Dec. 3, 1929. G. CRISSON 1,737,830

MEANS FOR AND METHOD OF VOLUME CONTROL OF TRANSMISSION

Filed Sept. 12, 1924 2 Sheets-Sheet 1

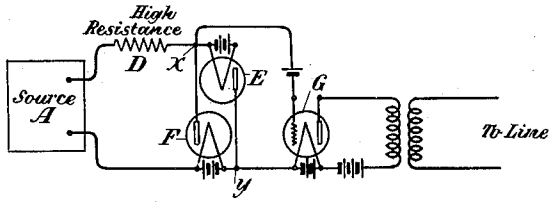


Fig. 1

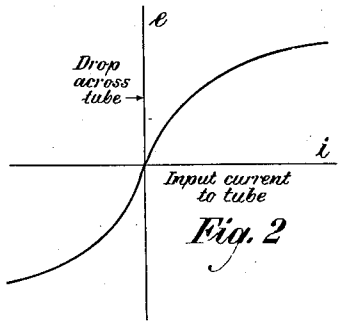


Fig. 2

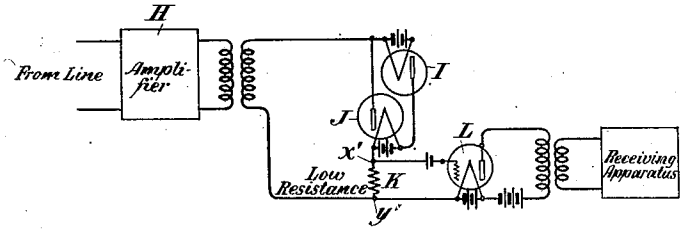


Fig. 3

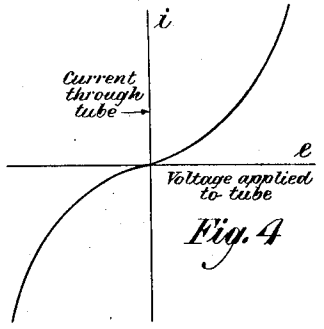


Fig. 4

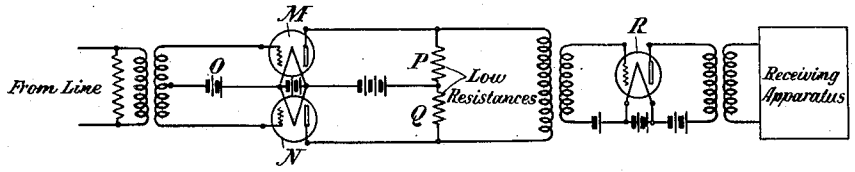


Fig. 5

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MEANS FOR AND METHOD OF VOLUME CONTROL OF TRANSMISSION

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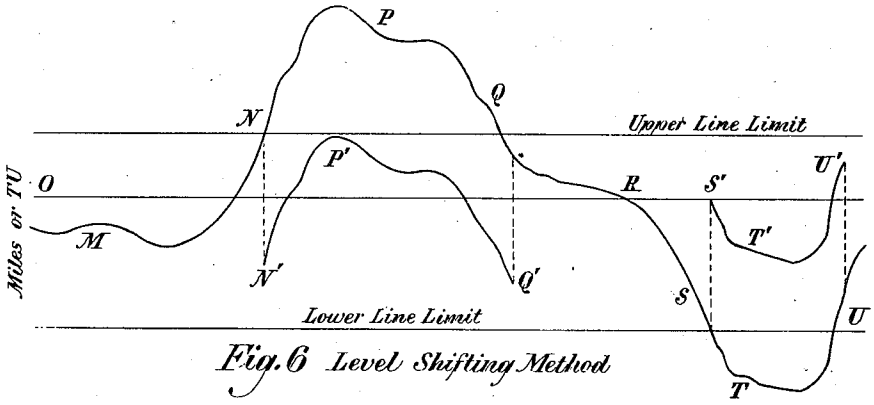


Fig. 6 Level Shifting Method

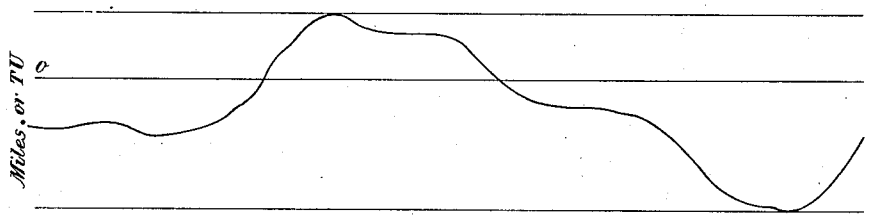


Fig. 7 Range Restoring Method

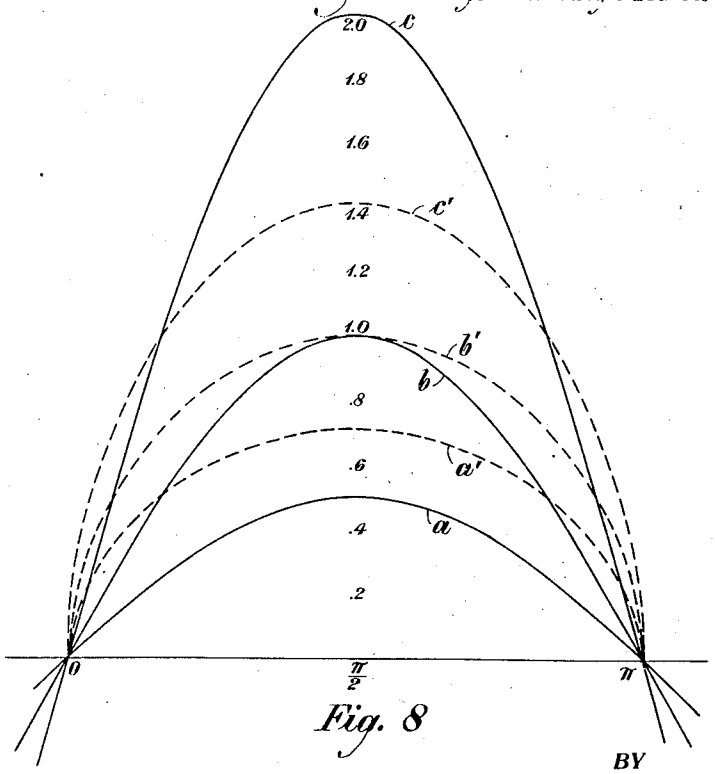


Fig. 8

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UNITED STATES PATENT OFFICE

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MEANS FOR AND METHOD OF VOLUME CONTROL OF TRANSMISSION

Application filed September 12, 1924. Serial No. 737,415.

This invention relates to the transmission of signals and more particularly to a means for and a method of changing the range of volume of the signal during transmission.

In telephone transmission and in other kinds of signaling as well it is often desirable to transmit sounds, such as music, which have an extremely wide range of volume, over telephone circuits in which the volume range of currents which can be satisfactorily transmitted is limited on one hand by interference from line noises and on the other hand by the necessity of avoiding distortion due to overloading repeaters and interference with other circuits. This is particularly true of such types of transmission systems as radio broadcasting circuits and public address systems.

Heretofore it has been proposed to accomplish this result by producing arbitrary changes in the transmission level whenever the signal to be transmitted exceeded the volume range of the circuit. For example, if the volume of the signal became greater than the circuit would carry a loss was introduced at the transmitting end to reduce the volume of the signal to within the limits of the circuit, while at the receiving end a corresponding gain was introduced at the same time. Consequently, the signal was transmitted over the circuit at low volume but at the receiving end its volume was increased in proportion to the decrease during transmission.

By the present invention it is proposed to bring the signal within the volume limits of the transmission system, not by shifting its level up or down, as may be necessary, but by actually changing the shape of the signal wave so that its amplitude will not pass the volume limits imposed by the transmission system. Heretofore, in telephonic systems a current has been produced which varied directly in proportion to the pressure of the original sound wave. Consequently, the ratio of the weakest to the strongest current is equal to the ratio of the pressure corresponding to the weakest and strongest sounds. In accordance with the present invention it is proposed to set up apparatus which will produce a current which is not directly proportional to the pressure of the sound wave but to some function of this pressure which will involve a relatively small change in the magnitude of the current. At the receiving end of the circuit this current will be passed through a device which restores the original wave form and the corresponding range of volume of sound.

In order to utilize fully the power transmitting capacity of the medium of transmission, the system would be so adjusted that the maximum transmitted wave will be produced by the loudest sounds that the system will be called upon to transmit. For sound of lesser volume, the apparatus at the transmitter will produce waves of relatively greater amplitude than the sounds which produce them. Conversely, at the receiving station, the apparatus is so arranged that for a transmitted wave corresponding to the loudest sound the system will be called upon to transmit, an output wave having a desired amplitude will be produced. For transmitted waves corresponding to sounds of smaller volume, the output wave will be reduced to a smaller fraction of the maximum than the transmitted wave.

It follows as a consequence of this arrangement that such a system will discriminate against noise currents. The noise currents originate at some point in the system between the transmitter and receiver and are consequently only affected by the apparatus at the receiving end. If, therefore, the noise currents arrive at the receiver smaller in amplitude than the smallest transmitted signal currents, their amplitude will, by the inherent action of the arrangement at the receiver, be reduced relatively to the signal current. The discrimination arises from the fact that the weak signal currents are operated upon by the apparatus at both ends of the system with the result that they are first increased in amplitude and thereafter reduced so that they ultimately arrive at the receiver with the same amplitude they would have had had they been transmitted directly without being acted upon by the range reducer and the range expander. The noise currents, on the other hand, are subjected only to the action of the

range expander and are therefore reduced in amplitude without undergoing any corresponding increase in amplitude.

The invention may now be more fully understood from the following description when read in connection with the accompanying drawing, Figure 1 of which illustrates the arrangements used at the transmitting end of the system, Fig. 2 is a curve illustrating the operation of the circuit of Fig. 1, Fig. 3 is a circuit illustrating the arrangements utilized at the receiving end of the system, Fig. 4 is a curve illustrating the operation of the arrangement of Fig. 3, Fig. 5 illustrates a modified form of receiving circuit, and Figs. 6, 7 and 8 are curves further illustrating the principles of the invention.

Fig. 1 represents the arrangement used at the sending end of the system. In this figure, A designates a source of telephonic current, such, for example, as the low power amplifier of a public address system. The voltage produced by this source has the usual characteristic of being proportional from instant to instant to the air pressure wave of the sound being transmitted. In circuit with the source A is a high resistance D and two 2-electrode vacuum tubes E and F. The vacuum tubes are in parallel with each other but in series with the resistance D and they are so connected that currents of one polarity pass through the tube E and currents of the opposite polarity pass through the tube F. The resistance D is made so large that the instantaneous current through the circuit D—E or D—F, as the case may be, is closely proportional to the voltage applied by the source A, regardless of variations in the resistances of the vacuum tubes E and F.

A vacuum tube amplifier G is connected in circuit beyond the tubes E and F, its grid filament connection being established across the terminals of the parallel combination E—F, that is, the grid of the tube G is connected to the point x and the filament of the tube G is connected to the point y so that the potential applied to the grid of the tube G will be determined by the drop through the tube E or the tube F, as the case may be, at any given instant.

If the impedance between the points x and y in Fig. 1 is equivalent to a simple resistance, it is apparent that the potential at the point x would at all times be directly proportional to the potential applied by the source A, which as already stated, is directly proportional from instant to instant to the air pressure wave of the sound being transmitted. That this proportionality would hold will be evident from the fact that in the case of the simple resistance the current and the voltage are related by the simple formula $E=IR$. It is well known, however, that in the case of a vacuum tube this simple relation does not hold but that the current is a function of some power of the voltage. For example, in the case of a 2-electrode tube of simple construction the current may be proportional to the 3/2 power of the voltage. Under these circumstances, it is evident that as the voltage drop through the tube E or F increases, the current flow through the tube will increase in greater proportion, or to state it another way, the larger the current flowing through the tube E or F, the smaller will be the ratio of the drop across x—y to the current, and since the current flowing through the tube is the same as the current flowing through the resistance D the smaller will be the ratio of the drop across x—y to the voltage of the source A.

Since the instantaneous voltage applied to the grid of the amplifying tube G is always the same as the drop across the points x—y, it will be seen that we here have a system in which an increase in the current (through D—E or D—F) will always be accompanied by an increase of the voltage (applied to the grid of tube G), but the ratio of the voltage to the current will become less as the current increases. This is shown by the curve of Fig. 2, in which the voltage applied to the grid of the tube G is plotted vertically and the current flowing through the circuit D—E or D—F, as the case may be, is plotted horizontally. Therefore, as the current wave corresponding to the signal from the the source A varies in amplitude, the voltage applied to the grid of the tube G will vary in amplitude but the variation will be proportionally smaller than that of the original wave. While the voltage wave thus produced will be distorted, all of the details of the current wave will be found in it. This voltage wave acts upon the amplifier G and sends out over the line a current presenting the desired characteristic of having a much smaller range of amplitude than exists in the original voice wave.

Fig. 3 shows an arrangement by which the transmitted current can be restored to its normal shape at the receiving end of the circuit. In this case, the current arriving over the line is passed through an amplifier H if necessary and impressed upon a circuit consisting of two 2-electrode vacuum tubes I and J, connected in parallel with each other and in series with a relatively low resistance K. These two vacuum tubes, as in the case of Fig. 1, are so arranged that one-half wave passes through one of the tubes and the other half-wave through the other tube. A vacuum tube amplifier L has its grid connected to one terminal x' of the low resistance K and its filament connected to the terminal y' of said resistance. The output circuit of the amplifier L is connected to the receiving apparatus.

Since the resistance K is low compared with the resistances of the vacuum tubes I

and J, the relation between the current flowing through the resistance K (which is the same as the current flowing through the circuit I—K or J—K, as the case may be) and the voltage applied to these circuits by the amplifier H will be as given by the curve of Fig. 4. Here we have a condition which is just the reverse of that in Fig. 1. As the current through I—H or J—K increases, the voltage drop through the tube also increases but in smaller proportion. Consequently, the ratio of the IR drop between the points x' and y' to the total drop through the tube and resistance K will increase with increase in current. Hence, if the voltage applied by the amplifier H to the circuit increases the voltage applied to the grid of the tube L will be increased in a greater ratio.

Fig. 5 shows a modified form of receiving circuit for restoring the wave shape and volume range at the receiving end. In this case the voltage from the incoming line is impressed between two vacuum tubes M and N, of the three-element type, connected in a push-pull circuit. The voltage of the grid battery O is made so large that the space currents of these two tubes are reduced approximately to zero when no disturbance is passing through the system. Low resistances P and Q are connected in series with the plates of the vacuum tubes, as shown, and a vacuum tube amplifier R is connected so that the drop in the two resistances is applied to its grid and its output circuit is connected to the receiving apparatus. Under these conditions the relations between the current in the resistances P and Q and the voltage applied to the grid of the amplifier will be as shown in Fig. 4, and the arrangement of Fig. 5 will therefore have an effect similar to that shown in Fig. 3, so far as restoring the wave shape and volume range of the transmitted signals is concerned.

In order that the principles underlying the invention may be more clearly understood the following theoretical considerations are given. The expressions "root" and "power" in this discussion refer to the arithmetical values only. The roots and powers are taken to be real and of the same sign.

Assume that the instantaneous current in the line is proportional to the rth root of the instantaneous current in the transmitting (or receiving) circuit at a point where there is no distortion. This undistorted current will be called the speech current to distinguish it from the line current.

Let i_L=instantaneous line current
i_S=instantaneous value of the speech current
K=constant depending upon the structure of the system

then the relation between the line and speech currents may be expressed by the parabolic equation—

$$i_L = K i_S^{\frac{1}{r}} \quad (1)$$

This expression is, of course, applicable to either the range contracting arrangement at the transmitting station or the range expanding arrangement at the receiving station. In the one case the output current is proportional to a root of the input current and in the other case the output current is proportional to a power of the input current. The expression for the relation between the input and output currents in either case is a parabolic equation.

Let I_L and I_S represent the maximum and I_L' and I_S' the minimum peak values of the line and speech currents, respectively.

The range of speech volume in TU is

$$R_S = 20 \log_{10} \frac{I_S}{I_S'} \quad (2)$$

The range of line current volume is

$$R_L = 20 \log_{10} \frac{I_L}{I_L'} \quad (3)$$

From (1)

$$I_S = \frac{1}{K^r} I^r{}_L \quad (4)$$

and

$$I_S' = \frac{1}{K^r} (I_L')^r \quad (5)$$

Substituting in (2)

$$R_S = 20 \log_{10} \left(\frac{I_L}{I_L'} \right)^r \quad (6)$$

$$R_S = r R_L \quad (7)$$

That is the ratio of the volume range of speech currents in TU (or any logarithmic units) to the volume range of line currents is equal to the index expressing the law of the relation between the speech and line currents.

Noise is in the nature of a small alternating current of constant value superimposed on the line current; consequently, it has the effect of a small increment added to that current. The volume of noise in the receiver will tend to increase with the received sound and is proportional to

$$\frac{di_S}{di_L}.$$

Letting n represent the noise current in the receiver corresponding to a given noise current n_L in the transmitting medium and N and N' the noise currents in the receiver corresponding to the same given current in the medium for the strongest and weakest transmitted currents, respectively

$$n = H n_L \frac{di_S}{di_L} \quad (8)$$

where H is a factor depending upon the structure of the receiving circuit.

From (1)

$$\frac{di_S}{di_L} = \frac{r}{K^r} i_L^{r-1} \quad (9)$$

$$N = \frac{Hr}{K^r} n_L I_L^{r-1} \quad (10)$$

$$N' = \frac{Hr}{K^r} n_L I_L'^{r-1} \quad (11)$$

Range of volume of noise in the receiving apparatus for a fixed value of the interfering current in the transmitting medium is

$$R_N = 20 \log_{10} \frac{N}{N'} \quad (12)$$

$$R_N = 20 \log_{10} \left(\frac{I_L}{I_L'}\right)^{r-1} \quad (13)$$

$$R_N = (r-1) R_L \quad (14)$$

from (7)

$$R_N = \frac{(r-1)}{r} R_S \quad (15)$$

The simple two-element vacuum tube circuits have an index of $r=1.5$. Consequently, to transmit a range of 50 TU of volume would require a range of

$$\frac{50}{1.5} = 33.3\ TU$$

in the line in accordance with equation (7).

The noise range in the receiving apparatus for a given interference in the medium would be

$$R_N = \frac{1.5-1}{1.5} \times 50 = 16.7\ TU$$

corresponding to the difference in the effect of the noise when superimposed on weak and strong transmission. So if the noise were tolerable at low volumes, it would not be amplified enough at high volumes to be harmful as it would become weaker relative to the transmitted sound. The latter statement would be true for all values of r greater than 1 which would cover all cases in which the system functions in the desired manner of transmitting currents having a narrower range of volume than the speech currents.

It will, of course, be obvious that by a proper design of the vacuum tubes or networks it will be possible to obtain a system having an index in which r is greater than 1.5 so that the reduction in volume range may be further increased, or two or more devices may be connected in tandem so as to successively expand or contract the volume range.

The discrimination against noise which is inherent in a system of the type herein described is an important feature of the present invention. It will be observed that the action of the range contracting arrangement at the transmitting station is to increase, relatively to the original sound, the amplitude of all waves whose volumes are less than the greatest wave that can be transmitted. As a consequence, the volume range of the transmitted waves is less than that of the original wave. On the other hand, the range expanding apparatus at the receiving station operates to decrease the amplitude of all waves whose volume is less than the maximum. This, of course, results in an expansion of the range received as compared with the range transmitted so that the overall result is that the signal affecting the receiver has the same volume range as it would have had in the case of direct transmission without the interposition of the range contracting and range expanding apparatus.

Since the noise currents arise at some point between the transmitting and receiving station, they will not be acted upon by the range contracting apparatus. If the noise currents are smaller in volume than the lowest volume of signal transmitted, they will not be first increased in volume as is the case with the small volume signals, but will be acted upon by the range expander at the receiving station only. Consequently, the received noise waves of small volume will be reduced in amplitude when applied to the receiver. The overall result is that small volume signal waves are applied to the receiver with the same amplitude they would have had if they had been transmitted directly without being acted upon by the range contractor and the range expander, whereas the noise currents are impressed upon the receiver reduced in volume. Experiments have shown that noise currents of the volume encountered in ordinary practice will be so reduced in volume when applied to the receiver that they will not be detected by the ear, while the low volume signal currents will be quite distinctly audible and, furthermore, nearly free from any interfering noise.

In the case of radio transmission, the system herein disclosed affords a practical solution of the problem of the reduction of static and other interfering currents, such as those received from interfering stations.

The difference between the principles underlying the present invention and the transmission level shifting method, previously referred to, will be clear from a comparison of the curves of Figs. 6 and 7. Fig. 6 illustrates how the volume is kept within the required limits by shifting the transmission level. In this figure the middle horizontal line represents the zero transmission level and the horizontal lines above and below the zero line represent the limiting levels of the transmission medium, the upper line representing the upper permissible limit of power determined by the power capacity of the line repeaters or

the necessity for avoiding interference with other circuits and the lower line representing the lowest transmission limit determined by the condition that line noise and cross-talk currents must be small as compared with the line current.

The curve MNPQRSTU is a curve representing the variations in the volume of sound. The equipment at the two ends of the line is adjusted so that when a moderate volume of sound is being transmitted the power of the line current falls between the allowable line limits, as illustrated by the portion MN of the irregular line representing the instantaneous power level of the sound current. When a loud burst of sound occurs, the level of the line current necessary to transmit it would rise above the upper limit for the line, as illustrated by the portion NPQ of the curve. Just before the sound current passes the upper limit, the special operator or some automatic arrangement will operate a device to reduce the gain of a repeater at the transmitting end. This has the effect of reducing the level at the input of the line with respect to the power at the sound source. At the same time an amplifier at the receiving end has its gain correspondingly increased so that the level will be raised at the receiving end by the same amount that it is reduced at the transmitting end. The shift in the level during transmission over the line is then indicated by the curve N′P′Q′ of Fig. 6. The overall loss in the line is not changed by this procedure but the power level is lower by the amount NN′.

After the power level falls to a value which will permit the restoration of the original condition but before it falls below the lower line limit, the original adjustment of the transmitting and receiving amplifiers will be restored so that the portion QRS of the curve is not shifted in level. In case the power falls below the lower limit of the line as shown by the portion STU of the curve, the gain at the transmitting end is increased and the gain at the receiving end correspondingly reduced so that the level of the power in the line relative to that delivered by the source is raised. The level of the line currents is raised as indicated by the curve S′T′U′ so that it falls within the limits of the line, and this occurs without disturbing the overall equivalent of the line.

The operation of the range reducing system of the present invention is illustrated by the curve of Fig. 7. In this case the source of sound produces sound currents which are passed through a network or device, as previously described, so that the instantaneous current transmitted to the line is proportional not to the instantaneous sound current but to some function thereof having any smaller range of amplitude.

After traversing the line the currents are passed through another network or apparatus having the inverse property of producing currents having a wider range of variation than that of the currents received. This network is designed so as to produce an effect which just compensates for the distortion caused by the network at the transmitting end so that as a consequence the original wave shape is restored. As already stated, a simple relation which would have considerable advantage would be to have the line current proportional to some root of the sound current, the quantitative relations involved being fully set forth in the mathematical exposition of the theory above given.

Assuming, for example, that the line current is proportional to the square root of the sound current, the range of volume of the line curret will be one-half the range of the sound current, the range being expressed in logarithmic units. If this range is equal to or less than the range permissible in the line the gains at each end of the line can be so set that the limits of the line will never be exceeded. This is illustrated by the curve of Fig. 7, which shows the power level curve of Fig. 6 redrawn to have one-half the original variation and adjusted in height so as to fall between the upper and lower line limits.

To show the effect of this distortion on the wave shape and amplitude of the sound current, the curves of Fig. 8 have been drawn. The three solid curves a, b and c are sinusoids having amplitudes of 0.5, 1 and 2, respectively, and represent sound current waves, while the dotted curves a', b' and c' are the corresponding line currents. It should be noted that the difference in the range of amplitude of the dotted and solid curves is due solely to the distorting networks and not to any change in the gain of the amplifiers of the system.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. The method of signaling which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous values are directly proportional to the corresponding values of the sound wave, and translating said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of said sound current wave.

2. The method of signaling which consists in producing under the control of telephonic sounds a varying electrical current wave each of whose instantaneous values is proportional solely to an invariable function of the cor-

responding value of the sound wave, said current wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of the sound wave.

3. The method of signaling which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous values are directly proportional to the corresponding values of the sound wave and translating said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding instantaneous value of said sound current wave, said translated current wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of said sound currents.

4. The method of signaling which consists in producing under the control of telephonic sounds a varying electrical current wave corresponding to the sounds, and translating said electrical current wave into an electrical wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding instantaneous value of said varying electrical current wave, said translated wave having a range of variation whose ratio of maximum to minimum amplitude is greater than that of said varying current wave.

5. The method of signaling which consists in producing under the control of telephonic sounds a varying electrical current wave each of whose instantaneous values is an invariable parabolic function solely of the corresponding value of the sound wave.

6. The method of signaling which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous values are directly proportional to the corresponding values of the sound wave, and translating said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable parabolic function solely of the corresponding value of the sound current wave.

7. The method of signaling which consists in producing under the control of telephonic sounds a varying electrical current wave each of whose instantaneous values is proportional to an invariable root solely of the corresponding value of the sound wave.

8. The method of signaling which consists in producing under the control of telephonic sounds an electrical sound current wave corresponding in amplitude to the sound intensity and translating said current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable root solely of the corresponding value of said sound current wave.

9. The method of signaling which consists in producing a varying wave under the control of telephonic sounds, and translating the said wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable power solely of the corresponding value of the sound wave.

10. The method of signaling which consists in producing under the control of telephonic sounds a varying electrical sound current wave corresponding to the sounds and translating said varying electrical sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable power solely of the corresponding value of the sound current wave.

11. The method of signaling which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, translating said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of the sound current wave, and translating the varying electrical current wave thus produced into an electrical wave each of whose instantaneous values is a non-linear function solely of the corresponding value of said varying current wave, said last mentioned non-linear function being complementary to said first mentioned non-linear function.

12. The method of signaling which consists in producing under the control of telephonic sound an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, translating said sound current wave into a varying electrical current wave, each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of the sound wave, said translated wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of the sound current wave, and translating the current wave thus produced into an electrical wave, each of whose instantaneous values is proportional to a function solely of the corresponding value of said varying electrical current wave, said final translated wave having a range of variation whose ratio of maximum to minimum amplitude is greater than that of said varying electrical current wave.

13. The method of signaling which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, translating said sound current wave into a varying electrical current wave each of whose instantaneous value is proportional to an invariable root solely of the corresponding value of said sound cur-

rent wave and in turn translating said varying current wave into an electrical wave each of whose instantaneous values is proportional to an invariable power solely of the corresponding value of said varying electrical current wave.

14. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, and means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of the sound wave.

15. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, and means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of the sound wave, said translated wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of the sound wave.

16. In a signaling system, a sound of telephonic sounds, means to produce under the control of said sounds a varying electrical current wave corresponding thereto, and means to translate said varying electrical current wave into an electrical wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of said varying electrical current wave, said translated wave having a range of variation whose ratio of maximum to minimum amplitude is greater than that of said varying electrical current wave.

17. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, and means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable parabolic function solely of the corresponding value of the sound wave.

18. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, and means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable root solely of the corresponding value of the sound wave.

19. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave corresponding to the sound intensity, and means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable power solely of the corresponding value of said electrical current wave.

20. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of the sound wave, and means to translate the varying electrical current wave thus produced into an electrical wave each of whose instantaneous values is a complementary non-linear function of the corresponding value of said varying electrical current wave.

21. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of the sound wave, said translated wave having a range of variation, whose ratio of maximum to minimum amplitude is less than that of said sound current, and means to translate the varying electrical current wave thus produced into an electrical wave each of whose instantaneous values is proportional to a function solely of the corresponding value of said varying electrical current wave, but having a range of variation whose ratio of maximum to minimum amplitude is greater than that of said varying electrical current wave.

22. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, a circuit upon which said sound current wave may be impressed, said circuit including in series a fixed impedance and a translating element in which an invariable non-linear relation exists between the current flowing therethrough and the voltage applied thereto for both positive and negative semicycles of the wave, a translating circuit, and means for applying to said translating circuit the voltage drop between

the junction point of said fixed impedance and said translating device and another point in said first mentioned circuit.

23. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, a circuit upon which said sound current wave may be impressed, said circuit including in series a fixed impedance and a translating element in which an invariable non-linear relation exists between the current flowing therethrough and the voltage applied thereto for both positive and negative semi-cycles of the wave, a voltage operated translating device, and means for applying to said voltage operated translating device the voltage drop between the junction point of said first mentioned translating device and said fixed impedance and another point in said first mentioned circuit.

24. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, a circuit upon which said sound current wave may be impressed, said circuit including in series a fixed impedance and a translating element in which an invariable non-linear relation exists between the current flowing therethrough and the voltage applied thereto for both positive and negative semi-cycles of the wave, a voltage operated translating device comprising a three-element vacuum tube, and means to connect the grid of said tube to the junction point between said first mentioned translating device and said fixed impedance.

25. The method of discriminating against extraneous noise in a signaling system which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, translating said sound current wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of said sound current wave, receiving the varying electrical current wave thus produced together with undesired noise current waves, and translating the composite received current wave into an electrical wave each of whose instantaneous values is a non-linear function solely of the corresponding value of the composite received current wave and complementary to said first mentioned non-linear function.

26. The method of discriminating against noise in a signaling system which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, translating said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of said sound current wave, said varying electrical wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of said sound current wave, receiving the current wave thus produced together with undesired noise current waves, and translating the composite received current wave into an electrical wave each of whose instantaneous values is proportional to a function solely of the corresponding value of the composite received current wave, said last mentioned translated wave having a range of variation whose ratio of maximum to minimum amplitude is greater than that of said composite received current wave.

27. The method of discriminating against noise in a signaling system which consists in producing under the control of telephonic sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, translating said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable root solely of the corresponding value of said sound current wave, receiving the current wave thus produced together with undesired noise current wave, and translating the composite received current wave into an electrical wave each of whose instantaneous values is proportional solely to a power of the corresponding value of the composite received current wave.

28. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable non-linear function solely of the corresponding value of the sound wave, means to receive the current wave thus produced together with undesired noise current waves, and means to translate the composite received current wave into an electrical wave whose instantaneous value is a non-linear function solely of the corresponding value of the composite received current wave and complementary to said first mentioned non-linear function.

29. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, means to translate

said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of the sound wave, said varying current wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of the sound current wave, means to receive the electrical current wave thus produced together with undesired noise current waves, and means to translate the composite received current wave into an electrical wave each of whose instantaneous values is proportional to a function solely of the corresponding value of the composite received current wave, said electrical wave having a range of variation whose ratio of maximum to minimum amplitude is greater than that of said composite received wave.

30. In a signaling system, a source of telephonic sounds, means to produce under the control of said sounds an electrical sound current wave whose instantaneous value is directly proportional to the corresponding value of the sound wave, means to translate said sound current wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable root solely of the corresponding value of the sound wave, means to receive the electrical current wave thus produced together with undesired noise current waves, and means to translate the composite received current wave into an electrical wave each of whose instantaneous values is proportional to a power solely of the corresponding value of the composite received current wave.

31. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said signal wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of the signal wave.

32. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said wave into a varying electrical current wave each of whose instantaneous value is proportional to an invariable function solely of the corresponding value of the signal wave, said functional wave having a range of variation whose ratio of maximum to minimum amplitude is less than that of the signal wave.

33. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable function solely of the corresponding value of the signal wave, said functional wave having a range of variation whose ratio of maximum to minimum amplitude is greater than that of the signal wave.

34. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said wave into a varying electrical current wave each of whose instantaneous values is an invariable parabolic function solely of the corresponding value of the signal wave.

35. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable root solely of the corresponding value of the signal wave.

36. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said wave into a varying electrical current wave each of whose instantaneous values is proportional to an invariable power solely of a corresponding value of the signal wave.

37. The method of signaling, which consists in producing a signal wave having a form corresponding to the signal, and translating said signal wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of the signal wave, and translating said varying electrical current wave thus produced into an electrical wave each of whose instantaneous values is a complementary non-linear function solely of the corresponding value of said varying current wave.

38. The method of discriminating against extraneous noise in a signaling system, which consists in producing a signal wave having a form corresponding to the signal, translating said wave into a varying electrical current wave each of whose instantaneous values is an invariable non-linear function solely of the corresponding value of said signal wave, receiving the varying electrical current wave thus produced together with undesired noise current waves, and translating the composite received current wave into an electrical wave each of whose instantaneous values is a non-linear function solely of the corresponding value of the composite received current wave and complementary to said first mentioned non-linear function.

39. In a signaling system, a source of sound waves, means to produce under control of said sound waves an electrical current wave whose amplitude is directly proportional from instant to instant to the amplitude of said sound wave, means to translate said electrical current wave into a varying electrical current wave whose amplitude is proportional from instant to instant to an

invariable function solely of the corresponding amplitude of said sound wave and having a range of variation whose ratio of maximum to minimum amplitude is less than that of the current wave so translated, a transfer medium arranged to be affected by the translated current wave, receiver means controlled from said transfer medium for reproducing electrical current waves transferred, including means for translating a reproduced current wave into a current wave having essentially the same form as the first-mentioned electrical current wave.

In testimony whereof I have signed my name to this specification this 10th day of September, 1924.

GEORGE CRISSON.