

2,406,978

3 Sheets-Sheet 1



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Sept. 3, 1946.

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SQUARE CODING WAVE GENERATOR FOR SECRET TELECOMMUNICATION SYSTEMS

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3 Sheets-Sheet 2

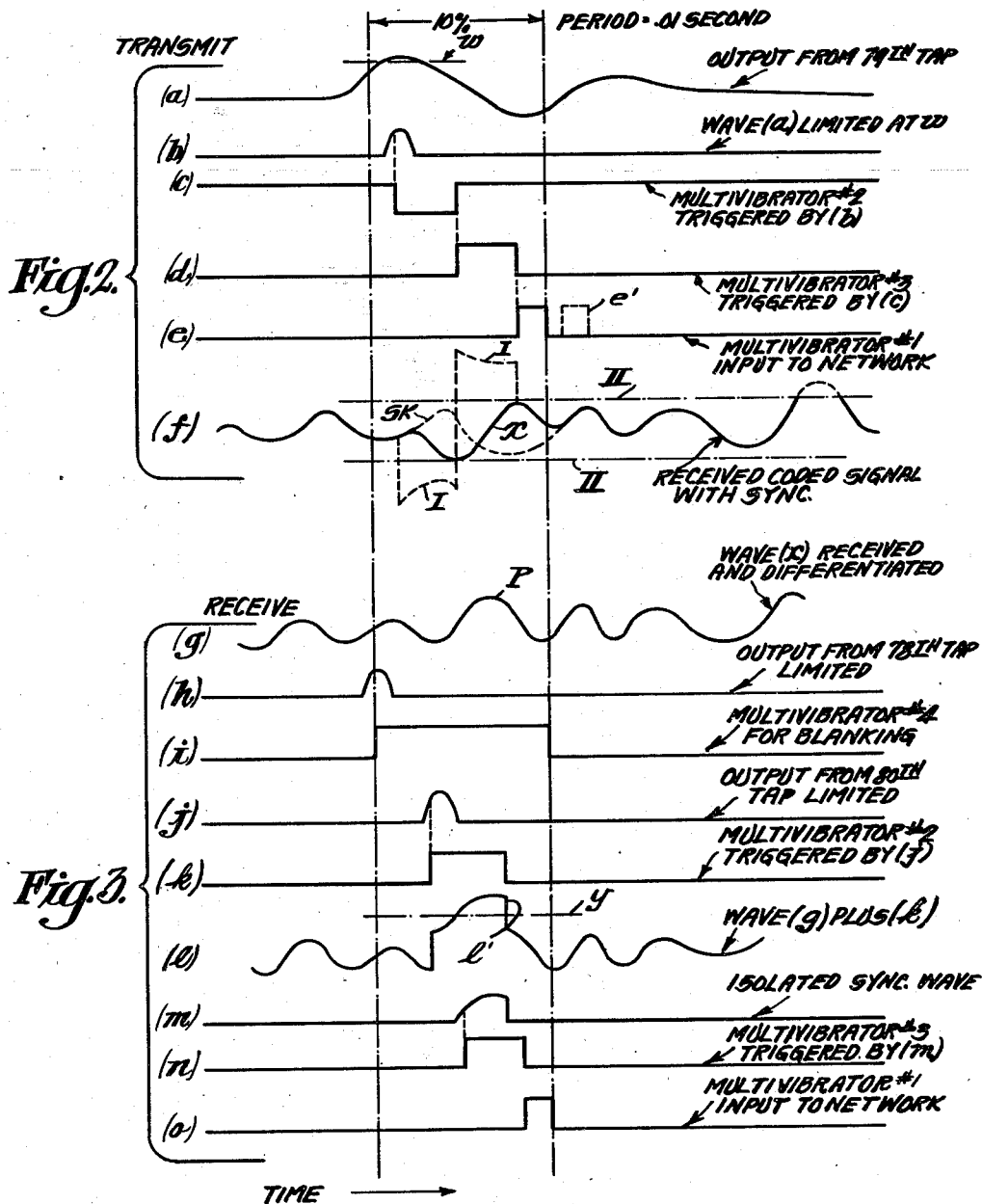
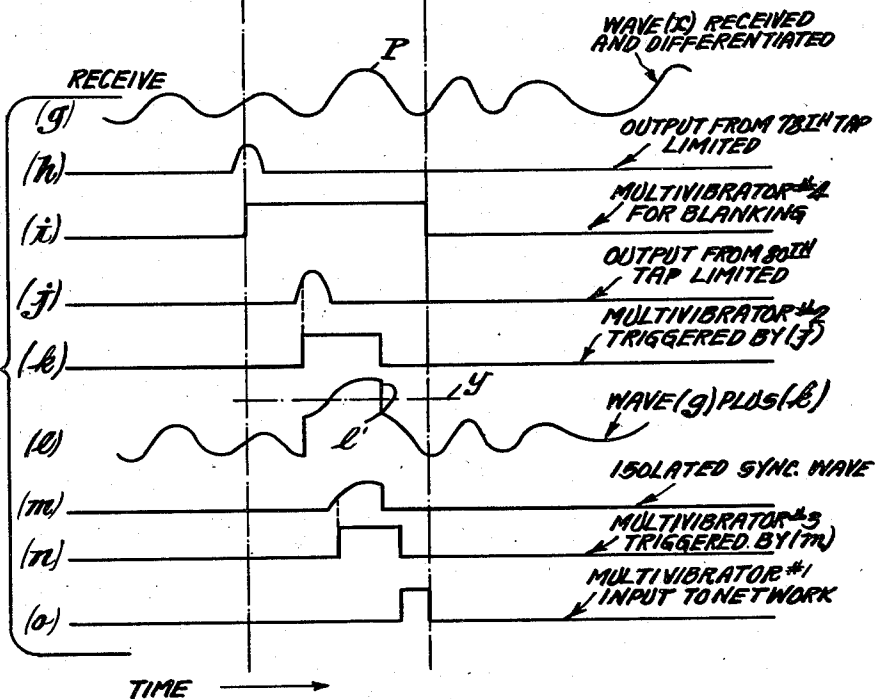


Fig. 3.



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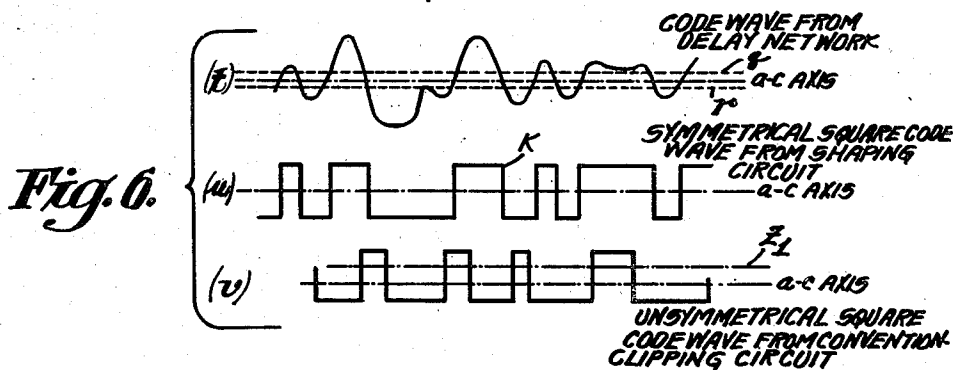
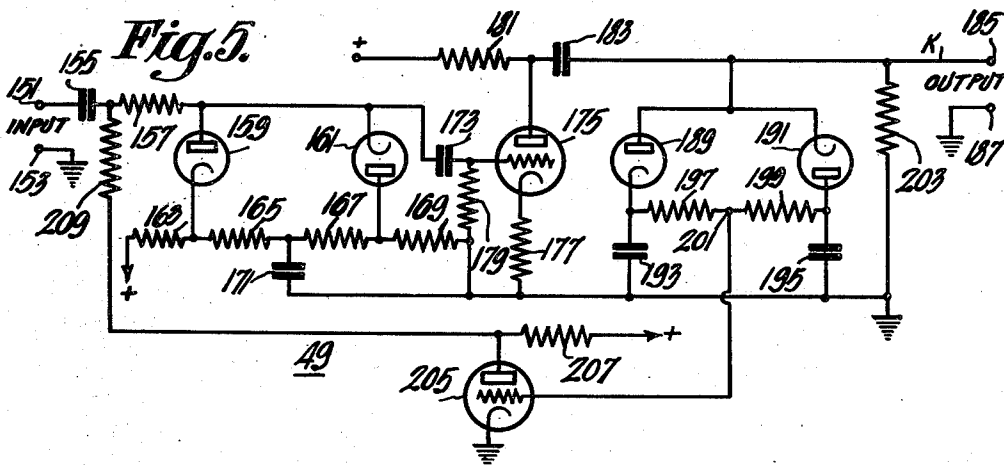
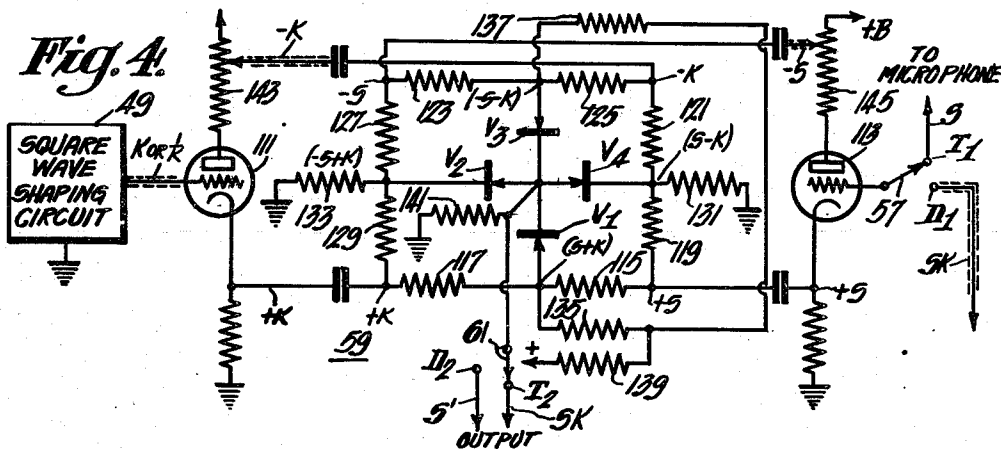
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SQUARE CODING WAVE GENERATOR FOR SECRET TELECOMMUNICATION SYSTEMS

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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

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SQUARE CODING WAVE GENERATOR FOR
SECRET TELECOMMUNICATION SYSTEMSKarl R. Wendt, Hightstown, and Alda V. Bedford,
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Application August 12, 1944, Serial No. 549,216

18 Claims. (Cl. 179-1.5)

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The present invention relates to secret telecommunication systems and more particularly to an improved method of and means for generating, utilizing and modifying square coding waves in such systems.

The invention, by way of example, will be described hereinafter as an improvement in a secret telecommunication system of the general type described in the copending U. S. application of Alda V. Bedford, Ser. No. 536,630 filed May 20, 1944. Said copending application discloses a system wherein, for example, a speech signal comprising a complex wave S is modified by means of a coding signal comprising a complex wave K in a manner whereby the instantaneous ordinates of the resulting coded signals are the product SK of the corresponding instantaneous ordinates of the speech signal and the coding signal. The resulting unintelligible coded signals are transmitted by any conventional means to a receiver wherein the coded signals are combined with decoding signals, generated in the receiver, and having instantaneous ordinates corresponding to the reciprocals of the corresponding instantaneous ordinates of the coding signal component of the transmitted signal. The final signals, therefore, are derived from the product of the transmitted signal SK and the decoding signal $1/K$. The coding and decoding signal generators, at the transmitter and receiver, respectively, are disclosed in said copending application as synchronized by means of special synchronizing pulse signals each comprising a first signal pulse immediately followed by a second signal pulse of opposite polarity, which pulses may be superimposed periodically upon the coded signals SK . At the receiver, the reversal in polarity between the two synchronizing pulses is employed to synchronize the decoding wave generator.

In said copending application, the coding wave K is generated by periodically pulse-exciting a multi-section delay network and selecting predetermined delayed pulse components which are combined in predetermined polarity to provide a rounded complex wave. The delayed pulse component selection is varied continuously by means of a complex switching mechanism to provide a code wave which is non-repetitive for a desired interval. Since the code wave is non-symmetrical, the reciprocal decoding wave $1/K$ must be derived from the synchronized code wave generator at the receiver by means of a novel wave reciprocal circuit described in said application.

The instant invention comprises a novel wave

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shaping circuit whereby the normally rounded complex coding wave is changed to a corresponding square wave having amplitude symmetry with respect to its A.-C. axis. The resulting square coding wave comprises an irregular combination of successively positive and negative uniform amplitude pulses of irregular duration, which are combined by multiplication with the speech signal S for transmission of a coded wave.

Since the square coding wave merely involves successive equal reversals of polarity, the reciprocal, or decoding, wave has the same general wave shape and polarity, differing, if at all, only in average amplitude. Therefore, the reciprocal circuit required in the system described in said copending application may be eliminated in the instant system, since the same square wave shaping circuit may provide both coding and decoding waves for transmission and reception, respectively.

While the invention is described herein, by way of example, as an improved method of and means for secret telecommunication, it should be understood that the novel wave shaping circuit may have numerous other applications wherein it is desirable to generate and utilize complex square waves having uniform amplitude symmetry with respect to their A.-C. axes. It should be understood that, as utilized herein, the A.-C. axis of a wave is the voltage or current level at which the summation of all of the areas of relatively positive wave increments equals the summation of all of the areas of relatively negative wave increments. Every complex wave has some such A.-C. axis, but all of such waves do not have uniform amplitude symmetry with respect to their A.-C. axes.

An outstanding advantage of employing such a symmetrical square coding wave in a secret telecommunication system is that the resulting coded signal always is at its maximum possible transmission level, since the speech signal is multiplied by uniformly equal amplitude coding wave increments. This results in maximum continuous transmitter efficiency and a correspondingly high signal-to-noise ratio. Also, the inherent distortion provided by the reciprocal circuits of prior systems is eliminated. The use of an A.-C. axially symmetrical coding wave eliminates the necessity of removing and later reinserting the D.-C. wave component comprising an essential part of axially dissymmetrical waves.

Among the objects of the invention are to provide an improved method of and means for producing complex square waves having A.-C. axis

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symmetry. Another object is to provide an improved method of and means for secret telecommunication. An additional object is to provide an improved method of and means for generating coding and decoding waves in a secret telecommunication system. A further object of the invention is to provide an improved wave shaping circuit. Another object is to provide a method of and means for converting complex dissymmetrical waves to equal amplitude square waves having A.-C. axis symmetry. A further object is to provide a method of and means for generating a complex electrical wave having a corresponding reciprocal wave of substantially the same waveform.

The invention will be described in greater detail by reference to the accompanying drawings of which Figure 1 is a schematic block circuit diagram of a complete secret telecommunication system employing the invention, Figure 2 is a series of graphs illustrating the circuit operation of the transmitting portion of the system shown in Figure 1, Figure 3 is a series of graphs illustrating the operation of the receiver portion of the circuit illustrated in Figure 1, Figure 4 is a schematic circuit diagram of the wave multiplier forming a portion of the circuit of Figure 1, Figure 5 is a schematic circuit diagram of a square code wave shaping circuit comprising the basic element of the invention, and forming a portion of the system shown in Figure 1 and Figure 6 is a series of graphs explaining the operation of said wave shaping circuit. Similar reference characters are applied to similar elements throughout the drawings.

Coding wave generator

Referring to Figure 1, the coding wave generator employed for both transmitting and receiving coded speech signals comprises a conventional free-running multivibrator circuit 1 which generates pulses at a rate, for example, of one hundred pulses per second. A typical multivibrator of this type, the frequency of which may be controlled by recurrent applied control pulses, is described in U. S. Patent 2,266,526, granted to E. L. C. White on December 16, 1941. It should be understood that pulses of either polarity may be applied in any known manner to key the multivibrator, and that, similarly, output pulses of either polarity may be derived therefrom. The generated pulses are applied to the input of a conventional delay network 2 comprising a plurality of series inductors 3, 5, 7, 9, 11 and a plurality of shunt capacitors 4, 6, 8, 10, 12, 14. The remote terminals of the resultant pulse delay network 2 are terminated by a resistor 13 matching the surge impedance of the network. It should be understood that the delay network 2 may include a relatively large number of filter sections as indicated by the dash lines interconnecting the filter sections 7, 8 and 9, 10, and that equalizers and booster amplifiers may be inserted in the delay network at desired points to maintain pulse amplitude relations at optimum values.

Pulses applied by the multivibrator 1 to the input of the delay network 2 provide similar pulses at the junction of each of the succeeding series inductors 3, 5, 7, 9, 11, wherein each succeeding pulse is delayed a predetermined amount with respect to pulses occurring at preceding terminals of the network. A complex, but generally rounded, coding wave thus may be obtained in response to each pulse applied to the

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delay network by combining in either polarity differently delayed pulses derived from a plurality of such predetermined points along the delay network.

Separate isolating resistors 15, 17, 19, 21, 23, 25, each have one terminal connected to different points along the delay network, and have their remaining terminals connected to separate movable contacts of a plurality of single-pole double-throw switches 27, 29, 31, 33, 35, 37. The corresponding fixed contacts of the several switches are connected together to provide two lines 39, 41, which are terminated through resistors 43, 45, respectively, to ground. The remaining terminal of the line 39 is connected through a coupling resistor 47 to the input circuit of a square wave shaping circuit 49, described in detail hereinafter by reference to Figures 5 and 6, which provides equal amplitude positive and negative wave increments having symmetry with respect to their A.-C. axis. The remaining terminal of the second line 41 is connected through a polarity-reversing amplifier 51 and a second coupling resistor 53 to said input circuit of the square wave shaping circuit 49.

Thus, each of the 100 pulses per second, derived from the multivibrator 1 and applied to the input of the delay network 2, provides a plurality of equal amplitude pulses of either polarity occurring at predetermined intervals during each one-hundredth second period, as determined by the points of connection to the delay network and the arrangement of the switches 27, 29, 31, 33, 35, 37. Therefore, a very complex symmetrical square coding wave may be applied from the output circuit of the square wave shaping circuit 49 to one input circuit of a wave multiplier, to be described hereinafter by reference to Figure 4 of the drawings, merely by selecting the desired arrangement of the pulse selecting switches. It should be understood that the total delay provided by the pulse delay network preferably should be at least slightly less than the pulse period of the multivibrator 1 in order that only one pulse may be traveling along the delay network at any predetermined instant.

In the typical secret telecommunication system, described in said copending application identified heretofore, the coding signal generator includes a delay network having 80 sections and a plurality of sequential switches which may be preset to any desired code and selectively actuated by a clock or motor mechanism to change the code continuously, or at predetermined desired intervals. Identical coding signal generators are employed at both the transmitter and receiver in such a secret telecommunication system. By means of simple "transmit-receive" switches the square wave coding signal either is combined with the speech signal for transmitting a coded wave, or the same wave shape reciprocal values of the coding signal are derived from the same square wave shaping circuit 49 responsive to the coding signal generator and are combined with the received coded signal to decode said received signal. Much of the decoding apparatus including the generator and wave shaping circuit for the code signal is identical to the coding apparatus. Hence, by means of the simple "transmit-receive" switches, the various elements of the apparatus may be employed at different times, and in some instances with somewhat different adjustment, for dual purposes in a single unit for either transmitting or receiving the coded signals.

Coding transmitter

Referring to Figures 1 and 2, the system may be employed as a coding transmitter by switching the movable contacts of each of the single-pole, double-throw "transmit-receive" switches included therein to engage the fixed contacts T₁, T₂, T₃, T₄, and T₅, corresponding to the "transmit" condition. Signals derived, for example, from a microphone 55, which may be fed through a speech amplifier, not shown, are applied through a first "transmit-receive" switch 57 to one input circuit of a wave multiplier 59, which will be described in detail hereinafter by reference to Figure 4 of the drawings. Coding signals, from the coding signal generator and wave shaping circuit described heretofore, are applied to a second input circuit of the wave multiplier 59, whereby coded signals SK having instantaneous ordinates corresponding to the products of the corresponding instantaneous ordinates of the speech signal S and the symmetrical square wave coding signal K are applied through a second "transmit-receive" switch 61 to one input circuit of a first signal mixer circuit 63, which may comprise any conventional network wherein applied signals are combined algebraically.

Transmitter synchronizing pulse generator

Regularly recurrent pulses indicated by the graph *a* of Figure 2 are derived, for example, from the seventy-ninth tap on the delay network 2 and are applied to a conventional thermionic tube amplitude limiter circuit 67, which clips the wave *a* at the level *w* to derive individual limited pulses represented by graph *b* of Figure 2. The limited pulses *b* are applied through a third "transmit-receive" switch 69 to key a second multivibrator 71 to derive a negative substantially square-wave pulse illustrated by graph *c* of Figure 2. The negative square wave pulse *c* is applied through a fourth "transmit-receive" switch 73 to a second input circuit of the first signal mixer circuit 63, and also is applied through a fifth "transmit-receive" switch 75 to key a third multivibrator 77 which generates a positive square wave pulse indicated by the graph *d* of Figure 2. It will be understood that the positive square wave pulse *d* will be initiated at the termination of the negative square wave pulse *c* in a manner well known in the multivibrator art. The positive square wave pulse *d* is applied to a third input circuit of the signal mixer circuit 63 whereby the coded signal SK, the negative square wave pulse *c* and the positive square wave pulse *d* are combined to provide a communication signal including the coded wave SK and the synchronizing signal comprising a negative square wave pulse immediately followed by a positive square wave pulse.

It should be understood that, if desired, the synchronizing signal may comprise a positive pulse followed by a negative pulse since multivibrators may be keyed by, and can provide, pulses of either polarity, providing proper connections thereto are provided in a manner known in the art. The combined coded signal and synchronizing signal derived from the mixer 63 will have a waveform, for example, of the type illustrated in graph *f* of Figure 2, including the pulses I, J, shown in dash lines.

A pulse derived from the third multivibrator 77 also is applied to key the first multivibrator 1 to generate a positive square wave pulse *e*, illus-

trated in Figure 2, which is applied to the input of the delay network 2 to initiate a succeeding pulse which will be progressively delayed along the delay network. Since the first multivibrator 1 is keyed by the pulse from the third multivibrator 77 immediately preceding the time for the generation of a normal pulse by said first multivibrator, it will be seen that the coding wave generator will be self-running, and will be maintained at a substantially constant frequency, since the pulse rate therethrough will be substantially dependent upon the time delay of the successive pulses applied to the delay network 2.

If for any reason the first multivibrator 1 is not properly keyed by the third multivibrator 77, the first multivibrator will merely generate a pulse *e'* which will be applied to the delay network 2 at a slightly later interval. The slightly delayed pulse upon reaching the seventy-ninth tap of the delay network therefore will key the second and third multivibrators in the manner described heretofore and provide a new set of synchronizing pulses which will actuate the first multivibrator 1 in synchronism thereafter.

The coded signals SK combined with the synchronizing pulses *c* and *d* are applied to a second limiter 79 whereby the high amplitude portions I of the synchronizing signal are clipped to a maximum level II indicated by the dash lines in graph *f* of Figure 2. The thus limited combined coded and synchronizing signals are applied as a communication signal to a conventional radio transmitter 81 which includes a transmitting antenna 83.

Coded signal receiver

In order to convert the circuit thus described to operate as a coded signal receiver, the movable contacts of each of the "transmit-receive" switches 57, 61, 69, 73 and 75 are switched to the corresponding fixed contacts D₁, D₂, D₃, D₄, D₅, corresponding to the "receive" condition. Because of the infidelity of the radio transmitter and receiver, the combined coded signal and synchronizing signals transmitted from the transmitter 81 and received by a conventional radio receiver 85 are "smeared" and phase-shifted somewhat to resemble the solid portion *x* of the graph *f* of Figure 2. These received signals are applied to a conventional wave differentiating network 87, which may be of any type well known in the art. For example, a wave may be differentiated by applying it to a network comprising a small series capacitor and a shunt resistor. The transmitted signal *x* of Figure 2 after being differentiated at the receiver resembles the graph *g* of Figure 3 wherein a relatively large pulse P occurs at an instant corresponding to the reversal in polarity between the received synchronizing negative and positive pulses and wherein low frequency components are substantially removed from the pulse P. It should be understood that instead of differentiating the received signal, it may be treated in any other known manner to derive a pulse in response to the reversal in polarity of the negative and positive synchronizing pulses.

The receiver first multivibrator 1 being free running, as described heretofore, the delay network 2 will provide recurrent pulses at its seventy-eighth tap which will be limited by means of a third limiter 89 to provide limited pulses represented by the graph *h* of Figure 3. The thus limited pulses *h* are applied to key a fourth multivibrator 91 which generates a relatively long

blanking pulse illustrated in graph *i* of Figure 3. The long blanking pulse *i* is applied to a blanking circuit 93 which blanks out portions of the received signal, as will be explained in greater detail hereinafter.

Receiver synchronizing circuits

Similarly, each of the recurrent pulses derived from the eightieth tap of the delay network 2 are applied to a fourth limiter 95 which clips the upper portion of the applied pulse as explained heretofore with respect to pulse *b*, to provide a short pulse illustrated by graph *j* of Figure 3. The limited pulse *j* is applied through the third "transmit-receive" switch 59 to key the second multivibrator 71 to provide a relatively long positive square wave pulse *k*. It will be noted that the positive pulse *k* is of relatively longer duration than the negative pulse *c* previously described as generated by the second multivibrator 71 when said multivibrator is employed in the transmitting circuit. The different pulse polarity and duration may be accomplished in any well known manner by changes provided in the multivibrator circuit constants and the connections thereto, when the multivibrator is switched from the "transmitting" to the "receiving" condition.

The positive square wave pulse *k* derived from the second multivibrator 71 is applied through the fourth "transmit-receive" switch 73 to a second mixer circuit 97, to which also is applied the differentiated wave *g* derived from the differentiating circuit 87. The thus mixed signals illustrated by graph *l* of Figure 3 include a pulse peak *l'* which corresponds in time to the occurrence of the large positive pulse *P* of the differentiated received wave *g*. As explained heretofore, the pulse *P* corresponds to the reversal in polarity of the received synchronizing negative and positive pulses. The wave *l* derived from the second mixer circuit 97 is applied to a fifth limiter 99 which clips the mixed signal at a level *y* to provide in its output circuit a short somewhat triangular pulse, illustrated by graph *m* of Figure 3.

The triangular pulse *m* is applied through the fifth "transmit-receive" switch 75 to key the third multivibrator 77 to provide a positive pulse represented by graph *n* of Figure 3 which is applied to key the first multivibrator 1 as described heretofore with respect to the pulse *d* in the transmitting network. It should be understood that, if desired for extremely precise synchronism, the pulse *m* may be changed from triangular to square wave shape by clipping at a low level and then by amplifying the clipped lower portion of the pulse in a manner known in the art. The pulse *n* therefore causes the first multivibrator 1 to generate a positive pulse *o* which is applied to the delay network 2 in the same manner as described heretofore with respect to the positive pulse *e* of the transmitting network.

As explained heretofore with respect to the operation of the multivibrator circuits in the "transmitting" condition, if the circuit falls out of synchronism, the various multivibrators will provide pulses at somewhat increased time intervals until such time as a synchronizing pulse occurs at a proper instant to pull all of the multivibrators back into synchronism. Since pulses are derived from the delay network 2 at intervals of the order of .01 second, it is apparent that the various circuits will fall into synchronism in a relatively short time which seldom will exceed one full second.

Due to phase distortion in the transmission or

radio circuits interconnecting the transmitter and receiver units, it is possible that the effective time of occurrence of the received synchronizing pulses will vary in different receivers with respect to the received coded speech. To correct for such variations, the circuit constants of the third multivibrator 77 may, in any known manner, be altered in the receiving condition so that the width of the pulse *n* may be varied to provide keying of the first multivibrator 1 at the precise desired instant. The manner of varying the circuit constants of multivibrators to provide pulses of desired polarity and duration in response to predetermined applied triggering pulses is well known in the art.

Signal decoding system

The received signals derived from the radio receiver 85 are applied to the input of the blanking circuit 93 which interrupts the received coded signals during the occurrences of the recurrent blanking pulses *i*, whereby the transmitted positive and negative synchronizing pulses may be removed from the received coded signal. This condition obtains when the coding signal generator of the receiver is in synchronism with the transmitter coding signal generator, since the fourth multivibrator 91 is responsive to pulses derived from the seventy-eighth tap on the delay network 2. Blanking circuits are well known in the art. They may comprise, for example, a push-pull amplifier for the signal, arranged so that the blanking pulses *i* are superimposed on the grid-cathode circuits so that both tubes are simultaneously driven to cut-off during the blanking period. The thus blanked received signals comprise the transmitted signal components *SK* which are applied through the first "transmit-receive" switch 57 to one of the input circuits of the wave multiplier 59.

Similarly, the signals generated by the receiver coding generator are applied to the input circuit of the square wave shaping circuit 49, which will be described in detail hereinafter by reference to Figure 5 of the drawings. The square wave output of circuit 49 has the same positive and negative amplitudes (measured from the A.-C. axis). Hence this wave is identical in shape to its own reciprocal wave, and the same wave may serve as *K* in the sending unit and as *1/K* in the receiving unit. Thus the square wave output of circuit 49 is applied (as the reciprocal wave *1/K*) to a second input circuit of the multiplier 59. Since the wave multiplier 59 provides output signals which have instantaneous ordinates corresponding to the product of the instantaneous ordinates of the waves *1/K* and *SK* applied thereto, the output signals *S'* applied through the second "transmit-receive" switch 61 to a reproducer 103 will be substantially characteristic of the original speech modulation signals *S*. The signals applied to the reproducer 103 have been indicated as *S'* since some distortion is inherent in the various circuits described and especially in many radio transmission circuits. It should be understood that the signals *S'* derived from the second "transmit-receive" switch 61 may be applied to actuate any other desired type of utilization apparatus, not shown.

Signal multiplier

Figure 4 shows a typical wave multiplier circuit forming a portion of both the coding wave transmitter and receiver circuits described heretofore with reference to Figure 1 of the drawings.

This multiplier circuit is described and claimed in the copending U. S. application of Alda V. Bedford, Serial No. 517,967 filed January 12, 1944 and assigned to the same assignee as the instant application. The circuit utilizes the property of well known electrical devices which provide an instantaneous output current or voltage which is proportional to the square of the instantaneous input voltage over a reasonable voltage range in a single polarity. Such circuits or devices will be referred to as "squaring circuits," and will be designated as "Q" where referred to hereinafter.

In the preferred form of the multiplying circuit, the waves S and K, (or SK and 1/K), to be multiplied, are added together with four different polarity combinations and "squared" in four different signal channels. Then the four "squared" signals are added together with suitable polarities to obtain the product SK, (or S), in the output circuit of the multiplier network, as will be illustrated by the following equations for obtaining the product of S and K:

$$\begin{array}{ll}
 (1) \text{ Output of } Q_1 = (S+K+A)^2 & = S^2 + K^2 + A^2 + 2SK + 2KA + 2AS \\
 (2) \text{ Output of } Q_2 = (-S-K+A)^2 & = S^2 + K^2 + A^2 + 2SK + 2KA - 2AS \\
 (3) \text{ Output of } Q_3 = -(-S+K+A)^2 = -(S-K+A)^2 & = -S^2 - K^2 - A^2 + 2SK + 2KA - 2AS \\
 (4) \text{ Output of } Q_4 = -(-S-K-A)^2 = -(S+K+A)^2 & = -S^2 - K^2 - A^2 + 2SK - 2KA + 2AS \\
 (5) \text{ Sum output} & 8SK
 \end{array}$$

It will be understood that the term A in the above equations is the D.-C. bias added to the A.-C. waves to cause all of the signal amplitude variations to have the same polarity with respect to the squaring devices.

The squaring circuit illustrated employs a plurality of small copper oxide rectifiers known commercially as "varistors". Because of the particular variable resistance characteristics of the "varistor," the current therethrough is substantially proportional to the square of the applied voltage over a reasonable range of applied voltage of a single polarity. The multiplier network 59 is shown as including a first triode thermionic tube 111 having its grid electrode connected to the output circuit of the square wave shaping circuit 49, whereby signals characteristic of either the coding wave K, or the reciprocal thereof 1/K, may be applied to the tube grid-cathode circuit. A second thermionic tube 113 has its grid electrode connected to the movable contact of the first "transmit-receive" switch 57, whereby either the speech signals S or the blanked, received signals SK may be applied to the tube grid-cathode circuit. The operation of the circuit will be explained hereinafter with the switch 57 in the "transmitting" position whereby the signals K and S, respectively, are applied, respectively, to the grid-cathode circuits of the tubes 111 and 113. Push-pull output signals are derived from each of the tubes by means of connections to the corresponding tube anode and cathode circuits as indicated in the drawings.

In order that the desired sum voltages be obtained, the signals S and K are applied to a closed network of serially-connected resistors in the following manner: Signals S and K, respectively, traverse resistors 115 and 117 to provide a signal proportional to (S+K) at the point (S+K); the signals S and -K respectively traverse resistors 119 and 121 to provide a signal (S-K); the signals -S and -K respectively traverse resistors 123 and 125 to provide a signal (-S-K); and the signals -S and K traverse resistors 127 and 129 to provide a signal (-S+K). Thus, at each of the four junction points, a sum of voltage is obtained as des-

igned in the circuit diagram. As shown, the network also includes shunt resistors 131 and 133 leading respectively from points (S-K) and (-S+K) to ground, and shunt resistors 135 and 137 leading respectively from points (S+K) and (-S-K) to the positive terminal of the source of bias voltage which is applied through a voltage-reducing resistor 139. An 8000-ohm resistance has been found satisfactory for the shunt resistors 131, 133, 135, and 137 while 100,000-ohm resistance has been taken as the value of the series bridge resistors 115, 117, 119, 121, 123, 125, 127, and 129.

The sum voltages at the four points of the network are applied with the bias voltage A and -A to four varistors V₁, V₂, V₃, and V₄ respectively, all of which control the current through the common load resistor 141 to provide thereacross the product output voltage SK. The output across the load resistor 141 is proportional to the sum of all the voltages which would have been generated if each varistor had supplied cur-

rent to a separate resistor, as indicated by the foregoing squaring equations. It is to be noted that the varistors V₂ and V₄ are connected with opposite polarities from the varistors V₁ and V₃, so that the D.-C. bias voltage must be different. By reference respectively to the third and fourth equations it will be seen that the values

$$(-S+K-A)$$

and (S-K-A) are each preceded by another minus sign and included in brackets before squaring to indicate properly mathematically the effect of the reversed connection on these two varistors. These five equations show that, ideally, only the desired voltage SK is produced across the output resistor 141.

For compensating for small dissimilarities in the varistors and other circuit elements, it has been found desirable to provide variable resistors 143 and 145 connected as voltage dividers in the anode circuits of the tubes 111 and 113, respectively, for adjusting the relative amplitudes of -S and -K.

While in the foregoing the term "multiplying circuit" has been used to define the circuit, it will be seen that the circuit acts like a modulator which is completely balanced in the sense that only the side band frequencies are produced, while the input frequencies and the harmonics thereof are suppressed.

The output signals SK derived from across the output resistor 141 are applied to the movable contact of the second "transmit-receive" switch 61, whereby they may be selectively applied to either the reproducer 103 or to the first mixer 63, depending upon the desired operation in the circuit of Figure 1.

Symmetrical square wave shaping circuit

Referring to Figures 5 and 6, the symmetrical square wave shaping circuit 49 includes an input terminal 151 connected to the output of the code wave generator coupling resistors 47, 53, and an input terminal 153 which is grounded. The ungrounded input terminal 151 is connected through a coupling capacitor 155 and a series resistor 157 to the anode and cathode, respec-

tively, of a pair of oppositely-connected diode limiters 159 and 161. The cathode of the diode 159 and the anode of the diode 161 are connected to suitable spaced points on a voltage divider 163, 165, 167, 169 which is connected across a source of bias voltage not shown. The junction of the voltage dividing resistors 165, 167 is connected through a capacitor 171 to ground. The output of the diode limiters 159, 161 is applied through a grid capacitor 173 to the control electrode of a triode amplifier 175. The cathode of the triode amplifier 175 is grounded through a cathode resistor 177 which provides normal bias therefor. The grid of the triode amplifier 175 is connected through a grid resistor 179 to ground. Therefore, the code wave shown in graph *t* of Figure 6 will be limited by the diodes 159, 161 at the levels *q* and *r* determined by the fixed bias voltages applied to the diodes, whereby the code wave will be changed to a substantially square waveform, the positive and negative wave increments of which are not necessarily symmetrical with respect to its A.-C. axis.

A source of anode potential, not shown, is connected through an anode resistor 181 to the anode of the triode amplifier 175. The anode of the triode amplifier 175 also is connected through an output coupling capacitor 183 to one of the circuit output terminals 185. The remaining output terminal 187 is grounded.

A pair of oppositely-connected diode peak detectors 189 and 191 are connected across the output terminals through capacitors 193, 195, respectively. A voltage divider comprising the serially-connected resistors 197, 199 is connected between the ungrounded terminals of the capacitors 193, 195 to provide a junction point 201 having a control voltage equivalent to the difference of the magnitudes of the positive and negative peaks of the square wave at the output terminals, with respect to ground, since one output terminal 187 is grounded and the remaining output terminal 185 is connected to ground through a loading resistor 203.

The time constant of the networks comprising the resistor 197 and capacitor 193, and the network comprising the resistor 199 and capacitor 195, being equal and relatively high, the voltage at the point 201 will vary relatively slowly between positive and negative values as the limited code wave varies in symmetry with respect to ground.

The control potential derived from the point 201 is applied to the control electrode of a triode control tube 205, the cathode of which is grounded. The positive terminal of the anode potential source is connected through a second anode resistor 207 to the anode of the control tube 205. The anode of the triode control tube 205 also is connected through a high impedance resistor 209 to the common terminals of the input coupling capacitor 155 and input coupling resistor 157, whereby a variable bias voltage of the proper polarity is applied to the diode limiters 159, 161 whenever the square coding wave across the output terminals 185, 187 tends to be dissymmetrical with respect to ground. The thus applied bias voltage thereby changes the normal limiting levels of the input signal to provide uniform amplitude positive and negative square wave pulses with respect to the wave A.-C. axis. In common with other automatic control circuits the control provided by the control tube 205 approaches ideal conditions if the control tube circuit has relatively high gain. An experimental circuit may

be readily constructed which provides symmetry within the order of two percent with stable circuit operation.

Thus the square coding wave K shown in graph *u* of Figure 6 comprises equal amplitude positive and negative square wave increments with respect to its A.-C. axis which is at ground potential.

A symmetrical square coding wave, as shown in graph *u* of Figure 6, is to be desired over an unsymmetrical square coding wave of the type shown in graph *v*, since the symmetrical square wave has a reciprocal wave which is the same shape as the original wave. As shown in graph *v* the A.-C. axis of an unsymmetrical square wave does not correspond with the zero axis *Z*₁ of the reciprocal of such a wave. Hence, if an unsymmetrical coding wave were employed, a D.-C. component equivalent to the difference between the A.-C. axis and *Z*₁ axis, illustrated, would be necessary to provide proper decoding of the received wave SK. Since the D.-C. component would vary continuously as the characteristics of the coding wave changed, extremely elaborate circuits would be necessary for such D.-C. insertion. If the proper D.-C. component were not present in the decoding wave generator, the decoded output would contain non-intelligible coded SK signal components which would distort the decoded signal component S'.

It should be understood that the symmetrical square wave shaping circuit thus described may be employed for many purposes other than that described herein with respect to secret telecommunication systems, since the network provides a convenient method of and means for converting any complex wave to a corresponding square wave having equal magnitude positive and negative wave increments with respect to its A.-C. axis.

Thus the invention described comprises a novel wave shaping circuit wherein a complex electrical wave may be changed to a corresponding wave having equal magnitude positive and negative square wave increments with respect to its A.-C. axis. The novel circuit has been illustrated herein as an element of a secret telecommunication system employing a communication signal which is distorted by multiplication with such a symmetrical square coding wave, and which is decoded by means of a similar synchronized symmetrical square coding wave.

We claim as our invention:

1. In a secret telecommunication system for a communication signal, means for producing a complex square coding wave having equal amplitude positive and negative wave increments with respect to its A.-C. axis, and means for combining said coding wave with said communication signal to provide a coded transmission signal.

2. In a system of the type described in claim 1, means for producing a second substantially identical square wave, and means for combining said second wave with said transmission signal to decode said signals.

3. In a system of the type described in claim 1, means for producing a second substantially identical square wave, means for synchronizing said substantially identical square wave producing means with said coding wave, and means for combining said second wave with said transmission signal to decode said signals.

4. The method of communication which comprises producing a communication signal and a square wave distorting signal symmetrical with

respect to its A.-C. axis, multiplying the values of said signals as measured from their alternating-current axes by each other to obtain their product, transmitting said product to the point of reception and there multiplying said product by a similar symmetrical square wave signal having substantially the same waveform as said distorting signal, said last multiplication also being a multiplication of the signal values as measured from their alternating-current axes.

5. The method of communication which comprises producing a communication signal and a square wave distorting signal having A.-C. axial symmetry, each of which comprises frequency components lying within a common frequency band, multiplying said signals by each other to obtain their product, transmitting said product signal to the point of reception and there multiplying said product signal by a similar symmetrical square wave signal that is substantially the reciprocal of said distorting signal.

6. A system for transmitting a communication signal from a transmission point to a reception point which comprises means at the transmission point for producing a square wave distorting signal having A.-C. axial symmetry, means for multiplying said communication signal by said distorting signal to obtain their product, and means located at the point of reception for multiplying said product by a similar symmetrical square wave signal having substantially the same waveform as said distorting signal, both of said multiplication being a multiplication of the signal values as measured from the alternating-current axes of the signals.

7. In a system for secret transmission of a communication signal, a communication unit that includes means for producing a square wave distorting signal having A.-C. axial symmetry, and means for multiplying the instantaneous amplitude of said communication signal as measured from its alternating-current axis by the instantaneous amplitude of said distorting signal as measured from its alternating-current axis to produce a product signal.

8. In a system for secret transmission of a communication signal comprising frequency components that lie within a certain frequency band, a communication unit that includes means for producing a square wave distorting signal having A.-C. axial symmetry and comprising frequency components that lie within a frequency band at least a portion of which is common to a portion of said certain frequency band, and means for multiplying said communication signal by said distorting signal to produce a product signal, said multiplication being a multiplication of the signal values as measured from the alternating-current axes of the signals.

9. A system for secret transmission of a communication signal from a transmitter to a receiver, said transmitter including means for producing a square wave coding signal having A.-C. axial symmetry and means for multiplying said communication signal by said coding signal to produce a product signal, means for transmitting said product signal to the receiver, said receiver including means for producing a similar square wave decoding signal having substantially the same waveform as said coding signal, and means for multiplying said product signal by said decoding signal, both of said multiplications being a multiplication of the signal values as measured from the alternating-current axes of the signals.

10. The invention according to claim 6 wherein means is provided for maintaining said code signal producing means and said decoding signal producing means in synchronism.

11. A transmitter-receiver unit for the transmission and reception of a communication signal, said unit comprising means for producing a square wave distorting signal having A.-C. axial symmetry, multiplier means for multiplying said signals by each other when applied thereto, switching means for applying said communication signal and said distorting signal to said multiplier means to obtain their product, means common with said distorting signal producing means for producing a similar square wave decoding signal having substantially the same waveform as said distorting signal, and switching means for supplying a received product signal and said decoding signal to said multiplier means to obtain and decode said received communication signal.

12. In combination with a secret telecommunication system of the type wherein a communication signal is combined with a modified coding signal by wave multiplication of the signal values with respect to the A.-C. axes of said signals, a wave modifying circuit for said coding signal comprising means for limiting positive and negative increments of said coding signal, means for amplifying said limited signal increments, means for peak detecting said amplified signal increments, means responsive to said detecting means for deriving control potentials characteristic of the algebraic sum of the amplitudes of said detected signals with respect to its A.-C. axis, and means for applying said control potential as a variable bias potential on said limiting means to provide from said phase inverting means a modified coding wave having equal amplitude positive and negative square wave increments with respect to its A.-C. axis.

13. A wave modifying circuit for a source of complex signals comprising means for limiting positive and negative increments of said signals, means for amplifying said limited signal increments, means for peak detecting said amplified signals, means responsive to said detecting means for deriving control potentials, and means for applying said control potentials as variable bias potentials to said limiting means to obtain therefrom modified signals having equal amplitude positive and negative square wave increments with respect to their A.-C. axis.

14. In a secret telecommunication system for a communication signal, a coding wave generator for producing a complex square coding wave having equal positive and negative wave increments with respect to its A.-C. axis, and means for multiplying the values of said communication signal and said coding wave as measured from their A.-C. axes to provide successive polarity reversals of said communication signal for coding said signal.

15. In a system of the type described in claim 14, means for generating a second substantially identical coding wave, and means for multiplying the values of said coded signal by said second coding wave as measured from their A.-C. axes to decode said communication signal.

16. The method of modifying a complex electrical wave to provide a substantially square wave having uniform peak values symmetrical with respect to its A.-C. axis, comprising limiting said complex wave at predetermined amplitude values, amplifying said limited wave, detecting said amplified wave potentials with respect to a reference

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potential, and controlling said limiting amplitude values in response to said detected wave amplitudes.

17. A circuit for modifying a complex electrical wave to provide a substantially square waveform having uniform peak values symmetrical with respect to its A.-C. axis, comprising means for limiting said complex wave to provide waves having substantially square waveform and means responsive to said limited wave amplitudes with respect to a point of reference potential for biasing said limiter to provide square waves of uniform amplitude peak values symmetrical with respect to their A.-C. axis.

18. A circuit for modifying a complex electrical wave to provide a wave having a substantially square waveform comprising positive and negative

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peaks of substantially equal amplitude with respect to the A.-C. axis of said square wave, said circuit including limiting means for limiting the positive amplitude and the negative amplitudes of said complex wave at levels controlled by a bias voltage applied to said limiting means, peak detecting means responsive to the relative amplitudes of said positive and said negative peaks of said square wave for generating a variable D.-C. voltage, and means for applying said variable D.-C. voltage as a bias voltage to said limiting means whereby said limiting levels are controlled to provide substantially equal amplitude positive and negative peaks of said square wave.

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