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MULTIPLEX TELEPHONY AND TELEGRAPHY OVER OPEN-CIRCUIT BARE WIRES LAID IN THE EARTH OR SEA[1]

INTRODUCTION

The "key problem" in the procurement of essential Signal Corps supplies in the United States during the World War, curiously enough turned out to be the production of the necessary braiding machines for finishing insulated wire. The bare wire itself could be obtained, the rubber insulation could be obtained, even the cotton thread with which the braiding was made could be obtained, but the necessary machinery for braiding the thread, which finally led us into the intricacies of the procurement of steel, was never anything like adequate for the enormous demands required in the field.

The braiding capacity of the entire United States, as of September 1, 1918, was about 8,000 miles of twisted pair insulated wire per month, while the requirements for the American forces alone at that date were about 40,000 miles a month. On October 1, 1918, the Allied Council reached the decision that beginning March 1, 1919, it would be necessary for the United States to furnish all of this type of wire used by the Allied armies in the field, and the estimated minimum requirements for this purpose were equivalent to four times around the earth a month. To supply this amount of insulated wire would have required cargo space for overseas

[1] Abstract of paper presented to the National Academy of Sciences at the session held at the National Museum, April 27, 1920.

shipment in the amount of 14,000 ship tons a month, but had it been possible to use single conductor bare wire in place of the twisted pair insulated wire, the space required would have been reduced to 2,500 ship tons a month, thus releasing the balance for transportation of food, and other vitally necessary supplies.

It is therefore of paramount importance to diagnose, as far as possible, the technical problems of equipment in the light of past experience and of the present trend of development.

The above facts show the necessity of developing, if possible, new methods by which a reduction may be effected in the enormous quantities of expensive and bulky insulated wire, which was so difficult to procure, and which must now be buried in the earth to a depth of 8 or 10 feet throughout the advance sectors of the front line of a modern army.

THREE MEDIA FOR ELECTRIC WAVE PROPAGATION

The following reasoning led to the carrying out of the experiments to be described:

1. Since we can already communicate by radio means between one submarine and another submarine, both completely submerged, it was considered that connecting two such stations by a submerged copper wire could have no other effect than to facilitate the propagation of the electric waves between the stations.

2. It was considered possible that the behavior of earth or water under the action of high frequency currents might exhibit greatly different properties from those with which we are familiar at direct or low frequency currents.

3. It was realized that whatever high frequency energy losses might occur in the case of bare wires laid in earth or water, yet the over-all efficiency would be higher than in the case of radio space transmission where the plant efficiency is so very low.

4. It was noted by the writer in September, 1910, and discussed by him in April, 1912,[2] that the three-electrode audion could be used as a potentially operated device on open circuits. This arrangement was considered suitable for the reception of the signals over bare wires in earth or water.

PRELIMINARY EXPERIMENTS

The first experiment was an extremely simple one as follows: A bare No. 18 phosphor bronze wire, such as is used for the Signal Corps field antenna, was laid across the Washington Channel of the Potomac River from the War College to the opposite shore in Potomac Park. It was paid out from a small boat with sufficient slack to lay on the bottom of the river. A standard Signal Corps radio telephone and telegraph set, SCR 76, was directly connected to each end of the wire, one set serving as a transmitter and the other as a receiver. At the receiving end of the line the bare wire was directly connected to the grid of the receiving set and the usual ground connection left open. A frequency of about 600,000 cycles a second was used and the line tuned at each end by the usual methods. Excellent telegraphy and telephony were obtained. Care was taken to make this preliminary experiment as simple and basic as possible and precaution taken to insure that the wire itself should be bright and clean entirely free from any grease or other insulating material.

[2] *Journal of The Franklin Institute*, April 1, 1912, "Some Experiments in 'Wired Wireless' Telegraphy for Field Lines of Information for Military Purposes," by Major George O. Squier, Signal Corps, U. S. Army.

The success of this simple experiment immediately led to more thorough consideration of the entire subject.

One of the questions to be investigated was the general efficiency of the electron tube when used as a potentially operated instrument. The following experiment was made:

A strip of wire netting was buried in the snow outside the office of the Chief Signal Officer in Washington and a wire attached thereto leading to the second story of the building. The upper end of this wire was connected directly to the grid of an electron tube. The reason for connecting the grid to the upper end of the antenna is of course obvious if we are to use the tube as a potentially operated device. It was necessary for maximum sensitiveness to connect it to the point of maximum potential of the antenna which in the case of a linear oscillator occurs at the open end. By this arrangement, messages were readily received from distant points in the United States.

These two simple experiments, above described, demonstrated the possibility of transmitting electromagnetic waves along bare wires submerged in water and the use of an electron tube as a potentially operated device for the reception of signals. The technical data will be published later.

SUMMARY

For military reasons, if for no other, as stated in the introduction of this paper, the Signal Corps has recently undertaken certain investigations in the phenomena connected with the transmission of high frequency electromagnetic waves over bare wires in earth and in water.

In carrying out these investigations and in attacking the problems from various angles, the research staff of the Signal Corps laboratory at Camp Alfred Vail, Little Silver, New Jersey, was directed to carry out experiments on bare wires laid on the surface of moist ground and also buried in earth. The staff at the Signal Corps research laboratory at the Bureau of Standards was directed to investigate fundamentally the transmission of electromagnetic waves over bare wires in fresh water. In addition to this, the engineering staff of the Office of the Chief Signal Officer has carried out from time to time certain experiments of a more or less crucial character which have come up for solution in the prosecution of this work at the other laboratories.

Certain data from each of these groups of engineers have been presented above. The phenomena associated with the transmission of high frequency waves over bare wires in earth or water are obscure and complex, and the writer has formulated no definite theory at the present time.

RESULTS OBTAINED

1. Telephone and telegraph communication has been established between Fort Washington, Maryland, and Fort Hunt, Virginia, across the Potomac River, below the city of Washington, over a distance of about three quarters of a mile, by the use of a bare No. 12 phosphor bronze wire laid in the water to connect the stations. The transmitter consisted of an electron tube oscillator which delivered a current of about 270 milliamperes to the line at a frequency of about 600,000 cycles a second. At the receiving end of the line an electron tube and a 6-stage amplifier were used without any ground connection. With this arrangement good tuning was obtained at both ends of the line, and telegraphic and telephonic transmission secured over the bare wires immersed in fresh water.

2. A resonance wave coil has been devel-

oped. The coil is in the form of a long helix wound with a large number of turns on which stationary waves are produced by the incoming radio signals. An electron tube is used as the detector, the grid being connected to the point of maximum potential on the coil. The wave coil may be used either as a part of the usual antenna system or a part of a line wire, or it may act itself as the antenna for picking up the energy of the signals. In the latter case the coil may be either free at both ends or grounded at one end. Good results have been obtained in either case. It has been also found that the open coil has directional properties and can be used as a goniometer not only for horizontal measurements but for vertical measurements as well. This form of radio goniometer has the great advantage that it permits not only of determining the plane where the signals are strongest but also the direction from which such signals proceed.

Telegraph and telephone communication has been also established between two stations at the Signal Corps Research Laboratories at Camp Alfred Vail, Little Silver, New Jersey, using a bare No. 16 copper wire buried in the earth to a depth of about eight inches to connect the stations. The distance between the two stations was three quarters of a mile. Frequencies as high as one million cycles a second were used. Similar communication has been carried on over a bare wire one and three quarter miles long laid on the surface of moist earth. The current at the transmitting station in these installations was about 100 milliamperes. It has been shown that a bare wire buried in moist earth with the distant end open can be tuned both at the transmitting end and at the receiving end.

SUGGESTIONS

1. In the older art of ocean telegraphy, the elaborateness of line construction has already reached a practical limit. The best Atlantic cable of the present day is limited in operation to electric waves of frequency of the order of magnitude of 10 per second. The electrical construction is such as to limit the voltage employed on any long cable to from 50 to 80. The relative values of the line constants in any ocean cable preclude the possibility of ocean telephony.

The most promising hope of improving the line construction for ocean cables is believed to be, to abandon the present method of design and construction and to start with the simple case of bare wires in water using high frequency currents and study the necessary changes to produce optimum transmission.

The use of a high frequency "carrier" has the inherent advantage that the distortion phenomena accompanying present methods of long distance transmission are eliminated, and we are principally concerned with the problem of reducing attenuation. The most suitable voltage may be employed and present multiplex methods may be utilized. The electron tube is available for both the generation and the reception of the waves.

2. During the last few years an intensive study has been made of the surface conditions of wires necessary to produce the emission of electrons, and to this intensive study, both by universities and industrial research laboratories, is due the high state of efficiency of the present electron tube. Nothing short of a similar study of the surface conditions of wires for preventing the emission of electrons instead of producing them, will finally give us the wire conductor of the future.

3. The development of types of reson-

ance wave coils, both open at one end and at both ends, for general radio work offers an interesting field for investigation. This involves the study of the electron tube as a potentially operated device. The application of such coils properly designed for specific purposes may lead to the practical solution of a number of radio problems such as directional effects, and wave coils antennæ of very small dimensions.

4. The account of the experiments thus far conducted and the reasons which have led to the undertaking of these experiments on the part of the Signal Corps, are presented to the National Academy of Sciences at this time in conformity with the new spirit of organization for national and international research so admirably typified by the National Research Council which is under the general direction of this official body.

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RÉSUMÉ OF RESEARCH IN THE PSYCHOLOGY OF AVIATION DURING THE YEAR 1919

THE writer has been in charge of the department of psychology of the Air Service Medical Research Laboratory since January 15, 1919. Members of the department engaged in research during that year included Drs. F. C. Dockeray, D. C. Rogers, H. C. McComas and J. E. Coover, as captains; Dr. English Bagby and Mr. Schachne Isaacs, as lieutenants; and Dr. F. C. Paschal, Miss Barbara V. Deyo and Mrs. Cressie Campbell Merriman, as assistants. Certain members of the group were present for but a short time; and others were present for several months. Dr. E. N. Henderson and Mr. L. J. O'Rourke, as captain and lieutenant, resepctively, were connected with the department for some time, but the exigencies of the service did not permit of their employment in research. Since October last the staff has consisted of Lieutenant Isaacs and the writer, with Miss Deyo and Mrs. Merriman as research assistants.

During the year the department prosecuted research along two distinct and independent lines: (1) an effort to gain a somewhat more intimate acquaintance with the effects of low oxygen on the integrity of response; and (2) an effort to develop more sensitive tests for the detection of (*a*) general aptitude for aviation work and (*b*) of its deterioration in the earlier stages of staleness. The reports of this work will probably appear in due time in the various American psychological journals, under the names of the authors who are individually or jointly responsible. Meanwhile, a résumé of the year's activities of the department as an organization may not be out of place here.

An extensive and detailed statistical study of the records of over 6,000 classification-tests for resistance to deprivation of oxygen, has been made under the direction of Captain Coover. He was assisted by Lieutenant Isaacs, Dr. Paschal, Miss Deyo, Mrs. Merriman and the writer. The results indicate the extent to which the subject's performance may be affected by atmospheric pressure, temperature and humidity; by the absolute quantity of oxygen supplied the subject in the air to be rebreathed; by the duration of the test; by the time of day at which the test is taken; by the judgmental eccentricities of the psychological and clinical observers; and by a lowered morale, such as that which immediately followed the armistice. With these data available it is now possible, by controlling or correcting for the influence of these variables, to approximate much more closely to uniformity and constancy of the standards of classification than has been possible hitherto.

An attempt was made by the writer, in collaboration with Dr. Paschal, to demonstrate the progress of impairment of behavior by the use of an objective record of the speed and accuracy which the subject can maintain in carrying on work of uniform difficulty as the supply of oxygen is being diminished.