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VOLUME RANGE CONTROL IN SIGNAL TRANSMISSION SYSTEMS

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FIG. 1

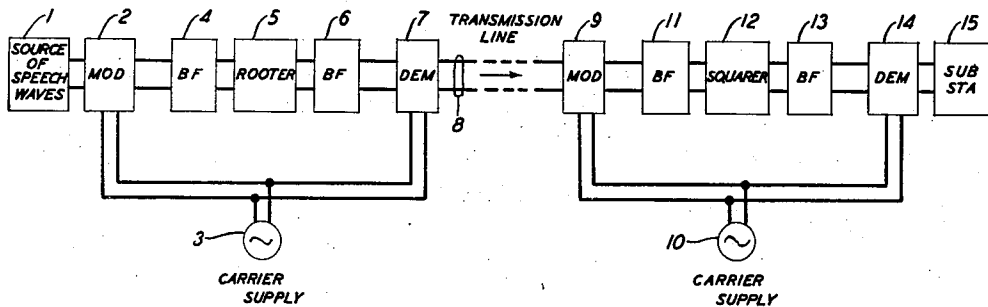
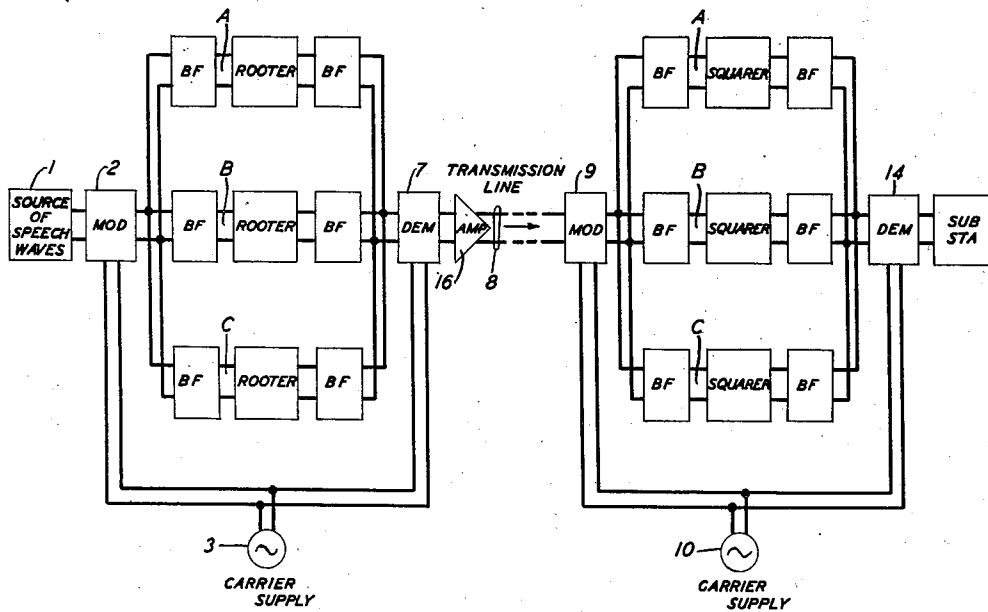


FIG. 2



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VOLUME RANGE CONTROL IN SIGNAL
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9 Claims. (Cl. 179—1)

The invention relates to signal wave transmission systems and particularly to circuits for controlling the volume range of signal transmission over such systems.

In telephone and other signal transmission systems it is often desirable to transmit signals having a considerable range of volumes. The range which can be efficiently transmitted is limited by the characteristics of the line or other medium over which the signals are transmitted and that of the transmission apparatus which must be employed. In order to prevent signal distortion, it is necessary that the minimum transmitted volume level be maintained above that of the noise introduced by the transmission medium and that the maximum transmitted volume be maintained below that which will cause the transmission apparatus to overload.

Rooters and squarers, which may be defined as transmission devices which respectively produce an output current which is proportional to a root or a power of the input current, or other similarly reciprocal non-linear transmission devices have been used at opposite ends of a toll telephone line or other signal transmission medium to increase the effective signal volume range of the line. These operate by changing the shape of the signal wave at the transmitting end so as to bring it within the volume limits of the transmission medium and producing a complementary distortion at the receiving end to restore the original signal wave form. In accomplishing this, the rooter or other distorting device at the transmitting end introduces certain harmonics or other modulation products which are necessary to the proper recreation of the original speech wave by the complementary apparatus at the receiving end. If the intervening medium is limited in frequency band transmitted, or if it produces delay distortion or amplitude distortion, the relations between the different components of the original wave will be disturbed and the extra components introduced by the squarer or other complementary device at the receiving end which should cancel the unwanted components introduced by the rooter, may fail to accomplish this and may even add to the undesired components so that the final received wave is distorted. Tests have shown that the equality of transmission is greatly degraded by a small amount of delay distortion.

An object of the invention is to increase the effective volume range of a signal transmission line or other medium by the use of such devices without the undesirable results referred to above.

This object is accomplished in accordance with the invention by the addition of suitable modulating and filtering apparatus at the transmitting end of the system properly located with respect to the rooter or similar device, whereby harmonics and other modulation products introduced by the rooter device are effectively eliminated before transmitting a rooted wave over the transmission medium, and the use of similar apparatus suitably located with respect to the squarer or similar device at the receiving end of the line for reintroducing the eliminated components and eliminating the distortion components introduced by the squarer, in order to recreate the original signal wave. The various objects and features of the invention will be brought out in the following detailed description when read in conjunction with the accompanying drawing in which:

Figs. 1 and 2 show in block schematic form different modifications of the invention embodied in a signal wave transmission system.

At the transmitting end of the system of Fig. 1, speech or other alternating signal waves are supplied from a suitable source 1, which may be a microphone or a telephone line to a carrier modulator 2 in which they are modulated with a carrier wave of a suitable frequency supplied from the carrier wave source 3, to raise the signal frequency band to a certain higher position in the frequency spectrum. Of the products of modulation one side-band is selected by the band-pass filter 4 and the selected side-band is then passed through a rooter 5 which operates to translate it into a wave each of the instantaneous values of which is proportional to the square (or other) root of the corresponding instantaneous values of the input wave. The output of the rooter 5 is then passed through a second band-pass filter 6 which selects the same frequency band as the filter 4. The band of frequencies selected by the filter 6 is then supplied to the input of a carrier demodulator 7 in which it is modulated with a carrier wave from the carrier wave source 3, as shown, or from another carrier wave source of the same frequency to restore the signal waves to frequencies corresponding to those supplied by the source 1. The signal output of the demodulator 7 is then transmitted over a telephone or other transmission line 8.

At the receiving end of the line 8, the received signal waves are supplied to a modulator 9 in which they are modulated with a carrier wave from the carrier wave source 10, of the same frequency as supplied to the modulator and demod-

ulator at the transmitting end of the line, to raise the signal band to the same higher frequency position as the waves in the output of the modulator 2 at the transmitting end of the line. Of the products of modulation, one side-band is selected by a band-pass filter 11 identical with the filters 4 and 6 employed at the transmitting end of the system, and the selected side-band is passed through a squarer 12 or other non-linear device which will change the wave shape of the supplied wave to the reciprocal of that produced by the rooter or other non-linear device 5 used at the transmitting end of the line. The waves in the output of the squarer 12 are then passed through a band-pass filter 13 which selects a band having the same frequency limits as the side-band selected by the band filter 11 in the input of the squarer device. The selected band is then supplied to the demodulator 14 in which it is modulated with a carrier wave supplied from the source 10 or other carrier wave source of the same frequency, to restore the signal waves to the same frequencies as supplied by the source 1 at the transmitting end of the line, the resulting signal frequency waves then transmitted to the subscriber's station or broadcasting station 15 having little distortion.

The rooter and squarer devices 5 and 12, respectively, used in this system of Fig. 1 may be a volume range compressor and expander, respectively, or any similarly reciprocal combination of non-linear devices. They may be, for example, of the type disclosed in the patent to Crisson, 1,737,830, issued December 3, 1929, and reference may be made to that patent for a more detailed description of the method of operation of these general types of devices.

The carrier supply which is indicated at each end of the system of Fig. 1 as being supplied to the modulator and demodulator in common could, of course, be separate for the two devices, thus permitting the output of the first demodulator 7 to be at a carrier frequency suitable for transmission over a carrier line transmission system. In fact, the demodulator 7 could be eliminated entirely if the carrier frequency supplied to the modulator 2 is selected such that the output frequencies of the second band-pass filter 6 at the transmitting end of the line are suitable for the transmission over the line directly. At the receiving end of the line, the modulator 9 could similarly be eliminated. If such modifications are not made, however, it is an advantage in having the modulator and demodulator at the two ends of the system using the same carrier supply since synchronism between the two carriers is then readily and cheaply obtained.

If the signal band to be transmitted in the system of Fig. 1 is between say 0 and f cycles, and a carrier frequency F is to be used, the band which is rooted will extend from F to $F + f$. The harmonics will be the third, fifth and other odd harmonics of these two frequencies, and all of these and any second harmonics will be eliminated by the band filters readily as long as F is, say, as great as f . In addition, however, there will be modulation products of the $mA-nB$ form. Let f_1 and f_2 be the two frequencies of interest, then the modulation products will be of the frequencies $m(F+f_1) \pm n(F+f_2)$. The plus products of this expression will fall outside the band filter range by considerable margin. If $m=n$ the minus products are $m(f_1-f_2)$ and since (f_1-f_2) is less than f , the output products of

the rooter will be in the band only when $F < mf < F + f$. Since such products decrease rapidly as m increases, it should be sufficient to make the ratio of F/f fairly large, say, ten times.

When $m=n+1$, these products will be $F+n(f_1-f_2)+f_1$. Some of these products will fall inside the band and might be important. However, it may be noted that in every case either n or $n+1$ must be positive. It would be feasible to design a rooter and squarer such that the even products will be negligible and no appreciable amount of these modulation products will fall within the band.

It appears, therefore, that the scheme of Fig. 1 will permit a rooter-squarer which can use the same line frequency band as the unrooted wave with little or no increase in distortion due to the line. It should be noted that changes in net loss of the circuit will still be amplified by such a rooter-squarer, and some effects will be caused by variations in the propagation constant of the line. However, the effect of such variations and particularly of the restricted band width will be very greatly decreased by this action.

The modified arrangement of the invention shown in Fig. 2 differs from that in Fig. 1 in the following particulars. In the transmitting station of Fig. 2 there are three parallel branch circuits A, B and C connected between the output of modulator 2 and the input of demodulator 7 each containing two band filters BF identical for each branch and an intermediate rooter, whereas the transmitting station of Fig. 1 has only one such branch. In the receiving station of Fig. 2, there are three corresponding parallel branch circuits A, B and C connected between the output of the modulator 9 and the input of the demodulator 14, each containing two band filters BF identical for each branch and an intermediate squarer, whereas the receiving station of Fig. 1 has only one such branch.

The individual band filters BF in the inputs of the respective branch circuits A, B and C at the transmitting station of Fig. 2 are narrow band filters passing three differing frequency ranges such as to divide one side-band component of the modulation products in the output of modulator 2 into three different subbands. The individual rooter in each branch extracts the square root of each of the instantaneous amplitudes of the particular subband selected by the preceding band filter BF, and the second band filter BF in the output of the rooter having the same frequency limits as the preceding filter eliminates all components created by the rooter which would fall in the range of the different subbands selected by the corresponding band filters BF in the outputs of the other branches. The rooted subbands selected by the band filters in the outputs of the three branches are combined and transmitted through the demodulator 7 which combines them with the carrier frequency supplied by source 3 to restore them to the same frequency position they had at the input of the modulator 2, and the resulting waves after amplification in the amplifier 16 are transmitted over the line 8 to the receiving station.

At the receiving station the received waves are modulated in the modulator 9 with the carrier wave from the source 10 of the same frequency as supplied to the modulator and demodulator at the transmitting stations, to raise them to the same position in the frequency spectrum as pro-

vided by the modulator 2 at the transmitting station. The individual band filters BF in the inputs of the parallel branch circuits A, B and C at the receiving station, which have the same pass ranges as the corresponding filters in the corresponding branches at the transmitting station, divide one side-band component of the modulation products in the output of modulator 9 into three different subbands, which are respectively supplied to the individual squarer in the respective branches which operates to expand their instantaneous amplitudes in the same ratio as they were compressed by the rooter in the corresponding channel at the transmitting station to restore them to their original amplitudes before being rooted. The band filter BF in the output of the individual squarer in each of the branches A, B and C, having the same pass band as the band filter BF in the input of the squarer in the same branch, operates to eliminate any distortion components introduced in the subband by the preceding squarer, which would fall in that of any of the subbands passed by the corresponding band filters BF in the other branches. The resulting subbands are combined in the input of the demodulator 14 in which they are modulated with the carrier wave from the source 10 to restore the original signal waves without distortion, which are transmitted to the subscriber station 15.

If the number of parallel filter-rooter and filter-squarer branches employed in the system such as illustrated in Fig. 2 is made sufficiently great, there will not be more than one distortion frequency component introduced by a rooter or squarer device appearing in any one subband at a time, so that effectively all distortion will be eliminated. Practically speaking, it is believed that two or three bands (the case illustrated) might be sufficient for this purpose, particularly if the rooting is done at carrier frequencies. One reason for this is that in addition to reducing the number of frequencies which may fall in any one rooter, breaking the band into n parts also reduces the delay distortion which might cause trouble, since only the distortion within one band is effective in preventing proper cancellation of added components. Another reason is that speech currents tend to be either mostly at one frequency or at two or three considerably separated frequencies at any given instant. By proper selection of a few subbands, it should be possible to guarantee that only quite rarely will two frequencies of strong amplitude fall within any one subband simultaneously.

When the bands are separated at the sending end in the system such as shown in Fig. 2, pre-emphasis may be introduced by putting more gain or loss in certain bands and deemphasis by the reverse action at the receiving end.

It should be noted that the process employed in the system of Fig. 2 is not the same thing as the usual rooting and squaring in a single band, and special consideration will need to be given to the amount of added gain which may be used at the receiving end. For example, suppose we have a two-frequency wave

$$A_1 \cos \omega_1 t + A_2 \cos (\omega_2 t + B)$$

If we transmit this normally over the line, a peak current of $(A_1 + A_2)$ will usually be observed. Now with a one-band rooter, the peak would be reduced to $\sqrt{A_1 + A_2}$, so that at the sending end an amplification factor of $g_1 = \sqrt{A_1 + A_2}$ would be allowable for the same peak as before. With a

multiband rooter, however, the peak would be $\sqrt{A_1} + \sqrt{A_2}$ and the allowable amplification factor would be

$$g_2 = \frac{A_1 + A_2}{\sqrt{A_1} + \sqrt{A_2}}$$

In the important limiting case, where $A_1 = A_2$,

$$g_1 = \sqrt{2A_1} \text{ and } g_2 = \sqrt{A_1}$$

which is a noise advantage reduction of three decibels. However, in the method such as illustrated in Fig. 2, the noise at the receiving end is generally not increased in the squarer by as much as in the simple rooter-squarer case of Fig. 1, giving a net over-all signal-to-noise advantage of three decibels or more for the method of Fig. 2. In addition, the improvement will tend to be greater if cross-talk to other channels is the limiting factor rather than the peak over-loading.

Another alternative method of obtaining the noise improvement of rooting and squaring without any added components over the line may be illustrated as follows. Suppose that a speech wave is recorded on a film track, and then the film track analyzed into its basic frequency components. The produced speech current, then, will be equal to

$$A_1 \cos (\omega_1 t) + A_2 \cos (\omega_2 t + B_2) + A_3 \cos (\omega_3 t + B_3) + \dots$$

Let a second curve with the following equation be plotted:

$$\sqrt{A_1} \cos (\omega_1 t) + \sqrt{A_2} \cos (\omega_2 t + B_2) + \sqrt{A_3} \cos (\omega_3 t + B_3) + \dots$$

Let the latter wave be converted into electrical current and amplified by a suitable factor. For example, let us suppose that peak overloading determines the allowable line level. Then the factor will be so chosen as to give the same peak current on the line as before. After transmission over the line, this wave may be broken down into its components again and restored to its original form and magnitude. Any weak noise picked up in the line will be substantially reduced compared to the signal by this process. In addition, since only the original signals are present on the line, and there is no cancellation of additional components by the squarer, delay distortion will not degrade the quality of transmission.

Various modifications of the circuits which have been described above and illustrated in the drawing which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. In a signal wave transmission system including an intermediate wave transmission medium, the method of signaling so as to effectively increase the transmission range of the system, which consists in first modulating a signal wave of a band of signal frequency components to be transmitted with a carrier wave of a given frequency to shift the band to a higher position in the frequency spectrum such that one side-band of the modulation products is within the frequency limits of said medium, compressing the volume range of said side-band in a given ratio to bring it within the volume range limits of said system, selecting from the compressed wave and transmitting over said medium a band of frequencies having the frequency limits of said side-band before compression, and at a receiving

point selecting the transmitted band, producing an expansion of the volume range of the selected band which is complementary to the compression produced at the transmitting end of said medium, selecting from the expanded wave a particular band having the same frequency limits as the selected band before expansion, and modulating said particular band with a second carrier wave of said given frequency to reproduce the original signal wave.

2. In a signal wave transmission system including an intermediate transmission medium, the method of increasing the effective transmission range of said system which consists in first modulating a signal wave comprising a band of signal frequency components to be transmitted with a carrier wave of given frequency to shift the band to a higher position in the frequency spectrum, selecting one side-band from the products of modulation, compressing the volume range of said subband in a given ratio to bring it within the volume range limits of said system, selecting from the compressed wave a band having the same frequency limits as said side-band before compression, modulating the resulting band with a carrier wave of said given frequency to restore each frequency in that band to its original frequency, transmitting the resulting modulation products over said medium and at a receiving point modulating the received waves with a carrier wave of said given frequency to shift the received band of signal frequencies to said higher position in the frequency spectrum, selecting a side-band from the resulting modulation products, producing an expansion in that side-band which is the reciprocal of the compression produced at the transmitting end of the medium, selecting from the expanded wave a band of frequencies having the frequency limits of the side-band before the expansion, and modulating the latter selected band with a carrier wave of said given frequency to reproduce the original signal wave.

3. A signal wave transmission system including stations connected by a signal wave transmission medium, the transmitting station including a non-linear transmission device for altering the ratio of the maximum amplitude to minimum amplitude in the signals before transmitting them to said medium, to bring them within the volume range limits of the system, and means for eliminating most of the distortion components introduced by said non-linear device, the receiving station including a reciprocal non-linear device for restoring the received signals to their original amplitude relations and means for eliminating most of the distortion components introduced by the latter non-linear device.

4. The system of claim 3, in which the means for eliminating the distortion components introduced by the non-linear transmission devices at the transmitting and receiving stations comprises at each station, modulating means for translating the signal wave input to said station to a higher position in the frequency spectrum before transmitting it through the non-linear device, filtering means for selecting from the output of the non-linear device a band of frequencies having the same frequency limits as the wave supplied to the input thereof, and demodulating means for translating the frequencies in the latter selected band to their original frequency values for transmission to said medium in the case of the transmitting station and for

transmission to a signal receiver in the case of the receiving station.

5. A signal wave transmission system comprising stations connected by a wave transmission medium, the transmitting station comprising modulating means for shifting the band of frequency components in the signal wave to be transmitted to a higher position in the frequency spectrum but such that the frequencies of one signal side-band of the modulation products are within the frequency limits of the transmission medium, a compressor for compressing the volume range of said one side-band within the volume range capacity of said medium, filtering means for selecting from the compressed wave and transmitting to said medium a band having the same frequency limits as the side-band in the input of said compressor, the receiving station comprising filtering means for selecting from the received waves the same band of frequencies selected by said filtering means at the transmitting station, and an expander for producing an expansion of the volume range of the selected band which is the reciprocal of that produced by the compressor at the transmitting station, other filtering means for selecting from the expanded wave a band having the same frequency limits as the band supplied to the input of the expander and demodulating means for shifting the signal frequency components in the band selected by said other filtering means to their original position in the frequency spectrum to reproduce the original signal wave.

6. A signal wave transmission system comprising stations connected by a wave transmission medium of limited volume range capacity, the transmitting station comprising modulating means for shifting the band of frequency components in the signal wave to be transmitted to a higher position in the frequency spectrum, filtering means for selecting one side-band from the resulting modulation products, a non-linear transmission device for translating said side-band into a varying electrical wave the amplitude of which from instant to instant is directly proportional to an invariable non-linear function of the corresponding amplitude of said side-band and the range of maximum to minimum amplitude of which is such as to bring it within the volume range limits of said medium, a second filtering means for selecting from the output of said non-linear device a band of frequency components having the frequency limits of said side-band, and demodulating means for shifting the band of frequencies in the selected band to their original positions in the frequency spectrum and supplying the resulting wave to said transmission medium, the receiving station comprising a second modulating means for shifting the frequency of the band of frequency components received over said medium to the same higher frequency position in the frequency spectrum to which the original signal frequency band was shifted by the modulating means at the transmitting station, a third filtering means for selecting one side-band from the resulting modulation products, a second non-linear transmission device for producing in that selected side-band a distortion which is complementary to that produced by the non-linear transmission device at the transmitting station, a fourth filtering means for selecting from the output of said second non-linear device a band having the same frequency limits as that impressed on the input of said second non-linear device and de-

modulating means for shifting the frequency of the latter selected band to restore each frequency to its original frequency value to produce a wave which is a reproduction of the original signal wave at the transmitting station.

7. A system for effectively reducing line and apparatus distortion of voice frequency signals in transmission over a signal transmission comprising at a transmitting station a modulator for shifting the band of voice frequencies in the signal wave to be transmitted to a higher position in the frequency spectrum, a filter for selecting one side-band from the output of said modulator, means for compressing the volume range of said side-band to bring it within the volume range limits of said system, a second filter for selecting from the output of said compressing means a band of frequencies having the same frequency limits as the side-band supplied to its input, a demodulator for shifting the latter selected band to its original voice frequency position in the frequency spectrum, and for then supplying it to said line, and at a receiving station the same modulator-demodulator-filter combination as at the transmitting station and a volume range expander having a characteristic which is the reciprocal of that of the compressing means at the transmitting station, in the same relative position with respect to the latter combination as said compressing means is with respect to the same combination at the transmitting station.

8. In a signal wave transmission system including an intermediate wave transmission medium, the method of signaling so as effectively to increase the transmission frequency range of said medium, which consists in dividing a band of frequency components in a signal wave to be transmitted into a plurality of different subbands, extracting the square root of each of the instantaneous amplitude values of each of subbands, selecting from each of the rooted subbands a different subband of frequencies having the same frequency limits as the corresponding unrooted subband to eliminate all created distortion components which would fall within the frequency limits of any of the other rooted subbands, combining the resulting subbands, trans-

mitting the resulting wave over said medium, and at a receiving point repeating the same process except that in place of the step of extracting the square root of the subbands the reciprocal step of squaring is substituted, so as to reproduce the original signal wave.

9. In a signal wave transmission system including stations connected by a wave transmission medium, the transmitting station comprising modulating means for shifting a band of frequency components in a signal wave to be transmitted to a higher position in the frequency spectrum, filters for separating one side-band of the resulting modulation products into a plurality of different subbands, a different compressor for compressing the volume range of each subband in the same ratio, filters for respectively selecting from the output of each compressor a subband having the same frequency limits as the corresponding subband in the input of the compressor, means for combining the selected compressed subbands into a common circuit and a demodulating means therein for shifting the frequency of the combination waves to restore the frequencies therein to their original values, and for supplying the resulting wave to said medium, the receiving station comprising modulating means for shifting the band of frequencies in the received signal wave to said higher position in the frequency spectrum, filters for dividing one side-band of the resulting modulation products into a plurality of different subbands, a different expander having a characteristic which is the reciprocal of that of the compressors at the transmitting station for respectively expanding the volume range of a different one of the latter subbands in the same ratio, filters for respectively selecting from the output of each of the expanders the subband having the same frequency limits as the corresponding subband in the input thereof, means for combining the selected expanded subbands into a single circuit and demodulating means therein for restoring the frequencies in the combination wave to their original positions in the frequency spectrum to reproduce the original signal wave.

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