Sept. 3, 1946. K. R. WENDT 2,406,977

SYNCHRONIZING SYSTEM

Filed July 29, 1944 5 Sheets-Sheet 1

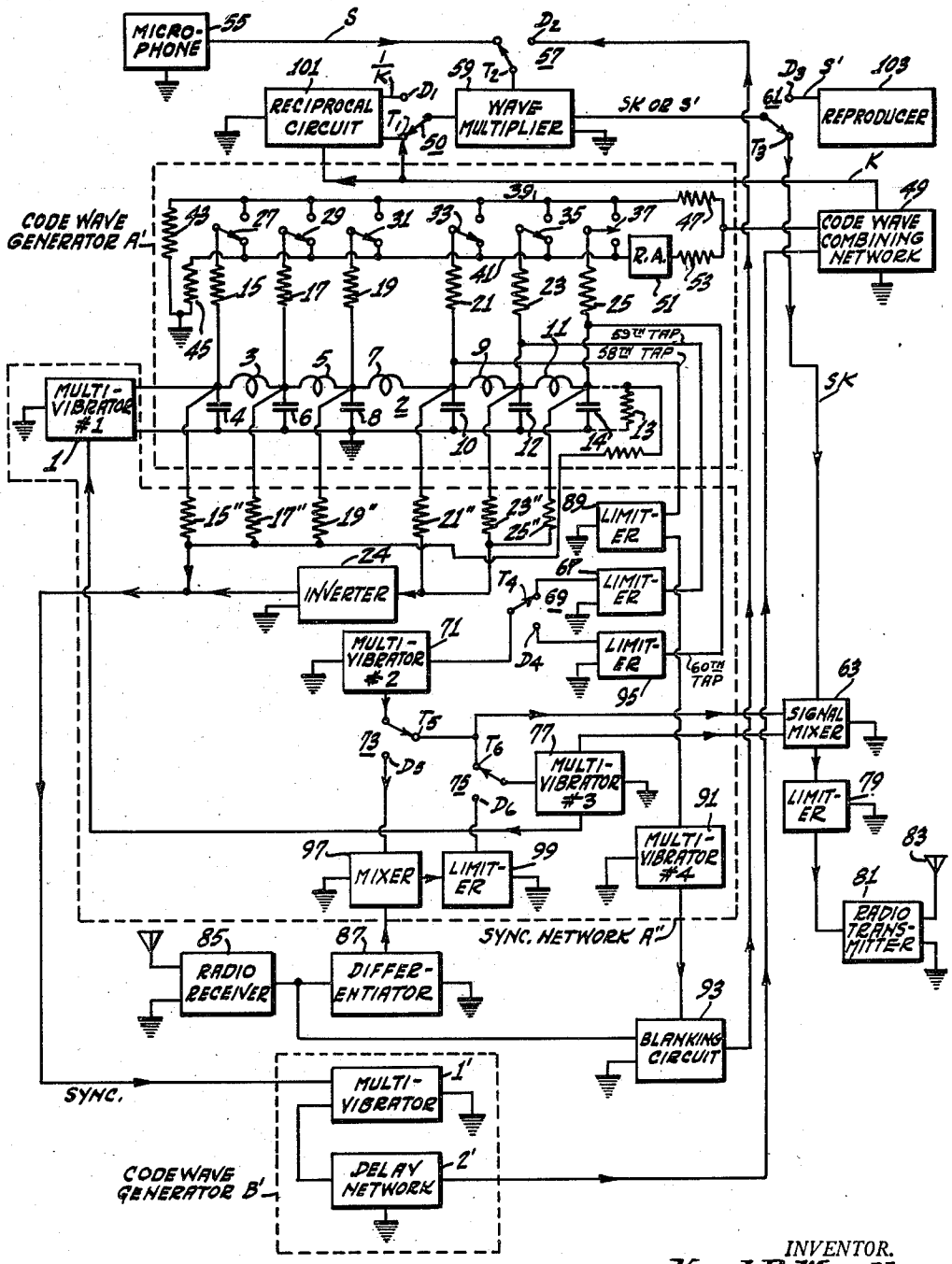


Fig. 1.

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SYNCHRONIZING SYSTEM

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Fig. 2.

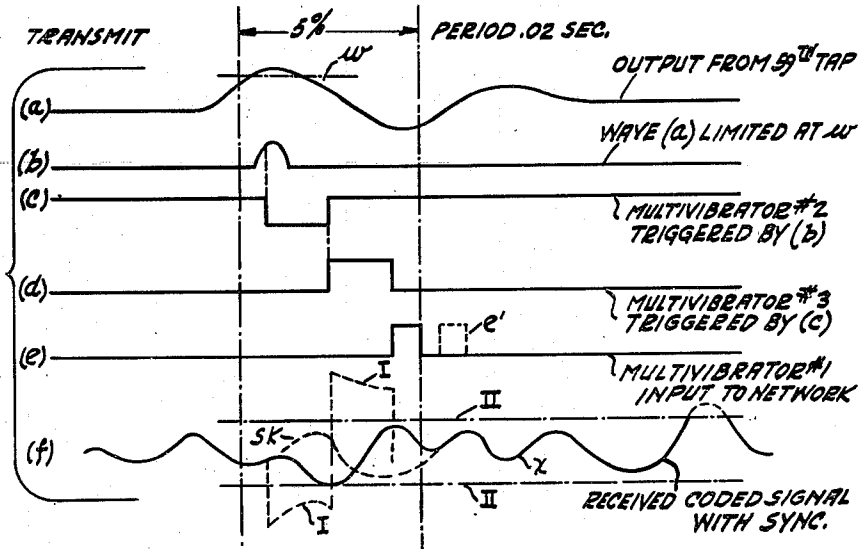
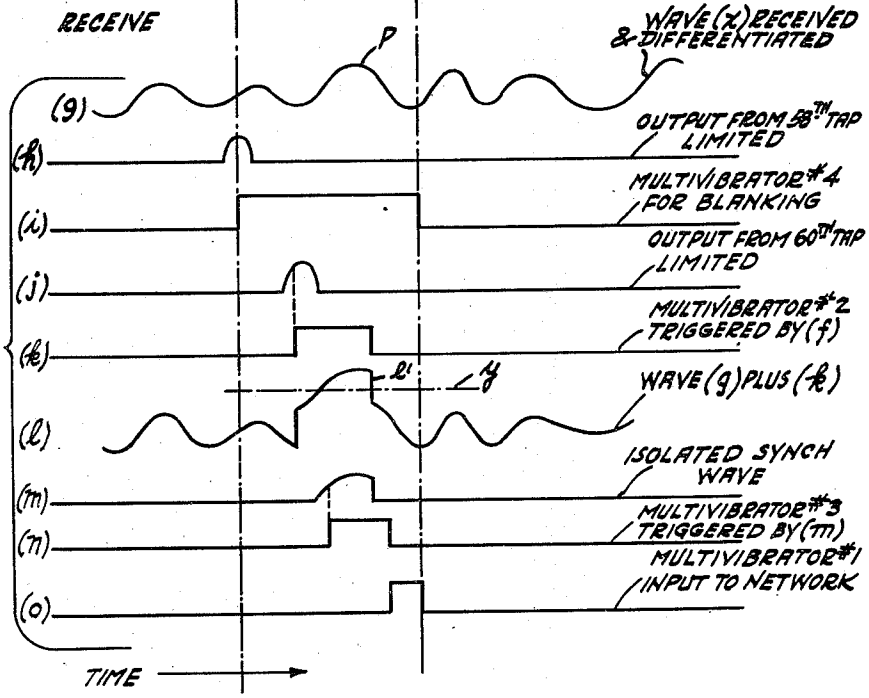


Fig. 3.



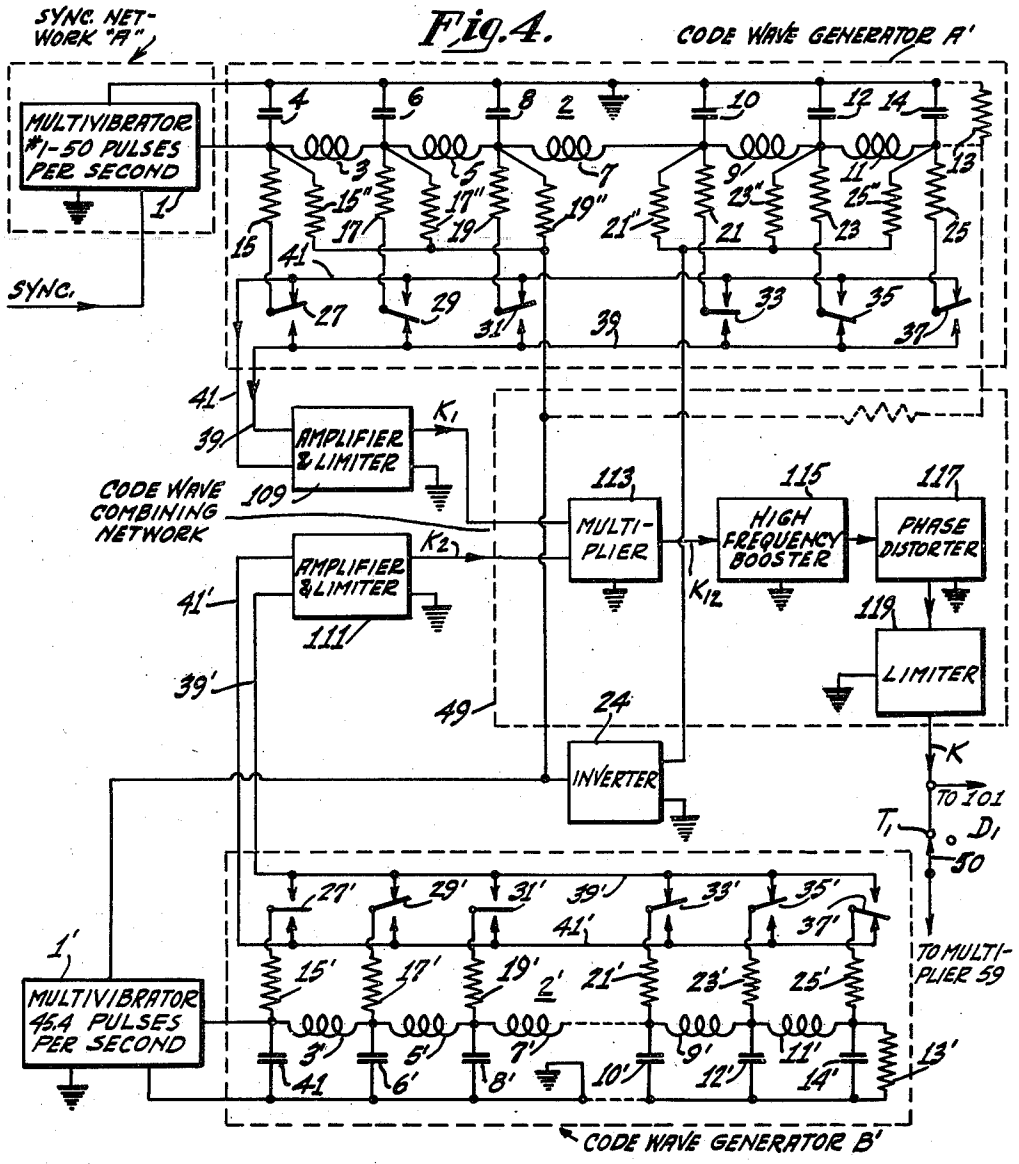
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Filed July 29, 1944 5 Sheets-Sheet 3

Fig. 4.



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SYNCHRONIZING SYSTEM

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Fig. 7.

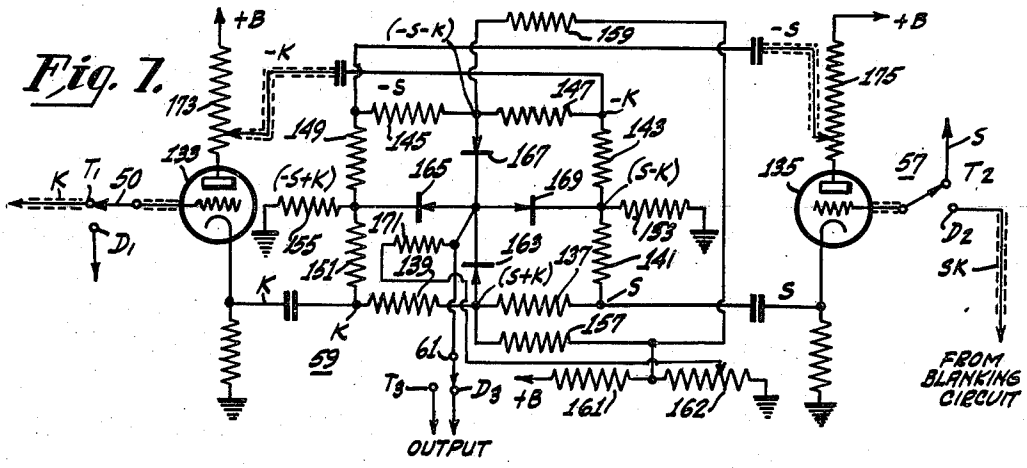


Fig. 8.

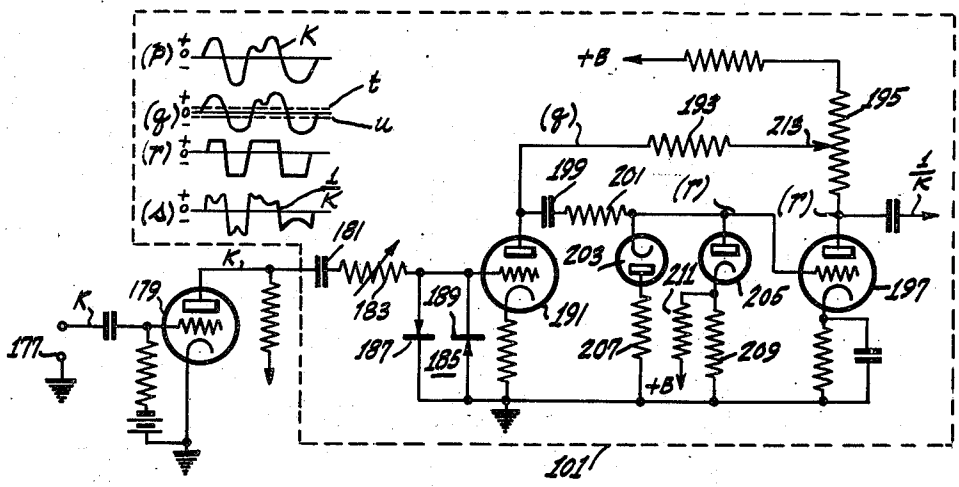
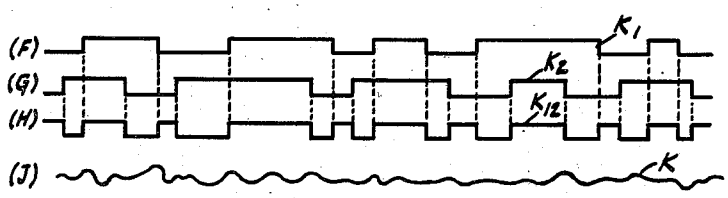


Fig. 5.



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SYNCHRONIZING SYSTEM

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Fig. 6.

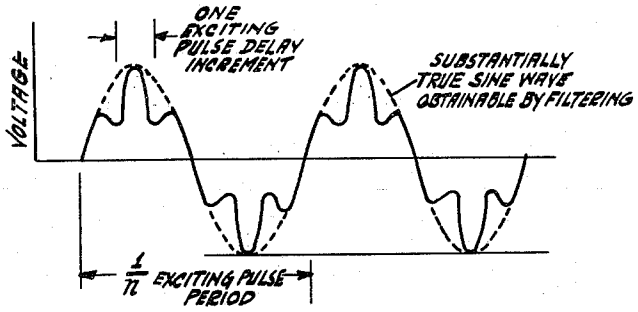


Fig. 10.

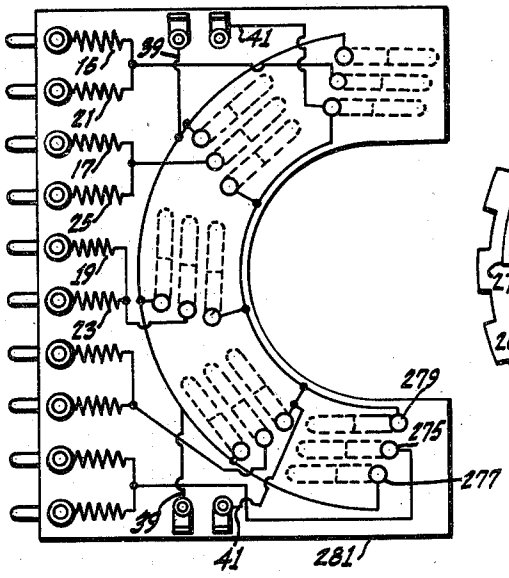
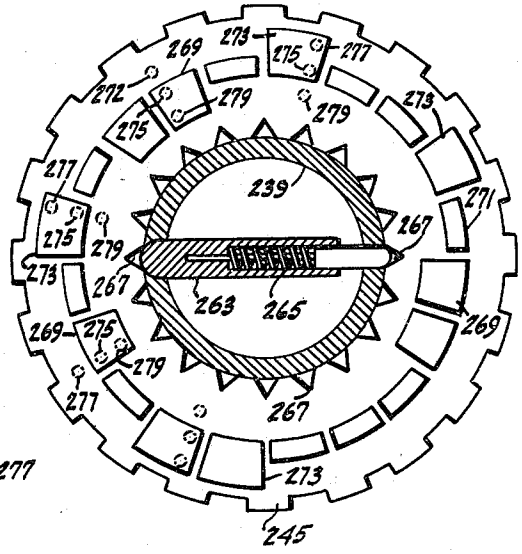


Fig. 9.



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UNITED STATES PATENT OFFICE

2,406,977

SYNCHRONIZING SYSTEM

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Application July 29, 1944, Serial No. 547,225

12 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 and synchronizing complex signals which may be utilized, for example, as coding and decoding waves in such systems.

The invention, by way of example, will be described hereinafter as an improvement in the synchronizing of coding wave generators of the dual delay network type which may be employed in a secret telecommunication system of the type described in the copending U. S. application, of Alda V. Bedford, Ser. No. 546,189, filed July 22, 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 with respect to their A.-C. axes. The coding wave K is generated by pulse-exciting separate delay networks at different rates, selecting predetermined delayed pulse components from each network, multiplying the component waves together, and distorting the resultant product wave. 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 reciprocal of the corresponding instantaneous ordinates of the coding signal component of the transmitted signal. The decoded signals are derived from the product of the transmitted signal SK and the decoding signal 1/K. Each of the component pulse-excited delay networks of the coding and decoding signal generators at the transmitter and receiver, respectively, are disclosed in said copending application as synchronized separately 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 for each component network occur at different rates and may be superimposed upon the coded signals SK. At the receiver, the reversals in polarity between the two synchronizing pulses are employed to synchronize separately each of the component delay networks of the decoding wave generator.

The instant invention comprises an improvement over the coding wave generator described in said copending application, in that synchronizing pulses for only one of the delay networks need be transmitted with the coded message signal. At both transmitter and receiver, the remotely synchronized networks each provide local auxiliary synchronizing signals which are employed to lock-in the other local pulse-excited network at the predetermined different pulse rate. The local auxiliary synchronization is accomplished by deriving a harmonic wave in a novel manner from each of the remotely synchronized networks, and by employing each of said harmonic waves locally to lock-in the other local network at some predetermined sub-harmonic rate.

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In order to change the coding wave continuously, the delayed pulses at a plurality of points in each of said networks are combined in predetermined polarities by a continuously-changing, differential-speed, selecting mechanism to provide a complex wave having a network periodicity of about .4 second which, by means of the switching, may be extended to over one hour.

Among the objects of the invention are to provide an improved method of and means for synchronizing a plurality of wave generators. Another object of the invention is to provide an improved method of and means for synchronizing a plurality of different frequency generators at a plurality of separated locations by means of a single synchronizing signal. Another object of the invention is to provide an improved method of and means for synchronizing secret telecommunication systems. An additional object is to provide an improved method of and means for synchronizing a plurality of different frequency generators by means of a single transmitted synchronizing signal and a plurality of locally generated synchronizing signals for synchronizing said generators at each of a plurality of separated locations. A further object of the invention is to provide an improved receiving network for synchronizing one of a plurality of different frequency wave generators, the remainder of said generators being synchronized by local synchronizing signals controlled by a received synchronizing signal. A further object of the invention is to provide an improved method of and means for synchronizing a plurality of wave generators including a delay network excited by waves from one of said generators, wherein a harmonic signal is produced from successively delayed wave components derived from said network, and wherein another of said wave generators is synchronized at a sub-harmonic frequency of said harmonic wave.

The invention will be described in greater detail by reference to the accompanying drawings of which

Figure 1 is a schematic, partly block diagram of a complete secret telecommunication system employing the invention,

Figure 2 is a series of graphs illustrating the operation of the transmitter synchronizing circuits of one of the wave generators of the system of Figure 1,

Figure 3 is a series of graphs illustrating the operation of one of the decoding wave generators of the receiver portion of the system illustrated in Figure 1,

Figure 4 is a schematic, partly block circuit diagram of a component code wave combining circuit comprising a portion of the circuit of Figure 1,

Figure 5 is a series of graphs illustrating the operation of the combining circuit illustrated in Figure 4,

Figure 6 is a graph illustrating the local synchronization signal derived from one delay network for synchronizing the second delay network at each local station,

Figure 7 is a schematic circuit diagram of the multiplier circuit forming portions of the circuits shown in Figures 1 and 4,

Figure 8 is a schematic circuit diagram of the reciprocal circuit forming a portion of the circuit shown in Figure 1,

Figure 9 is a side elevational view of one of the rotatable contactor disks forming a portion of the code wave switching mechanism, and

Figure 10 is a side elevational view of one of the fixed brush holders forming another portion of said switching mechanism which operates complementarily with said contactor disk.

Similar reference characters are applied to similar elements throughout the drawings.

Coding Wave Generator

Generator unit—A'

Referring to Figure 1, the coding wave generator which may be employed alternately for both transmitting and receiving coded speech signals includes a conventional, free-running multi-vibrator circuit 1 which generates pulses at a rate, for example, of 50 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. The generated pulses are applied to the input of a first conventional delay network 2 comprising a plurality of series-connected inductors 3, 5, 7, 9, 11 and a plurality of shunt-connected 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, for example, sixty filter sections as indicated by the dash lines interconnecting the filter sections 11, 14 and the terminating resistor 13, 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, etc., whereby each succeeding pulse is delayed a predetermined amount with respect to pulses occurring at other prior network terminals. A complex coding wave thus may be obtained in response to each pulse applied to the delay network by combining in either or both polarities 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 of a code wave combining network 49 which may be of the type described in detail hereinafter by reference to Fig. 4 wherein the first component of the coding wave is combined with a second component of the coding wave which second component is derived from a second coding wave generator B' of the same general type as said first coding wave generator A' described heretofore but which is excited at a different frequency, such, for example, as 45.4 cycles.

The output of the code wave combining network is connected to one fixed contact T_1 of a first transmit-receive single-pole, double-throw switch 50. The remaining terminal of the second line 41 is connected through a polarity reversing amplifier 51 and through a second coupling resistor 53 to said first coupling resistor 47 and to the input of the combining network 49. Thus each of the pulses derived from the multivibrator 1 and applied to the input of the delay network 2, provides a plurality of pulses of either polarity occurring at predetermined intervals during each applied pulse 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 complex coding wave component may be applied to the input circuit of the code wave combining network 49 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 should be at least slightly less than the normal pulse period of the multivibrator 1 in order that only one pulse may be traveling along the delay network at any predetermined instant.

Thus far, the coding wave generator A' is similar to that described in the copending application identified heretofore.

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 T_1, T_2, T_3, T_4, T_5, T_6, etc. 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 second transmit-receive switch 57 to one input circuit of a wave multiplier 59, which will be described in detail hereinafter by reference to Figure 7 of the drawings. Coding signals, comprising component waves provided by the coding wave generators A' and B' are derived from the coding signal generator combining network 49, and are applied, through the first switch 50, to a second input circuit of said 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 coding signal K are applied through a third "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

Synchronizing unit A''

Regularly recurrent pulses indicated by the graph *a* of Figure 2 are derived, for example, from the fifty-ninth tap on the delay network 2 of the code wave generator A' and applied to a conventional thermionic tube 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 fourth "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 fifth "transmit-receive" switch 73 to a second input circuit of the first signal mixer circuit 63, and is applied through a sixth "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 and the main synchronizing signals. The combined coded signal and synchronizing signals derived from the signal mixer 63 will have a waveform, for example, of the type illustrated in graph *f* of Figure 2, including the pulses I, I, shown in dash lines. The coded signal SK and synchronizing pulses I, I are clipped at levels II, II in a limiter 79 and are applied through a conventional radio transmitter 81 to an antenna 83. As received the waveform may resemble the wave *x*.

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*, illustrated 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 the first multivibrator 1 is not properly keyed by the third multivibrator 77, the first multivibrator merely will 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 fifty-ninth tap of the delay network therefore will key the second and third multivibrators in the manner described heretofore, and will provide a new set of synchronizing pulses

which will actuate the first multivibrator 1 in synchronism thereafter.

CODING WAVE GENERATOR B'

The second coding wave generator B' comprises a second delay network 2' excited by pulses from a multivibrator 1' which has a normal operating frequency, for example, of 45.4 cycles. The delay network 2' is similar in all respects to the first delay network 2, with the exception that its total delay is of the order of $\frac{1}{45.4}$ second. The second code wave generator B' includes isolating resistors, network switching elements, polarity reversing amplifier, and terminating resistors, not shown, of the same types and connected in the same manner as described heretofore with respect to the first code wave generator A'. Signals derived from the network switches and from the polarity reversing amplifier of the generator B', (which may be connected as shown in the first code wave generator A'), are combined in both polarities and connected to a second input circuit of the code wave combining network 49. In the combining network, the signals from each of the code wave generators A' and B' may be modulated or multiplied and otherwise treated to provide a complex coding signal K.

SYNCHRONIZATION OF CODING WAVE GENERATOR B'

A harmonic frequency signal, such, for example, as 500 cycles, may be derived from the 50 cycle-excited first delay network 2 by deriving signal components from successive network sections and by reversing the polarity of predetermined ones of said derived delayed signal components. For example, resistors 15'', 17'' and 19'' connected to successive delay points on the delay network 2, if properly proportioned, will provide a half wavelength signal having a period of $\frac{1}{20}$ the delay period of the entire 60 section network 2. Similarly, resistors 21'', 23'' and 25'' connected to the next three successive points on the delay network, may be connected through a thermionic tube signal inverter 24 to provide a second half wavelength signal of opposite polarity but having the same periodicity as the first half wavelength signal derived from the resistors 15'', 17'' and 19''. If the signals derived from the first group of resistors are combined with the inverted signals derived from the second group of resistors a complete cycle of a wave is produced which is the tenth harmonic of the 50 cycle exciting frequency applied to the delay network 2. Successive delay points on the delay network 2 therefore may be connected through additional suitable isolating resistive groups, and combined in proper polarity to provide successive positive and negative half cycles of the tenth harmonic wave, in order to provide a substantially continuous harmonic signal, as shown in the graph of Fig. 6, which may be employed for synchronizing the second code wave generator B'. If desired, selected spaced delayed pulse components of a single polarity may be derived to provide a harmonic wave comprising only half cycles of one polarity.

The graph of Fig. 6 shows the combination of differently delayed, differently polarized and different amplitude exciting pulses which approximate a harmonic sine wave. Actually, each exciting pulse acquires a "tail" upon being delayed, whereby the summation of the exciting pulses and their tails in selected delayed relation closely

approximates the sine wave illustrated. Filtering may further improve the waveform.

The thus derived tenth harmonic 500 cycle local synchronizing signal may be applied to excite the multivibrator 1' of the second code wave generator B' at its eleventh sub-harmonic to provide a 45.4 cycle signal which may excite the second delay network 2' in step with the 50 cycle excitation of the first delay network 2. Thus the excitation of the two delay networks may be phased by means of the generator harmonic local synchronizing signal, and the single group of synchronizing pulses described heretofore may be transmitted with the coded signal for synchronizing the second wave generators of a remote receiver.

Coded Signal Receiver

In order to convert the circuit thus described to operate as a decoding signal receiver, the movable contacts of each of the "transmit-receive" switches 50, 57, 61, 69, 73, and 75 are switched to the corresponding fixed contacts D_1, D_2, D_3, D_4, D_5, D_6 corresponding to the "receive" condition. The combined coded signal and principal synchronizing signals transmitted from the transmitter 81 are "smeared" and phase-shafted somewhat in transmission to resemble the solid portion x of the graph f of Fig. 2, and as received by means of a conventional radio receiver 85 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 shunt resistor. The received 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 first multivibrator 1, being free-running during transmission and reception, will apply pulses to the delay network and the delay network 2 will provide recurrent pulses at its fifty-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 Fig. 3. The long blanking pulse i is applied to a blanking circuit 93 which blanks out the synchronizing pulse portions of the received signal as will be explained in greater detail hereinafter.

Receiver Synchronizing Circuits

Unit A''

Similarly, each of the recurrent pulses derived from the sixtieth 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 similar, but later, short pulse illustrated by graph j of Fig. 3. The limited pulse j is applied through the fourth "transmit-receive" switch 69 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 obtained 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 fifth "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 sixth "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 .02 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 circuit 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 keying pulses is known in the art.

RECEIVER CODING WAVE GENERATOR B'

The second coding wave generator B' of the receiver comprises the identical elements employed for the purpose in the coding wave transmitter described heretofore. No switching is necessary to convert the second code wave generator B' from the "transmitting" to the "receiving" condition, since at all times it is locked in step with the first code wave generator A' by means of the tenth harmonic synchronizing signal derived from the first delay network **2** and applied to key the first multivibrator **1'** of the code wave generator B' at its eleventh sub-harmonic.

Thus the receiver code wave generators A' and B' may be synchronized with the code wave generators at the transmitter by means of the single group of synchronizing pulses transmitted with the coded signal. As in the transmitter, the output of the second delay network **2'** of the second code wave generator B' is applied to the code wave combining network **49** to provide the complex code wave K which may be changed to reciprocal form as described herein for decoding the received coded signal.

It should be understood that the harmonic local synchronizing signal may comprise harmonic pulses all of the same polarity, in which case the inverting amplifier **24** may be omitted at both transmitter and receiver. The wave shape of the harmonic synchronizing signal may be varied by limiting, or by filtering, or by varying the connection points on the first network **2**, as desired. Similarly, the harmonic relation may be varied by proper selection of delay points on said first network **2**.

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 time intervals of the recurrent blanking pulses *i*, whereby the transmitted positive and negative synchronizing pulses for the code wave generator A' may be removed from the received coded signal. This condition obtains when the coding signal generators of the receiver are in synchronism with the transmitter coding signal generators, since the fourth multivibrator **91** is responsive to pulses derived from the second from last tap on the first 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 second "transmit-receive" switch **57** to one of the input circuits of the wave multiplier **59**.

Similarly, the combined coding signals K generated by the receiver coding generators and code wave combining circuit **49** are applied to the input circuit of a reciprocal circuit **101**, which will be described in detail hereinafter by reference to Figure 8 of the drawings. Signals derived from the reciprocal circuit **101** will have instantaneous ordinates corresponding to the reciprocal values of the instantaneous ordinates of the synchronized coding wave K generated in the receiver. The reciprocal wave 1/K is applied through the first "transmit-receive" switch **50** 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 applied through the third "transmit-receive" switch **61** to a reproducer **103** will be substantially characteristic of the original speech modulation signals S (not graphically illustrated). The signals applied to the reproducer **103** have been characterized as S' since some phase distortion is inherent in the various circuits described, and especially is encountered in many radio transmission circuits. It should be understood that the signals S' derived from the third "transmit-receive" switch **61** may be applied to actuate any other desired type of utilization apparatus, not shown.

In Figure 4, a preferred type of component code wave combining circuit comprises two separate code wave generators A' and B', having separate multivibrators **1**, **1'** which excite them at different frequencies, such, for example, as 50 pulses per second and 45.4 pulses per second, which are, respectively, the 10th and 11th submultiples of the frequency of the 500 cycle local synchronizing harmonic wave shown in Fig. 6. The operation of the individual component code wave generators, and the synchronizing thereby by both transmitted and local synchronizing signals has been described heretofore.

The first code wave generator A' may include, for example, sixty delay network sections of the type, described heretofore in connection with Figure 1, having a total delay of $1/50$ second which results in a cutoff frequency of the order of 660 cycles. The second code wave generator B' may include, for example, fifty-eight delay network sections having a similar cutoff frequency, but providing a delay of the order of $1/45.4$ second.

As a matter of convenience, circuit components of the second code wave generator B' are given primed reference characters corresponding to the component reference characters in the first code wave generator A'. The coding switches **27**, **29**, **31**, **33**, **35**, **37**, and **27'**, **29'**, **31'**, **33'**, **35'**, **37'**, for selecting delayed pulses from preselected terminals of both delay networks, may be combined in a differential-speed, multi-section switching unit of the type described in said copending application and partially shown in Figures 9 and 10 which are described in detail hereinafter.

For each position of the coding switches of the delay network **2**, an irregular wave is generated at both the sending and transmitting apparatus. This wave is transmitted over the lines **39** and **41** to an amplifier-limiter circuit **109** in a manner whereby the differently delayed components of the wave are applied in either polarity to the amplifier input circuit. This may be accomplished in any manner known in the art, such, for example, as shown in the circuit of Fig. 1, or by coupling the lines **39** and **41** to the grid circuit and cathode circuits, respectively, of the amplifier circuit. The sharp limiting action of the amplifier-limiter **109** produces a corresponding irregular rectangular wave K_1 shown in graph F of Figure 5. In a similar manner the second delay network **2'** is connected to a second amplifier-limiter **111** through the lines **39'**, **41'** whereby a second irregular rectangular wave K_2, shown in graph G of Figure 5 is generated.

The rectangular irregular waves K_1 and K_2 are applied to a multiplier circuit **113**, of the type

shown and described herein with respect to Figure 7 of the drawings, to derive a more complex rectangular wave K_{12} shown in graph H of Figure 5.

The complex wave K_{12} will have a period of .4 second although it is composed of two waves K_1 and K_2 each having periods of the order of .02 second. Also, the complex wave K_{12} will have the combined number of crossovers of the A.-C. axis of the rectangular waves K_1 and K_2. Since, however, the crossovers of the complex wave K_{12} have short term repetition rates of the order of $1/45.4$ second and $1/50$ second, it is necessary to distort the wave further to insure transmission security.

The limiting action of the limiters **109** and **111** increases the frequency spectrum of the waves K_1 and K_2 to about 2000 cycles, although each of the delay networks have cutoff frequencies of the order of 660 cycles. Since high frequency components of the wave K_{12} are of low magnitude, the complex wave is passed through a high frequency booster network **115** of any conventional type which equalizes the frequency components up to about 2000 cycles per second. The equalized complex wave derived from the high frequency booster network **115** is applied to a phase distortion circuit **117** such, for example, as an RC lattice network which has the property of delaying various frequency components by different amounts whereby the relative phases of the various harmonic components of the complex wave are changed to form a radically different wave shape. The phase distortion circuit **117** also alters the square wave form of the complex wave form K_{12} so as to obliterate the sharp corners thereof and to vary the lobes thereof over a wide variety of amplitudes. Excessively high lobes occurring in the distorted wave are removed by a limiting amplifier **119** from which is derived the final extremely complex coding wave K. The complex coding wave K is applied to the reciprocal circuit **101** and to the fixed contact T_1 of the first transmit-receive switch **50** of the circuit of Figure 1 as explained heretofore.

Judging from oscillographic observations of a complex coding wave of the type described, it is believed that the steps of multiplying and phase distorting the component waves K_1 and K_2 effectively masks all significant 45.4 cycle and 50 cycle characteristics which ordinarily would be observable in the transmitted coded signal. Therefore, the dual delay network wherein the separate code wave components are multiplied together and distorted, appears an economical and efficient electrical device for generating a code wave having a period as long as .4 second.

Signal Multiplier

Figure 7 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, and a portion of the code wave combining network **49** of the circuit of Fig. 4 of the drawings. This multiplier circuit is described and claimed in a copending application of Alda V. Bedford, U. S. 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 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_1, Q_2, Q_3, Q_4, where referred to hereinafter.

In the preferred form of the multiplying circuit, the waves S and K, for example, 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 in the output circuit of the multiplier network, as will be illustrated by the following equations:

(1)	Output of $Q_1=(S+K+A_1)^2$	$=S^2+K^2+A_1^2+2SK+2KA_1+2A_1S$
(2)	Output of $Q_3=(-S-K+A_1)^2$	$=S^2+K^2+A_1^2+2SK+2KA_1-2A_1S$
(3)	Output of $Q_4=-(-(-S+K+A_1))^2$	$=-(S-K+A_1)^2=-S^2-K^2-A_1^2+2SK+2KA_1-2A_1S$
(4)	Output of $Q_2=-(-(S-K-A_1))^2$	$=-(-S+K+A_1)^2=S^2-K^2-A_1^2+2SK-2KA_1+2A_1S$
(5)	Sum output	$8SK$

It will be understood that the term A_1 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 applied voltage range in a single polarity. The signal multiplier network is shown as including a first triode thermionic tube **133** having its grid electrode connected to the movable contact of the first "transmit-receive" switch **50**, 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 **135** has its grid electrode connected to the movable contact of the second "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 switches **50** and **57** in the "transmitting" position whereby the signals K and S, respectively, are applied to the grid-cathode circuits of the tubes **133** and **135**. 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 network of resistors in the following manner: Signals S and K respectively traverse resistors **137** and **139** to provide a signal proportional to $(S+K)$ at point $(S+K)$; the signals S and $-K$ respectively traverse resistors **141** and **143** to provide signal $(S-K)$; the signals $-S$ and $-K$ respectively traverse resistors **145** and **147** to provide signal $(-S-K)$; and the signals SK and K traverse respectively resistors **149** and **151** to provide signal $(-S+K)$. Thus, at each of the four junction points, a sum of voltage is obtained as designated in the circuit diagram. As shown, the network also includes resistors **153** and **155** leading respectively from points $(S-K)$ and $(-S+K)$ to ground, and resistors **157** and **159** 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 divider **161**, **162**. An 8000-ohm resistance has been found sat-

isfactory for the resistors 153, 155, 157, and 159 while 100,000 ohm resistance has been taken as the value of resistors 137, 139, 141, 143, 145, 147, 149, and 151.

The sum voltages at the four points of the network are applied with bias voltage A and −A to four varistors 163, 165, 167 and 169 respectively, all of which control the current through the common load resistor 171 to provide thereacross the product output voltage SK. The output voltage across resistor 171 is proportional to the sum of all the voltages which would have been generated if each varistor had supplied current to a separate resistor, as indicated by the foregoing squaring equations. It is to be noted that the varistors 165 and 169 are connected with opposite polarities from the varistors 163 and 167, 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 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 171.

For compensating for small dissimilarities in the varistors and other circuit elements, it has been found desirable to provide variable resistors 173, and 175 connected as voltage dividers in the anode circuits of the tubes 133 and 135 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 actually is a sort of 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 171 are applied to the movable contact of the third "transmit-receive" switch 61 whereby they may be selectively applied to either the reproducer 103 or to the first signal mixer 63 depending upon the desired operation of the circuit of Fig. 1.

Signal Reciprocal Circuit

The reciprocal circuit 101 shown in Figures 1 and 8 of the drawings is described and claimed in the copending application of Carl A. Meneley, Serial Number 484,304, filed April 23, 1943, and assigned to the same assignee as the instant application. In this circuit instantaneous reciprocal values of an applied coding wave K are obtained by means of an electrical network in which the wave K is clipped on both its positive cycle and on its negative cycle to produce a substantially rectangular wave, and in which the wave K and the rectangular wave are added together with one of them reversed in polarity preferably after the peaks of the positive and negative cycles of the wave K have been "squashed" or flattened somewhat. The circuit includes no appreciable capacitive or inductive reactances (the blocking capacitors in the circuit presenting negligible impedance) and, therefore, provides the reciprocal of substantially any applied signal wave form regardless of its frequency components.

Referring to Figure 8, the graph p represents a typical coding wave K which is applied to the input terminals 177 of the circuit. The graph s represents the reciprocal wave 1/K, which is the sum of the flattened wave K, represented by the graph q, of reversed polarity, and of the rectangular wave shown in graph r. The squashed or flattened wave q may be obtained by passing the wave p through a circuit that changes its resistance with a change in applied voltage. The rectangular wave r may be produced by clipping the positive and negative cycles of the wave q at the voltage levels t and u respectively, for example, close to the A.-C. axis of the signal, and then by amplifying the clipped signal.

The wave K applied to the input terminals 177 may, if desired, be amplified by means of an amplifier tube 179 to provide a peak-to-peak amplitude, for example, of the order of 60 volts. The amplified K wave then is applied through a blocking capacitor 181 and a resistor 183 to a copper oxide rectifier unit 185 which functions as a non-linear resistor having the property of decreasing in resistance as the applied voltage increases. The resistor 183 is of high enough resistance so that the driving source for the non-linear resistance unit 185 is of high impedance whereby there is only a slight variation in the current flow through the unit 185. The unit 185 may consist of a pair of copper oxide rectifiers 187 and 189 connected to conduct current in opposite directions.

The voltage appearing across the non-linear unit 185 is the voltage wave q, which is the wave K having a flattened wave form. This voltage is amplified by a cathode biased vacuum tube 191, and appears across an anode resistor 193 and a portion of the anode resistor 195 of a second amplifier tube 197.

The rectangular wave r is produced, in this particular example, by applying the output of the tube 191 through a blocking capacitor 199 and a high impedance resistor 201 to a pair of diodes 203 and 205, which are connected to conduct in opposite directions. Resistors 207 and 209, of comparatively low resistance are connected in series with the diodes 203 and 205, respectively. A biasing voltage drop for opposing current flow through diode 205 is produced across the resistor 209 by connecting a source of voltage (not shown) thereacross, a resistor 211 being in series with the voltage source. The diodes 203 and 205 clip the applied wave q symmetrically about its A.-C. axis, because a voltage which causes current flow through the diode 203 and resistor 207 is built up across the capacitor 199 by the positive cycle pulses flowing through the diode 205. Thus, the diodes 203 and 205 become conducting on alternate cycles when the signal voltage exceeds predetermined D.-C. voltage values. The resulting rectangular wave r is amplified and reversed in polarity by the tube 197. The wave q and the flattened wave r add in the portion of the anode resistor 195 that is common to the tubes 191 and 197 to produce the desired reciprocal wave 1/K shown in graph s.

If the wave q is flattened correctly, and if the waves q and r are added with the correct relative amplitudes, the resulting signal will be substantially a true reciprocal of the wave K. The only substantial departure from a true reciprocal signal will be where the wave K crosses the A.-C. axis. Here the reciprocal value is infinity whereas the maximum amplitude of the wave 1/K necessarily has a finite limit. The waves q and r may be mixed with the correct relative amplitudes by adjusting a variable tap 213 on the anode resistor 195. The correct shaping of the flattened wave q may be obtained by selecting a non-linear

resistor unit 185 having a suitable voltage-resistance characteristic and by adjusting the value of the variable resistor 183.

As previously noted, the above-described reciprocal circuit is purely resistive so that its operation is independent of frequency. The instantaneous voltage output of the circuit is always substantially the reciprocal of the instantaneous applied voltage. It follows that if the reciprocal circuit is adjusted to produce the reciprocal of an applied signal having one wave form, the circuit will then always produce the reciprocal of an applied signal regardless of its wave form. There are various ways of determining when the circuit has been adjusted to give substantially a true reciprocal. One way is to connect the reciprocal circuit into the signalling system of Fig. 1, and, while transmitting speech or music, adjust the resistor 183 and the variable tap 213 at the receiver until the speech or music has a minimum of distortion.

It should be understood that oppositely-connected diodes may be substituted for the copper oxide rectifiers 187 and 189, described heretofore. When properly biased, the two diodes should be operated along the lower knee of their operating characteristic and in the proper region to shape the wave K in the desired manner to provide the wave *q*.

It will be understood that the reciprocal circuit is not limited to the particular circuit components illustrated since the waves *q* and *r* may be derived from the wave K in various other ways, and since the two waves may be combined by means of a variety of other circuits.

Motor-Driven Selector Switch Mechanism

Referring to Figures 9 and 10, portions of a motor-driven selector switch mechanism are shown, which in any known manner may change the characteristics of the complex coding wave K slightly at intervals of .4 second whereby the coding wave characteristics are continuously changed over a period of approximately one hour and six minutes for a predetermined initial setting of a plurality of differential-speed coding contact discs of the type shown in Fig. 9. A complete mechanism for providing differential rotation of said disks is described in said copending application, but it may be varied in any known manner.

Predetermined rotational arrangements of the coding discs with respect to their complementary fixed brush holders permits continuous variation of the complex coding wave characteristics for a period of the order of one hour and six minutes at a motor speed of 100 R. P. M. By means of detent mechanisms on each of the switch contact discs, the relative disc rotational arrangement may be changed manually at hourly intervals to provide an entirely different coding wave for each hour of operation, whereby the coding wave characteristics may be made substantially non-repetitive over an extremely long period.

A switch motor drive at the transmitter unit may be synchronized with a similar switch motor drive at the receiver unit in any manner known in the art such, for example, as the inclusion of a synchronizing tone in the transmitted signal. Alternative arrangements may employ crystal, or fork, controlled generators at both transmitter and receiver which operate at substantially constant frequencies to synchronize the motors over extended operating periods. Various well known methods of phasing synchronizing motors may be employed if desired.

More detailed construction of one of the contact discs is shown in Figures 9 and 10, wherein a typical one of the contactor discs 245 is mounted upon a tubular shaft 239 and adjustably keyed thereto by a diametrically disposed two section telescoping pin 263. The pin normally is expanded by an intermediate compression spring 265 to project at opposite sides of the shaft and engage a pair of notches 267 provided in the inner face of the disc 245. In effect, the pin 263 and the notches 267 which extend entirely around the inner face of the disc comprise a detent mechanism which permits the disc to be rotated manually for presetting the individual disc position with respect to a motor driven gear mechanism.

Concentrically arranged around the central axis of the disc are three series of side face contactors 269, 271 and 273, preferably comprising silver segments insulated from each other. The silver segments are of three types which are located in irregular order of different radial dimensions, but all of which have a portion in the same intermediate radial circular path. Thus the short intermediate contactors 271 define neutral positions of the switches; the long outer contactors 273 define positive positions of the switches and long inner contactors 269 provide negative positions of the switches in terms of the pulse components of the coding wave. As shown, the inner edges of the long outer contactors 273 align circumferentially with the inner edges of the short intermediate contactors 271 but the radial length of such long outer contactors 273 is approximately twice that of the intermediate contactors 271. The outer edges of the long inner contactors 269 align circumferentially with the outer edges of the short intermediate contactors 271, but the radial length of such long inner contactors 269 is also approximately twice that of the intermediate contactors 271.

Hence, in the rotation of the disc, the intermediate contactors 271 are arranged to wipe successively one intermediate series of brushes 275; the long outer contactors 273 successively wipe said intermediate series of brushes 275 and an outer series of brushes 277 in pairs, one brush of each series being wiped simultaneously. Similarly, the long inner contactors 269 successively wipe said intermediate series of brushes 275 and an inner series of brushes 279 in pairs, one brush from each of the latter series being wiped simultaneously.

Referring to Figure 10, each of the brush series 275, 277, 279 has five brushes, corresponding brushes of each series being spaced at similar or slightly different angular intervals so as to be wiped concurrently by the contactors on the contactor disc 245. The sets of brushes are mounted upon an insulating plate 281, which in assembled condition, is in close proximity to the contactor side of the rotatable disc 245, in order that the respective contactors may contact with and bridge any pair of brushes to be selected, so as to close predetermined circuits for the generation of the coding waves.

Thus the invention disclosed comprises an improved method of and means for generating and synchronizing extremely complex electrical waves which are generated by selecting predetermined delayed signal components from a plurality of differently-pulse-excited delay networks, and wherein said derived signal components are combined to form said complex wave. The invention is illustrated herein, by way of example, as a component of a secret telecommunication system

wherein such complex wave generators are employed to provide coding and decoding waves at a transmitter and receiver, respectively. The invention comprises a synchronizing system for such coding wave generators wherein the synchronizing signals are transmitted from transmitter to receiver to synchronize one generator in each unit, and novel local synchronization is provided for the second generator in each unit. A motor driven switching mechanism is briefly described which provides continuously changing selection of the delayed signal components in each of the delay networks in a manner whereby the derived complex signal is non-repetitive for an extended time interval.

I claim as my invention:

1. A device including a plurality of wave generators, a delay network excited by waves from one of said generators, means for deriving from said network different successively delayed components of said exciting waves, predetermined ones of said derived delayed wave components being successively reversed in polarity, means for combining said derived wave components of both polarities to generate a wave which is a predetermined harmonic of said exciting wave frequency, and means for synchronizing at least one other of said generators at a predetermined sub-harmonic of said generated harmonic wave.

2. In a system comprising a plurality of devices of the type described in claim 1, means for synchronizing a corresponding one of said exciting wave generators of each of said devices whereby at least one other generator of each of said devices is synchronized with respect to a corresponding other one of said generators of another of said devices.

3. A device including a plurality of pulse generators, a delay network excited by pulses from one of said generators, means for deriving from said network different successively delayed pulse components of said exciting pulses, means for phase inverting predetermined ones of said delayed pulse components, means for combining predetermined ones of said derived and said phase-inverted pulse components to generate a wave having a predetermined harmonic relation to the frequency of said exciting pulses, and means for applying said generated wave to synchronize another of said generators at a predetermined sub-harmonic of said generated wave frequency.

4. In a system comprising a plurality of devices of the type described in claim 3, means for synchronizing a corresponding one of said pulse exciting wave generators of each of said devices whereby at least one other of said generators of each of said several devices is synchronized with respect to a corresponding other one of said generators of another of said devices.

5. A device including a plurality of pulse generators, a delay network excited by pulses from one of said generators, means for deriving from said network different successively delay pulse components of said exciting pulses, amplifier means for phase inverting predetermined ones of said delayed pulse components, means for combining predetermined ones of said derived and said phase-inverted pulse components to generate a wave having a predetermined harmonic relation to the frequency of said exciting pulses, and means for applying said generated wave to synchronize another of said generators at a predetermined sub-harmonic of said generated wave frequency.

6. Apparatus of the type described in claim 3 including means for selecting predetermined signal components from each of said generators, and means for combining said selected signal components to generate a complex electrical wave.

7. In a system comprising a plurality of devices of the type described in claim 3, means for synchronizing a corresponding one of said pulse-exciting wave generators of each of said devices whereby others of said generators of said several devices are synchronized with respect to corresponding generators of another of said devices, means for selecting predetermined signal components from said generators of each of said devices, and means forming parts of each of said devices for combining said selected signal components therein to generate a plurality of synchronized complex electrical waves.

8. A synchronizing system for a plurality of wave generators comprising means for synchronizing two of said generators, separate delay networks excited by each of said synchronized generators, means for deriving from each of said networks different successively delayed signal components of each of said exciting generators, means for combining said derived delayed signal components from each of said networks to generate separate waves each having predetermined harmonic relation to the frequency of the corresponding one of said exciting generators, and means for applying each of said generated harmonic waves to synchronize separately with each of said exciting generators others of said generators at predetermined sub-harmonics of said harmonic waves.

9. A device including a plurality of wave generators, a delay network excited by waves from one of said generators, means for driving from said network different successively delayed components of said exciting waves, means for combining said derived wave components to generate a wave which is a predetermined harmonic of said exciting wave frequency, and means for synchronizing at least one other of said generators at a predetermined sub-harmonic of said generated harmonic wave.

10. In a system utilizing a plurality of electrical waves, the method comprising delaying one of said waves, deriving from said delayed wave different successively delayed wave components, combining said derived wave components to generate another wave which bears a predetermined harmonic relation to said delayed wave, and synchronizing another of said waves at a predetermined subharmonic of said harmonic wave.

11. In a system utilizing a plurality of electrical waves, the method comprising delaying one of said waves, deriving from said delayed wave different successively delayed wave components, successively reversing in polarity predetermined ones of said derived delayed wave components, combining said derived wave components of both polarities to generate a wave which bears a predetermined harmonic relation to said delayed wave, and synchronizing another of said waves at a predetermined subharmonic of said generated harmonic wave.

12. The method described in claim 11 including the step of synchronizing a third of said electrical waves with said delayed wave, and synchronizing a fourth of said waves at a predetermined subharmonic of a harmonic of said third wave.

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