RADIATED AND RECEIVED ENERGY IN RADIO-TELEGRAPHY.

By L. W. AUSTIN.

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Duddell and Taylor[1] were the first experimenters to attempt to determine the laws relating currents in the sending and receiving antennas used in radiotelegraphy. Their first experiments were carried on near London with distances of only a few hundred yards between the antennas. A little later these experiments were repeated on a larger scale on the Irish Sea between a land station and the steamer *Monarch,* the experiments in this case being extended up to about sixty miles. Their work served to show that up to the distances mentioned the received current fell off directly in proportion to the distance in accordance with the Hertzian equation for the electric force in the equatorial plane of an oscillator.

The determination of this law at once aroused great hopes in the minds of all workers in radiotelegraphy for the establishment of long distance communication. It was well known that with 2 K.W. and with moderate sized antennas it was quite possible to send messages over distances of three hundred miles in the daytime. From this it was easily calculated in accordance with the Duddell and Taylor law, that it would be necessary to use only 10 K.W. with antennas 400 feet high to carry on communication up to 3,000 miles. When the attempt was made, however, it was found that only on exceptionally favorable nights was any communication at all possible, even with two or three times the calculated power, and of course none at all in the daytime. This showed at once that the Duddell and Taylor law was not applicable at great distances, and it began to be assumed that for communication over water an absorption

[1] Duddell and Taylor, *Electrician,* 55, p. 260, 1905.

existed similar to that which had long been recognized in overland communication.

In 1909/10 the United States Navy carried on experiments between the high power Fessenden station at Brant Rock and the scout cruisers *Birmingham* and *Salem*.[2] In these experiments regular day communication[3] was obtained up to 800 miles between the ships, and about 1,200 miles between the high power station and the ships. Quantitative experiments on the effect of the height of sending and receiving antennas were also carried on at this time, which verified the results of Marconi, Duddell and Taylor, and Pierce. The results of all this work were finally summarized in the formula

$$I_R = 4.25 \frac{h_1 h_2}{\lambda d} I_S \epsilon^{-\frac{ad}{\sqrt{\lambda}}}, \tag{1}$$

where I_R is the receiving antenna current, I_S the sending antenna current, h_1 and h_2 the heights to the centers of capacity of the two antennas, λ the wave-length, and d the distance; the currents being measured in amperes and the lengths in kilometers. In this formula the resistance of the receiving antenna was arbitrarily taken as 25 ohms, that being the resistance of the Brant Rock station under the conditions of experiment. That the resistance was the same at both wave-lengths used (1,000 meters and 3,750 meters) was due to the fact that a series condenser was used in the Brant Rock antenna at the shorter wave-length. On the ships, however, there was undoubtedly a very considerable difference in resistance at the different wave-lengths. As a matter of fact, we have never had an opportunity to measure accurately the antenna resistance on these ships. From measurements on other ships, however, it is estimated that the antenna resistance at 1,000 meters would be from 15 to 18 ohms, while at 3,750 meters it would probably be about 35 ohms. No more quantitative work at long distances was carried on by the Navy Department until the autumn of 1912, although in the meantime a number of observations were made at moderate distances which all

[2] Bulletin Bureau of Standards, 7, p. 315, 1911.

[3] Night signals, while generally stronger than those in the day time, are freakish and irregular and unfitted for quantitative comparisons.

tended to verify the general accuracy of our formula. The new series of experiments has been made in connection with the high power naval station at Arlington, Va. This station was equipped by the National Electric Signaling Co. with a 100-K.W. rotary gap sending set, and was intended for communication with the Canal Zone and with the fleet in the North Atlantic Ocean. The original plan for the antenna as submitted by the National Electric Signaling Co. showed an umbrella supported by a single tower 600 ft. high. The experiments at Brant Rock, however, showed the experts of the Navy Department that an umbrella antenna gave a center of capacity too low for the most effective working. In fact, comparative results indicated that the effective height was but little if any higher than the bottom of the umbrella, about 150 ft. in the case of the Brant Rock tower, although the total height was 420. For this reason the Arlington station has been supplied with a platform antenna supported by three towers about 400 ft. between centers, one being 600 ft. high and the other two 450 ft. The antenna has been put up in sections and consists of two flat top antennas 350 ft. long, and one 315 ft. long. These are 88 ft. wide with 23 wires each. The triangular space between the flat tops is filled in with a triangular fan of 25 wires supported independently of the flat top sections. The vertical portion of the antenna consists of a fan of 23 wires, 88 ft. wide at the top, narrowing to 10 ft. at 75 ft. above the earth, from which point the wires are brought down in a cage of the Fessenden type. The capacity of this antenna is 0.01 m.f., its natural period approximately 2,100 meters and its height to the center of capacity 400 ft. The ground system consists of a radiating network of wires covering the space between the triangle of towers and extending to some distance outside. The towers were built so that they were insulated from the earth with switches by which they could be connected with the ground net system. With the towers insulated, the antenna resistance exclusive of the inductance at a wave-length of 4,000 meters is approximately 8 ohms. Grounding the towers reduces the resistance to 1.8 ohms, and curiously enough, no perceptible difference in capacity is observed, nor is the natural period changed by more than a few meters. Theoretically it is difficult to understand how this great difference in antenna resistance can be produced without changing the field distribution so as to vary the capacity and wave-length, but what is still more remarkable, is that it is found that the ratio between the current in a receiving antenna a few miles distant and the sending current at Arlington remains absolutely unchanged whether the towers are grounded or insulated. But since the sending current with the towers grounded is approximately 50 per cent. larger than when the towers are insulated, they are always kept grounded. For receiving at Arlington there is practically no difference.

Referring again to the formula for the received current

$$I_R = 4.25 \frac{h_1 h_2}{\lambda d} I_S e^{-\frac{\alpha d}{\sqrt{\lambda}}},$$

it will be noticed that, if we disregard the absorption term, it bears a striking resemblance to the Hertzian equation for the amplitude of the electric force in the equatorial plane of an oscillator.[4] This equation in the form given by Zenneck is[5]

$$(2) \qquad E_0 = 2\pi \frac{l I_0}{\lambda d} 3 \cdot 10^{10} \text{ C.G.S.}$$

where E_0 is the electric amplitude at the distance d, l the length of the oscillator, and I_0 the current amplitude in the oscillator, and was derived for continuous oscillations and for an oscillator consisting of two large spheres connected by thin wires with a spark gap in the middle; an arrangement which produces a uniform current distribution throughout the wires. If we substitute the effective values of the electric field E and current I in the antennas, in place of the amplitudes, the equation will, of course, remain true. Therefore, if we are able to determine the length of the Hertzian oscillator which will be equivalent to a wireless antenna, we have at once a very convenient means of calculating the electric field at any distance not great enough to have the absorption come into play. Theoretical

[4] This applies strictly only to values of d amounting to a large number of wave-lengths.

[5] J. Zenneck, "Lehrbuch der drahtlosen Telegraphie," p. 45.

formulæ for this purpose have been given by Rudenberg,[6] and attempts have been made to apply them to the case of the scout cruisers *Birmingham* and *Salem* by H. Barckhausen[7] and myself.[8]

The formulæ are based on the assumption that if an antenna be erected on a conducting surface, its field will be the same as that of an antenna in space of twice the height, the lower portion being exactly like the real antenna but inverted beneath it; that is, the

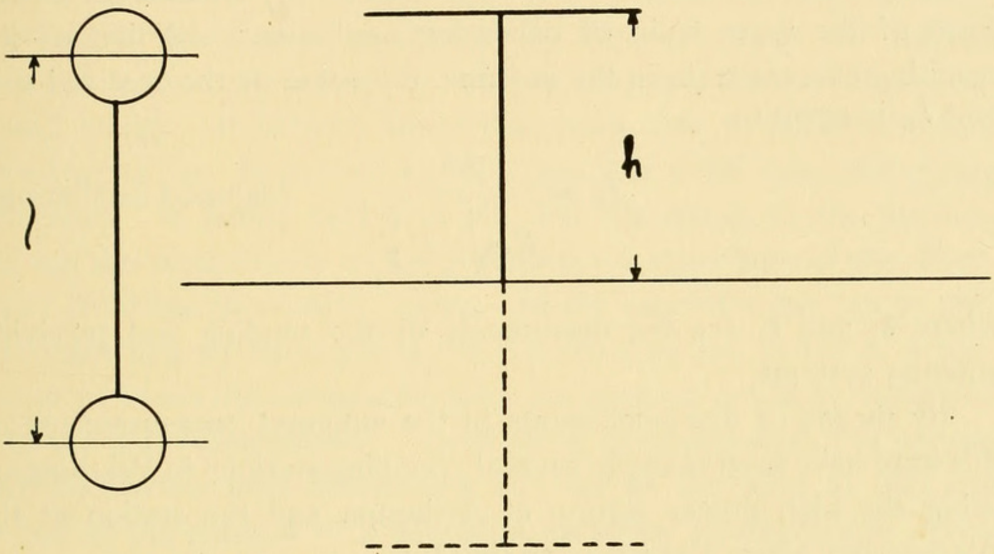

FIG. 1.

length of the equivalent Hertzian oscillator will be twice the height from the earth to the center of capacity of the antenna. As Rudenberg observes, however, the imaginary portion does not contribute to the energy radiated by the antenna. Then since the energy is proportional to l, the length of the oscillator, squared

$$l^2 = \frac{(2h)^2}{2}, \quad \text{or} \quad l = h\sqrt{2}.$$

Hence to get the length of the equivalent Hertzian oscillator we must multiply the height h to the center of capacity of the antenna by $\sqrt{2}$. In order to determine the theoretical value of the received current we must determine the electromotive force on the receiving antenna

[6] R. Rudenberg, *Ann. d. Phys.*, 25, p. 446, 1908.
[7] H. Barckhausen, *Jahrb. d. drahtlosen Telegraphie*, V., p. 261, 1912.
[8] *Journ. Wash. Acad.*, 1, p. 275, 1911.

by multiplying the effective value of the field E by the height to the center of capacity of the receiving antenna. If we are dealing with continuous oscillations, the received current will then be given by

$$(2)\qquad I_R = \frac{Eh_2}{R} \qquad \text{(undamped oscillations)}$$

where R is the high frequency resistance of the receiving system.

In the case of damped oscillations, however, on account of the form of the wave train of oncoming oscillations and that of the resulting current train in the antenna, the value of the received current I_R is equal to

$$I_R = \frac{Eh_2}{R\sqrt{1 + \frac{\delta_1}{\delta_2}}}, \qquad \text{(damped oscillations)}$$

where δ_1 and δ_2 are the decrements of the sending and receiving antenna systems.

By means of thermoelements in the antennas, measurements of this kind have been made in several receiving stations in Washington using the high power station at Arlington and the station at the Washington Navy Yard for sending.[9]

The results of the calculated and observed values are given in Table I. It is seen that the observed values vary between 40 per

TABLE I.

Sending Station.	Receiving Station.	Distance.	Received Obs.	Current Cal.	Obs/Cal.
		Km.	Amp.	Amp.	%
Arlington					
(λ = 3900 m.)	Bureau of Standards	7.8	$5.8 \cdot 10^{-3}$	15.10^{-3}	39
"	Capitol	6.4	12.0	27.5	45
"	Navy Yard	7.2	10.3	17.2	60
Navy Yard					
(λ = 1000 m.)	Bureau of Standards	10.0	4.1	7.6	54
"	Capitol	1.9	8.5	15.0	57

[9] In these experiments the distances between the sending and receiving stations lay between 1.5 and 10 wave-lengths. The greatest possible error due to the inapplicability of the inverse distance law to these short distances would be about 10 per cent. No evidence of ground absorption at these distances has been observed.

cent. and 60 per cent. of the calculated values; that is, the effective length of the equivalent Hertzian oscillator is apparently too great. This may be due either to the shape of the antennas or to the fact that the earth beneath them is not properly conducting as is assumed in the derivation of the formula. If the last supposition is true, a better agreement between the theoretical and observed values ought to be obtained in the case of ships' antennas where the ground consists of sea water. Unfortunately, however, in the case of warships at least, the problem is complicated by the steel masts and rigging which it is generally supposed tend to absorb a portion of the radiated energy. It is to be hoped that some time in the near future experiments may be carried out on ships free from these disturbing influences. It seems very possible that the shape of the antenna and not the conductivity of the ground is the real cause of the divergence from the theoretical values. In the case of a flat top or umbrella antenna we have nearly the condition of two plates of a condenser in which the distance between the plates is not large compared with the plate dimensions. Under these circumstances it is certain that the electric field distribution will not be the same as that due to one of the spheres of a Hertzian oscillator placed at the center of capacity of the antenna system. However this may be, the experiments show that the length of the oscillator equivalent to the antenna of a land station is somewhat less instead of greater than the height to the center of capacity.

Observations at Greater Distances.

In the Brant Rock experiments already mentioned it was found that for distances of more than 100 miles over sea water a measurable absorption of the radiated energy took place, so that to represent the received current the full form of equation (1) including the absorption factor must be used. In the experiments mentioned, observations were made on the scout cruisers up to about 1,200 miles. The figure (Fig. 2) shows that at a distance of 1,000 miles, at a wave-length of 1,000 meters, the received current was only one seventeenth of what would have been received if there had been no absorption, and since the strength of signal in the telephone is proportional to the square of the received current, the signal was reduced to approximately one three-hundredth.

During the months of February and March of this year, the cruiser Salem was sent on a voyage to Gibraltar for the purpose of

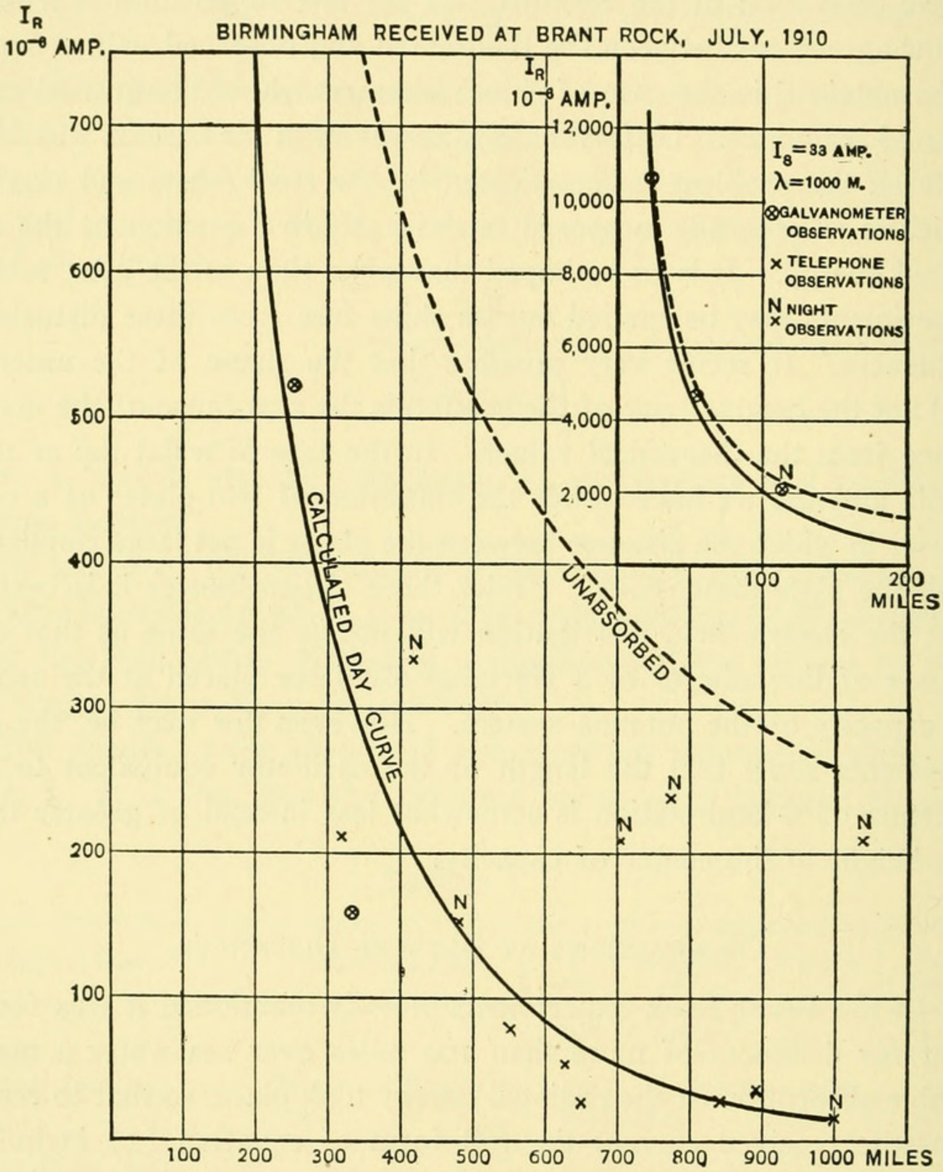

FIG. 2.

carrying out tests with the Arlington station. Successful observations with the electrolytic detector were made in the daytime up to 1,920 nautical miles, while by other detecting devices not sufficiently quantitative for measurement purposes, messages were read up to about 2,100 nautical miles. The results of the measurements are shown in Fig. 3. The wave-length used by Arlington was 3,900 meters, and the average sending current was 110 amperes. The effective height of the Arlington antenna was 400 ft., while that of the Salem was taken as 130 ft., this being the value which was used in the calculation of the formula of the Brant Rock test. This is probably somewhat too high but is retained in the present calculation

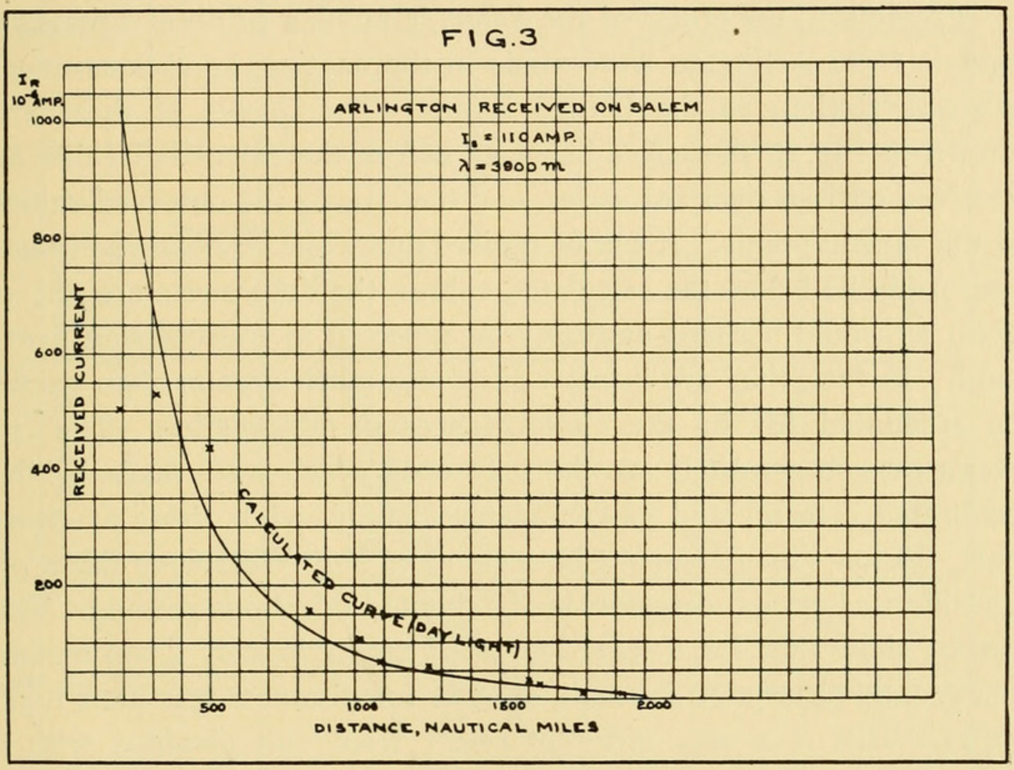

Fig. 3.

for purposes of comparison. The curve of the figure is calculated from Tables XVI. and XVIa. of the article already cited.[10] The observed values of the received currents, as indicated by the crosses in the figure, were calculated from the audibility measurements made by the shunted telephone method on the electrolytic detector in exactly the same way as in the Brant Rock experiments, except that on account of the increased efficiency of the receiving set, the least audible antenna current was taken as seven microamperes instead of ten. The observer was Mr. Lee, who also took the most impor-

[10] Bulletin Bureau of Standards, 7, p. 315, 1911.

tant observations during the Brant Rock test. Considering the difficulties of taking these measurements, the agreement with the theoretical curve is all that could be desired. It is especially to be noted that the signals became inaudible at almost the exact distance indicated by the formula.

Other Observations.

Previous to the cruise of the *Salem*, a number of observations on signals from Arlington were made in the daytime at various naval wireless stations in the United States. The results of these are shown in Fig. 4, the curve being as before the calculated value of received current over sea water, and the crosses the observed values at the various points. It will be noticed that while the observed values uniformly lie below the calculated values, the differences are not as great as would perhaps naturally be expected in transmission overland. In fact, they are in most cases not much greater than would be accounted for by the circumstances of observation. The St. Augustine observations are the only ones which were made by the calibrated detector and galvanometer method, while those at Newport, Boston, Guantanamo, Charleston and Key West were taken on uncalibrated crystal detectors by the shunted telephone method. The results show that for a wave-length of approximately 4,000 meters the ground absorption is small, at least for distances less than 1,000 miles. This is a very different result from that obtained with a 1,000 meter wave-length between New York and Washington, where the received current in the summer time is reduced to 10 per cent. of the value which it would have over salt water.[11] Of course, it must be considered, in the Arlington experiments just mentioned, that most of the stations lie on the sea coast so that the waves either pass during a portion of their course over water or might be conceived to follow along the shore rather than to pass in direct line. New Orleans is the only station in which the propagation could be considered to be entirely unaffected by the sea, and in this case the

[11] For great distances over sea, and distances of more than 100 miles over land, long waves should be used on account of their decreased absorption; while for short distances shorter waves are better on account of their more vigorous radiation.

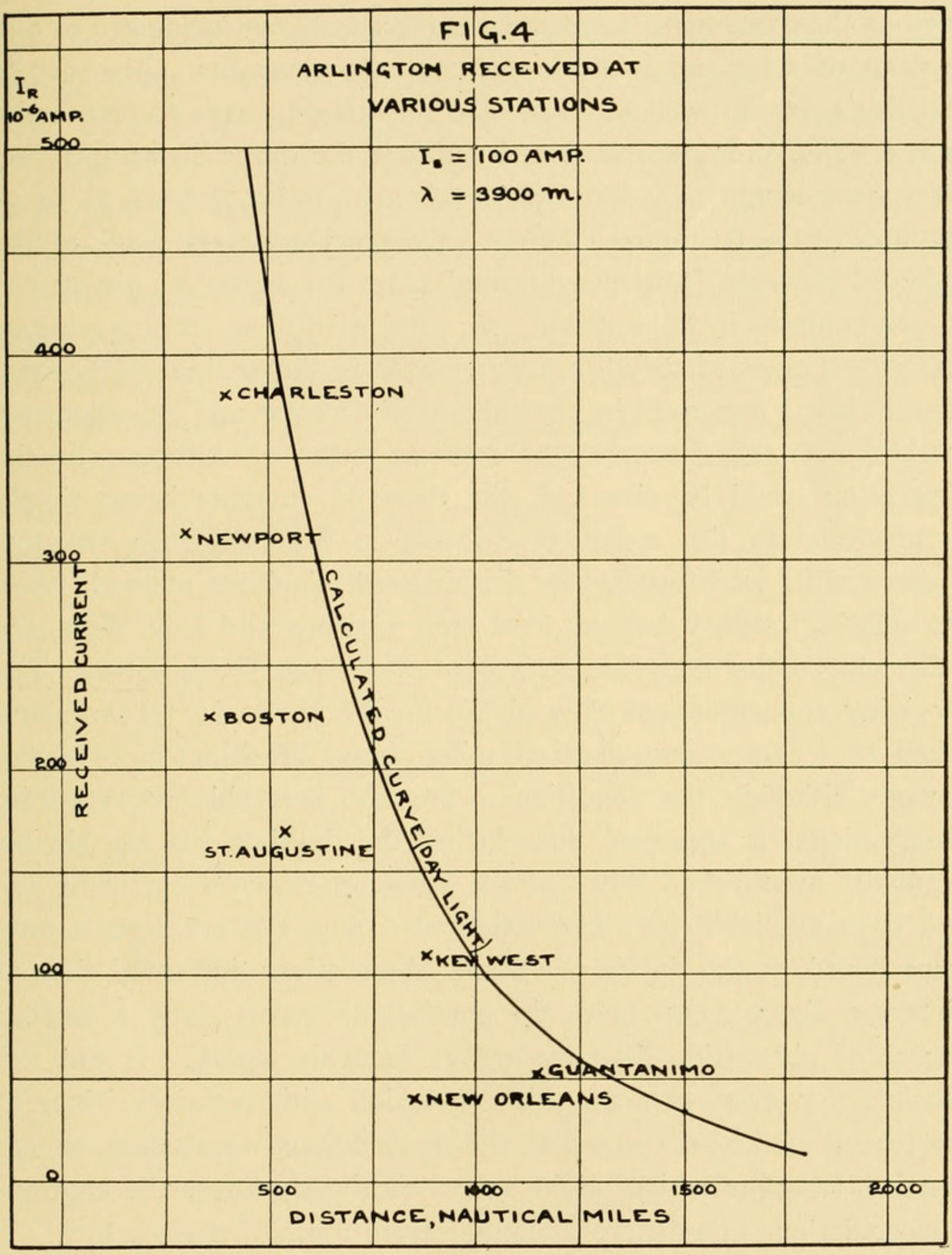

Fig. 4.

received currents lie relatively lower than for most of the other stations.

Comparison of Arc and Spark Apparatus.

It has long been claimed by advocates of the use of continuous oscillations in radiotelegraphy that these waves travel over the surface of the earth with a smaller degree of absorption than the discontinuous wave trains produced by spark apparatus. In order to test this point, as well as some others connected with arc transmission, a 30-K.W. arc operated with 500-volt d.c. current was obtained. At a wave-length of 4,100 meters this arc produced from 48 to 53 amperes in the Arlington antenna. Comparisons were made of the received currents from this arc and from the spark set giving 100 to 120 amperes in the antenna. A very careful set of observations on the two types of radiation was made at St. Augustine, the received current being measured by the calibrated detector and galvanometer method. At this distance, 530 nautical miles, no difference in the absorption could be observed, the received currents being simply proportional to the radiation currents in the Arlington antenna. These results were verified by the shunted telephone method, using the slipping contact detector,[12] at New Orleans and Key West, the latter place being approximately 900 miles from Washington. The receiving apparatus was then placed on the U. S. S. *Arkansas* and taken to Colon, 1,800 nautical miles from Washington. On the voyage, although the conditions were not favorable for accurate observations, it appeared that during the daytime the arc signals gradually approached those of the spark in intensity. During the two days available for observation at Colon, the arc signals only were heard in the daytime. These observations indicated that at distances above 1,000 miles the continuous waves show a smaller degree of absorption than the waves from the spark. It was not possible, however, to draw this conclusion with certainty, since at the season of the year in which the observations were taken, exceptional days occur which might very conceivably affect the continuous oscillations in a different manner from those of the spark.[13]

Further observations were made during the recent voyage of the Salem already mentioned. Here it was found, in verification of our former conclusions, that for distances over 1,400 miles the arc as received in the day time on a special receiver was equal to or

[12] *Journ. Wash. Acad.*, 1, p. 5, 1911.

[13] It is frequently observed that at night one type of wave is strengthened more than the other.

somewhat better than the spark, notwithstanding the fact that the spark radiation current at Arlington was considerably more than twice as great as the corresponding arc current. This normally, if the absorption had been equal for the two types of radiation, would have made the spark signals more than four times stronger than the arc, the amplitude of signal being proportional to the square of the high frequency current. Regular communication with both arc and spark was continued up to 2,100 miles in the day time. Several times day signals were heard at greater distances, and in these cases the arc was uniformly louder. The night signals were heard all the way to Gibraltar.

U. S. Naval Radiotelegraphic Laboratory,
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