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COMPENSATING NETWORK

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FIG. 1

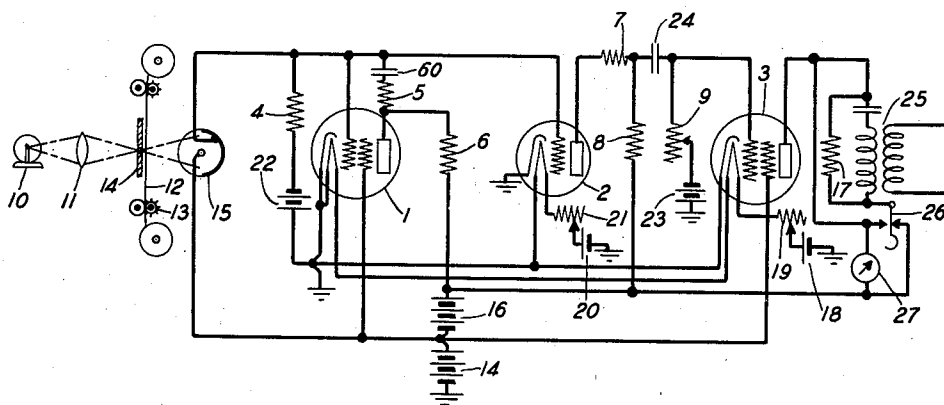
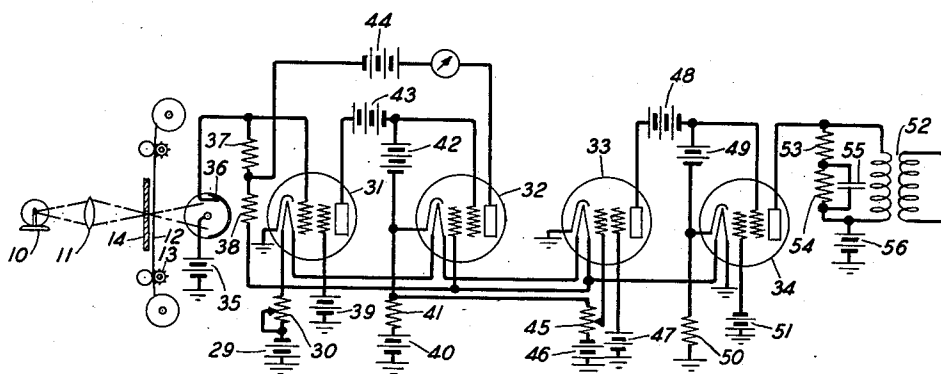


FIG. 2



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COMPENSATING NETWORK

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This invention relates to a method and means for compensating for distortion in signal currents and particularly to the distortion produced on the reproduction of signal currents from a variable density photographic record of substantially constant gamma.

The object of the invention is, by electrical means, to compensate for the distortion in the reproduced signal currents.

A feature of the invention is the insertion of an amplifying network in the transmission channel of the signal currents to modify the reproduced signal currents.

Another feature of the invention is a variable mu tetrode amplifier with feedback to modify the characteristic curve of the amplifier.

Another feature of the invention is a circuit connection cooperating with the tetrode amplifier to produce a logarithmic characteristic.

Another feature of the invention is a second tetrode amplifier cooperating with the other amplifiers to produce an exponential characteristic having a desired exponent.

A further feature of the invention is a means for rapidly and easily measuring by electrical means the gamma of a distorted variable density record of substantially constant gamma.

In the conventional variable density method of recording signal currents, the exposure of the film is restricted to the region of correct exposure, which, by definition, is the region in which the logarithm of the exposure is linearly proportional to the logarithm of the opacity produced after development. The ratio of the logarithm of the opacity to the logarithm of the exposure is known as the gamma, and, in this case, the gamma of the record is substantially constant. On reproducing such a record, the light passing through the film is linearly proportioned to the transmission of the film. As the transmission of the film is, by definition, the reciprocal of the opacity, the logarithm of the reciprocal of the transmission will be linearly proportional to the logarithm of the exposure, that is, the ratio of the logarithm of the transmission to the logarithm of the exposure will be equal to the negative of the gamma, commonly called the negative gamma. Thus, when an original record of this character is reproduced, the reproduced signal currents will be distorted, because the light passing through the film in reproduction is not linearly proportional to the light falling on the film in the original exposure.

Under normal conditions, the original record

is not reproduced, but is photographically printed on to a reproduction print and by proper control of the printing operation, the distortion in the original record is corrected by a counter-distortion due to the photographic characteristics of the print, so that the signal currents reproduced from the reproduction print are substantially undistorted. Under certain conditions, it is advantageous to be able to reproduce the original record, and thus save the time taken to print and develop the reproduction prints. In the production of many feature films, the director wishes to have the sound played back as soon as possible after the original record is made, to decide if the record is satisfactory. Naturally, the signal currents reproduced during the playback must not be distorted or a false opinion of the original record will be formed.

In the present invention, the original record may be played back as soon as it is developed, the distortion in the reproduced signal currents being corrected by the counter-distortion in the reproducing channel due to the special amplifier. While the present invention is particularly fitted to compensate for the distorted signal currents reproduced from an original record, the invention is not limited to this use but is applicable to the correction of similarly distorted signal currents derived from any other source.

In the known method of recording sound, the acoustic waves are transformed into electrical waves and supplied in substantially undistorted form to the recording device, which produces a corresponding variation in the recording beam impressed on the film. The negative record thus produced is developed to a gamma related to the anticipated gamma of the positive, usually having a value of about 0.5. Positive prints are made of this negative and developed to a gamma such that the overall gamma (the product of the gammas of the negative and positive) is substantially unity. Owing to the distortion produced by the photographic processes used, such a negative cannot be reproduced in a regular reproducing channel. The distortion in the negative is compensated by an inverse distortion produced by the development of the positive, so that the positive is substantially undistorted. The present invention may be used, in recording, to produce a materially different result. The undistorted electrical waves are supplied to the corrective network adjusted to produce a known distortion.

tion equivalent to the distortion produced by the negative. The distorted waves are supplied to the recording device and modulate the recording beam. The resulting record is then developed to a gamma which is the reciprocal of the exponent of the distortion introduced by the network, and may be reproduced without distortion in a regular reproducer. Prints may be made of such records, without distortion, if the prints are developed to a gamma of plus unity.

In accordance with the present invention, an original variable density record is scanned in known manner and the reproduced distorted signal currents supplied to a communication channel having a resistor in parallel relation to a variable mu tetrode vacuum tube shunted across the communication channel. The output circuit of the tetrode is arranged to feed back into the input circuit so that the exponential characteristic of the tetrode is modified to a logarithmic characteristic. The signal currents, modified by the communication channel, are supplied to a thermionic amplifier, having a linear voltage amplification characteristic. The output of the amplifier is supplied to a variable resistance in parallel relation to the input circuit of a second variable mu tetrode. By adjustment of this variable resistance the effective voltage amplification of the linear amplifier may be made equal to the reciprocal of the negative gamma of the original record, that is, the positive gamma which would be required to produce an undistorted reproduction print of the original record. The output of the second tetrode will then be the undistorted signal currents.

A direct current meter may be placed in the output circuit of either tetrode. In order to adjust the circuit, let an original record of a sinusoidal signal current be scanned and the distorted signal currents be applied to the corrective network. It is well known that a sinusoidal function integrated over a complete cycle is zero. Thus, the variable resistance in the input of the tetrode may be adjusted until the direct current meter shows a steady deflection. The output of the network is then an undistorted sinusoidal current. The setting of the variable resistance will be a measure of the gamma of the record reproduced and may be calibrated in terms of negative gamma. The invention may thus be used to measure the gamma of a record.

While the invention is of peculiar utility in correcting the distortion due to an original photographic record, the invention is not limited to this use, but is applicable to the correction of any distortion of signal currents which has a definite exponential characteristic. Also, while the variable mu tetrode forms a convenient device having an exponential characteristic, it is apparent to those skilled in the art that other devices may be used, and that the invention is in no way limited to the variable mu tetrode.

In the drawing, Fig. 1 shows in schematic form a simple embodiment of the invention. Fig. 2 shows in schematic form another embodiment of the invention.

In both Figs. 1 and 2 light from a source 10 is focused by an optical system represented by the lens 11 on a photographic film carrying a record. The record on the film 12 is one in which the photographic density is linearly proportional to the logarithm of the original exposure, that is, the gamma of the record is

constant. Records of this character are well-known in the art and the record may, for example, be a negative record of sound accompanying a motion picture. The invention is, however, in no way limited to such a record but is applicable to any photographic record having the characteristic that the density is linearly proportional to the logarithm of the exposure. The film 12 is traversed at constant speed in known manner by the sprocket 13 and the scanned area is defined by an opaque slotted plate 14. The area scanned may be further defined by a slit operated in conjunction with the lens system 11. The elements described above form a known method of scanning a developed photographic record but the present invention is in no way limited to the particular scanning device disclosed which is intended to be merely illustrative of any suitable scanning method.

In Fig. 1 current from the battery 18 flows through the resistor 19 to the heater elements of the thermionic devices 3 and 1 and then through ground back to the battery 18. Current flows from the battery 20 through the resistor 21 thence through the heater of the thermionic device 2 to ground back to the battery 20. A polarizing potential is supplied by the battery 14 to the anode of the photoelectric device 15 and to the screen grid of the thermionic devices 1 and 3. The battery 22 supplies a biasing potential to the control electrode of the thermionic devices 1 and 2. The battery 23 supplies a polarizing potential to the control electrode of the thermionic device 3.

In Fig. 1 the light impressed on the photoelectric cell 15 causes a current, varying in accordance with the transmission of the film 12, to flow from the battery 14 through the cell 15 and the resistor 4 to ground and thence back to the battery 14. The current flowing in the resistor 4 causes a difference of potential to be developed across the resistor which is applied between the cathode and control electrode of the thermionic device 1.

The thermionic device 1 is preferably an active transducer having an exponential relationship between the output current or voltage and the input voltage such as the variable-mu tetrode described in an article "Reduction of distortion and cross-talk in radio receivers by means of variable-mu tetrodes" by S. Ballantine and H. A. Snow, Proceedings of the Institute of Radio Engineers, vol. 18, No. 12 December 1930, page 2102. Such devices are well-known in the art and in the present system may have the form of a variable-mu screen grid tetrode. The varying potential difference across the resistor 4 causes a varying potential difference to be developed across the resistor 6 which is fed back through the resistor 5 and the capacitor 60 to the resistor 4. The voltage fed back through the capacitor 60 opposes the potential difference developed across the resistor 4 and due to the exponential characteristic of the device 1 the voltage fed back is not linearly related to the input voltage. The potential difference developed across the resistor 4 as modified by the potential fed back by the device 1 is applied to the input circuit of the amplifier 2 where it is linearly amplified and produces a potential difference across the resistor 8 which is applied through the capacitor 24 and produces a potential difference across the resistor 9.

As will be explained more fully hereinafter the potential difference developed across the re-

sistor 9 is in the form of the difference of two logarithmic voltages. The potential difference developed across the resistor 9 is applied to the input circuit of the thermionic device 3 which has the same exponential characteristic as the thermionic device 1. The thermionic device 3 exponentially amplifies the logarithmic voltages developed across the resistor 9 and supplies them through the transformer 25 to a utilization circuit.

By operating the key 26 the anode current of the device 3 flows through the meter 27. If the anode current of the device 3 is a pure sinusoid the current integrated over a complete cycle will be constant and the meter 27 will indicate a current without any fluctuation. The resistor 9 may thus be adjusted until the meter 27 gives a constant indication. Under these conditions the output of the device 3 is an undistorted sinusoid. The setting of the variable resistor 9 will then be a measure of the gamma of the record being scanned at the time.

In Fig. 2 current flows from the battery 29 through the variable resistor 30 and thence through the heater elements of the thermionic devices 31, 32, 33, and 34 to ground and thence back to the battery 29. The thermionic devices 31 and 33 are linear amplifiers which may be, as shown, the well-known screen grid amplifiers. The thermionic devices 32 and 34 are active transducers having an exponential characteristic between the input voltage and the output current and may be as shown screen grid variable-mu tetrodes. The thermionic devices 32 and 34 are respectively equivalent to the devices 1 and 3 in Fig. 1. The thermionic device 33 in Fig. 2 is equivalent to the thermionic device 2 in Fig. 1. The difference between Fig. 2 and Fig. 1 resides largely in the preliminary amplifier 31 and in the way the voltage is fed back to the input of the amplifier 31. Current flows from the battery 35 through the photoelectric cell 36 thence through the resistors 37 and 38 and the heater of the thermionic device 34 to ground then back to the battery 35. The modulated light falling upon the photoelectric cell causes a fluctuating difference of potential to be developed across the resistors 37 and 38 varying in accordance with the transmission of the record 12. The battery 39 supplies a polarizing potential to the screen grid of the thermionic device 31. Current flows from the battery 40 through the resistor 41 and the batteries 42 and 43 thence through the thermionic device 31 from the anode to the cathode and then through ground to the battery 40. The varying potential differences supplied to the control electrode of the thermionic device 31 cause the current flowing through the resistor 41 to vary in accordance with the applied voltage and produce an amplified potential difference across the ends of the resistor 41. The cathode of the thermionic device 32 is connected to the upper end of the resistor 41 while the control electrode of the thermionic device 32 is connected through the heater of the device 34 to ground and thence through the battery 40 to the lower end of the resistor 41. The potential differences developed across the resistor 41 are thus applied between the cathode and control electrode of the thermionic device 32. Current can flow from the battery 44 through the anode-cathode circuit of the thermionic device 32 thence through the resistor 41 and battery 40 to ground, thence through the heater element of the thermionic device 34 and the resistor 38 back to the battery

44. The varying potential difference applied between the cathode and anode of the thermionic device 32 will cause the current flowing in the anode circuit to vary. This variation in the current flowing in the anode circuit of the device 32 will cause a potential difference to be developed across the resistor 38. This potential difference opposes the potential difference developed in the resistors 37 and 38 by the current flowing through the photoelectric cell. Due to the exponential characteristic of the thermionic device 32, the potential differences developed across the resistor 38 are not linearly related to the potential differences developed across the resistors 37 and 38 by the photoelectric cell current. Thus, due to the feed-back from the thermionic device 32 the input voltage applied between the control electrode and cathode of the thermionic device 31 is modified and this modified voltage appears in an amplified form across the resistor 41 in the output circuit of the thermionic device 31. The potential difference developed across the resistor 41 is applied across the variable resistor 45. A controllable portion of the potential difference developed across the resistor 45 is applied between the control grid of the thermionic device 33 and ground. As the cathode of the thermionic device 33 is grounded this variable voltage is effectively applied between the control electrode and cathode of the device. The battery 46 applies the usual biasing potential to the control electrode of the thermionic device 33. The battery 47 polarizes the screen grid. Current can flow from the batteries 49 and 48 through the thermionic device 33 to its cathode and thence through ground and through the resistor 50 back to the battery. The variations in this current produce a potential difference between the cathode of the thermionic device 34 and ground. The battery 49 places a polarizing potential upon the screen grid of the thermionic device 34. As the control electrode of the thermionic device 34 is connected through battery 51 to ground the fluctuating potentials produced across the resistor 50 are effectively applied between the control grid and the cathode of the thermionic device 34. The battery 51 places the usual biasing potential upon the control electrode of the thermionic device 34. The output of the thermionic device 34 is applied through the transformer 52 to a utilization circuit. The resistors 53, 54 and the capacitor 55 may be used to correct the high frequency response of the transformer 52. The battery 56 supplies power for the anode circuit of the thermionic device 34. The setting of the variable resistor 45 may be adjusted until the output current of the thermionic device 34 is a pure sinusoid. Under these conditions the distortion due to the characteristic of the film record is completely compensated. The setting of the variable resistor 45 will be a measure of the gamma of the record.

Let

m = the instantaneous modulation applied to the recording light beam

γ = the slope of the characteristic of the film record

i_0 = the steady current flowing in the photoelectric cell

i_1 = the instantaneous current in the photoelectric cell

it may be shown from photographic theory that

$$i_1 = i_0 \cdot m^{-\gamma} \quad (1)$$

In Fig. 1, let

eg_2 = the input voltage applied to device 2

ip_1 = the output current of device 1

R_{p1} = the internal impedance of device 1

then, neglecting the small impedance of the capacitor 50,

$$eg_2 = i_1 R_4 - ip_1 \cdot R_4 \left(\frac{R_5 + R_{p1}}{R_4 + R_5} \right) \quad (2)$$

$$i_1 R_4 - eg_2 = ip_1 \cdot \frac{R_4 (R_5 + R_{p1})}{R_4 + R_5} \quad (3)$$

Due to the potential difference from the feedback current opposing the potential difference due to the photoelectric cell current the resultant potential difference eg_2 will be very small compared to $i_1 R_4$ and may be ignored.

The characteristic of the exponential transducer 1 may be expressed as:

$$ip_1 = 10^{C_1 \cdot eg_1 + K} \quad (4)$$

where C_1 and K are constants.

Also the potential difference applied to the input circuits of the devices 1 and 2 is the same, that is:

$$eg_1 = eg_2$$

Thus from (1), (3), and (4)

$$i_0 m^{-\gamma} R_4 = 10^{C_1 eg_2 + K} \cdot R_1 \frac{(R_2 + R_{p1})}{R_1 + R_3} \quad (5)$$

$$C_1 eg_2 + K = \log \left(i_0 \cdot \frac{R_1 + R_3}{R_2 + R_{p1}} \cdot m^{-\gamma} \right)$$

$$eg_2 = \frac{1}{C_1} \cdot \log \left(i_0 \cdot \frac{R_1 + R_3}{R_2 + R_{p1}} \right) - \frac{\gamma}{C_1} \cdot \log m - \frac{K}{C_1} \quad (5)$$

As the device 2 is a linear amplifier, and the impedance of the capacitor 24 may be made small, the voltage eg_3 applied to the input circuit of the device 3 will be:

$$eg_3 = -eg_2 \cdot \frac{R_0 \cdot R_8}{R_0(R_7 + R_8 + R_{p2}) + R_8(R_5 + R_{p2})} \quad (6)$$

The exponential transducer 3 may have the same characteristic as the transducer 1, thus

$$ip_3 = 10^{C_1 eg_3 + K_1} \quad (7)$$

Let

$$X_1 = \frac{R_1 + R_3}{R_2 + R_{p1}} \quad (8)$$

$$X_2 = \mu_2 \cdot \frac{R_0 \cdot R_8}{R_0(R_7 + R_8 + R_{p2}) + R_8(R_5 + R_{p2})}$$

Then from (5), (6), and (7)

$$ip_3 = 10^{-X_2 \cdot \log(i_0 \cdot X_1) + X_2 \gamma \log m + K(1 + X_2)} \\ (i_0 \cdot X_1)^{-X_2 \cdot m^\gamma \cdot X_2 \cdot 10^{K(1 + X_2)}} \quad (9)$$

Thus for no distortion $\gamma \cdot X_2 = 1$, that is

$$\mu_2 \frac{R_0 \cdot R_8}{R_0(R_7 + R_8 + R_{p2}) + R_8(R_5 + R_{p2})} = \frac{1}{\gamma} \quad (8)$$

This result may evidently be attained by a suitable choice of R_5 , R_7 , R_8 and the adjustment of R_0 . The setting of the variable resistor R_0 will also evidently be a measure of the gamma of the record.

After adjusting R_0

$$ip_3 = \left[\frac{R_0 + R_{p1}}{i_0(R_1 + R_3)} \right]^{\frac{1}{\gamma}} \cdot 10^{K \left(\frac{1}{\gamma} + 1 \right)} \cdot m \quad (9)$$

The first two parts of this expression are a constant current which is modulated by the third part. As the modulation m is to the first power,

the output current is a faithful copy of the original recording current and the distortion due to the record has been compensated.

In Fig. 2, let

eg_1 = input voltage to amplifier 31

ip_2 = output current of tetrode 32

eg_2 = input voltage to tetrode 32

and let the characteristic of the tetrode 32 be:

$$ip_2 = 10^{Ceg_2 + K} \quad (10)$$

$$eg_1 = i_1(R_{37} + R_{38}) - ip_2 \cdot R_{38} \quad (11)$$

$$i_1(R_{37} + R_{38}) - eg_1 = R_{38} \cdot 10^{Ceg_2 + K} \quad (12)$$

$$eg_1 < i_1(R_{37} + R_{38}) \\ i_1 \left(\frac{R_{37} + R_{38}}{R_{38}} \right) = 10^{Ceg_2 + K}$$

From Equation 1:

$$i_0 \cdot \left(\frac{R_{37} + R_{38}}{R_{38}} \right) \cdot m^{-\gamma} = 10^{Ceg_2 + K} \quad (13)$$

$$Ceg_2 + K = \log \left(i_0 \cdot \frac{R_{37} + R_{38}}{R_{38}} \cdot m^{-\gamma} \right) \quad (13)$$

Now the voltage eg_2 is the potential difference developed across the resistor 41 and this is applied across the resistor 45. A portion of this potential difference, depending on the setting of the slider on resistor 45, is applied to the input of the amplifier 33. Thus,

$$eg_3 = X \cdot eg_2$$

Then, from (13)

$$eg_3 = \frac{X}{C} \log \left(i_0 \cdot \frac{R_{37} + R_{38}}{R_{38}} \right) - \frac{X}{C} \cdot \gamma \cdot \log m - \frac{X \cdot K}{C} \quad (15)$$

If this Equation 15 is compared with Equation 5, it will be noted that the two equations are identical in form, the only difference being in certain constants, which may be selected, if desired, to produce identical conditions.

Let

μ_3 = the amplification factor of amplifier 33

R_{p3} = the internal impedance of amplifier 33

eg_4 = the input voltage to tetrode 34.

$$eg_4 = -eg_3 \cdot \mu_3 \cdot \frac{R_{50}}{R_{p3}} \quad (16)$$

Also, let the tetrode 34 have the characteristic

$$ip_4 = 10^{Ceg_4 + K}$$

Let

$$X_3 = \frac{R_{37} + R_{38}}{R_{38}} \quad (17)$$

$$X_4 = \mu_3 \cdot \frac{R_{50}}{R_{p3}} \quad (18)$$

From (15), (16), (17), and (18)

$$ip_4 = 10^{-X \cdot X_4 \log(i_0 \cdot X_3) + X \cdot X_4 \gamma \log m} \\ + K(1 + X \cdot X_4) \\ = (i_0 \cdot X_3)^{-X \cdot X_4 \cdot m^\gamma \cdot X \cdot X_4 \cdot 10^{K(1 + X \cdot X_4)}}$$

For no distortion $\gamma \cdot X \cdot X_4 = 1$, that is

$$X \cdot R_{50} \cdot \frac{\mu_3}{R_{p3}} = \frac{1}{\gamma} \quad (19)$$

This result may be obtained by adjusting the value of X , that is, the setting of the potentiometer 45. The setting of the potentiometer to produce sinusoidal current in the output circuit will then be a measure of the gamma of the record being reproduced and may be calibrated in terms of gamma.

When X is adjusted,

$$i_{P4} = \left[\frac{R_{38}}{i_0(R_{37} + R_{38})} \right]^{\frac{1}{\gamma}} \cdot 10^{K\left(\frac{1}{\gamma} + 1\right)} \cdot m \quad (20)$$

It will be noted that Equation 20 is identical in form with Equation 9, the only difference being in certain constants.

The circuit shown in Fig. 2, while more complicated than the circuit shown in Fig. 1, has certain advantages, as the current from the photoelectric cell is amplified before being applied to the feedback circuit, and the elimination of the capacitors 60 and 24 renders the circuit more easily responsive to steep current waves and transients. In a practical embodiment of the circuit disclosed in Figure 2, the devices 31 and 33 were Western Electric 259—A vacuum tubes, the devices 32 and 34 were Western Electric 283—A vacuum tubes and the transformer 52 was a Western Electric 150—A output transformer. The resistors shown had the following values: 30 was 3 ohms; 37 was 1 megohm; 38 was 1000 ohms; 41 was 45,000 ohms; 45 was 1/2 megohm; 53 was 7,000 ohms; 53 was 20,000 ohms and 54 was 50,000 ohms. The various batteries had the following voltage with respect to ground, 46 minus 34.5; 51 minus 16.5; 29 minus 12; 49 plus 54; 39 and 47 plus 67.5; 42 plus 77; 40, 44, 43 and 56 plus 144 and 43 plus 167. The above values are merely illustrative of one practical embodiment of the invention and do not in any way limit the scope of the invention. From the formulae given in the preceding pages, many other combinations of the circuit elements shown may be formed into an operative network.

The impedance across the input circuit of the amplifier 2 in Fig. 1 has been shown as a resistor 4 and similarly the impedance across the input circuit of the amplifier 31 in Fig. 2 has been shown as two resistors 37 and 38. When resistors are used in these places, the amplification of the complete circuit will be the same for all frequencies. If, in addition to the feature of correcting all the amplitudes for the distortion due to the gamma of the record, a discrimination is desired between different frequencies, then these resistors may be replaced by any suitable frequency discriminative impedances.

What is claimed is:

1. In a communication system for signal waves having a negative exponential distortion, a communication channel containing an active transducer having a linear input-output transconductance characteristic, an impedance connected in parallel relation to the input of said transducer, a second active transducer having an exponential input-output transconductance characteristic in parallel relation with said impedance, a degenerative connection from the output to the input of said second transducer, a variable impedance in the output circuit of said first transducer, and a device actuated by the voltage developed across said variable impedance.

2. A corrective network for signal waves having a negative exponential distortion comprising, in combination, an impedance conducting said waves, an active transducer having a linear input-output transconductance characteristic connected across said impedance, a variable impedance in the output circuit of said transducer, a device actuated by the potential difference developed across said variable impedance, a second active transducer having an exponential input-output transconductance characteristic connected across the input of said first transducer, and a

degenerative connection of said second transducer to effectively modify said exponential characteristic to a logarithmic characteristic.

3. In a communication system for distorted signal waves, a communication channel containing an active transducer having a linear input-output transconductance characteristic, an impedance in parallel relation to the input of said transducer, a second active transducer having an exponential input-output transconductance characteristic in parallel relation with said impedance, a degenerative connection from the output to the input of said second transducer, a variable impedance in the output circuit of said first transducer, a third active transducer having an exponential input-output transconductance characteristic in parallel relation with said variable impedance, and a device actuated by the output of said third transducer.

4. A corrective network for signal waves having a negative exponential distortion comprising, in combination, a resistor conducting said waves, an active transducer having a linear input-output characteristic connected across said resistor, a second active transducer having an exponential input-output characteristic connected across said resistor, a degenerative connection of said second transducer to effectively modify said exponential characteristic to a logarithmic characteristic, a variable resistor in the output of said first transducer, a third active transducer having an exponential input-output characteristic in parallel relation with said variable resistor, and a device actuated by the output of said third transducer.

5. A corrective network for signal waves having a negative exponential distortion comprising, in combination, a resistor conducting said waves, a vacuum tube having a linear transconductance characteristic connected across said resistor, a variable resistance in the output circuit of said vacuum tube, a second vacuum tube having an exponential transconductance characteristic connected across said variable resistor, a device actuated by the output of said second tube, a third vacuum tube having an exponential transconductance characteristic connected across said first resistor, and a degenerative connection of said third tube to effectively modify said exponential characteristic to a logarithmic characteristic.

6. The method of reproducing an original variable density record of substantially constant gamma which comprises producing a signal current varying in accordance with said record, deriving a voltage varying as the difference between the logarithm of a constant current and the logarithm of the modulation in the current, linearly amplifying said voltage, adjusting said amplification to equal the reciprocal of the gamma of the record, exponentially amplifying the adjusted output and reproducing the output of said exponential amplification.

7. The method of reproducing an original variable density record of substantially constant gamma which comprises producing a signal current varying in accordance with said record, producing a voltage varying with said signal current, exponentially amplifying said voltage, degenerating said amplified voltage to produce a voltage varying with the logarithm of the signal currents, linearly amplifying said logarithmic voltage, adjusting the degree of amplification to equal the reciprocal of the gamma of the record, exponentially amplifying the adjusted output and reproducing the output of said exponential amplification.

8. The method of measuring the gamma of an original variable density photographic record of substantially constant gamma which comprises producing a voltage varying in accordance with said record, deriving an amplified voltage varying as the logarithm of said voltage, exponentially amplifying said amplified logarithmic voltage, observing the unidirectional component of said exponentially amplified voltage, adjusting the degree of linear amplification until said unidirectional component is of constant magnitude and deriving the gamma from said degree of linear amplification.

9. The method of reproducing an original variable density record of substantially constant gamma which comprises producing a signal current varying in accordance with said record, deriving a voltage varying as the difference between the logarithm of a constant current and the logarithm of the modulation in the current, linearly amplifying said voltage, exponentially amplifying the output and reproducing the output of said exponential amplification and adjusting the linear amplification of said voltage to equal the reciprocal of the gamma of the record under which condition the output of said exponential amplifier is undistorted.

10. The method of reproducing an original variable density record of substantially constant gamma which comprises producing a signal current varying in accordance with said record, producing a voltage varying with said signal current, exponentially amplifying said voltage with degeneration to produce a voltage varying with the logarithm of the signal current, linearly amplifying the logarithmic voltage, exponentially amplifying the output of the linear amplifying, reproducing the output of the exponential amplification and adjusting the linear amplification of the voltage to equal the reciprocal of the gamma of the record under which condition the output of the exponential amplifier is undistorted.

11. The method of correcting an electrical wave having a negative exponential distortion which comprises deriving a voltage varying as the difference between the logarithm of a constant wave and the logarithm of the modulation in the wave, linearly amplifying said wave, ex-

ponentially amplifying the output of the linear amplification, reproducing the output of the exponential amplification, and adjusting the linear amplification to equal the reciprocal of the exponent of the original distorted wave.

12. The method of correcting a negative exponential distortion of an electrical wave which comprises deriving a voltage varying in accordance with said wave, exponentially amplifying said voltage, degeneratively feeding back a portion of the amplified wave to produce a voltage varying as the difference between the logarithm of a constant wave and the logarithm of the modulation of the original wave, linearly amplifying said logarithmically varying voltage, exponentially amplifying the output of said linear amplification, supplying the output of said second exponential amplification to a receiver and adjusting the degree of linear amplification to equal the reciprocal of the exponent of the distortion of the electrical wave.

13. A corrective network for signal waves having a negative exponential distortion comprising, in combination, means for deriving a voltage varying in accordance with said waves, a variable-mu tetrode controlled by said voltage and having a degenerative feedback connection to produce an output voltage varying as the difference of two logarithmic voltages, means for controllably, linearly amplifying said output voltage, a second variable-mu tetrode controlled by said output voltage, a circuit for utilizing the output of said second tetrode and means for controlling the degree of linear amplification whereby the output of said second tetrode is substantially undistorted.

14. A corrective network for signal waves having a negative exponential distortion comprising, in combination, a resistor conducting said waves, a variable-mu tetrode controlled by the voltage developed across said resistor, a degenerative feedback connection of said tetrode, a linear amplifier controlled by the output of said tetrode, a variable resistor for controlling the effective amplification of said linear amplifier, a second variable-mu tetrode controlled by the output of said linear amplifier, and a device actuated by the output of said second tetrode.

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