Feb. 26, 1946. R. K. POTTER 2,395,758

WAVE TRANSLATING SYSTEM

Filed Feb. 9, 1944

FIG. 1

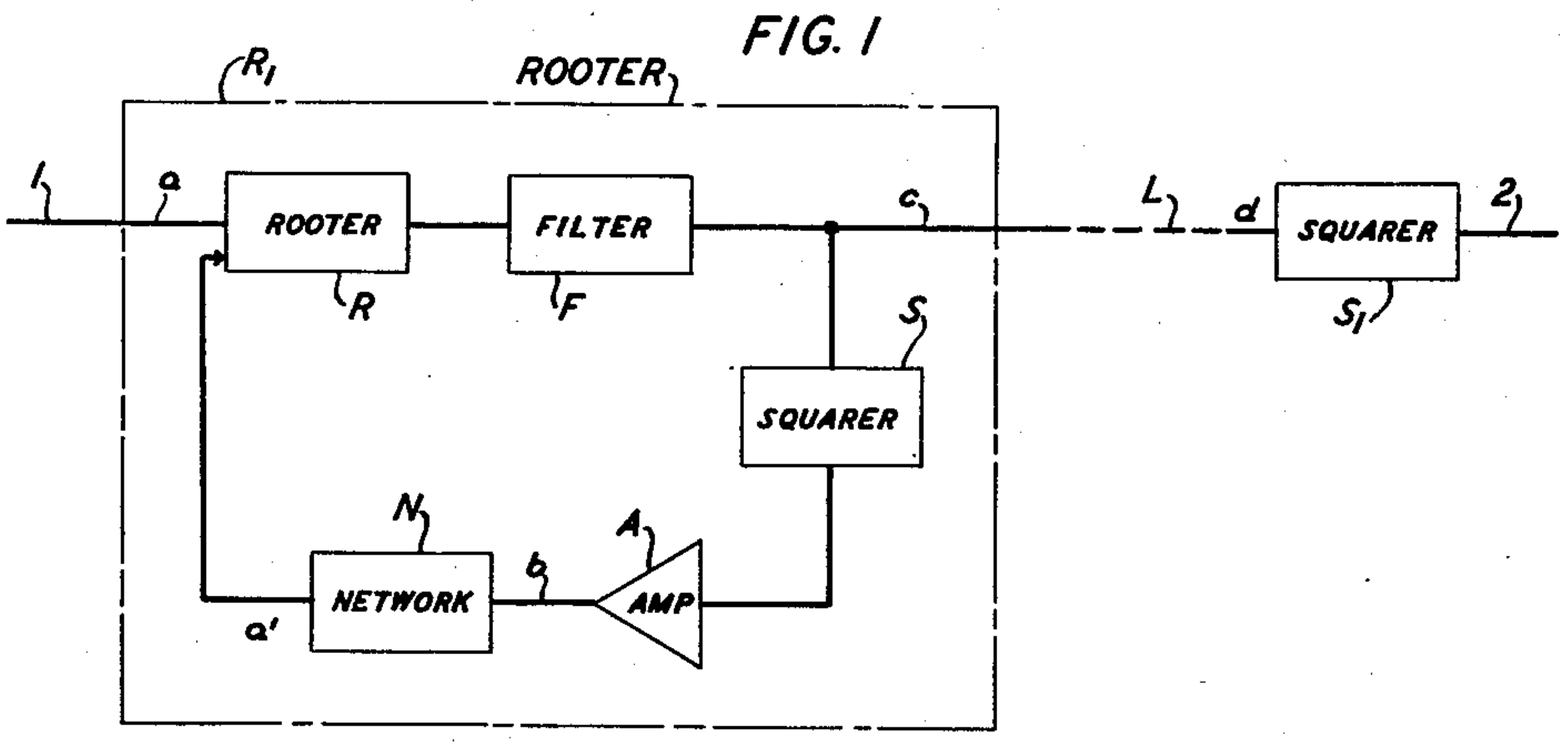


FIG. 2

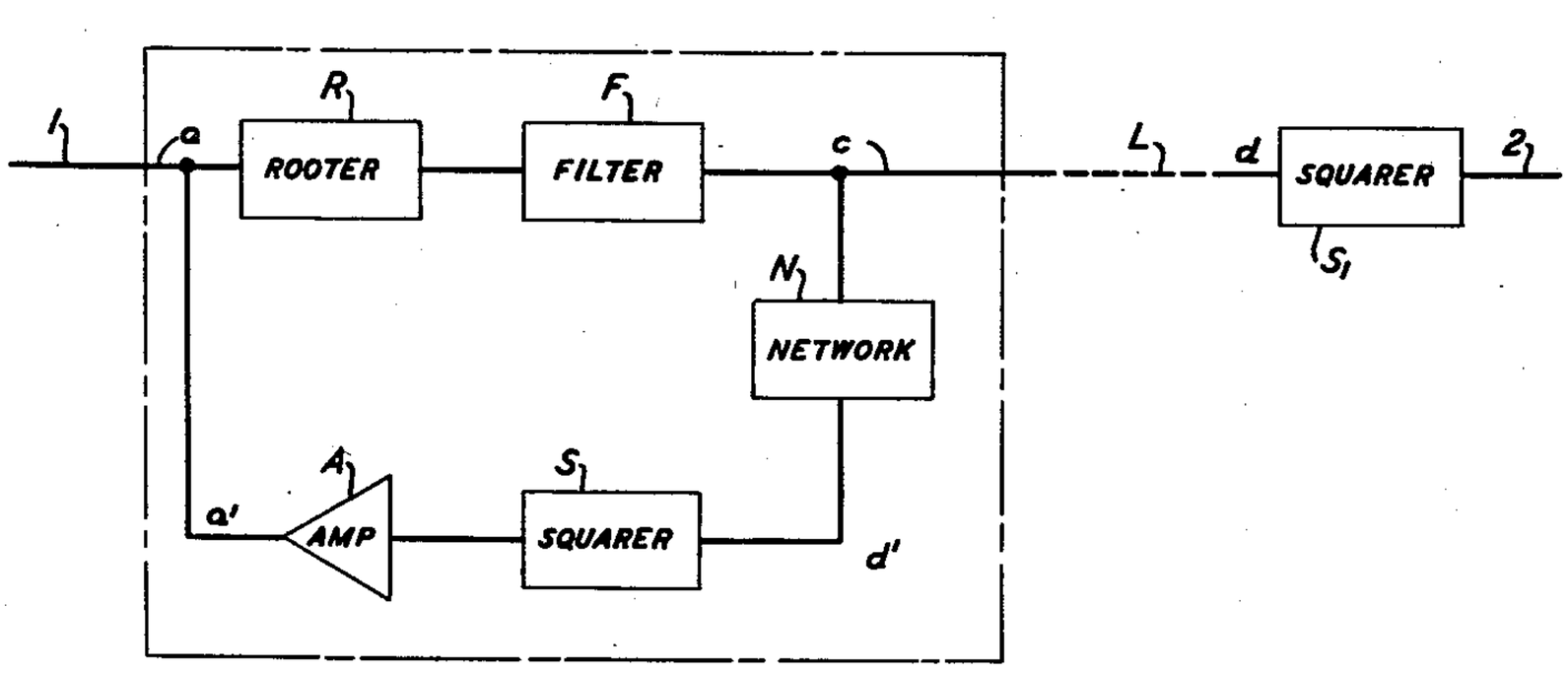
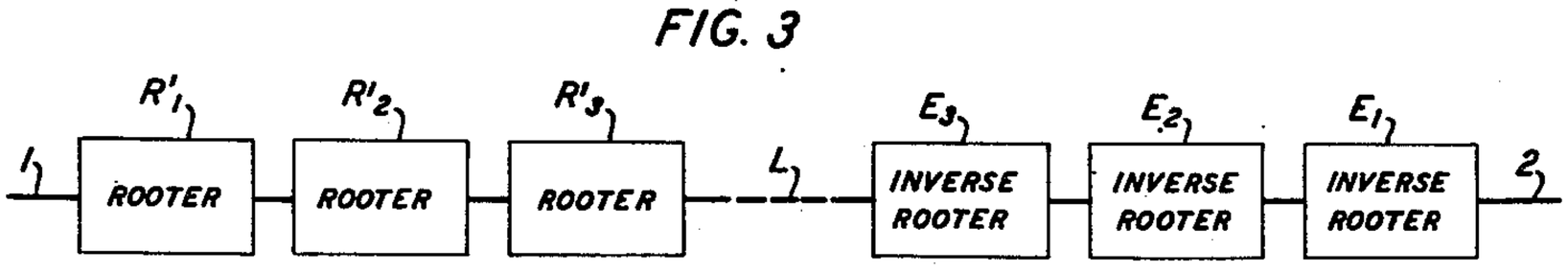


FIG. 3



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WAVE TRANSLATING SYSTEM

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10 Claims. (Cl. 178—44)

This invention relates to wave translating systems and particularly to amplitude range control of signaling waves.

An object of the invention is to reduce signal distortion in a compandor system (amplitude range compressing and expanding system), particularly one in which the compressor at the transmitting end of the system and the expander at the receiving end are of the rooter and squarer or other quick acting or instantaneously acting type and the line or other transmission medium between them has such limited frequency transmission range that it fails to transmit satisfactorily all the harmonics that normally need to be transmitted to make this type of compandor system operate properly and, therefore, tends to produce over-all distortion in signals transmitted through the compandor system.

In one specific aspect the invention is such a rooter-squarer compandor system in which the rooting or compression is obtained by a rooter in the direct amplifier path (mu circuit) with a complementary squarer in the feedback path (beta circuit) of a negative feedback loop at the transmitting end of the system. A low-pass filter, with its cut-off frequency approximating or less than the top frequency of the undistorted signals to be transmitted or the cut-off frequency of the line or other medium between the compressor at that end and the expander at the other end, is included, for example, in the mu circuit of the loop so as to limit the width of the frequency band fed back. By the use of sufficient feedback, the signal wave at the output of the squarer in the loop can be made to simulate closely the signal wave applied to the loop, throughout the pass-band of the filter. Then the limited frequency range of the line need not cause further distortion, since the restricted frequency input to the squarer at the sending end is the input wave required at the squarer at the receiving end of the line to make the output of the letter squarer simulate closely the signal wave applied to the loop. It would be possible to eliminate the rooter in the direct transmission path and to obtain the same characteristic at the output of the combination by means of the squarer in the feedback path alone. However, it would be expected that this would require greater feedback than when the rooter is also provided and would make the problem of maintaining proper phase shifts around the feedback circuit more difficult. This does indicate, however, that it is not essential that the rooter and squarer used in this way be exactly complementary, since the over-all rooting characteristic of the compressor tends to approach the complementary characteristics of the squarer in the feedback path as the feedback is increased.

Thus, the invention reduces the required width of the line frequency band, that is, the frequency band width which the line or medium must transmit for satisfactory results with a rooter-inverse rooter compandor system.

Other objects, aspects and features of the invention will be apparent from the following description and claims:

Fig. 1 shows the specific form of rooter-squarer compandor system referred to above;

Fig. 2 shows a rearrangement of the elements in the feedback path of Fig. 1, to make it more readily apparent that the line L and the network N are in complementary positions within their respective paths relative to the squarer S_1 and the squarer S; and

Fig. 3 shows a modification of the system of Fig. 1.

In Fig. 1, R is a rooter, S is a squarer or an inverse rooter, F is a filter, A is an amplifier and N is a feedback network. Network N may be distortionless. These elements form a rooter R_1 connected between path *a*, fed by signal wave source 1, and the transmitting end of signal transmission line or path L. S_1 is a squarer or an inverse rooter. It is in tandem with the line L and signal receiving circuit 2 at the receiving end of the line, and is a duplicate of S. R and F are in tandem with the line L and source 1 at the transmitting end of the line. S, A and N form a negative feedback circuit or path from the output of F to the input of R, for producing negative feedback around the path or circuit comprised by R and F of waves of frequencies within the pass-band of filter F. This filter may be, for example, a low-pass filter having a cut-off frequency approximately that of the line L. For instance, the pass-band of the filter and of the line may be the frequency range of the signals applied to rooter R_1 from source 1. These signals may be speech currents, for example. R, F, S, A and N form a negative feedback loop connected between paths *a* and L.

The combination of elements R, F, S and A may be considered as an amplifier in which there is some inherent distortion, and circuit N may be regarded as a feedback path for producing a large amount of negative feedback around this amplifier to correct or reduce the distortion at *b*. The amount of distortion reduction feasible depends upon the characteristics of F, i. e., phase shift

versus amplitude change with frequency, and the filter should be given characteristics of attenuation versus frequency and phase shift versus frequency consistent with the amount of feedback desired over its pass-band.

Referring to Fig. 2, with sufficient negative feedback to make the wave shape of the output from A the same as that of the output from I and assuming N has the transmission characteristics of line L in so far as phase shift and attenuation change with frequency are concerned, the wave shape at *c* will be such that the wave shape at *d* will be the same as at *d'* and will, therefore, be that required for application to the input of squarer S_1 to give a distortionless signal at the output of squarer S_1. Line L_1 might be made substantially distortionless throughout its transmission frequency band, as, for example, by connecting suitable attenuation and phase equalizers or correctors in the line in known fashion, thus permitting N to be a distortionless pad. The signal at *c* is restricted in band width and, if this restriction has been made such that the line from *c* to the input of S_1 has no appreciable effect in further restricting the band, the frequency limitation of this line will not cause distortion. In other words, the signal from *c* is a narrow band rooter signal that does not contain all the harmonics and modulation products that ordinarily (without filter F and the feedback) would need to be transmitted (as brought out, for example, in L. G. Abraham Patent 2,287,077, June 23, 1942, or the articles on "Amplitude Range Control" and "Devices for Controlling Amplitude Characteristics of Telephone Signals," Bell System Technical Journal, October 1938) to make the instantaneous compandor operate properly.

There is a limit to the restriction that can be tolerated in F, which is analogous in some respects to the amplitude restriction that can be corrected by feedback in a normal amplifier. As indicated above, with the filter F restricting the band sufficiently to fit a channel of normal width, the frequency limitation of the line will not cause distortion.

The rooter R serves to reduce the amount of negative feedback required to obtain the proper wave shape at *c*. The rooter R and the squarers or inverse rooters S and S_1 may include amplifiers, if desired, and may be of any suitable type as, for example, the type disclosed in Crisson Patent 1,737,830, December 3, 1929.

In Fig. 3, at the transmitting end of the line L, instead of using merely the rooter R_1 as in Fig. 1, rooters R_1', R_2' and R_3', each a unit of the type of R_1, are used in tandem to increase rooting of the device. For example, if one rooter would have an output range which is half the range in decibels of the input range, two sending end devices in tandem might make the output range of the combination ¼ of the input range, three in tandem might make the output range ⅛ of the input range, etc. These tandem connected units may be alike, with the same control ratio and with the same cut-off frequency for their filters F. Any desired number of the tandem connected units may be used, and at the receiving end of the line L an equal number of inverse rooters may be used, as indicated at E_3, E_2 and E_1. For example, E_3 may be an expander with its input-output characteristic the inverse of that of R_3'; E_2 may be an expander with its characteristic the inverse of that of R_2'; and E_1 may be an expander with its characteristic the inverse of that of R_1'.

What is claimed is:

1. A wave translating system comprising a wave transmission path, a second wave transmission path of limited frequency range, a negative feedback loop connected between said paths, a wave source connected to one of said paths for supplying thereto waves for transmission therethrough to said other path via said loop, means in said feedback loop having a wave-distorting transmission characteristic complementary to a distorting characteristic to be imparted thereby to said feedback loop for said transmission between said paths via said loop, said means producing in response to waves of said limited frequency range components of frequencies outside said limited frequency range, and wave transmitting means in said feedback loop in tandem with said first-mentioned means having a limited transmission frequency range corresponding to that of said second path.

2. A signal translating system comprising a signal transmission line having an upper cut-off frequency, a signal wave path coupled to one end of said line, a feedback circuit connected around said path and forming therewith a negative feedback loop, a volume range changer in said circuit originating wave components of frequency above said cut-off frequency, a filter in said loop in tandem with said range changer having an upper cut-off frequency approximating that of said line, and a volume range changer having an input-output characteristic simulating that of said first volume range changer coupled to the other end of said line in tandem with said line and said path.

3. A wave translating system comprising a transmission medium having an upper cut-off frequency, a wave path connected to said medium, a feedback circuit connected around said path for producing negative feedback from its output to its input, an amplitude range changer in said feedback circuit having a given input-output characteristic and introducing in waves transmitted through said path and said range changer components of frequencies above said cut-off frequency, an amplitude range changer in said path having an input-output characteristic approximately complementary to said given characteristic, and a filter having an upper cut-off frequency approximating said upper cut-off frequency of said medium connected in tandem with said range changers in the feedback loop formed by said path and said feedback circuit.

4. A signaling system comprising a signal transmission line having an upper cut-off frequency, a signal wave path coupled to one end of said line, a feedback circuit connected around said path and forming therewith a negative feedback loop, an amplitude range changer in said feedback circuit having a given input-output characteristic and introducing in waves transmitted through said path and said range changer components of frequencies above said cut-off frequency, an amplitude range changer in said path having an input-output characteristic approximately the inverse of said given characteristic, wave transmitting means in said feedback loop in tandem with said range changers having an upper cut-off frequency approximating said upper cut-off frequency of said line, and an amplitude range changer having an input-output characteristic simulating said given characteristic coupled to the other end of said line in tandem with said line and said path.

5. A wave translating system comprising a circuit including a non-linear instantaneous am-

plitude range changing device having a given input-output characteristic, a feedback path for said circuit forming therewith a negative feedback loop, a non-linear instantaneous amplitude range changing device in said feedback path having an input-output characteristic approximately complementary to said given characteristic, a wave transmission medium having an upper cut-off frequency connected to said loop between the output of one of said devices and the input of the other, said devices producing frequencies above said cut-off frequency, and frequency selective means connected in said loop between the output of said one device and the input of said other device, said means having an upper cut-off frequency substantially equal to that of said medium.

6. A system for transmitting signal waves comprising a source of said signal waves, a transmission medium having an upper cut-off frequency approximately equal to the top frequency of said signal waves, a path comprising an instantaneous amplitude range compressor connecting said source to said medium for supplying said signal waves thereto, a feedback circuit forming with said path a negative feedback loop, an instantaneous amplitude range expander in said feedback circuit having its input-output characteristic approximately the inverse of that of said compressor, and a filter in said loop in tandem with said compressor and said expander between the output of said compressor and the input of said expander, said filter having an upper cut-off frequency approximating that of said medium.

7. A wave translating system comprising wave transmitting means, wave receiving means, a wave transmission circuit connecting said transmitting and receiving means, an amplitude range control device having a wave distorting transmission characteristic connected in tandem with said circuit at one of said means, an amplitude range control device having a transmission characteristic approximately complementary to the first-mentioned characteristic, connected in said circuit at the other of said means, a feedback path for producing negative feedback around the second-mentioned range control device, and an amplitude range control device in said feedback path having a transmission characteristic simulating that of said first-mentioned amplitude range control device.

8. A signal wave translating system comprising an amplitude range control device non-linearly responsive to said signal waves in accordance with a given input-output characteristic, a negative feedback path around said device, and an amplitude range control device in said feedback path non-linearly responsive to said signal waves in accordance with an input-output characteristic approximately complementary to said given characteristic.

9. A wave translating system comprising a source of waves representing speech, a wave amplitude range changer responsive to said speech waves to change its transmission efficiency in accordance with a given input-output characteristic, a negative feedback path from the output to the input of said range changer, and a wave amplitude range changer in said feedback path responsive to said speech waves to change its transmission efficiency in accordance with an input-output characteristic approximately complementary to said given characteristic.

10. A wave translating system comprising a plurality of amplitude range changers in tandem, each producing amplitude range change of the same sense, each of said range changers comprising a forwardly transmitting circuit having therein an amplitude range changing device and a feedback path having therein a range changing device whose input-output characteristic is approximately complementary to that of said first-mentioned device, and a filter in each of said paths, said filters having their pass-bands approximately the same.

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