve A, the change from the equal heterodyne to the two-to-one ratio gave a response in the telephones four times as great as for the one-to-one ratio. The reason for this will be found in the energy relations in the tube with respect to the radio frequency current. The rectifying characteristic shows that the charging current of the grid condenser and hence the grid potential is proportional to the square of the radio frequency current. The useful telephone current is proportional to the change in potential of the grid and hence to the square of the radio frequency current. The energy in the telephones available for producing a tone is therefore proportional to the fourth power

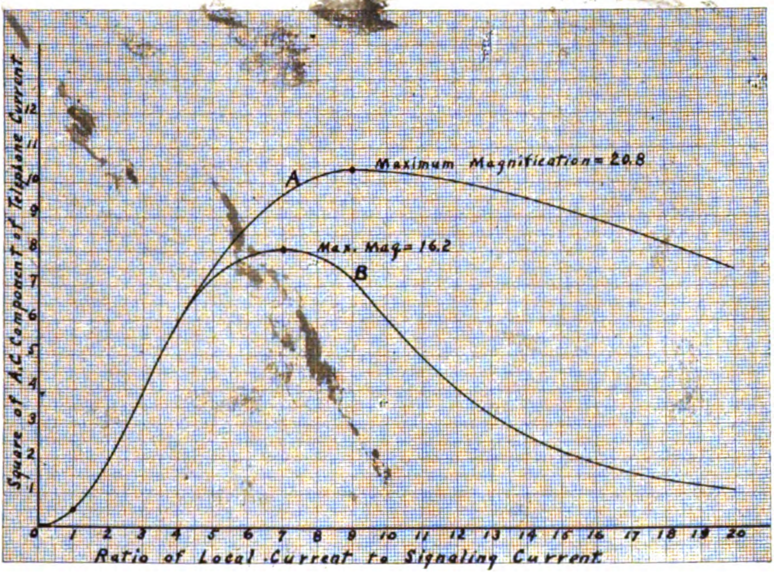

FIGURE 8

of the radio frequency current. In the case of the equal heterodyne, the variation in amplitude, assuming unity value of signaling current, is between 2 and 0, and for the 2:1 ratio it is between 3 and 1. The relative telephone currents are therefore proportional to 2^2 and (3^2-1^2) or to 4 and 8. The relative telephone signals are according to the square of these values or in the ratio of 1:4. This corresponds almost exactly with the experimental result.

The shape of the valve characteristic also explains the interesting fact discovered by Dr. Austin,* that the plate current is proportional to the second power of the radio frequency current in the non-oscillating state but to the first power in the oscillating state. In the non-oscillating state, the rectification takes place

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* "Bulletin Bureau of Standards," **11**, 77, Reprint 226, 1914.

on the lower part of the curve where the square law holds (with reference to zero current). In the oscillating state the operation takes place on an upper part of the curve which, for small changes of potential is practically a straight line.

It is evident from this that a regenerative receiver in the oscillating state delivers to the telephones an amount of energy which is proportional to the energy of the radio frequency current in the antenna. The relative amplitude of stray to signaling current in the telephones is therefore independent of the size of the antenna, and barring physiological effects and the possibility of overloading the tube, the readableness of signals should also be independent of antenna size. In ordinary practice this seems to be the case.

In the non-oscillating state the first power proportionality between antenna and telephone energies is maintained only for strong signals. For weak signals or even moderately strong signals the telephone current is proportional to the square of the antenna current. This means that in the working range the telephone energy will fall off very rapidly with a decrease in antenna energy with the result that the smaller the antenna the greater the ratio of the intensities of strays to signals in the telephones. Hence it follows that the larger the antenna the more readable the signals.

The relative effect of antenna size on readability of signals is well illustrated by experiences in the reception of the continuous waves of Nauen and Eilvese and the damped waves of Glace Bay at stations in the vicinity of New York. It is a well known fact that on a small antenna the German stations give more readable signals thru strays than the Glace Bay station. On a large antenna the conditions are reversed and the Glace Bay signals are by far the best.

In conclusion, the writer wishes to state that this paper does not pretend to be in any way an exhaustive treatment of the heterodyne phenomena. Only the outstanding features have been considered, but it is believed that it has been established from an experimental and physical basis that there is a very definite limit to the amplification which can be produced by the heterodyne action. The analysis of the mechanism of the amplification occurring in the electron relay receiver supports in every respect the conclusions of Liebowitz.

SUMMARY; The amplifying action of the regenerative oscillating electron relay is carefully studied. It is found, by separation of the various effects, that there exist three distinct types of amplification. The first, or ***equal heterodyne*** type, occurs when the local oscillating current is equal to the signaling current. The second, or ***optimum heterodyne*** type, occurs when the local oscillating current is increased to the critical value for maximum response. The third, or ***regenerative*** type, results from the amplifying action of the relay and its associated circuits. The roughly approximate numerical values of the three types are five-, twenty-, and fifty-fold, making a total amplification of five thousand times or more.

The mechanism of these phenomena is considered in detail with especial reference to the limitations of each process.

DISCUSSION

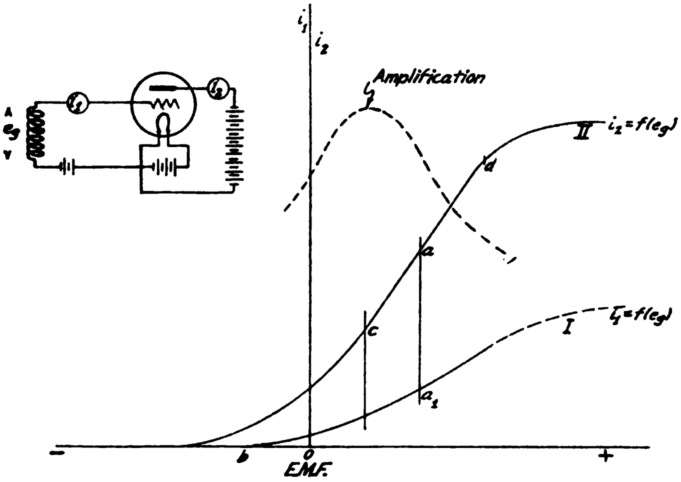
C. J. De Groot (by letter): Mr. Armstrong's paper has made quite clear numerous matters of interest. He has shown how many functions the vacuum amplifier may have independently and simultaneously when used as a beat receiving device of the internal heterodyne type. He has shown further how astonishingly large may be the amplification of signal thus produced by these simultaneous functions as compared to plain reception with a detector valve or tikker. The separations of these different functions and a determination of the amount which each contributes toward the total amplification including the values which have been checked by direct measurement, have indeed been thoroly planned and well executed.

There is one point for which I would submit an explanation of my own for the consideration of the speaker. This is the limitation of amplification which is found to occur for strong local currents.

Instead of showing, as did Mr. Armstrong, the filament-to-grid characteristic, should we not rather show simultaneously two characteristics, namely the following: the filament-to-grid characteristic and the filament-to-plate characteristic. Let us suppose that the E.M.F. of both the filament heating battery and the plate circuit battery to be constant, and give these the values V_1 and V_2. Let us alter only the E.M.F. between the filament and the grid and plot the grid and plate currents as functions of this applied E.M.F. Then the two characteristics have the general shape shown in the Figure. The function of the local current is firstly to produce beats (and there is no advantage in this regard in going beyond the *equal* heterodyne), and secondly to work at a local current which brings us to the most favorable part of the characteristic for amplification.

If then we take into consideration only curve II of the Figure, we reach the conclusion that we should supply the amplifier with a local current corresponding to the point *a* of the curve, since for this part of the curve $\frac{d i_2}{d e_{gr}}$ is a maximum, and therefore the current change (or amplified signal) is greatest for a given change in E.M.F. (or incoming signal).

On the other hand, we see from curve II that working at this point implies a certain current i_1 in the grid-to-filament circuit, and this current involves a *loss of energy* in its passage thru the resistance of the circuit. Thus part of the input will be absorbed. Since we desire a maximum amplification we must search not only for the condition where the output is a maximum (i.e., the condition corresponding to point *a*) but for the condition whereby this large output is attained by the smallest possible input and the condition, therefore, for which output divided by input is a maximum. Now, since the output



is a maximum near *a* and the input a maximum near *b*, it follows that the maximum amplification will be secured for a point somewhere between *a* and *b*, say at *c*. This condition will be reached whenever the tube is so adjusted that it works at what has been called the "optimum heterodyne." For more powerful locally generated oscillations we have to work at those points of the characteristic curve which require a considerable expenditure of input energy in the grid-to-filament circuit, and the efficiency of the device (output divided by input) is diminished. In consequence, we explain the results shown in Mr. Armstrong's curves in Figures 4 and 8 as follows: As we increase the strength of the local oscillations past the point of equal heterodyne, we cannot improve the beat production but the amplification increases because the larger local oscillating circuit (when considered in conjunction with the tube characteristics) brings us to the point *a* where $\frac{d\,i_2}{d\,e_{gr}}$ is a maximum. A second reason is that $\frac{d\,i_2}{d\,e_{gr}}$ increases to the point *a* after which it falls again, and there should result a decrease of amplification beyond the point *a*. This decrease is emphasized by the fact (seen from curve I) that the larger the local oscillating current, the larger $\frac{d i_1}{d e_{gr}}$ that is, the greater the waste of input energy, $(d i_1)^2 r$, for the same incoming signal, $d e_{gr}$. A third reason for the decrease of amplification may be the fact, stated by Mr. Armstrong himself, that even working at the most suitable point of the curve (*c*), a strong signal may exceed the limitations of the characteristic curve II, thus giving a $\frac{\Delta i_2}{\Delta e_{gr}}$ smaller than the $\frac{d i_2}{d e_{gr}}$ for infinitesimal signals at *c*.

We should keep in mind that, for reasons of convenience, we have used static characteristics (as also did Mr. Armstrong) tho, strictly speaking, dynamic characteristics should be used.

The method of shifting the maximum amplification to points of higher local oscillating current as shown in Figure 8 of the paper is readily explained by the considerations here given. The steady E.M.F. applied in the grid-to-filament circuit, which is there recommended, displaces curve I horizontally relative to curve II, so that the point *b* of curve I is brought below point *a* of curve II. We can therefore work the system nearer the point *a* which is the point of maximum amplification. In this case the amplification should be quite independent of the signal strength as long as the signals added to the local current do not run beyond the portion *cd* of the curve II. For stronger signals a decrease of amplification will occur because of the general shape of curve II.

Edwin H. Armstrong (by letter): Dr. de Groot has raised a very interesting point concerning the factors which limit the amplification obtainable by the optimum heterodyne. It is in line with the explanation of Liebowitz when the electrostatic telephone is the detecting agency; viz.: that the increase in efficiency of the detecting apparatus as the auxiliary current is increased creates a counter E.M.F. or an increase in the effective resistance of the circuit to which it is connected. I expected to find that this increase in effective resistance of the main circuit would be the most predominant factor in limiting the amplification obtainable by the optimum heterodyne and was exceedingly astonished to find that the effect was a relatively unimportant one.

This was readily determined with the arrangement of Figure 1 and the experiment was made in the following way. With condenser C_2 short-circuited to eliminate the regenerative feature and with a predetermined value of signaling current, the equal and optimum heterodyne telephone currents were measured. A resistance of 5,000 ohms was then introduced into circuit N between the loading coil of the circuit and the coupling coil connecting it with the antenna. The signaling current was restored to its initial value by increasing the power of the system X, and the equal and optimum heterodyne currents again measured. Little difference was observed in the amplification obtainable with the low resistance circuit, which measured about 300 ohms and the high resistance circuit which was approximately 5,300 ohms, and this, in itself, is conclusive evidence that the effective limitation is not due to an increased resistance in the main circuit. Further investigation developed that the predominant limiting factors lie along those lines presented in the paper.

The result was so unexpected that some further experiments were made with a view of determining, if possible, the reason for the absence of the phenomena so clearly brought out by Dr. de Groot. While lack of opportunity prevented a complete investigation, the reason appears to be in the fact that the relay, which was of the same structure as the standard de Forest audion, did not fit efficiently into the circuit to which it was connected. The relay contributed only about 15 per cent. of the total effective resistance of the circuit, and it was hardly possible to improve this very much and still keep the capacity across which the relay was connected at a reasonable value. About 0.0004 microfarad was normally used, which is, perhaps, as low as good commercial practice permits. As a consequence of this low efficiency, other factors exert their influence upon the maximum amplification before the increase in efficiency of the detector produces any noticeable effect. The practical significance of this is that the tube used was ill adapted to fit into ordinary commercial circuits, and that a larger tube could be more efficiently used. Aside from the relative magnitude of the effect indicated by Dr. de Groot, I am entirely in accord with the points he has so clearly presented.

Carl Ort (by letter): The paper under consideration constitutes a very thoro investigation of the so-called "heterodyne" receivers, and shows that this system, when used in conjunction with a rectifying detector, operates on an entirely different principle from that explained by Messrs. J. L. Hogan, Jr., and L. Cohen. Professor Fessenden first used a sustained wave oscillator for the purpose of producing beat tones in the receiver. As far as the patent literature or other publications indicate, he used an electromagnetic receiver; and later, when it was shown by Mr. Rieger and myself that the electrostatic receiver could be made very sensitive by proper construction (see articles on condenser receivers in "Elektrotechische Zeitschrift," 1909, page 655 and "Archiv für Elektrotechnik," 1, 1912 page 192) he replaced the electromagnetic receiver by an electrostatic one with much success. Mr. Lee and Mr. Hogan later replaced the electrostatic receiver by a crystal detector (See the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1, July, 1913, and U. S. patent 1,141,717) with the result that much higher sensitiveness was obtained than with any previous receiving system. Messrs. Hogan and Cohen explained the large amplification by assuming that the process amplifies the received antenna energy, and that the crystal detector rectifies merely this amplified energy. But it was shown by Mr. B. Liebowitz that the maximum amplification of this combination should be 4. (See the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 1915, page 185). Mr. Armstrong's experiments have shed new light on these phenomena and have indicated that the amplification obtained with a rectifying detector depends on the energy of the local oscillations which are applied to the detector, and that while the energy received is not magnified at all, the sensitiveness of the detector is increased. This increase is independent of the frequency of oscillation of the local source.

It may be of interest to describe some experiments which I began in December, 1912, in a small town in Austria. At the time I was carrying on radiophone experiments, using a small Poulsen arc as a transmitting source. One day it happened that I received not only the speech from my arc station but also the noon time signals of the German Post Office station at Norddeich. This latter station was distant from my home about 380 miles (600 km.), the entire distance being over mountainous land. Two things struck me at once. To begin with, I was impressed by the great distance over which I was receiving with my small antenna, this being only about 30 feet (9 m.) high and about 90 feet (27 m.) long. Furthermore, I noticed that the tone of the signals received with a crystal detector was no longer musical but resembled that obtained when a tikker was used. (The Norddeich station sends out noon signals with a 10 K. W. Telefunken quenched spark transmitter, with a 1,000 cycle note). Later I investigated the latter phenomenon, applying sustained oscillations directly to the detector, and found that the amplification was due to the increase of sensitiveness of the detector. Every integrating (rectifying) detector showed this characteristic. I found that the amplification could be obtained with any frequency not audible to the human ear. The limit of amplification was determined by the maximum impressed voltage of sustained radio frequency at which the detector burned out. I was able to obtain amplifications of about 20-fold. In order to explain this effect, I applied the polarisation theory given for the condenser receiver (as cited above), stating that the amplification was proportional to $(i_1+i_2)^2=i_1^2+2\,i_1\,i_2+i_2^2$ where i_1 is the received current and i_2 the local current produced in the detector circuit by the local source of sustained oscillations. I called this phenomenon the "polarisation of integrating detectors" because every detector with a rectifying characteristic can be polarised in this way by applying a polarisation radio frequency sustained voltage at its terminals. For this reason the latter term may be applied to this method in place of the "equal and optimum heterodyne" designation used by Mr. Armstrong. From the very beginning of my experiments I considered the production of beats by this method when used for receiving sustained oscillations as a natural consequence. However, it is not at all necessary to produce beats for receiving sustained oscillations when this method is used with equal frequencies and an Einthoven thread galvanometer is used as an indicating instrument. The same amplifying effect is then obtained, and I do not see any reason why it should be called a "heterodyne" method in this case. The same amplifying effect can be used at equal frequency for radio telephony.

It is unnecessary for me to explain the great advantages of the "polarised integrating method" because they are very well known to the readers of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. The purpose of this communication is merely to indicate my part in the development of this method. Mr. Armstrong's paper and Mr. Liebowitz's conclusions verify the conclusions which I drew from my observations four years ago, but could not publish for patent reasons and because of war conditions abroad.

Edwin H. Armstrong (by letter): As Mr. Ort points out, the function of the auxiliary circuit, when carried beyond the "equality of current" stage, is a polarizing one, and in the present case the phenomenon referred to as the optimum heterodyne is that of a polarised integrating detector. The terms "equal and optimum heterodyne" were used purely for purposes of convenience of reference, and if more suitable terms be suggested, we should, of course, employ them. In view of Mr. Ort's proposals, I would suggest that the matter be taken under consideration by the Committee on Standardization of THE INSTITUTE OF RADIO ENGINEERS.

Lee de Forest (by letter): I doubt if the simplicity of Mr. Armstrong's explanations of audion phenomena is satisfying to those who have extensively experimented with the audion.

For example, readers of his previous paper on the audion might well be satisfied with his theory of the rectification phenomena which obviously *must* there occur—until there transpires the simple experiment of making all three audion electrodes incandescent! The fact that the audion action is thereby unaffected, while the Edison hot-to-cold rectification is made impossible is yet to be explained by the advocates of the Fleming valve theory.

Similarly, in criticism of the too simple explanations advanced in the present paper, an easy experiment with the incandescent grid shows that the ultraudion amplifying processes are unaffected. And it is well known that with the proper audion and "wing-and-grid" oscillating circuits, a grid-charging or "*C*" battery is unnecessary to obtain a maximum efficiency detector of sustained oscillations.

These are experimental facts and not theory, and Mr. Armstrong must search more deeply before the ultimate explanation of audion phenomena is revealed.

This writer has sophistically misinterpreted my discussion on Dr. Austin's recent paper (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 4, number 3, page 266). There is nothing therein contained to lead any one to suppose that I am an advocate of the unconstitutionality of the law of the conservation of energy.

Edwin H. Armstrong (by letter): In reference to Dr. de Forest's discussion, I feel that he must have failed in some way to understand the present paper because his discussion clearly seems to apply not to the present paper but to some of the more faundamental and elementary matters which were published by me several years ago. However, in view of the part which the fundamental theory played in the Fleming valve litigation of recent date, I take the present opportunity of laying before the membership of the INSTITUTE the details of what has been to me a most interesting controversy.

During the course of the litigation in question (Marconi vs. de Forest), plaintiffs introduced as evidence showing infringement an article on the operation of the audion which I published in the "Electrical World" of December 12, 1914. This article showed clearly, with oscillographic proof, the manner of the filament-to-grid valve action as well as other methods of use for producing rectification. A most determined effort was made by the de Forest experts and counsel to invalidate the theory. About fifty pages of testimony were introduced showing experiments designed to prove that when signals were received, the charge on the grid became *positive* and hence that any theory of rectification based on the grid becoming negative was incorrect. It was stated that these experiments had been repeated and confirmed by the United States Bureau of Standards.

The manner in which these tests had been made was briefly as follows. A voltmeter consisting of a sensitive galvanometer in series with a resistance of the order of a megohm was connected between the grid and filament of an audion which was arranged in the usual way with a tuned circuit and stopping condenser. Coupled with this tuned circuit was a second tuned circuit driven by a buzzer exciter. It was stated by the de Forest experts that when the circuits were excited and radio frequencies applied to the grid the deflection of the voltmeter showed a positive charge on the grid. I repeated these experiments with buzzer excitation and under certain conditions found that the voltmeter would indicate a positive charge on the grid, but that when the receiver was connected to an antenna and outside signals were received, the grid invariably became *negative*. Investigation showed immediately that a rather curious effect produced on the tube by the high voltage across the break of the buzzer was responsible for the apparent indication of a positive charge. I was able to testify in court to these interesting facts with the result that counsel for the de Forest Company were forced to withdraw all fifty pages of testimony and *admit on the record that the grid became negatively charged.* After this collapse of the positively charged grid theory, the defense built up another based on a "sensitive medium" ionized to an "optimum value" and constructed an audion with an incandescent grid to prove that rectification was not essential to the operation of the device as a detector. The manner of operation of this device will appear from the oscillograms of Figures 11 and 12 of the "Electrical World" article from which it will be obvious that the rectifying action of the tube will continue irrespective of the temperature of the grid.

In upholding the validity of the Fleming patent and finding that the use of the audion as a detector was an infringement thereof, the Court stated that the "Electrical World" article might be considered as read into his opinion. In view of this fact and in view of the fact that the theory has withstood intact the test of publication and discussion in the PROCEEDINGS, the controversy must now be considered as settled, and I must refuse to enter into any further discussion of these elementary matters.