METHODS OF REDUCING THE EFFECT OF ATMOSPHERIC DISTURBANCES*

By

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Summary—*The transmitter sends the dots and dashes on one frequency and the spaces on a slightly different frequency. At the receiver a local frequency is superimposed producing two audio frequencies. The paths of the two audio frequencies are combined differentially so they would oppose if they occurred at the same time; also, they would pull the marking pen in the opposite direction if they occurred at the same time. Since one audio frequency is due to the dots and dashes while the other is due to the spaces, they do not occur at the same time. Since static hasn't a definite frequency it may produce about the same amount of audio-frequency current in each path, thereby more or less neutralizing its own effects. The tape records made with this system and an ordinary system show marked advantage in this system for reducing the effects of static and for increasing speed of recording.*

IT is the purpose of this paper to describe a method of reducing the effects of atmospheric disturbances by selective means as distinguished from that means which depends on the geography of the situation: directional reception.

The method is based on the fact that the distribution of energy with respect to frequency of the waves of natural origin is such that over short periods of time the energy in the component at a given frequency is substantially equal to the energy at a closely adjacent frequency, and that in a "crash" or burst of static both these frequencies will be present simultaneously.

In the respect that the energy of the disturbances is distributed through a band and the energy of the signal concentrated in substantially one frequency there lies a fundamental difference which has been utilized to the utmost to effect the separation of the two by means of electrical tuning.

In the respect that the energy of the disturbances and the energy of the signal is alternately present or absent, the first by reason of the irregularities of nature, the second by reason (in telegraphy) of the Morse code or equivalent, there is no fundamental difference. In this respect the two are the same, the difference being one of degree only.

The method which is here described is based on the establishment of a difference between the natural waves and the signaling waves which lies in imparting to the signaling waves a charac-

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teristic not found in the waves of natural origin. This difference is established by producing at the transmitter two waves of closely adjacent frequency and radiating them alternately. Now consider that band of frequencies which just includes the two frequencies selected for signaling. Energy from the waves of natural origin will be received simultaneously in substantially equal amounts throughout the band. Energy from the signaling waves will be received alternately at the upper and lower ends of the band. With this fundamental difference it becomes possible

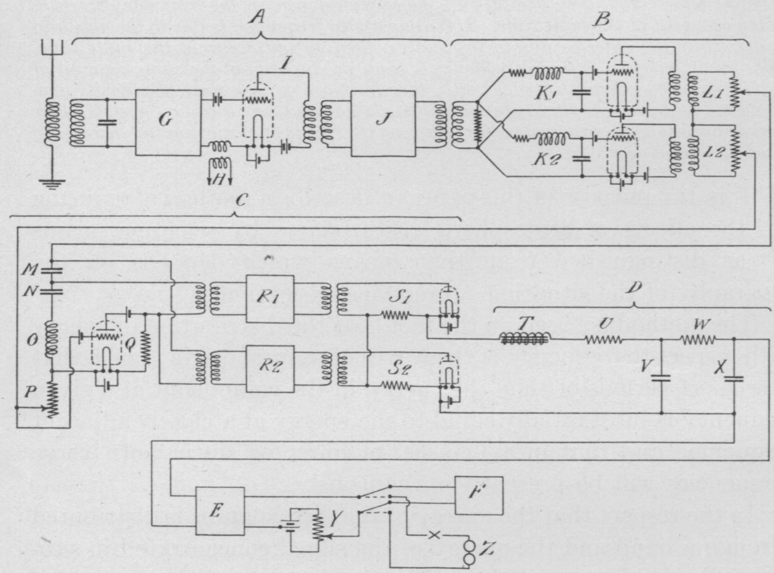


Fig. 1

to provide that long looked for device, the receiver which acts cumulatively with respect to the signal but differentially with respect to the "static." This receiver is one which produces a certain effect on the indicator when one of the two frequencies in question is present alone; an opposite effect on the indicator when the other frequency is present alone; but a neutralized or zero effect when both frequencies are present simultaneously.

Both the nature of the problem and the conditions of practical working require that the two signaling frequencies shall be very close to each other. Hence the method of selection must be capable of effectively separating the two frequencies in a minimum of time to meet the requirements of rapid signaling. In general, on the long waves used in trans-oceanic signaling, a frequency variation of from 25 to 100 cycles is sufficient; on the shorter waves a greater variation (where the variation lies in the fundamental and not in a modulated or superimposed frequency) is necessary although the increase is not in any sense a proportional one.

The method of transmitting the two signaling frequencies requires no further comment than to say that the key is arranged to change the frequency transmitted when the key is down from, say 20,000 cycles, to 20,050 when the key is up.

The method of reception is illustrated by the arrangement of Fig. 1. In this figure A represents the usual form of receiver comprising a tuned amplifier G, a detector I, heterodyne H, and

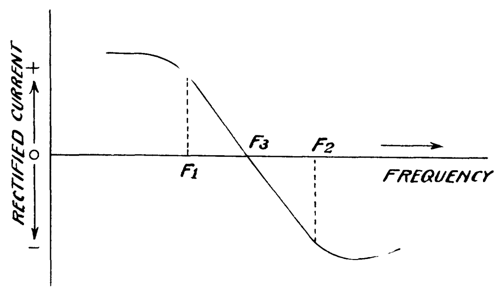


Fig. 2

low frequency amplifier J. Connected to the output of this low frequency amplifier are two tuned circuits K_1 and K_2 resonant respectively to the two beat frequencies composing the signal. In the case to which the curves hereinafter shown refer, these two frequencies were 1200 and 1280 cycles. Each circuit controls an amplifier and the outputs of the amplifiers are differentially connected through transformers and potentiometers L_1 and L_2. The organization just described has the double function of selectively responding to the two signaling frequencies with equal facility and of equalizing the energy of the natural waves between these two frequencies so that such irregularities as do occur are minimized.

The organization connected to the output of the equalizer and shown under the heading C represents the selective system for separating the two signaling frequencies, converting them to continuous currents and combining the resulting effects cumulatively. M, N, and O are condensers and an inductance whose values are so chosen that the combination of N and O is non-reactive for 1220 cycles and the combination M, N, and O is non-reactive for 1280 cycles. The two combinations form the basis for the rapid separation of the two signaling frequencies. P, Q, and the associated vacuum tube amplifier is a resistance compensator for neutralizing the effect of the resistance in the condensers M and N, and of the inductance O. Q is a large resistance, normally four to five thousand ohms, and P is a resistance commensurate with the resistance of the combination M, N, O. Connected across the combinations N, O and the compensator and M N O and the compensator are two transformer primaries of

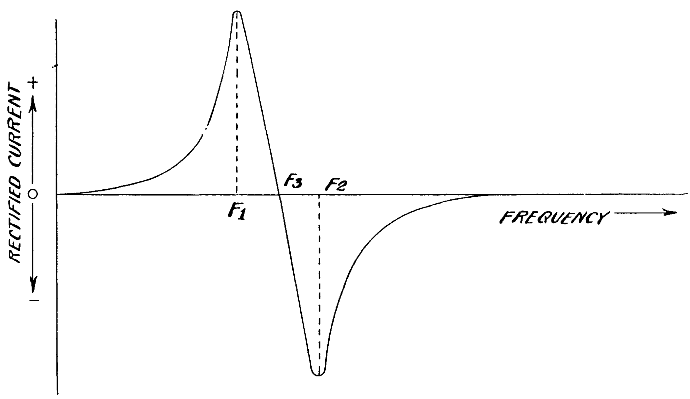


Fig. 3

sufficiently high impedance so that the characteristics of the system M N O are not affected. The secondaries of these transformers control two equal amplifiers R_1 and R_2 whose outputs are connected respectively to two valve rectifiers which are furnished with series resistances S_1 and S_2 of such value, that for the strength of signal used, substantially straight line rectification is effected. The outputs of these rectifiers is then differentially combined.

The relation between the combined continuous current output of the rectifiers and the alternating current input to the combination M N O with respect to frequency is shown in Fig. 2. As the frequency of the input current is increased the rectified current does not vary materially until a certain frequency F_1 is reached (1220 cycles). Further increase in frequency causes a decrease in the rectified current until it reaches zero at a certain frequency F_3. Still further increase of input frequency causes the output current to flow in the opposite direction and to increase until a certain frequency F_2 is reached beyond which the current again does not vary materially. The combined characteristic of the equalizer B and selector C is illustrated in Fig. 3. Here the frequencies above F_2 and below F_1 are substantially cut off and a maximum and opposite response is obtained at each of these frequencies respectively.

Referring again to Fig. 1 the combined outputs of the rectifiers are fed into a low pass filter D as shown. The output of this filter is connected to a d-c. amplifier E whose output controls a siphon recorder F.

With this description of the system of Fig. 1 in mind examine the action of the arrangement for incoming signals (in the absence

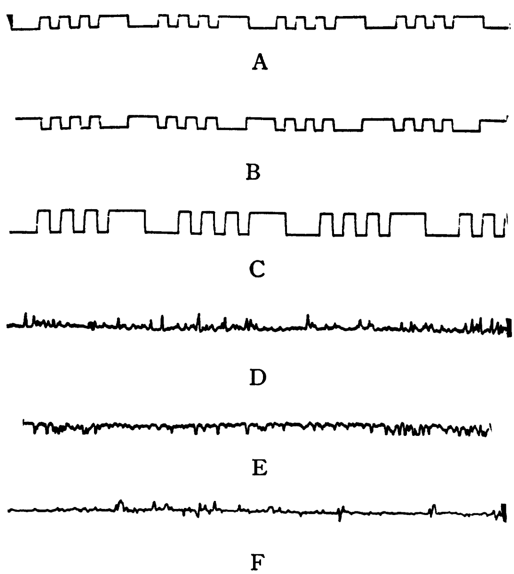
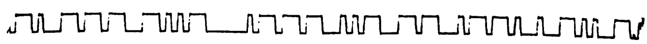


Fig. 4

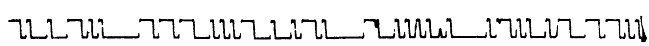
of static): Suppose that the transmitted signal, with the key down, is 20,000 cycles and with the key up 20,060 cycles. Suppose the heterodyne to be adjusted to 18,780 cycles. Then when the key is up a beat frequency of 1280 cycles is produced and in accordance with the curve of Fig. 3 a rectified current having the polarity and magnitude corresponding to F_2 results. This passes through the filter D, is amplified by the d-c. amplifier E, and produces a deflection of the marker of the siphon recorder from the neutral position in a direction which depends on the polarity of the rectified current.

When the position of the transmitter key is reversed (i.e., down, 20,000 cycles transmitted) a beat frequency of 1220 cycles is produced and this produces a rectified current corresponding in magnitude and direction to F_1 in Fig. 3. This rectified current is of substantially the same amplitude as that produced by the 20,060 cycles when the key was up, but it is of opposite polarity. This rectified current causes the marker of the siphon recorder to return to and pass through its neutral position and to be deflected in the direction opposite to that in which it was deflected when the transmitter key was up. Hence the total deflection of the siphon recorder is double that which would be obtained with the standard

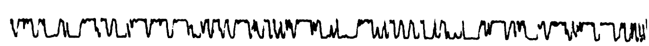


Balanced 20 Words per Minute

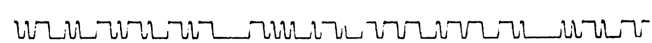
Standard 20 Words per Minute



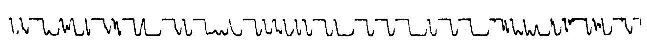
Balanced 40 Words per Minute



Standard 40 Words per Minute



Balanced 75 Words per Minute



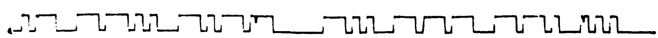
Standard 75 Words per Minute

Fig. 5

method of signaling. The three tapes shown in Fig. 4 illustrate this action. Tape A is a record in which only the 20,000 cycle current was transmitted, the letter V being sent by ordinary keying, (i.e., interruption). Tape B is the record produced when the same letter V is transmitted on 20,060 cycles, keying in the same way. In this case the response is inverted. Tape C is the record produced when keying is accomplished by alternately radiating both frequencies. In this case the response is substantially the cumulative combination of A and B.

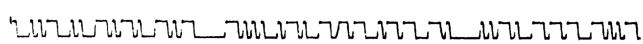
Now consider the action of the system for the waves of natural origin (in the absence of signals). Over a period of time there will be substantially the same amounts of energy received from these waves between the frequencies F_1 and F_3 as between the frequencies F_3 and F_2. Over short intervals of time due in part to the inequalities of heterodyning,* as well as to the irregularities of nature, more energy may be in the lower or higher of the two frequency bands. The equalizer B reduces this inequality so that there are delivered to the selector system C two bands of frequencies of about the same energy. These two bands are separated by the selector C into high and low frequency groups which are supplied respectively to the rectifiers. The character of the currents produced in the output of each of these rectifiers is illustrated in Fig. 4 by tapes D and E. Each current is a pulsating unidirectional one. When the two are combined differentially the resultant current shown in tape F is produced. It will be observed that this resultant current is irregularly alternating and that the

Standard 20 Words per Minute



Balanced 20 Words per Minute

Balanced 40 Words per Minute



Balanced 60 Words per Minute

Fig. 6

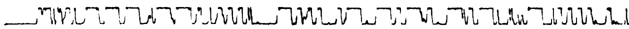
average values above and below the zero line are equal. It will also be observed that during the interval of a dot or dash that the signaling current is unidirectional over a longer period than is required for the residual currents produced by the atmospherics to reverse themselves. Hence the two currents are capable of further separation by means of the low pass filter D interposed between rectifiers and recorder.

The foregoing analysis describes in a general way what happens in this system when signals are being received alone and when static is being received alone. While a great deal more might be written about the action when both are received in combination since the particular phase relation between the signaling currents and the disturbing currents modifies the behavior of the system somewhat, yet it will be along the lines laid down and this part of

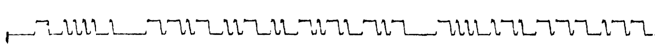
(* The particular initial phase relation between the heterodyne current and the individual natural waves.)

the operation can best be followed by an analysis of the tapes taken under conditions of practical working.

There are two bases upon which comparisons may be made between the standard method of signaling and the method herein described. One is to make a record of the balanced method at a speed at which the tape is just readable without error and to compare it with a record taken at the same speed with the standard method, estimating the extent to which the signal has been buried



Standard 40 Words per Minute

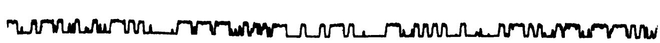


Balanced 100 Words per Minute

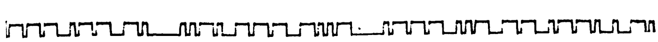
Fig. 7

in the second case. The other is to make a comparison of the relative speeds of the two methods at which it is possible to work without error.

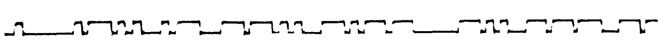
The first method of comparison is perhaps the most spectacular and interesting to the engineer, particularly those who have spent much time on the problem. The second method is the one which



Standard 30 Words per Minute



Balanced 30 Words per Minute



Balanced 60 Words per Minute

Fig. 8

will appeal to the traffic manager and to all those who deal with the delicate balance between paid words handled, and overhead operating expense and cable competition.

The results obtained with either of these methods will vary depending on the type of atmospheric disturbances encountered. For example, assuming extremes, we might have a condition where the disturbances were due entirely to lightning strokes occurring in the immediate neighborhood of the station. Even though the balanced method were capable of reducing the effect of these disturbances to a few per cent of their original value the overpowering effect of the residual would make its mark upon the tape and destroy the signal to the same extent as in the standard method, and no advantage would be gained. On the other hand the disturbances might consist wholly of grinders of about the same amplitude as the signal but present in such quantities as to bury it completely when using the standard method. These grinders, if reduced to a few per cent of their value, would disappear as a factor and a signal readable at any speed within the capabilities of the recorder would result. Between these two theoretical limits there lie the conditions of practical working, although both extremes are sometimes approached.

There are illustrated in Figs. 5, 6, 7, and 8, photographic reproductions of representative sections of records which have been taken over a long period of time under the varying conditions referred to and with both methods of comparison. The comparisons were made between the arrangement shown in Fig. 1 and the standard form of receiver now widely used in trans-oceanic work. This latter consisted of a tuned amplifier system for the 20,000-cycle current, comprising four tuned circuits arranged for a maximum of selectivity, a push pull detector system with separate heterodyne, and a low frequency amplifier whose output, when rectified by a simple valve, produced a current of 6–8 mil amperes in the coil of an R.C.A. standard siphon recorder. The comparisons were made on the non-directional antenna at Columbia University of a single wire about 100 feet high and 500 feet long. Signals were transmitted from a local oscillator feeding into the antenna and arranged to transmit either the normal type or the double frequency type of signal. The frequency used was about 20,000 cycles with a variation of 40 cycles. The ordinary Wheatstone automatic was used throughout. On account of the difficulty of operating two systems with two separate recorders simultaneously the records for comparison were made consecutively, usually within a few seconds of each other. In all practical cases this gives a sufficiently accurate comparison.

Fig. 5 shows some tapes taken according to the first method of comparison at three different speeds—20, 40, and 75 words per minute. In each case the record for the balanced method was taken first, the strength of the transmitted signal being adjusted to give just readable tape. As soon as this record was completed the record for the standard method was taken, both speed and signal strength remaining constant. These records were taken under conditions encountered on the ordinary summer evening and speak for themselves.

Fig. 6 shows some records taken according to the second method of comparison. In each case the tape for the standard was taken first, the signal strength being adjusted to give a readable signal. The recorder was then connected to the balanced system, and, with the same signal strength, the speed of the

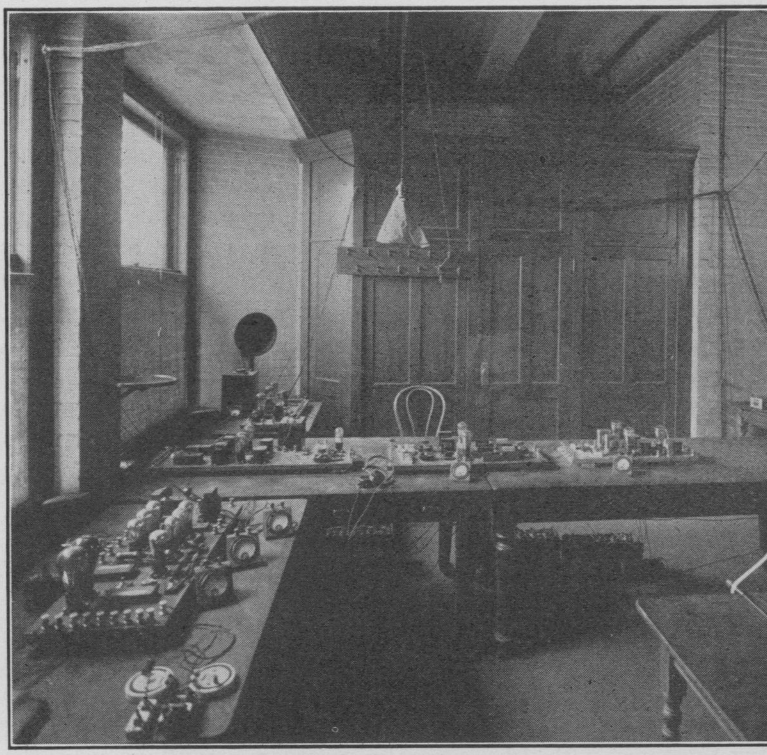


Fig. 9—Balanced Receiver Set-up in Hartley Research Laboratory.

Wheatstone increased until the limit of readability was reached. This set of tapes shows that a signal on the standard which is just readable at 20 words per minute is easily readable with the balanced method at 60 words per minute. Another set of tapes illustrated in Fig. 7 shows a signal readable at a speed of 40 words per minute on the standard reaching easily 100 words per minute with the balanced method. In this particular case the limit was not the atmospheric disturbances but the inability of the transmitter relays available to behave properly above this speed. The records of Figs. 6 and 7 were both made on a normal summer evening. Fig. 8 illustrates a comparison made according to the second method during a heavy thunder storm. An improvement of double the speed was obtained.

Figs. 9 and 10 show the principal parts of the balanced receiver set-up in the Hartley Research Laboratory at Columbia University and give a general idea of the amount of apparatus involved.

Fig. 10—Balanced Receiver Set-up in Hartley Research Laboratory.

Referring to Fig. 9 the apparatus mounted on the two center tables and the table in the lower left of the photograph corresponds to the apparatus designated, in Fig. 1, by J, B, C, D, and E.

Summing up the results of a long series of tests it appears that, in Morse signaling, the speed obtained with the standard method can at all times be doubled and, under certain conditions, improved from three to five times. In facsimile transmission it is probable that the improvement will be even greater, for the criterion to be applied there is not one of intelligibility to a skilled operator who is the medium between a ragged tape and a typewritten copy. The criterion in facsimile transmission is one of intelligibility plus the question of how much permissible smudge may be forwarded to the customer on his message. In this last respect the difference between the two methods is even more pronounced than in the matter of speed.

In closing this paper I want to make an acknowledgment of the debt I owe to my old professor, Michael Idvorsky Pupin. Over thirteen years ago we began an investigation of the problem of atmospheric disturbances. For three years we continued it to the exclusion of all other work. The result was barren in the sense of arriving at a solution, yet the instruction that I received in electrical transients and the knowledge that I gained of that particular kind of transient which we designate as static, lies at the base of the present development. I want also to express my appreciation to Mr. Thomas J. Styles, whose assistance throughout the course of this work has been invaluable.