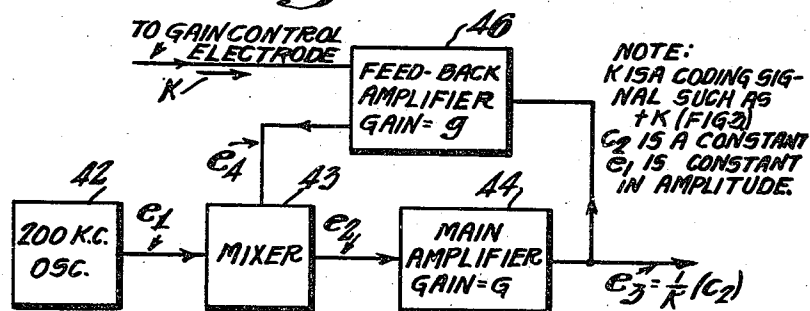
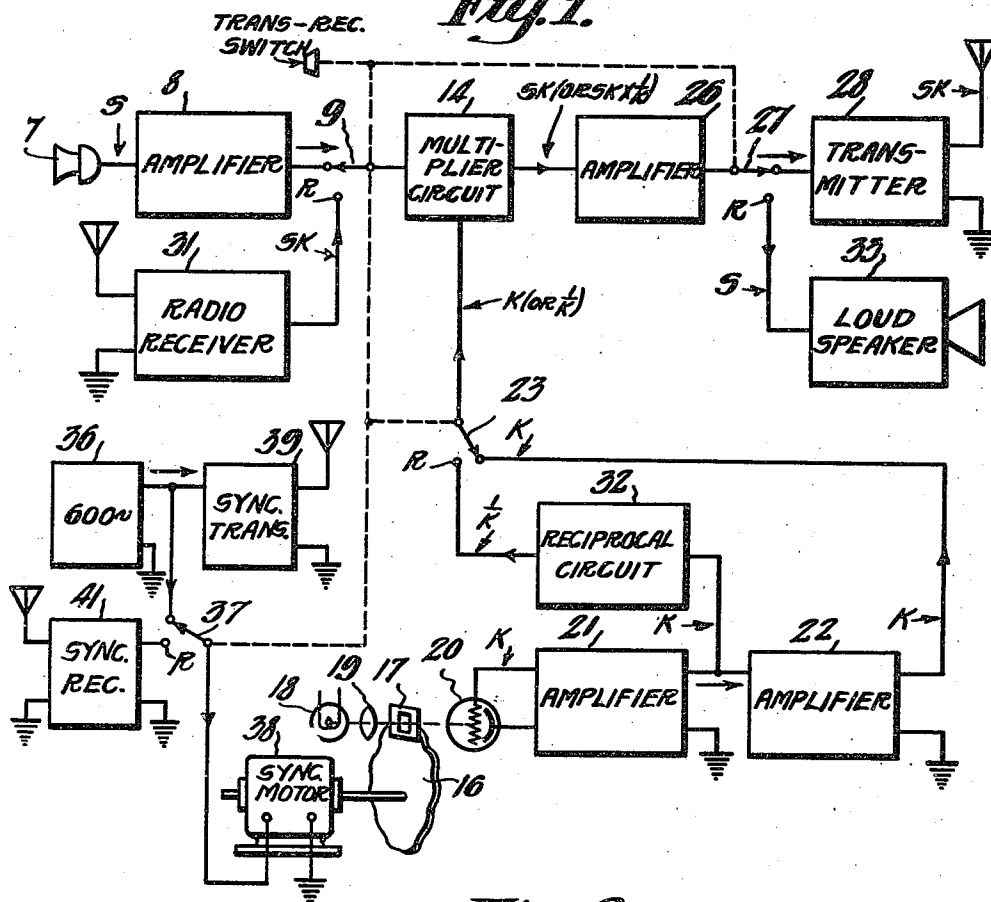


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RECIPROCAL CIRCUIT FOR SECRET COMMUNICATION

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4 Sheets-Sheet 1



Attorney

June 4, 1946.

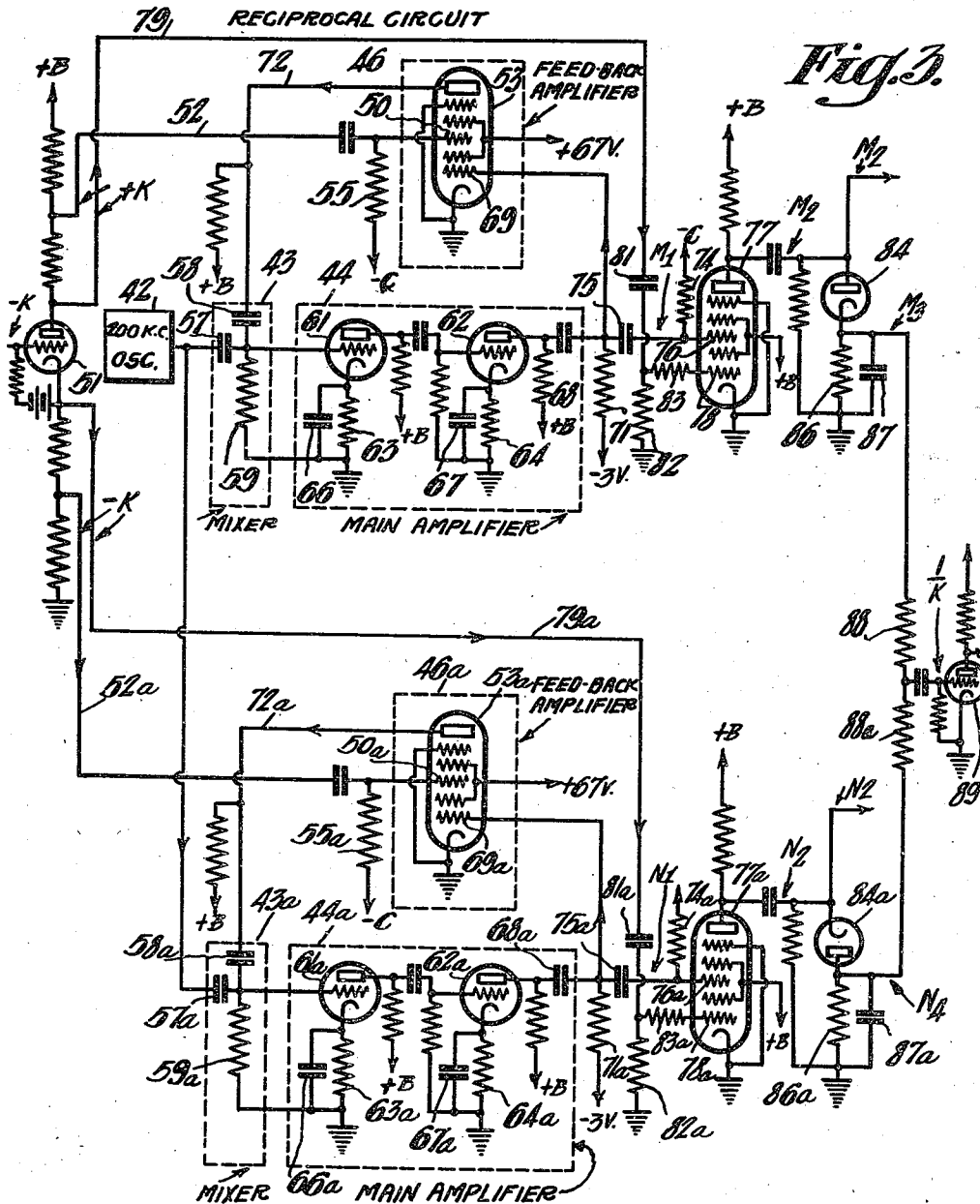
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RECIPROCAL CIRCUIT FOR SECRET COMMUNICATION

Filed March 26, 1943

4 Sheets-Sheet 2



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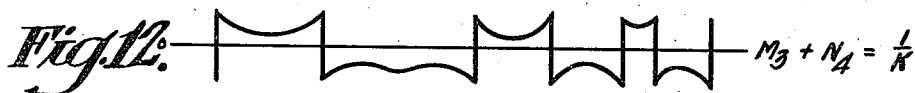
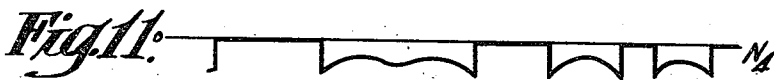
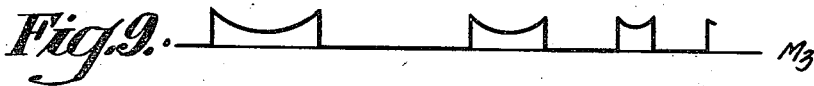
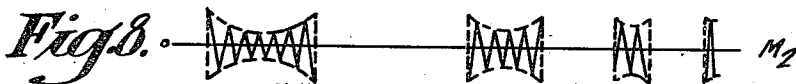
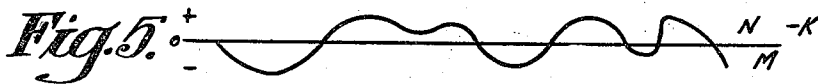
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RECIPROCAL CIRCUIT FOR SECRET COMMUNICATION

Filed March 26, 1943

4 Sheets-Sheet 3



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RECIPROCAL CIRCUIT FOR SECRET COMMUNICATION

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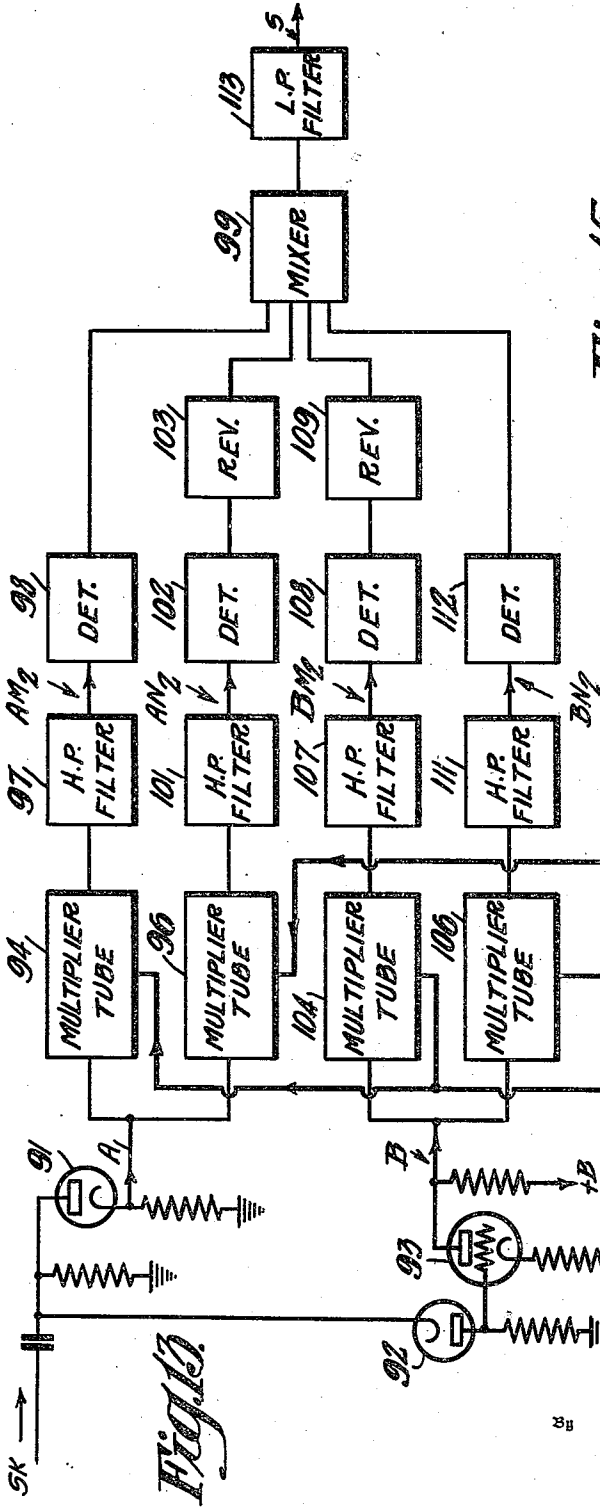


Fig. 13.

Fig. 15.

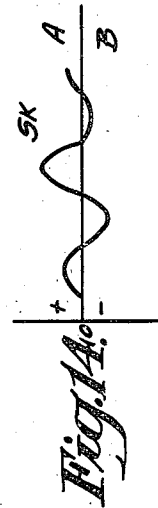
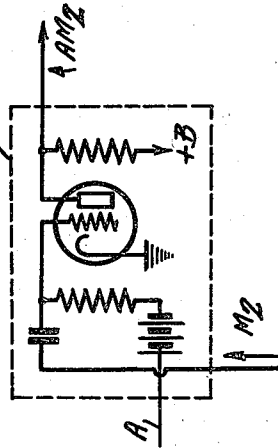


Fig. 14.

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RECIPROCAL CIRCUIT FOR SECRET COMMUNICATION

Alda V. Bedford and Frank P. Wipff, Princeton, N. J., assignors to Radio Corporation of America, a corporation of Delaware

Application March 26, 1943, Serial No. 480,716

14 Claims. (Cl. 179—1.5)

Our invention relates to the production of the reciprocal of a signal or wave and particularly to the production of such a signal for use in a system for secret communication.

In the copending application of Alda V. Bedford, Serial No. 456,578, filed August 29, 1942, and entitled Secret communication system, there is described a communication system in which the speech or other communication signal S is multiplied by a coding signal K and in which the product SK is transmitted. At the receiver the incoming signal SK is multiplied by the reciprocal of the coding signal K to obtain the original signal S , that is, $SK \times 1/K = S$. According to the above Bedford application the coding signal K may be generated by means of a code disc which is cut to make its periphery have the wave form of the signal K while the decoding signal $1/K$ may be produced by a different disc which is cut in accordance with calculated values to make its periphery have the wave form of $1/K$.

An object of the present invention is to provide an improved method of and means for producing the reciprocal of a signal or wave.

A further object of the invention is to provide an electrical circuit which will convert an applied signal having a certain wave form to a signal having a wave form that is a reciprocal of the applied wave form.

A further object of the invention is to provide an improved communication system for secret signalling.

In practicing our invention we supply a carrier wave e_1 of constant amplitude through a mixer circuit to a main amplifier. A negative feed-back amplifier is connected to feed signal from the output circuit of the main amplifier back to the mixer circuit where the signal e_1 and the output of the feed-back amplifier are added. This added signal is the signal that is impressed upon the input terminals of the main amplifier. The coding signal K is applied to the feed-back amplifier to vary its gain in direct proportion to the amplitude of the coding signal K . It can be shown mathematically that if the gain of the amplifiers is large, the output of the main amplifier, to a close approximation, is the reciprocal $1/K$ times a constant. However, it should be noted that in the embodiment to be described the apparatus works only on the positive swing of a signal and, therefore, two units such as shown in Fig. 2 are required in the practical embodiment.

In utilizing our reciprocal circuit in a communication system, a coding signal K is generated in any suitable manner at the transmitter, as by

means of a coding disc, the speech signal S is multiplied by the signal K , and the signal SK is transmitted to the receiver. At the receiver there is another signal generating device for producing the signal K ; it may be a coding disc like that at the transmitter, the two coding discs being run in synchronism. The signal K generated at the receiver is supplied to the reciprocal circuit to obtain the decoding signal $1/K$ which is then multiplied with the received signal SK to obtain the original signal S .

The invention will be better understood from the following description taken in connection with the accompanying drawings in which

Figure 1 is a block diagram of a communication system embodying our invention,

Figure 2 is a block diagram illustrating the principle of a reciprocal circuit embodying our invention,

Figure 3 is a circuit diagram of a reciprocal circuit embodying our invention,

Figures 4 to 12, inclusive, are graphs which are referred to in explaining the operation of the reciprocal circuit of Fig. 3,

Figure 13 is a block diagram showing another embodiment of our invention,

Figure 14 is a graph that is referred to in explaining Fig. 13, and

Figure 15 is a circuit diagram of a signal multiplier unit that may be employed in the multiplier circuits of Figs. 1 and 13.

In the several figures similar parts are indicated by similar reference characters.

Referring to Fig. 1, the invention is shown applied to radio apparatus that may be switched for operation either as a transmitter or as a receiver. The several switches are shown in the position for transmitter operation. This is the operation of the apparatus that will first be described. A microphone and a speech amplifier are shown at 7 and 8, respectively. The signal S is applied through a switch 9 to a multiplier unit 14 which may be of the same design as that described in the above-identified Bedford application. The code signal K may be produced by means of a code disc 16, a mask 17, a light source 18, a condensing lens 19, and a photoelectric cell 20. The signal K is supplied through amplifiers 21 and 22 and through a switch to the multiplier unit 14. The resulting multiplier output signal SK is supplied through an amplifier 26 and through a switch 27 to a radio transmitter 28 or to a wire line, if preferred.

The receiver for decoding the signal SK may be the same apparatus as in Fig. 1 with switches

9, 23 and 27 thrown to their contact positions R. The multiplier 14 is unchanged. The signal SK is supplied from a radio receiver 31 through the switch 9 to the multiplier 14. The coding signal K produced by the disc 16 is supplied through the amplifier 21 to a reciprocal circuit 32 designed in accordance with our invention and shown in detail in Fig. 3. The reciprocal circuit 32 supplies the decoding signal $1/K$ through the switch 23 to the multiplier 14. The resulting output of multiplier 14 is the original communication signal S since $SK \times 1/K = S$. The signal S is amplified by the amplifier 26 and supplied through the switch 27 to headphones or to the loudspeaker 33.

The code disc 16 at the transmitter and the corresponding code disc at the receiver are held in synchronism and in the proper phase relation by suitable synchronizing means. For example, at the transmitter a 600-cycle per second current from a source 36 may be supplied through a switch 37 to a synchronous motor 38 which rotates the code disc 16. The 600-cycle current also modulates a radio transmitter 39 for the transmission of synchronizing signal to the receiver. At the receiver the switch 37 is in its contact position R whereby the received 600-cycle current is supplied from a radio receiver 41 to the synchronous motor 38. In some cases it may be preferable to transmit the synchronizing signal over a wire line.

Fig. 2 shows in block diagram the basic part of the reciprocal circuit 32. It comprises an oscillator 42 which supplies a carrier-frequency voltage e_1 of constant amplitude and frequency. The voltage e_1 passes through a mixer or voltage-adding circuit 43 to a main amplifier 44 having a gain G. The voltage output e_3 of amplifier 44 is fed back to the mixer 43 through a feed-back amplifier 46 having a gain g which is varied in direct proportion to the coding signal K which is impressed thereon. The voltage output of amplifier 46 is e_4 , this voltage being added to the voltage e_1 in the mixer 43 whereby the mixer output voltage is $e_2 = e_1 + e_4$.

It may be shown as follows that the output voltage $e_3 = 1/K(C_2)$ where C_2 is a constant. In practice C_2 represents a direct-current voltage which is blocked by coupling capacitors. The values e_1 , e_2 , e_3 and e_4 used in the following equations are the instantaneous amplitudes of the envelopes of the carrier wave voltages e_1 , e_2 , e_3 and e_4 , respectively.

$$\begin{aligned} e_2 &= e_1 G \quad \text{or} \quad e_2 = e_1 / G \\ e_4 &= -e_2 g \\ e_3 &= e_1 + e_4 = e_1 - e_2 g \\ e_1 / G &= e_1 - e_2 g \quad \text{or} \quad e_2 (1 + gG) = e_1 G \end{aligned}$$

Then

$$e_2 = \frac{e_1 G}{1 + gG} \quad \text{But } gG \text{ is large compared with } 1$$

Therefore

$$e_2 \cong \frac{e_1 G}{gG} \cong e_1 / g$$

If $g = KC_1$, where C_1 is a constant then

$$e_2 \cong e_1 \frac{1}{KC_1} \quad \text{and if } e_1 \text{ is constant,}$$

$$e_2 \cong 1/K(C_2) \quad \text{where } C_2 \text{ is a constant.}$$

Fig. 3 shows the circuit diagram for the complete reciprocal circuit 32. It will be noted that it includes two groups of mixer, main amplifier, and feed-back amplifier units as indicated by the

broken line blocks 43, 44, 46 and 43a, 44a and 46a, one group acting upon the positive portions of the K wave and the other group acting upon the negative portions of the K wave.

The signal $-K$ is impressed upon an amplifier tube 51 which supplies the signal $+K$ from its anode circuit and the signal $-K$ from its cathode circuit. The signal $+K$ is supplied over a conductor 52 to a grid 50 of the pentagrid tube 53 (comprising the feed-back amplifier 46) to control its gain. A suitable negative bias is supplied to the grid 50 through a grid-leak resistor 55. The signal $-K$ is supplied over a conductor 52a to a grid of the pentagrid tube 53a comprising the feed-back amplifier 46a, to control its gain.

A carrier wave oscillator 42, such as a 200 kc. sine wave oscillator, supplies a carrier wave to the mixer circuits 43 and 43a which comprise blocking capacitors 57, 58 and 57a, 58a, respectively, and resistors 59 and 59a, respectively.

The output of mixer 43 feeds into the main amplifier 44 which includes a pair of resistance coupled amplifier tubes 61 and 62 biased to operate as class A amplifiers. In the example illustrated, they are biased by means of cathode resistors 63 and 64 having bypass capacitors 66 and 67. The output of the tube 62 is applied through a blocking capacitor 68 to a control grid 69 of the feed-back tube 53. A suitable negative bias is supplied to the grid 69 through a grid resistor 71. The output of the feed-back tube 53 is supplied over a conductor 72 to the mixer circuit 43 where this output voltage adds to the carrier wave voltage supplied from oscillator 42. As described in connection with Fig. 2, since the main amplifier 44 and the feed-back amplifier 46 have high gains G and g , respectively, the instantaneous amplitude of the envelope of the carrier wave output M_1 of the amplifier 44 is the reciprocal of the instantaneous amplitude of the coding wave K, except during periods when the feed-back amplifier 46 is blocked as will be explained below.

The output M_1 of amplifier 44 is shown in Fig. 6. It will be seen that it is modulated downward during the positive parts M of the wave K shown in Fig. 4; during the negative parts N of the K wave, the carrier wave remains at full amplitude. This is a result of biasing the grid 50 of the feed-back tube 53 so that the tube 53 is driven to cut-off during the occurrence of the negative parts N of the wave K, there, of course, being no negative feed-back while the tube is cut-off.

The output wave M_1 is supplied through a blocking capacitor 75 to a grid 76 of a pentagrid amplifier tube 77. A normal negative bias is applied to the grid 76 through a grid-leak resistor 74. The wave K is supplied from the anode circuit of the tube 51 over a conductor 79 to the grid 78 for the purpose of making the tube 77 effective to pass a signal only during the positive parts M of the wave K. During the negative parts N of the wave K, the grid 78 is driven negative sufficiently to drive the tube 77 to anode current cut-off. During the positive portions M of the wave K, the tube 77 is made operative to pass the signal M_1 because the portions M drive the grid 78 slightly positive so long as they are being applied to the grid. The wave K from conductor 79 is of large amplitude to ensure proper control of the tube 77. It will be noted that the wave K is supplied from the conductor 79 to a blocking capacitor 81 and through a grid-leak resistor 82

in the input circuit of tube 77. The grid 78 is prevented from going more than slightly positive by means of a resistor 83 which has a large voltage drop produced therein by any substantial flow of grid current.

As shown in Fig. 8, the envelope of the carrier wave output M_2 of the tube 77 is proportional to the reciprocal of only the positive portions M of the coding wave K , there being no signal during the negative portions N . The signal M_2 is rectified by a diode 84 which has an output resistor 86 shunted by a bypass capacitor 87. The rectified signal M_3 (Fig. 9) is supplied through a resistor 88 to the grid of an output tube 89.

The circuit and the operation of the other group of mixer and amplifier units 43a, 44a and 46a and of the amplifier 77a and diode 84a are the same as described above, the only difference being that in this second group of units it is the negative portions N of the wave K that determine the modulation of the carrier. It will be noted that the wave $-K$ (Fig. 5) is supplied from the cathode circuit of the tube 51 over the conductors 52a and 79a. The two groups of units have similar parts indicated by the same reference numerals with the letter "a" following the numerals applied in the second group of units.

The carrier wave output N_1 (Fig. 7) of the main amplifier 44a is modulated only by the portions N of the wave K . The unmodulated portions of the wave N_1 are removed by the amplifier tube 77a to produce a wave N_2 (Fig. 10) which corresponds to the wave M_2 but which contains only the reciprocal of the negative portions N of the wave K . The output of the diode 84a is the signal N_4 illustrated in Fig. 11. The combined diode output signals M_3 and N_4 are the desired reciprocal signal $1/K$ shown in Fig. 12. It will be noted that the diode 84a is reversed with respect to the diode 84 in order to give the N portions of signal K their original negative polarity.

If desired, the carrier wave signals M_2 and N_2 may be utilized in the multiplier circuit 14 (Fig. 1) without rectification. This is illustrated in Fig. 13 which shows a multiplier circuit of the type described in the above-identified Bedford application, the difference in the multiplier circuit of Fig. 13 and in that of the Bedford application being that in Fig. 13 the coding signal (or decoding signal) is on a carrier wave whereas in the Bedford application the communication signal S is on a carrier wave.

Referring to Fig. 13, which is illustrated for the condition of reception, the received signal SK is passed through rectifiers 91 and 92 to obtain the positive and negative portions A and B of the signal as indicated in Fig. 14. The negative portion B is reversed in polarity by a tube 93. The positive portion A is multiplied in multiplier tubes 94 and 96 by the reciprocal signals M_2 and N_2 , respectively. One of the resulting signals AM_2 is passed through a high pass filter 97 to remove the original low frequency signal (primarily to remove signal S when the multiplier is used for transmission) and is demodulated by a detector 98 to obtain an audio signal which is supplied to an adding circuit or mixer 99. The other signal AN_2 is passed through a high pass filter 101, a detector 102 and a reversing tube 103 to obtain a second audio signal which is supplied to the mixer 99.

Similarly, the signal portion B is multiplied in multiplier tubes 104 and 106 by the reciprocal signals M_2 and N_2 , respectively. The signal BM_2 is passed through a high pass filter 107, a detector

108 and a reversing tube 109 to supply a third audio signal to the mixer 99. The signal BN_2 is passed through a high-pass filter 111 and a detector 112 to supply a fourth audio signal to the mixer 99.

The four audio signals add at the mixer 99 to give the desired signal S . Any carrier frequency components that may be present are filtered out by a low pass filter 113.

Fig. 15 shows one possible multiplier tube arrangement that may be employed for the multiplier units 94, 96, 104 and 106 of Fig. 13. It consists of a three-element vacuum tube, for example, that is biased to operate on a curved portion of its characteristic. This bias is varied by the audio signal, such as signal A , so that a carrier wave signal, M_2 for instance, applied to the grid of the tube is modulated by the audio signal. This modulation also is a multiplication of the two signals whereby the output, in the example assumed, is AM_2 . It is evident that a tube operating as described as a multiplier is capable of multiplying only voltages which are swung in a positive direction with respect to the A. C. axis of the wave.

From the foregoing description it will be seen that by means of our invention it is possible to obtain the reciprocal of any electrical signal regardless of its wave form merely by passing the signal through an electrical circuit. This method of obtaining a reciprocal wave is much superior to the method comprising calculating and cutting a reciprocal wave form on a disc, both because it saves time and labor, and because it adds flexibility to the design of a signalling system. It should be understood that our method and means for obtaining reciprocal values are not limited to use in a secret signalling system, but are of more general application.

We claim as our invention:

1. The method of communication which comprises producing a communication signal and a distorting signal, multiplying said signals to obtain their product, transmitting said product to a receiver, producing at the receiver a second distorting signal which is substantially a duplicate of the first distorting signal, producing substantially the reciprocal of the second distorting signal by passing it through an electrical circuit, and multiplying the received product signal by said reciprocal signal to obtain the original communication signal.

2. The method of communication which comprises producing a communication signal and a distorting signal, multiplying said signals to obtain their product, transmitting said product to a receiver, producing at the receiver a second distorting signal which is substantially a duplicate of the first distorting signal, converting the second distorting signal to a signal that is substantially a reciprocal of the second distorting signal, and multiplying the received product signal by said reciprocal signal to obtain the original communication signal.

3. A communication system which comprises means for producing a communication signal, means for producing a distorting signal, means for multiplying said signals to obtain their product, means for transmitting said product to a receiver, means for producing at the receiver a second distorting signal which is substantially a duplicate of the first distorting signal, means at the receiver for producing from the second distorting signal a signal that is substantially the reciprocal thereof, and means for multiplying the

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received product signal by said reciprocal signal to obtain the original communication signal.

4. A communication system which comprises means for producing a communication signal, means for producing a distorting signal, means for multiplying said signals to obtain their product, means for transmitting said product to a receiver, means for producing at the receiver a second distorting signal which is substantially a duplicate of the first distorting signal, means comprising an electrical circuit through which said second distorting signal is passed for converting it to a signal that is substantially the reciprocal thereof, and means for multiplying the received product signal by said reciprocal signal to obtain the original communication signal.

5. The invention according to claim 4 wherein means is provided for maintaining between the communication signal and the distorting signal substantially the phase relation at the receiver as at the transmitter.

6. In a circuit comprising a main amplifier, a negative feed-back amplifier, and an adding circuit, the method of obtaining the reciprocal of an electrical signal which comprises producing a carrier wave signal and passing it through said adding circuit, amplifying the output of the adding circuit in said main amplifier, feeding back the amplified signal through said negative feed-back amplifier to said adding circuit, and varying the gain of the feed-back amplifier substantially in direct proportion to said electrical signal whereby its reciprocal appears in the output of the main amplifier.

7. An electrical circuit for obtaining the reciprocal of a signal which comprises a main amplifier, a negative feed-back amplifier having its input circuit connected to the output circuit of the main amplifier and having its output circuit connected through a voltage adding circuit to the input circuit of the main amplifier, means for supplying a carrier wave signal to said adding circuit, and means for varying the gain of the feed-back amplifier in direct proportion to the amplitude of said first signal whereby its reciprocal appears in the output of the main amplifier.

8. In a circuit for obtaining the reciprocal of a signal, two main amplifiers, each main amplifier having a negative feed-back circuit that includes a feed-back amplifier, the output circuit of each feed-back amplifier being connected through a signal adding circuit to the input circuit of the associated main amplifier, means for supplying a carrier wave signal to said signal adding circuits, and means for varying the gain of the two feed-back amplifiers in direct proportion to the amplitudes of the positive and negative portions, respectively, of said first signal whereby the reciprocal values of said portions appear in the output circuits of the main amplifiers.

9. The invention according to claim 8 wherein means is provided for supplying the outputs of said main amplifiers to two channels, respectively, each of which includes a signal blocking means, and means for unblocking said channels only when signal portions having reciprocal values are being supplied thereto.

10. The invention according to claim 8 wherein means is provided for rectifying the outputs of said main amplifier and wherein means is provided for reversing the polarity of one of the rectified outputs and for adding it to the other rectified output.

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11. An electrical circuit for obtaining the reciprocal of a signal having positive and negative portions, said circuit comprising a main amplifier, a negative feed-back amplifier having its input circuit connected to the output circuit of the main amplifier and having its output circuit connected through a voltage adding circuit to the input circuit of the main amplifier, means for supplying a carrier wave signal to said adding circuit, means for varying the gain of the feed-back amplifier in direct proportion to the amplitude of the positive portions of said first signal whereby the reciprocal of said positive portions appears in the output of the main amplifier, a second main amplifier, a second negative feed-back amplifier having its input circuit connected to the output circuit of the second main amplifier and having its output circuit connected through a second voltage adding circuit to the input circuit of the second main amplifier, means for supplying a carrier wave signal to said second adding circuit, and means for varying the gain of the second feed-back amplifier in direct proportion to the amplitude of the negative portions of said first signal whereby the reciprocal of said negative portions appears in the output of the second main amplifier, and means for adding said reciprocals of said two portions to obtain the reciprocal of said first signal.

12. An electrical circuit for obtaining the reciprocal of a signal having positive and negative portions, said circuit comprising a main amplifier, a negative feed-back amplifier having its input circuit connected to the output circuit of the main amplifier and having its output circuit connected through a voltage adding circuit to the input circuit of the main amplifier, means for supplying a carrier wave signal to said adding circuit, means for varying the gain of the feed-back amplifier in direct proportion to the amplitude of the positive portions of said first signal whereby the reciprocal of said positive portions appears in the output of the main amplifier, a second main amplifier, a second negative feed-back amplifier having its input circuit connected to the output circuit of the second main amplifier and having its output circuit connected through a second voltage adding circuit to the input circuit of the second main amplifier, means for supplying a carrier wave signal to said second adding circuit, and means for varying the gain of the second feed-back amplifier in direct proportion to the amplitude of the negative portions of said first signal whereby the reciprocal of said negative portions appears in the output of the second main amplifier, means for rectifying the outputs of said main amplifiers, means for reversing the polarity of one of said rectified outputs and for adding it to the other rectified output to obtain the reciprocal of said first signal.

13. Wave shaping means for reshaping an electrical wave, said means comprising an electrical network that converts said electrical wave to a second electrical wave having a wave form that is substantially the reciprocal of the wave form of the first wave.

14. In combination, means for producing an electrical coding or signal distorting wave having a certain wave form, and electrical network means for converting said wave to a second electrical wave having a wave form that is substantially the reciprocal of the wave form of the first wave.

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