April 22, 1947. E. H. B. BARTELINK 2,419,193

COMMUNICATION SYSTEM

Filed Dec. 9, 1942

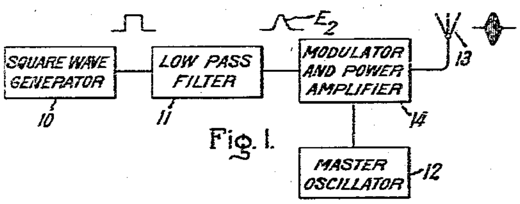


Fig. 1.

Fig. 2.

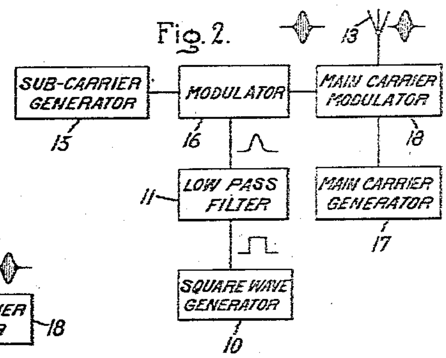


Fig. 3.

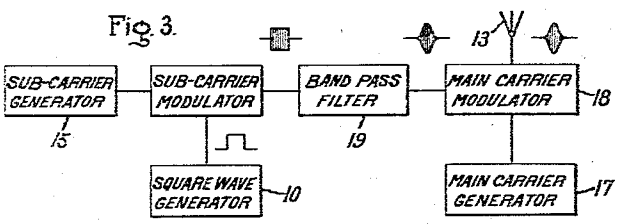


Fig. 4.

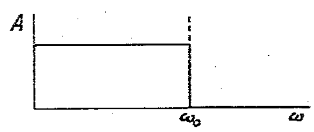


Fig. 5.

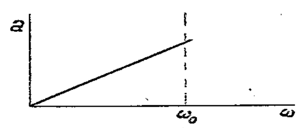


Fig. 6.

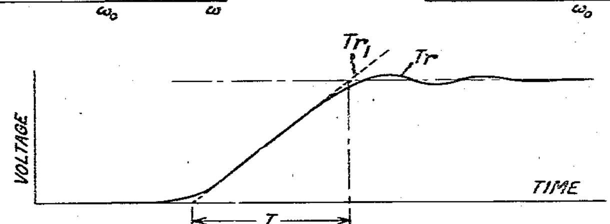


Fig. 7.

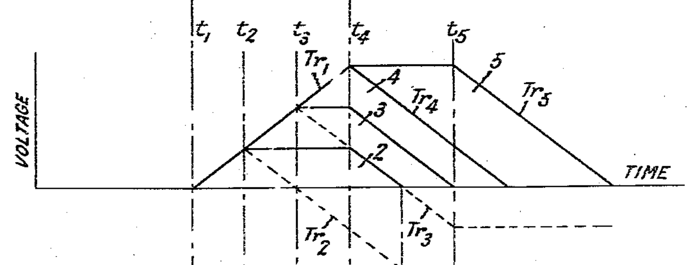
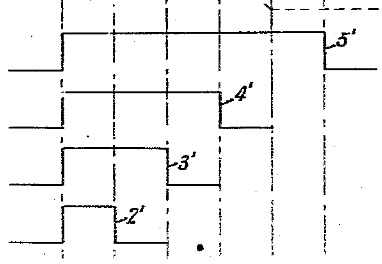


Fig. 8.



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UNITED STATES PATENT OFFICE

2,419,193

COMMUNICATION SYSTEM

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Application December 9, 1942, Serial No. 468,346

9 Claims. (Cl. 250—17)

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My invention relates to radio communication systems or the like, and particularly to radio communication systems in which signals are transmitted by means of pulses.

It is an object of my invention to provide a new and improved method of and apparatus for the transmission of signals of the above type which results in a substantial saving in power input for a given power output or a substantial increase in the power output for a given power input to such a transmitter, as compared with more conventional transmitting systems, without impairing receiver operation.

The novel features which are considered to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Figs. 1 to 3 illustrate in block form radio transmitters embodying the principles of my invention, and Figs. 4 to 8 inclusive are curves illustrating the theory of operation of my invention.

Pulse systems of radio communication have been proposed hitherto. Such systems have been operated at relatively high frequencies as for example 500 to 3000 megacycles because of the preemption of lower frequencies for other services, because of difficulties in obtaining sufficient band width at lower frequencies, and also because directional transmission of signals, or "beaming," has been required in some applications. The pulse system of radio transmission enables a relatively high instantaneous voltage and power to be safely utilized, resulting in a favorable signal-to-noise ratio, without seriously overloading available types of electron discharge tubes. Moreover, the transmission of pulses is advantageous for other uses such as the detection of distant objects, range finding, and the like.

Hitherto relatively square pulses have been employed in high frequency, high power audio transmitters. It can be shown that the operation of a receiver is not adversely affected by the transmission of triangular pulses instead of square pulses if the same peak power is maintained. A comparison of pulse shapes shows that for a square pulse of given width and for substantially the same receiver performance, 30% more power is necessary for transmission than if a triangular pulse of the same peak voltage

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but whose base is twice the width of the square pulse is used to modulate the carrier. In other words, the same receiver performance may be obtained at a 30% saving in input power or, for a given input power to the transmitting system, a 30% increase in receiver performance or received signal may be obtained if triangular pulses are used rather than the relatively square pulses hitherto employed.

In Fig. 1 of the drawing, there is illustrated in block form the component parts of a radio transmitter suitable for the impression of substantially triangular pulses on an antenna and typical pulse shapes at different parts of the system. Means for producing a succession of discrete substantially square impulses is provided. For example, a square wave generator 10 of any desirable type, such as a multivibrator and a suitable clipping circuit may be used. The square pulses are passed through a low pass network or filter 11 which transforms the pulses into triangular shape in accordance with principles explained hereinafter. Such pulses are then used to modulate a carrier wave obtained from a source of high frequency oscillations such as a master oscillator 12. The modulated carrier may be applied to the antenna 13 either directly or through a power amplifier. The transmission of the high frequency oscillations is thus controlled by the extent and duration of the impulses. Modulator and power amplifier are grouped in a single block indicated by the numeral 14.

It may be desirable to modulate a carrier wave by means of a sub carrier. In Fig. 2 there is illustrated a system in which square waves from a suitable generator 10 are transformed into triangular pulses in a low pass filter 11 and used to modulate a sub carrier from a source of high frequency oscillations or sub carrier generator 15. The modulator is indicated by the block 16. Up to this point the system arrangement is the same as that shown in Fig. 1. However, instead of impressing the modulated signals on the antenna 13, the signals are used to modulate the main carrier from a second source of high frequency oscillations, or main carrier generator 17, as indicated by the block 18.

In Fig. 3 there is illustrated a system similar to that of Fig. 2 except that the square waves from generator 10 modulate the sub carrier and then are transformed into triangular form by means of a suitable band pass filter 19.

The conversion or transformation of square waves or pulses to triangular pulses rests upon the following theoretical principles, the practical application of which is illustrated in Figs. 4 to 8, inclusive.

Fig. 4 represents an idealized relationship between the filter transfer factor A (which is defined as the ratio of the output voltage of the filter to its input voltage), plotted as ordinates, and frequency, plotted along the abscissa. In Fig. 4, the transfer factor A is constant from zero frequency to the cutoff value ω_0 of the circular frequency of the filter 11.

Fig. 5 represents an idealized relationship of the phase angle a between input and output voltages of the filter 11, plotted as ordinates, to frequency, plotted along the abscissa.

Figs. 6, 7 and 8 illustrate the manner in which the square pulses are transformed or converted into the desired shape or form. In Figures 6 and 7 the ordinate represents the output voltage of the filter and Fig. 8 the input voltage of the filter. The curves of Figs. 6 and 7 represent the rise and decay of the output voltage after application to the filter of pulses such as those shown in Fig. 8. The abscissa in Figs. 6, 7 and 8 represents time. Particular instants of time are represented by the vertical dot-dash lines running through Figs. 6, 7 and 8 and designated t_1, t_2, etc. The scale for both voltage and time is the same in each figure. More particularly, Fig. 6 represents a typical transient curve when a voltage E_0 is applied to the filter 11. Fig. 8 illustrates square pulses of different widths which can be derived from a square wave generator. The width of the pulses generated depends upon the choice of circuit constants for the square wave generator and since means for establishing desired pulse widths is well known, no detailed description is required. Fig. 7 depicts the pulses of Fig. 8 after passage through a filter section of the type shown in Figs. 1, 2 and 3. As will be clear from the following explanation, the pulse shapes of Fig. 7 are only approximations which, however, are accurate for all practical purposes.

Referring to Fig. 1, the voltage relationship between the input and output voltages of the network 11, assuming steady-state, sine-wave operation, is given by:

$$\bar{E}_2 = A(\omega)\epsilon^{ia(\omega)t}\bar{E}_1 \qquad (1)$$

in which $\bar{E}_1$ and $\bar{E}_2$ are the sine wave input and output voltages, respectively, $A(\omega)$ represents the transfer factor as a function of ω, ω is equal to $2\pi f$ in which f is the frequency of the impressed voltage, i is equal to $\sqrt{-1}$, $a(\omega)$ is the transfer angle as a function of ω, and t is time.

Let a voltage of magnitude E_0 be suddenly applied to this network. The resulting voltage transient can be represented mathematically by the equation:

$$E_1 = \frac{E_0}{2\pi i}\int_{-\infty}^{+\infty} \frac{d\omega}{\omega}\epsilon^{i\omega t} \qquad (2)$$

where E_1 is the voltage as a function of time. Then the expression for the voltage at the output of the network can be written:

$$E_2 = \frac{E_0}{2\pi i}\int_{-\infty}^{+\infty} \frac{A d\omega}{\omega}\epsilon^{i(\omega t - a)} \qquad (3)$$

Let it be assumed that the transfer factor A has a constant value up to a frequency $\omega = \omega_0$ and is zero for greater values of frequency, as shown in Fig. 4, and that the phase angle is a linear function of frequency over the pass band from zero frequency to a frequency $\omega = \omega_0$ as represented in Fig. 5. If Equation 3 be integrated under these conditions, the transient curve of the output voltage E_2 is substantially as represented by the solid line Tr in Fig. 6. The slope of the curve is determined by the characteristics of the filter system 11. For all practical purposes, the distance between the intersection of a line which is tangent to the center part of the slope of the transient curve Tr with the initial and final values of voltage represents reasonably accurately the time of duration of the transient or the transient time T. From Equation 3 it can be shown that the distance T between these intersections has the value of approximately

$$T = \frac{\pi}{\omega_0} = \frac{1}{2f_0} \qquad (4)$$

where

$$f_0 = \frac{\omega_0}{2\pi}$$

is the cut-off frequency of the filter. In Fig. 6, the origin represents the initial value of voltage and the horizontal dot-dash line represents the final value of voltage. For nearly all calculations of transient time in transmission systems this approximation may be substituted for the actual transient with sufficient accuracy for all practical purposes.

If at time t_4, the signal or pulse is terminated, a voltage transient similar to Tr results except that the voltage decreases with time and the intersections of a tangent to the center portion of the decreasing transient curve with initial and final values of voltage indicates the time duration of the second transient as indicated by the line Tr_4 in Fig. 7. From the foregoing it is seen that the resulting pulse, indicated by the numeral 4 in Fig. 7, is substantially triangular, although actually rounded at the corners.

A study of Figs. 6, 7 and 8 of the drawing indicates that for maximum voltage output the width of the pulse should be such that the decreasing transient begins at the instant that the increasing transient reaches its maximum value. In other words, if a pulse of width t_1—t_4 as indicated at 4′ in Fig. 8 is utilized, the increasing transient Tr_1 and the decreasing transient Tr_4 combine to provide a resultant pulse, triangular in shape and having a base twice that of the pulse 4′, as indicated at 4 in Fig. 7. If the duration of the pulse is made shorter than that of pulse 4′, the transients of the beginning and end portions of the pulses overlap; that is, the decreasing transient begins before the increasing transient has reached its peak and the resultant of the transients is a flat topped pulse. For example, if the square pulse width is only that indicated at 2′ in Fig. 8, the output pulse is determined by the resultant of transients Tr_1 and Tr_2 as indicated at 2 in Fig. 7. This pulse has a base width four times that of the square pulse 2′ and the maximum voltage of this trapezoidal pulse is much less than the maximum voltage of the triangular pulse 4. Thus, graphical addition methods show that the maximum amplitude of the signal is materially reduced if the pulse width is less than that of the pulse 4′ and an increase of the pulse duration up to time t_4 results in increased signal strength at the output of the filter. If the pulse duration is longer than that of pulse 4′, as indicated at 5′ of Fig. 8, a flat top pulse whose base width is one and one-half times that of the square pulse results as indicated by the numeral 5 in Fig. 7. A flat-topped pulse is undesirable and unnecessary because the flat portion of the wave or pulse conveys no intelligence. Thus beyond the point indicated by t_4, no increase of signal intensity is obtained and the optimum pulse duration is t_1—t_4 or T.

In the case of band pass filters passing a modulated carrier, analogous conditions exist.

From the above discussion it is seen that a square pulse is received as a substantially triangular or trapezoidal wave or impulse depending upon the pulse duration and optimum results are obtained when the square pulse width is equal to time T and the triangular pulse has a base width equal to 2T or twice the transient time of the overall system. While the foregoing discussion related to the production of pulses in the transmitter, the same considerations lead to the conclusion that a pulse signal applied to a receiver has a triangular shape in the receiver output irrespective of the shape of the impressed pulse. Therefore, if the pulse is shaped into a triangular form at the transmitter, receiver action will be unimpaired and if the conversion of the pulse to a triangular shape is accomplished before the pulse is impressed on the modulator and power amplifier, the energy otherwise consumed in the pulse at this stage is reduced.

While I have shown and described a particular embodiment of my invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention in its broader aspects, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a system in which pulses of high frequency oscillations are radiated and received for the transmission of signals, the combination of means for reducing the power required by the transmitting means to produce in the receiving means pulses of desired intensity, said means comprising means for producing a succession of pulses, means for transforming said pulses into pulses substantially triangular in shape, and means for modulating said high frequency oscillations by said triangular pulses to produce triangular shaped pulses of said high frequency oscillations.

2. In a system in which pulses of high frequency oscillations are radiated and received for the transmission of signals, the combination of means for reducing the power required by the transmitting means to produce in the receiving means pulses of desired intensity, said means comprising a source of substantially rectangular pulses, means for transforming said pulses into pulses substantially triangular in shape having duration, as measured at the base of said pulses, which is twice the duration of the transient time of the overall system, and means for modulating said high frequency oscillations to provide pulses shaped in accordance with said triangular pulses.

3. In a system in which pulses are radiated and received for the transmission of signals, the combination of means for reducing the power required by the transmitting means to produce in the receiving means pulses of desired intensity, said means comprising means for producing a succession of substantially rectangular pulses, a low pass filter circuit for transforming said pulses into pulses substantially triangular in shape, said filter circuit having a transient period no greater than the duration of said rectangular pulses, and means for controlling the transmission of said high frequency oscillations according to said triangular pulses.

4. In a system in which pulses are radiated and received for the transmission of signals, the combination of means for reducing the power required by the transmitting means to produce in the receiving means pulses of desired intensity, said means comprising a source of high frequency oscillations, means for producing a succession of substantially rectangular pulses, means for modulating said oscillations with said pulses, a band pass filter circuit for transforming said modulated oscillations into impulses substantially triangular in shape, said filter circuit having a transient period of the same order of magnitude as the duration of said rectangular pulses, a second source of high frequency oscillations, and means for modulating said last mentioned high frequency oscillations in accordance with said triangular pulses.

5. In a system in which signaling is effected by transmission of pulses of carrier wave oscillations from a transmitting station to a receiving station, the method of reducing the power required at the transmitting station to produce pulses of desired intensity at said receiving station which comprises the step of shaping the envelope of each carrier wave pulse transmitted in the form of a triangle.

6. In a system in which signaling is effected by transmission of pulses of carrier wave oscillations from a transmitting station to a receiving station, the method of reducing the power required at the transmitting station to produce pulses of desired intensity at said receiving station which comprises the step of shaping the envelope of each carrier wave pulse transmitted in the form of an isosceles triangle.

7. In combination, a carrier wave transmitter, a source of square wave pulses, means to modulate the output of said transmitter into pulses corresponding to said square wave pulses but the intensity of which increases from zero to maximum and starts to decrease to zero when said maximum is reached, said means comprising a network having an input and output, and having a transient period for buildup of voltage in said output in response to voltage supplied to said input, means to supply said square wave pulses to said inut, said pulses having a duration so related to said transient period of said network that the intensity of said pulses as reproduced in said output attains its maximum simultaneously with termination of the pulse supplied to the network.

8. In combination, a carrier wave transmitter, means to modulate the output of said transmitter to produce recurrent triangular shaped pulses, said means comprising a filter having a transient time between its input and output circuits, means to supply substantially square wave pulses of duration substantially equal to said transient time to said input, and means to modulate the output of said transmitter in accord with the shape of said pulses as reproduced in said output.

9. A pulse communication system comprising means for transmitting a series of recurrent pulses of high frequency oscillations, said transmitting means comprising a source of substantially rectangular pulses, means including coupling means having input and output circuits for integrating the leading edges of said rectangular pulses without appreciably reducing their peak intensity, said coupling means having a transient period of build up of voltage in said output circuit no greater than the duration of said rectangular pulses thereby to provide in said output

circuit a series of recurrent pulses of substantially triangular configuration, a source of high frequency carrier waves, and means for modulating said carrier waves in accordance with said triangular pulses whereby to reduce the input power required to transmit pulses of a predetermined desired intensity.

EVERHARD H. B. BARTELINK.

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Certificate of Correction

Patent No. 2,419,193.

April 22, 1947.

EVERHARD H. B. BARTELINK

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Column 1, line 46, for "audio" read *radio*; column 6, line 48, claim 7, for "inut" read *input*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 10th day of June, A. D. 1947.

[SEAL]

LESLIE FRAZER,
First Assistant Commissioner of Patents.