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ELECTRICAL COMPRESSION SYSTEM

Filed May 28, 1941 2 Sheets-Sheet 1

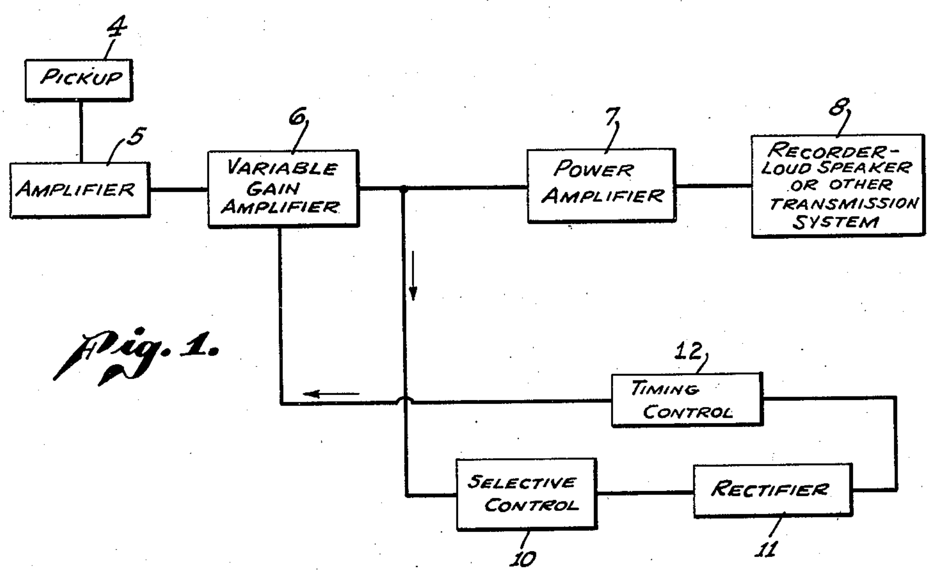
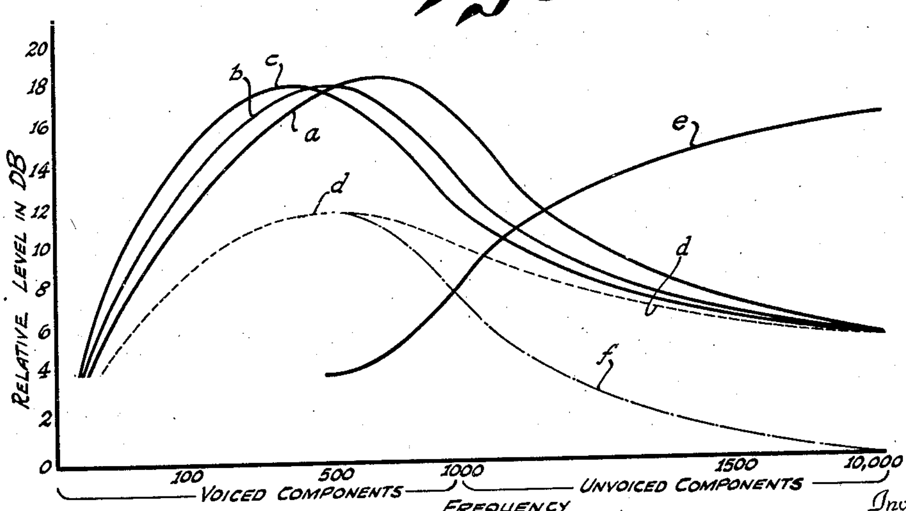


Fig. 1.

Fig. 3.



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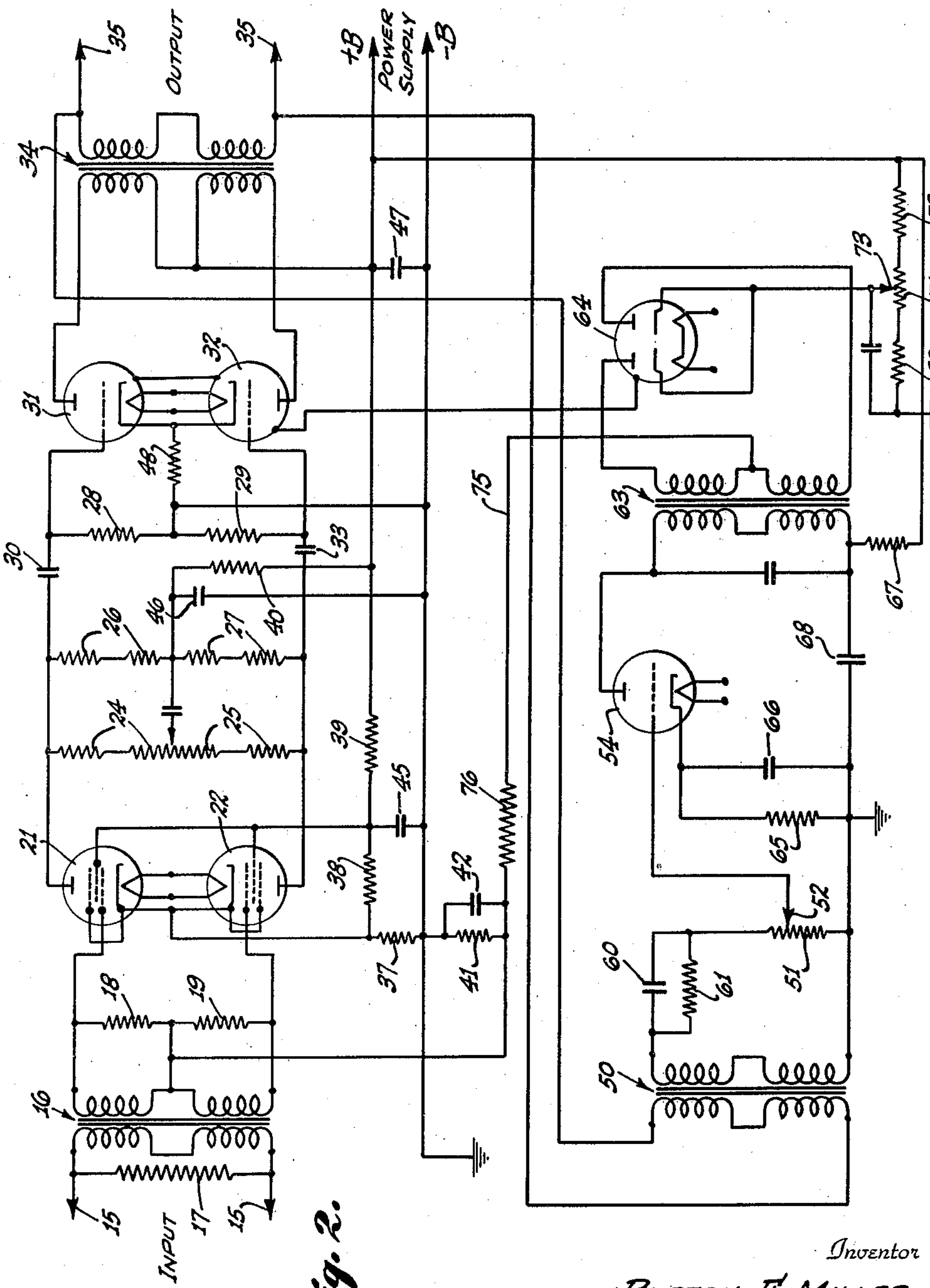

Fig. 2.

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ELECTRICAL COMPRESSION SYSTEM

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13 Claims. (Cl. 178—44)

This invention relates to electrical current transmission systems and particularly to transmission systems wherein the amplitudes of the currents are decreased or increased in amounts dependent upon their original amplitudes, such amplitude variations being commonly known as compression and expansion, respectively.

In the art of signal current transmission, particularly in the audio range of frequencies, it has been found that by reducing the higher amplitudes of certain signals to a greater degree than their lower amplitudes, beneficial results are obtained. This is particularly true where the audio signals are reproduced in auditoriums or theatres by public address or sound motion picture film systems.

It is well known that an original sound signal source may have a level or amplitude range of the order of 40 to 80 db., but it has frequently been found undesirable to reproduce such a volume range in theatres and homes. For instance, in the reproduction of sound in theatres, the minimum level of reproduction is determined by the level of the theatre background noise produced by the audience or by theatre apparatus which may be operating, such as air-conditioning systems, etc. Therefore, the minimum sound reproduction level must be set at a higher value than the theatre noise level or it would otherwise be masked and rendered unintelligible. Thus, a certain minimum level is fixed, and the reproducing system must be set to reproduce this minimum sound level for the lowest level passages recorded, this minimum sound level usually being higher than the lowest level of the original sound.

Therefore, since the lowest level of reproduction is generally righer than the lowest level of the original signal, it is obvious that with a linear relationship existing between reproduced levels and the original levels, the highest level of reproduction will exceed the highest level of the original signal by a corresponding ratio. It has been found that such a maximum signal level is entirely too loud for theatre or auditorium reproduction purposes since it is not only annoying to the listeners, but may even be painful. It is thus desirable to introduce into the original signal channel means of compressing the volume range of the signal being transmitted.

In sound pictures this compression may be introduced either during the recording or the reproduction of the film, while in public address systems, it may be introduced at some point between the microphone and the loudspeaker. It is also applicable to radio broadcast systems.

Thus, the use of compression accomplished by varying the relative amplitudes of the signal in accordance with their original levels has been adopted, particularly in sound recording for motion pictures, the variation in level being accomplished by the use of variable gain amplifiers in the signal transmission circuit. Signal level control is usually obtained by rectifying a portion of the original signal and applying the products of rectification to control the gain of one of the signal amplifiers. Such a compressor system is disclosed and claimed in U. S. Patent No. 2,225,683 of September 9, 1941. The operation of such a compressor system is usually made dependent upon the short-period average value of the signals being transmitted. Thus, the variation in the gain of the amplifier is proportional to the short-period energy content of the signaling currents passing therethrough.

The term "short-period" as herein used, refers to the approximate time interval required for the transmission of any essentially constant amplitude portion of the signal wave train, and may be of the order of one to ten milliseconds or more.

In general, since the spectral energy distribution of complex sounds is non-uniform, the degree of compression obtained at any instant of time is actually dependent upon the amplitude of the predominant frequency or frequencies being transmitted. For example, certain words are formed of a predominant vowel portion and a less prominent sibilant portion, as in the case of the word "same," where the "s" portion of the word is an unvoiced component, while the remainder of the word "ame" is a voiced component. That is, the "s" portion is formed by air passing through the teeth and lips, while the "ame" portion is produced by the vocal cords. It has been found that in the compression of electrical currents corresponding to such a word, the small amount of energy of the unvoiced component is insufficient to decrease the gain of the controlled amplifier to the same degree as the "ame" or voiced portion of the word. Thus, the result is that the "s" becomes predominant upon reproduction in comparison with the remaining portion of the word. The normal type of compression system, therefore, produces a signal whose spectral energy distribution is no longer similar to that of the original sound, and which exhibits a spectral energy distribution characteristic which is a function of the signal level being transmitted. This is true regardless of the order of the voiced and unvoiced components within the word, and constitutes a basic form of signal distortion.

In the past it has frequently been necessary in sound recording practice to manually paint over the sound track portions of the sound record representing the unvoiced components of the signal to reduce their excessive amplitudes with respect to the amplitudes of the voiced components of the signal, in order to obtain faithful reproduction of the original signal. This was a very tedious, time-consuming, and costly operation. The present invention solves this problem by providing essentially uniform compression of all portions of words or phrases regardless of their energy content or spectral energy distribution.

It is well known that the general spectral energy distribution curves for speech and musical sounds indicate that the bulk of the energy of such sounds extends throughout the lower portion of the audio spectrum, while such sounds as the unvoiced components of speech, lying in the upper frequency portion of the audio spectrum, contain relatively small amounts of energy. Therefore, a compressor was devised wherein the variable gain amplifier was selectively controlled with respect to the spectral energy distribution of the signals being compressed.

The principal object of the invention, therefore, is to improve the action of compressors of electrical signals.

Another object of the invention is to so compress audio signals as to substantially retain their original spectral energy distribution.

A further object of the invention is to provide a signal transmission system wherein the signals are increased or decreased in amplitude at a certain uniform variation with respect to their original amplitudes.

A further object of the invention is to vary the gain of an amplifier in such a manner as to retain substantially the same spectral energy distribution in the compressed signal as existed in the original signal.

Although the novel features which are believed to be characteristic of this invention are pointed out with particularity in the appended claims, the manner of its organization and the mode of its operation will be better understood by referring to the following description read in conjunction with the accompanying drawings forming a part thereof, in which

Fig. 1 is a diagrammatic arrangement of an electrical current transmission system embodying the invention;

Fig. 2 is a detailed schematic drawing of the variable gain amplifier and control circuits for the system of Fig. 1; and

Fig. 3 is a graph illustrating the action of the system of Figs. 1 and 2.

Referring now to Fig. 1, a pickup 4, which may be either a microphone, film or disc phonograph or other source of signal current, is connected to an amplifier 5 which feeds a variable gain amplifier 6. The output of the variable gain amplifier 6 is impressed upon a power amplifier 7 and then on either a recorder, loudspeaker, or a transmission system 8. For instance, if the system is a sound recording system, the pickup 4 will be a microphone, while the output of the power amplifier will be impressed on a sound recorder which may be monitored by a loudspeaker. If the invention is embodied in a public address system, the pickup unit 4 may be a microphone and the unit 8, a loudspeaker, while the invention may be embodied in a phonograph reproducing system wherein the pickup 4 may be either a film soundhead or a disc phonograph pickup unit. Also connected to the output of the variable gain amplifier is a selective control device 10 feeding a rectifier 11, the output of the rectifier being connected to the variable gain amplifier 6 through a timing control unit 12. Although the rectifier is shown connected to the output of the variable gain amplifier, it is to be understood that it may also be fed from the input thereto.

Referring now to Fig. 2 in which the circuit details of the variable gain amplifier 6, selective control unit 10, rectifier 11, and timing control unit 12 are illustrated, it will be observed that the general arrangement of the system is similar to that shown in the above-mentioned U. S. Patent No. 2,225,683 of September 9, 1941. The input to the variable gain amplifier is at terminals 15 which are connected to the primary of a push-pull transformer 16, the primaries and secondaries of which are shunted by resistances 17, 18 and 19 to provide suitable terminations. The secondary of transformer 16 is connected to the control grids of variable mu tubes 21 and 22. The plates of tubes 21 and 22 are coupled through a resistance capacity network comprising resistances 24, 25, 26, 27, 28 and 29, and condensers 30 and 33, to the grids of triode amplifier tubes 31 and 32. The plates of amplifier tubes 31 and 32 are connected to the primary of a transformer 34, the secondary of which is shown connected to output terminals 35.

Normal grid bias for the variable mu tubes 21 and 22 is obtained from the voltage drop across a resistance 37 through which flow the plate and screen grid currents of tubes 21 and 22 and the bleeder current of a voltage divider composed of resistances 37, 38 and 39, resistances 37, 38 and 39 providing the correct potential to the screen grids of tubes 21 and 22. Resistance 40 and condenser 46 form a decoupling filter or network to prevent feedback due to a plate voltage supply common to tubes 21, 22, 31 and 32. Condenser 45 and resistance 39 form a decoupling filter or network between the screen grid circuit of tubes 21 and 22 and the other tube circuits. Condenser 47 is a plate power supply by-pass condenser. Grid bias for tubes 31 and 32 is obtained from the voltage drop across a resistance 48 due to plate current flow in these tubes.

The portion of the circuit just described is the variable gain amplifier unit shown at 6 in Fig. 1, the gain of which is varied in a manner now to be described. The voltage generated across the secondary of transformer 34 is impressed on a selective control unit including a transformer 50, the secondary of which is shunted by a potentiometer resistance 51 having a slider 52 for fixing the initial voltage impressed upon the grid of a triode amplifier 54. Also connected in the secondary circuit of transformer 50 is a selecting or energy discriminating network comprising a condenser 60 and a resistance 61, the purpose of which will be explained hereinafter. The output of the amplifier tube 54 is fed through a transformer 63 to the plates of a full-wave rectifier tube 64.

Grid bias for the amplifier 54 is obtained from the voltage drop caused by plate current flow through a resistance 65. Condenser 66 is a bypass condenser for resistance 65, while a resistance 67 and a condenser 68 form a decoupling filter or network for the plate circuit of tube 54. For obtaining an initial positive bias on the cathodes of rectifier 64 with respect to its plates, a voltage divider comprising resistances 70, 71 and 72 is employed, resistance 71 being a potentiometer with an adjustable slider 73 for adjusting the level at which compression is initiated.

The rectified current from the rectifier 64 flows over a conductor 75 through a resistance 76 in series with a resistance 41 shunted by a condenser 42. The voltage drop across resistance 41 controls the negative biasing voltage applied to the control grids of variable mu tubes 21 and 22. In the compressor disclosed in the above-mentioned U. S. patent, this bias voltage varied in accordance with the average voltage changes across the secondary of transformer 34 and thus produced variations in gain or transmission in accordance with the short-period average value of the signal levels, as explained above. Such gain variations of tubes 21 and 22 were thus based on the short-period average energy content of the signals since they were the direct result of a linear rectification of the signal currents by the rectifier 64. However, as mentioned above, since the spectral energy distribution of words and other sounds varies in accordance with the character of the voiced and unvoiced components thereof, it is necessary, in order to make the degree of control of the amplifier independent of the spectral location of these components, to make the products of rectification provide a control voltage whose magnitude varies with the frequency of the predominant components of the signal being transmitted through the variable gain amplifier in a manner corresponding to the inverse characteristic of the average spectral energy distribution curve for words and other sounds.

To explain how this is accomplished, reference is made to Fig. 3 in which there are illustrated spectral energy distribution characteristics of the voiced and unvoiced components of typical signals. The three solid-line curves *a*, *b* and *c* represent three typical signals and show that the voiced components thereof lie in the lower frequency range taken, for purposes of illustration, as from zero to approximately 1000 cycles, while the unvoiced components lie in a range between 1000 cycles and 10,000 or above. In general, therefore, the frequencies of the sibilants lie at the high end of the audio spectrum, while the vowel components lie at the low end.

Now, under the action of prior compressors, the compressed wave form of any one of signals, *a*, *b* or *c* will be as illustrated by the dotted curve *d*. This is caused by the fact that there is insufficient energy in the unvoiced component range to reduce the gain of the variable gain amplifier to the same extent as the gain is reduced by the voiced component range. There is thus introduced a very marked degree of distortion in the recording and reproduction of the signals, the effect being very noticable by the strong emphasis placed upon the "s's" and other forms of sibilants. This gives a whistling character to the sibilants when reproduced.

To enable the compression to be properly proportionate over the entire frequency range, the circuit including elements 60 and 61 is provided, these elements serving to accentuate the amplitude of the high-frequency components of the control signal applied to tube 54 and associated control portions of the circuit to the necessary degree that essentially uniform compression is obtained for both voiced and unvoiced components of the signal. The degree of accentuation produced by elements 60 and 61 is substantially as shown by the curve *e*, this curve being approximately the complement of the average signal curves *a*, *b* and *c* in the unvoiced component range. Thus, instead of compression occurring in accordance with curve *d*, the signals will be compressed in the manner shown by the combination curve *d*—*f*. It is to be understood that under certain conditions of operation, it may be desirable that curve *e* complement the average of curves *a*, *b* and *c* throughout the entire frequency spectrum.

To illustrate a typical characteristic curve *e*, the following data indicates the manner in which the relative grid to cathode signal voltage applied to tube 54 varies with frequency when constant voltage is applied to transformer 50:

Frequency	Relative grid voltage in db.
100	0.0
500	0.0
1000	2.0
2000	6.0
3000	10.0
4000	11.0
5000	13.0
6000	14.0
7000	15.5
8000	17.2

As mentioned above, the variation in the voltage drop across resistance 41 due to the rectified current flowing therein produces the variation in bias on tubes 21 and 22. The resistance 41 is shunted by a condenser 42, which condenser has a double function. It serves as a by-pass condenser for the alternating components of the rectified current which varies the bias and also determines, in conjunction with resistances 41 and 76, the internal resistance of the rectifier, and the impedance of the secondary of the rectifier output transformer, the rapidity with which voltage changes across the resistance 41 can take place. That is, a certain time constant for the control circuit is determined by this combination.

Although it is known that a compressed record may be expanded during reproduction to obtain the original sound volume range, the present application of compression serves to reduce the sound volume range through linear reproduction of the compressed record.

Therefore, the present invention may not be necessary when the signal is to be expanded during reproduction since the reverse spectral energy distribution distortion is obtainable in the expanding reproducer. However, by the use of the invention in compression, the recorded record may be reproduced either in a linear manner with a standard reproducer or with a simple expanding reproducer embodying a complementary selective control network. Thus, the present invention permits the record to be reproduced in either a linear or expanding type of system, whereas without the invention the record could be faithfully reproduced only through a complementary expander. Another feature of the present invention is that it permits a compressed record to be reproduced in a standard linear reproducing system without spectral energy distribution distortion, there being no type of equalization as such which will remove this distortion. Thus such a distorted compressed record must be reproduced by a complementary expander system in order to faithfully convert the signals to their original amplitude relationship.

Although the invention has been shown associated with a variable gain amplifier, it is to be understood that it may also be embodied in any type of variable transmission system using other types of variable transmission elements.

What I claim as my invention is:

1. In an electrical current transmission system in which the amplitudes of the current are automatically varied in accordance with their original relative values, the combination of means for generating an electrical current corresponding to a signal, a variable transmission element for said current, means for varying the relative transmission of said currents through said transmission element, said varying means including a rectifier connected to said element, and means connected in the input to said rectifier for varying the rectifier output energy impressed on said element in accordance with the average spectral energy distribution of said signal to provide an output signal whose spectral energy distribution substantially corresponds to the spectral energy distribution of the input signal.

2. An electrical current transmission system in accordance with claim 1 in which said element is a variable gain amplifier and said last-mentioned means selectively discriminates between the voiced and unvoiced portions of said signal.

3. The method of proportionately varying the amplitude of electrical currents corresponding to a signal having voiced and unvoiced components which normally receive different degrees of amplification, comprising passing the signal through a signal channel including an amplifier, deriving a control signal from the signal channel having an average spectral energy distribution characteristic varying in accordance with the inverse average spectral energy distribution characteristic of the signal, and utilizing said control signal to vary the gain of said amplifier to provide an output signal whose spectral energy distribution characteristic corresponds to the energy distribution characteristic of the input signal.

4. The method of variably transmitting signals in accordance with their amplitudes, said signals having an energy distribution dependent upon the frequency of the components of said signals, comprising passing the signals through a signal channel including an amplifier, deriving control signals from said signal channel directly proportional to the short-period average energy content of said signals, said control signals having respective spectral energy distribution characteristics varying in accordance with the inverse average spectral energy distribution characteristics of the signals being transmitted, and utilizing said control signals to vary the gain of said amplifier to obtain correspondence between the respective spectral energy distribution characteristics of the input and output signals.

5. A system for transmitting signaling currents at compressed amplitudes comprising a transmission line for said currents, a variable gain amplifier in said line, means for rectifying a portion of said signaling currents, means for connecting the input and output of said rectifying means to said variable gain amplifier, and means connected in the input to said rectifying means for obtaining a rectified current from said signaling currents in accordance with the inverse average spectral energy distribution of said signalling currents to provide an output signal whose spectral energy distribution substantially corresponds to the spectral energy distribution of the input signal.

6. A system in accordance with claim 5 in which said last-mentioned menas comprises a frequency discriminating filter.

7. A system in accordance with claim 5 in which means are provided in the output of said rectifying means for controlling the rate of impression of said rectified currents on said variable gain amplifier.

8. An electrical current compressor system for audio signals comprising a variable gain amplifier, a rectifier, means for connecting the input and output circuits of said rectifier to said variable gain amplifier, means connected in the input circuit of said rectifier for varying the relative amplitude of impression of said audio signals on said rectifier, said last-mentioned means varying the ratio of rectified control signal magnitude to average rectifier signal input magnitude in accordance with the inverse average spectral energy distribution characteristic of said signals to provide output signals whose spectral energy distribution characteristics substantially correspond to the spectral energy distribution characteristics of respective input signals.

9. An electrical current compressor system in accordance with claim 8 in which a timing circuit is provided in the output circuit of said rectifier.

10. An electrical current compressor system in accordance with claim 8 in which said last-mentioned means includes a corrective network having a transmission characteristic approximating the inverse average spectral energy distribution characteristic of said signals.

11. An electrical current compressor system for audio signals comprising a source of electrical signals, a variable gain amplifier for variably amplifying said signals, a rectifier for said signals, said rectifier producing a direct current whose amplitude is proportional to the short-period average energy distribution of said signals, means for connecting the output of said rectifier to said variable gain amplifier to vary the gain thereof in inverse proportion to the amplitude of said direct current, and means in the input of said rectifier for varying the impression of said signals on said rectifier in a relationship whereby the output of said rectifier varies with the frequency of the predominant components of said signals being transmitted through said variable gain amplifier in accordance with the inverse characteristic of the average spectral energy distribution curve of said signals to provide an output signal whose spectral energy distribution substantially corresponds to the spectral energy distribution of the input signal.

12. In an electrical signal variable gain amplifier system in which the spectral energy distribution of the output signal does not correspond with the spectral energy distribution of the input signal, the method of producing a correspondence between the input and output spectral energy distributions which consists in passing the signal through a signal channel including a variable gain amplifier, deriving a control signal from the signal being controlled, said control signal having a relative spectral energy distribution characteristic corresponding to the inverse average relative spectral energy distribution characteristic of the input signal, and utilizing said control signal to vary the gain of said variable gain amplifier to provide an output signal whose spectral energy distribution substantially corresponds to the spectral energy distribution of the input signal.

13. The method in accordance with claim 12 in which the control signal varies the control of said variable gain amplifier at a predetermined rate.

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