AUTOMATIC GAIN CONTROL DEVICE FOR HIGH FIDELITY AUDIO SYSTEMS

Filed Dec. 20, 1962 2 Sheets-Sheet 1

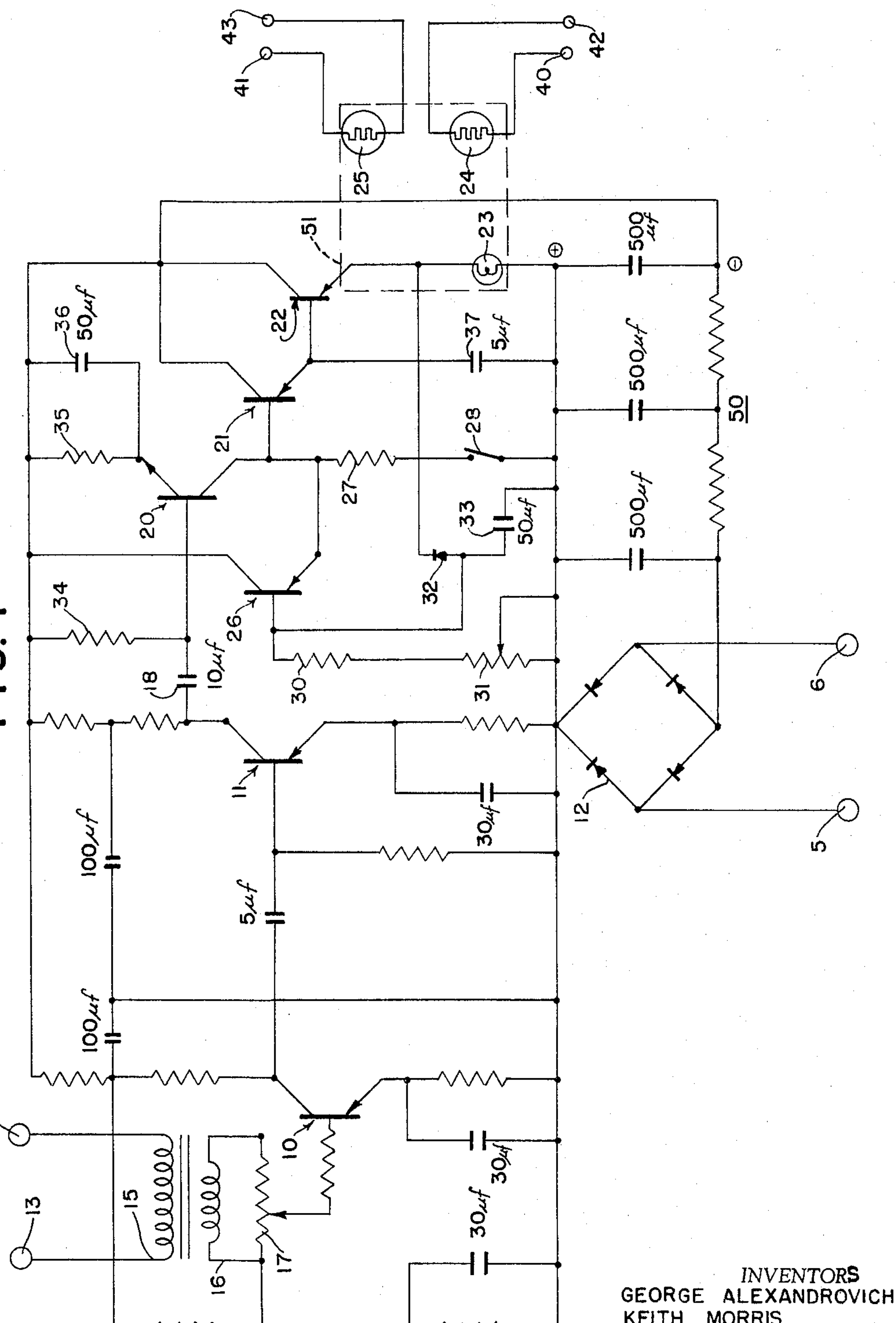

FIG. 1

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FIG. 2

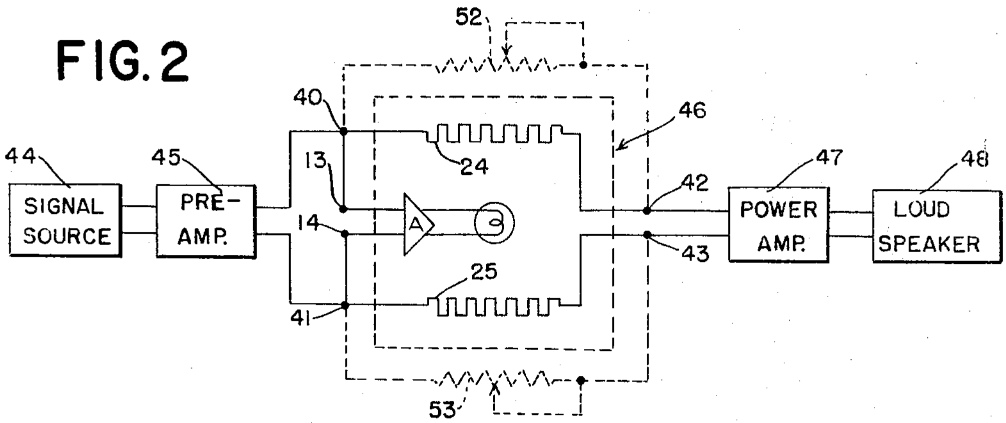


FIG. 3

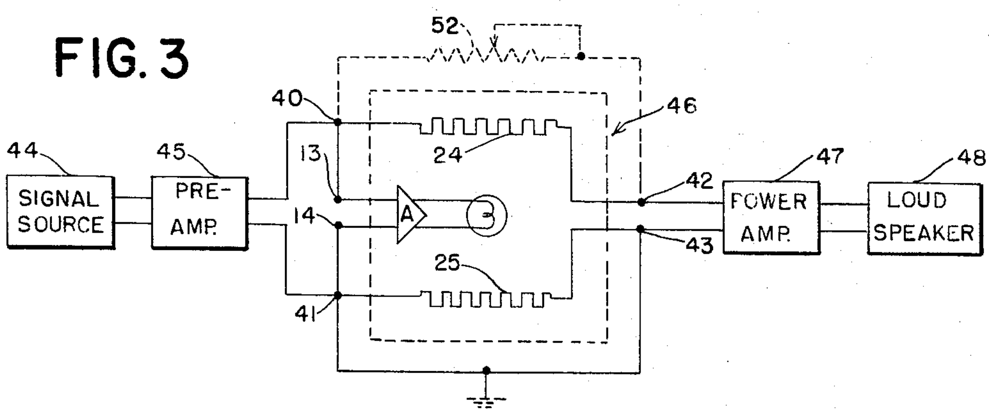
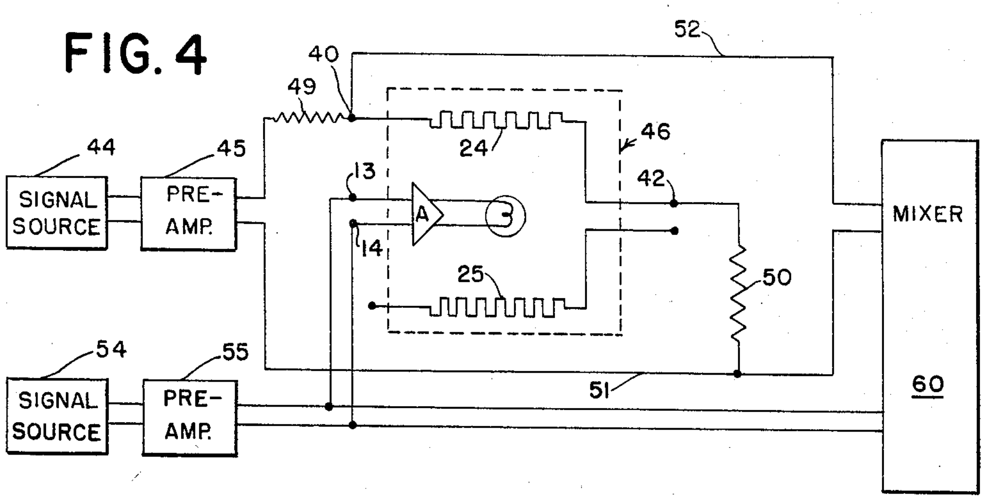


FIG. 4



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AUTOMATIC GAIN CONTROL DEVICE FOR HIGH FIDELITY AUDIO SYSTEMS

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The present invention relates to automatic gain control devices for use with audio signals and particularly to an automatic attenuator for opening or closing an audio channel when the signal level changes.

More particularly still the invention relates to such a device which introduces a desired amount of attenuation (for example, 60 db) in response to decrease of an input signal below a predetermined threshold level, and in which the threshold at which the attenuation is initiated is adjustable and can be set so that all audio signals below this threshold will be greatly attenuated and signals above the threshold will pass without decrease in level. Additionally means is provided for introducing an adjustable "release time," which is, the time interval between the moment the applied signal drops below the threshold value and the instant the attenuation is introduced into the channel. The release time governs the time required for the automatic attenuator to take over after the signal has dropped below the selected threshold. In one particular instance the release time may be adjusted from 0.1 second to 7.0 seconds, although this range may be varied.

At the present time in audio work it is often desirable to eliminate some audio signals from the program such as low-level signals, or to select only signals with higher intensity or level. For example, in an audio system with a number of microphones, it is desirable to automatically close unused microphones, so as to improve signal-to-noise ratios and to reduce the danger of extraneous noise pickup on an unused microphone. One example is in picking up sound signals from an orchestra or a performer plus orchestra, with multiple microphones, where the present invention can automatically cut out a microphone when its particular orchestra section or performer is silent. In the case of a multi-microphone set up, the present invention attains these advantages without requiring continued manual switching among microphones. In the case of stereo systems, improved separation may be obtained by using the present invention to have only performance microphones open, which also minimizes some acoustic phasing problems.

As an example of another of the various uses of the present device, may be mentioned the recording or broadcasting from a studio or hall where the acoustics are such as to cause a considerable amount of reverberation. It may well be desirable to prevent the "echoes" from being effective on microphones not in use at some instants, while at the same time assuring that the same microphones are fully operative to convert the sound signals to effective electrical signals when those sound signals are received directly from a source thereof, usually at higher level.

As another illustration of the use of this invention "print-through" problems can be reduced or eliminated. Print-through of a magnetic recording tape occurs when

one heavily recorded layer of the tape on the spool transfers or imprints its recorded magnetic signal on an adjacent layer. If the latter layer has a very low level for its desired recorded signal or none at all, in playing the tape back the print-through signal will be heard. This annoying condition can be eliminated by this invention. If one selects the threshold value so that all print-through information, which is always at low amplitudes, is below the threshold, then all such unwanted signals will be greatly reduced in intensity to be below the audible level. Without this automatic attenuation these sounds originating in print-through would be played back and would detract from the quality of the recording.

In a similar manner the automatic attenuator is effective to prevent noise in the audio channel resulting during the silent spiral portion of a disc recording, as well as other noise originating during the unrecorded portions of the groove between selections in a long-play record.

As a further example of use of the automatic attenuator, one can be placed in each of the voice and music channels of a broadcasting station in such operations as are commonly called "disc jockey" broadcasts, in which an announcer both operates the record turntable and makes announcements. In this situation the announcer may be assured that low-level noise or sounds will not be broadcast by way of the voice microphone but announcements, being at a higher level, will be broadcast.

Furthermore, the attenuator in the sound pickup channel will permit the operator to merely activate the turntable motor to cause the recorded music to be broadca t since the signal level in the pickup channel will be so attenuated as not to be effective until the pickup stylus has reached a portion of the record which has recorded material thereon in comparison to grooves without program material.

A still further use of the automatic attenuator is as a "ducker" either in broadcasting or public address systems. In this use the automatic attenuator is activated from one channel and controls the attenuation of a second channel, so that when the level of signal input of the first channel increases above threshold the attenuation of the second channel increases whereby the first channel is the controlling channel and the second the controlled channel. By way of example, the first channel may be an announcer who wishes to break into and speak over a recorded musical program. He can do this by the present invention by merely talking into his microphone (first channel) to cut down the program (second channel). Automatic mixing is thereby accomplished and the invention serves as a "third hand" for such a situation.

Although the primary use of the attenuator of the present invention is as a discretionary switch, there are some instances where the device may be utilized as an expander, that is, as a device to increase signal level in a non-linear manner, so that as the signal level of the sound source increases, the level of the output signal increases at a greater rate. Such an expander arrangement is frequently used in high-fidelity sound playback systems to compensate for the compression which has occurred in recording, for example, compression to prevent over-modulation of the sound groove on the disc and a break-through of one groove into another during intervals of recording at high amplitude.

In all the uses heretofore referred to, except the expander usage, it is also desirable to have the release time variable. The desirability of this feature is illustrated when the recording or broadcasting of brass instruments is contrasted with such instruments as the piano. With the brass instruments the sound decreases rapidly from its maximum volume or amplitude to zero, and it is therefore desirable to have the release time short to prevent extraneous sounds from being effective on the microphone. On the contrary, when a piano is considered, the amplitude frequently diminishes slowly and if the release time of the attenuator were to be short the final note of a passage might well be cut off. By providing a variable presettable release time the automatic attenuator of this invention can be effectively utilized in both of these situations, for the variable release time provides discretion as to the amount of time taken for complete attenuation to occur.

The attenuator of our invention is furthermore so designed that there is no feedback from its power amplifier to the attenuation network either directly or indirectly and it is therefore adapted for utilization over a wide range of input impedances and can be used between any two pre-amplifiers and power amplifiers, or more generally, between any two amplifiers. This attenuator is capable of operation with impedances in a wide range of 150 ohms to 47,000 ohms and may be utilized in both balanced and unbalanced lines.

Moreover, the automatic attenuator of our invention utilizes a light-sensitive resistor as the attenuating element and there is therefore no direct coupling of the control signal to the circuitry of the attenuator and no signal distortion results, as is the case with conventional types of attenuators or other automatic devices having similar functions. Additionally, the unit operates without frequency discrimination so long as it is within the impedance values set forth above.

The action of the automatic attenuator of this invention is smooth and continuous as contrasted with the step type of operation of mechanical attenuators. Further, the attenuator of this invention is intended to utilize a power supply to its amplifier at a normal voltage and can thus be utilized with any normal signal channel circuit having a 6.3-volt A.C. supply for the amplifier tubes or the conventional 9 volts D.C. supply for transistor amplifier operation.

It is an object of the invention to provide an automatic attenuator which is capable of handling signals over a wide range of signal level and which, throughout that range, is distortionless and does not discriminate as to frequency.

It is another object of the invention to provide such an automatic attenuator which utilizes a light-sensitive resistor and which operates essentially as a smoothly operating switch.

It is a still further object of the invention to provide such an automatic attenuator having means to preset the threshold signal level, i.e., the level of input signal which when exceeded will be effective to cause the switching operation to occur and the attenuation to be reduced to a value at which the signals will be effective in the following transducer.

It is a still further object of the invention to provide an automatic attenuator in which the release time is adjustable whereby the restoration of the attenuation to its original value is delayed a predetermined desired time after the signal level falls below the threshold thereby making it possible to utilize the attenuator in many different circuits, examples of which have been set forth hereinabove.

Other objects and features of the invention will be apparent when the following description is considered in connection with the annexed drawings, in which,

FIGURE 1 is a schematic diagram of the automatic attenuator of our invention;

FIGURE 2 is a block diagram showing the attenuator as used between the pre-amplifier and power amplifier of a sound channel, the channel in this case being a balanced line. This figure also shows in dotted lines the mode of utilizing external resistors to convert the attenuator to an expander for certain operations;

FIGURE 3 is a block diagram similar to FIGURE 2 but showing the attenuator as used in an unbalanced line; and

FIGURE 4 is a block diagram illustrating the use of the attenuator as a "ducker."

Referring now to the drawings and particularly to FIGURE 1, audio signals from any signal source such as a microphone or pickup pre-amplifier following a microphone or pickup are fed to input terminals **13** and **14** and thereby to the primary of coupling transformer **15**. Signals generated in the secondary **16** of the coupling transformer **15** are supplied by way of an adjustable potentiometer **17** (which thus functions as a threshold control) to a conventional first amplifier stage utilizing a transistor **10** provided with the usual direct voltages by means of conventional bias circuits and the power source represented as a rectifier bridge **12** with a smoothing circuit **51**, the bridge fed from an alternating voltage source connected to terminals **5** and **6**. The output of amplifier stage **10** is supplied to a second conventional stage formed by a transistor **11** and its associated circuitry.

The ouput of transistor **11** is coupled by means of capacitor **18** to the base of an NPN transistor **20**. The transistor **20** is normally biased to cutoff by bias circuit **35**, **36** but when conductive the output from the collector of this transistor **20** is fed to the base of PNP transistor **21**, which transistor is, by means of the voltage divider comprising the leakage resistance of transistor **20** and resistor **27**, normally biased to cutoff when (a) switch **28** is closed, (b) transistor **20** is not conductive and (c) transistor **26** (to be described later) is likewise not conductive.

The emitter of transistor **21** is directly coupled to the base of PNP transistor **22** which is also normally biased to cutoff. The emitter of transistor **22** is connected to one terminal of an incandescent lamp **23**, the other terminal of which is connected to the positive side of the power supply **12** whose negative side is connected to the collectors of transistors **21** and **22**.

Thus, when the signal level at input terminals **13** and **14** or the setting of threshold control **17** is sufficient, it is amplified by transistors **10** and **11**, and the amplified signal overcomes the bias on transistor **20** to cause current to flow in its output resistor **27** (with switch **28** closed). This unblocks transistor **21** which in turn causes transistor **22** to conduct and the lamp **23** is energized. This circuit is a type of latching circuit, which maintains transistor **22** conductive once it has been unblocked, so that lamp **23** remains excited until the circuit is released.

This lamp **23** is placed in a light-proof housing **51** in which the light-sensitive or light-dependent resistors **24** and **25** are also placed. These resistors present maximum (nearly infinite) resistance when in total darkness, the resistance decreasing as the intensity of light falling upon them increases. The light-dependent resistors may, for example, be cadmium sulfide cells.

The operation is such that the lamp is usually maintained dark during periods of below-threshold input; however, where desired, as for faster response or more limited attenuation change, a bias current may be supplied to continuously traverse the lamp so as to keep it at a very faint glow or dull-red. When the input exceeds the threshold, the circuit unblocks to energize the lamp **23**. For a limited input-signal range above the threshold (of the order of 4 or 5 db) the lamp excitation varies in correspondence with the input; for input levels above that limited range, the lamp excitation remains fixed. This action provides a smooth transition from high to low attenuation, rather than an abrupt switching action. This lamp excitation is sufficient to cause resistors **24**, **25** to decrease to a very low level of resistance, of the order of a few ohms to a few hundred ohms, as may be desired.

As will appear hereinafter, when the attenuator is used in a balanced circuit configuration both resistors **24** and **25** are included in the circuit whereas in an unbalanced circuit configuration only one of the resistors is effectively in circuit.

As has been indicated, a holding circuit is provided whereby the lamp **23** may be maintained in energized condition for a predetermined time interval after the input signal falls below the set threshold level and then extinguished.

The holding or release circuit comprises the PNP transistor **26** together with the diode **32**, capacitor **33**, resistor **30** and variable resistor **31**. The circuit cooperates with the voltage divider formed by transistor **20** and resistor **27**, in performing its function of timing the release and extinguishing of the lamp.

When transistor **22** conducts and lamp **23** is energized as heretofore described, capacitor **33** is substantially instantaneously charged through the diode **32**. The voltage at the junction of diode **32** and condenser **33** is applied to the base of the normally cutoff transistor **26** rendering that transistor conductive and causing transistors **21** and **22** to likewise become slightly more conductive and maintaining the voltage of lamp **23** at a slightly higher level.

This condition continues until the input signal level falls below the predetermined threshold value, at which time transistor **20** cuts off and as a result transistor **21** becomes slightly less conductive, the amount being determined by the parameters of the resistor **27** and transistor **20**. As a result the voltage supplied to capacitor **33** falls slightly and the capacitor discharges through resistors **30**, **31** rendering transistor **26** slightly less conductive which in turn, by modifying the current in resistor **27**, causes transistor **21** and, in turn transistor **22**, to become less conductive. This again decreases the voltage applied to the capacitor **33**, which discharges through resistors **30**, **31** and reduces the conduction of transistor **26** and hence of transistor **22**. This process continues until the capacitor **33** is fully discharged at which time the lamp becomes entirely extinguished due to the transistor **26** being rendered substantially non-conductive.

In this way, the lamp is gradually extinguished over the release period, so that the attenuation is gradually increased, avoiding undesirable sharp changes.

Since the capacitor **33** discharges through the fixed resistor **30** and the variable resistor **31**, the time required for it to fully discharge can be predetermined and adjusted by movement of the arm of the adjustable resistor **31**. The time interval for capacitor **33** to discharge depends upon the time constant of the RC circuit **30–31**, **32**, which can be selected to have desired values and can be varied over wide limits by means of adjustment of resistor **31**.

It is desirable also to have a means of causing the lamp **23** to be continuously energized to thereby reduce the attenuation of the resistors **24** and **25** to the maximum extent and thus operate as if the automatic attenuator were not present in the circuit. In the present instance this is accomplished by means of the switch **28** which switch open-circuits the resistor **27** thus causing the base of transistor **21** to be constantly biased to conduction, thus retaining the lamp **23** energized continuously, and effectively disabling the attenuator to cause no attenuation.

In practice the switch **28** is preferably mechanically connected to the arm or slider of the variable resistance **31** so that in introducing attenuation switch **28** is closed, after which the slider is moved along the resistor **31** to vary the release time from minimum to maximum. Preferably, the resistor **31** is tapped and the switch moved by predetermined increments to thereby vary the time in like manner by calibrated steps.

The release circuit operates as described to deenergize the lamp **23** after a time corresponding to the setting of the slider or contactor along the variable resistance **31**, the particular results described being achieved when the various circuit elements have the following representative values:

Transistor **20**	Type 2N35.
Transistor **21**	Type 2N323.
Transistor **22**	Type 2N307.
Transistor **26**	Type 2N323.
Resistor **34**	12,000 ohms.
Resistor **36**	4,700 ohms.
Resistor **27**	10,000 ohms.
Resistor **30**	4,700 ohms.
Resistor **31**	0 to 50,000 ohms.
Capacitor **33**	50 microfarads.
Capacitor **36**	50 microfarads.
Capacitor **37**	5 microfarads.
Diode **32**	Type IN96.

As is indicated in FIGURE 2, the light-sensitive resistors **24** and **25** are provided with terminals **40** and **41** and with terminals **42** and **43**, respectively.

Referring now to FIGURE 2, there is shown a mode of using the automatic attenuator of our invention in a sound channel of balanced configuration. In this figure the signal source is designated **44**, and its output feeds a pre-amplifier **45**, the output of which is connected to the automatic attenuator of FIGURE 1 generally designated **46**.

One side of the line from the pre-amplifier **45** is connected to terminals **13** and **40** while the other side of the line is connected to terminals **14** and **41**. The output terminals **42** and **43** of the attenuator are connected to an amplifier **47** which is in turn connected to a transducer **48** which is in this instance a loudspeaker, although it might of course be a modulator for impressing the output signals upon the carrier wave of a radio or television transmitter. The signal source **44** may be a microphone, a playback head of a tape recorder, a pickup cartridge of a record player or other such device.

As will be clear from the description of the attenuator, the threshold level control **17** thereof is set to a desired value as is the release control **31**.

When the signal at terminals **13**, **14**, is below the level required to excite the lamp **23**, the resistors **24**, **25** have a very large value, reducing the input to power amplifier **47** by a maximum amount, of the order of 60 db, when input signals exceed this threshold value, lamp **23** is fully excited, reducing resistors **24**, **25** to a very low value, and allowing substantially full signal to pass to the power amplifier **47**.

It should be noted that the only elements in the path of the signal are resistors **24**, **25** which are essentially frequency-independent and linear, so that no distortion is introduced in the main channel. Any non-linearity or rectification in the control portion of attenuator **46** is isolated from resistors **24**, **25** and cannot cause signal distortion. This is an important advantage of the present system.

The release time adjustment is effective as has been heretofore pointed out to vary the time after signals fall below the threshold level at which the attenuation will be restored to its original value, to thus care for different types of signals as desired. The settings of the threshold and release time controls are largely empirical and the user of the atteunator will, by experience, utilize such settings as yield the best result. It might be stated at this point that the release time can be varied from 0.1 to 7.0 seconds with the values for the circuit elements illustratively set forth above.

FIGURE 3 is very similar to FIGURE 2 and the elements have therefore been given the same reference characters as in FIGURE 2. The difference between the two figures lies in the fact that in FIGURE 3 an unbalanced circuit configuration is shown and in this configuration the terminals **14** and **43** are directly connected together and to ground, thus shorting out the light-sensitive resistor **25**. The operation of the circuit is, however, substantially identical with that described in connection with FIGURE 2.

FIGURE 4 is a schematic representation of the use of the attenuator of our invention as a "ducker." In this figure two signal sources **44** and **54** are shown, each being connected to its pre-amplifier respectively designated **45** and **55**. Output leads of amplifier **55** are connected to the input terminals **13** and **14** of the attenuator and in addition are connected to a mixer **60** feeding any desired circuit. The output of pre-amplifier **45** is connected through a resistor **49** to terminal **40** of the attenuator **46**. Output terminal **42** of the attenuator **46** is connected through a resistance **50** to the other side of the output of the pre-amplifier **45** by means of the conductor **51** and is also connected to the mixer **60**. There is also a connection by means of conductor **52** from the input terminal **40** of atteunator **46** to the other side of the line entering mixer **60**.

We may now assume for illustrative purposes that the signal source **44** is a phonograph pickup for producing audio signals from a recorded program, and that source **54** is a microphone, intended to be dominant. So long as the microphone output produces an input signal level for the attenuator **46** below its adjusted threshold level, the lamp **23** will be unexcited and resistor **24** will be very large. The voltage divider formed by resistor **49** and by resistors **24, 50** together, will reduce the level in channel **52, 51** very little, and this channel supplies signal to mixer **60** without hindrance. If desired, a second attenuator may be inserted between pre-amplifier **55** and the shown terminals **13, 14** to cut off all signal from source **54** at the mixer **60**.

When the signal from source **54** exceeds the threshold level, the lamp **23** will be excited and will reduce the resistance presented by the light-sensitive resistor **24** to a very low value. Since this resistor **24** is in series with resistors **49, 50**, shunted across the channel between pre-amplifier **45** and mixer **60**, the signal level appearing in the mixer **60** from the source **44** will be reduced (to an extent depending upon the relation between resistor **49, 50**) and thus the volume of the recorded program will be reduced so that voice signals impressed upon the source **54** will predominate in the output of the mixer **60**.

As indicated hereinabove, an arrangement of this type is extremely useful in connection with broadcasting systems. In public address systems it may be desirable to utilize this arrangement also. For example, in a public address system utilized in a factory where music is broadcast throughout the day but it is desirable at times to make announcements, this "ducker" arrangement provides for automatically decreasing the volume of the broadcast music during times of making announcements so that music forms merely a low-level background for the announcement.

The attenuator of this invention may also be utilized as an expander. Illustrations of use in this manner are shown in FIGURES 2 and 3 wherein a dotted resistor **52, 53** is shown in shunt with each of the light-sensitive resistors **24** and **25** or in the case of FIGURE 3 in shunt with the effective light-sensitive resistor **24** only. The shunting resistors are variable resistors and are so adjusting as to provide the degree of expansion required. When below threshold signals are applied to the terminals **13, 14**, light dependent resistors **24, 25** have large resistances (much larger than resistors **52, 53**) and accordingly have little effect on the net resistance in the channel, which net resistance is then determined primarily by the settings of resistors **52, 53** and creates a predetermined attenuation. When the threshold is exceeded, the very low value of resistors **24, 25** shunts resistors **52, 53** to reduce the attenuation to nearly zero. Hence not only has the signal level itself increased, but the attenuation has decreased, producing an expansion for all above threshold signals, but not disturbing the linearity of the channel. As has been indicated, the expander can be utilized in restoring dynamic realism to threatre or public address systems and to the higher fidelity home playback systems. In like manner the expander can be utilized with particular advantage to provide noise reduction in motion picture or tape recording. Whenever the recorded signal falls to a low level, where noise would be particularly troublesome, the system offers greater attenuation, and for higher levels, expansion is provided.

The variable release time (whether with or without expansion) offers further advantages. In combination with the fast attack time which is obtained here, it can modify the acoustics of a hall or studio. It permits maintaining "tight" sound on a microhpone in a "live" hall, particularly for "close-up" microphone, for desirable performance and intelligibility effects.

It will be obvious that many further uses of this system exist or may be found, and that those skilled in the art will readily conceive variations within the general principles illustratively described. While we have described a preferred embodiment of the invention, it will be understood that we wish to be limited not by the foregoing description, but solely by the claims granted to us.

What is claimed is:

1. In a signal magnitude control device adapted for use with a source of signals and a utilization means the combination comprising:

light dependent impedance means whose impedance varies as a function of the light impinging thereon adapted to be connected between said source and said utilization device,

a light source arranged to illuminate said light dependent impedance means,

control means responsive to the amplitude of the signals from the source adapted for connection to said signal source and connected to said light source to control its energization, said control means including means for controlling the energization of said light source from a first condition of illumination to a second condition of higher intensity illumination when the signals from said source exceed a predetermined amplitude,

and release circuit means connected to said control means and to said light source and responsive to the amplitude of the signals from the source to operate said control means to control energization of the light source to decrease its illumination intensity in a predetermined time responsive manner after said signals from said source fall below said predetermined amplitude.

2. A control device as in claim **1** wherein said means for controlling the energization of the light source comprises an amplifier, and means electrically connected to said amplifier to bias it to cut off at a selected amplitude of the signals from the source, which selected amplitude determines said predetermined amplitude above which the illumination intensity of the light source is increased from said first condition of illumination.

3. A control device as in claim **1** wherein said means for controlling the energization of the light source comprises an amplifier, means electrically connected to said amplifier to bias it to cut off and hold the light source in said first condition of illumination until the signals from the source reach said predetermined amplitude, and said release circuit means includes further biasing means electrically connected to said amplifier for changing the bias on said amplifier means in a predetermined manner after the signals from the source fall below said predetermined amplitude to return said amplifier means to the cut off condition.

4. A control device as in claim 3 wherein said further biasing means includes a resistor and capacitor time constant circuit, means electrically connecting said capacitor to said light source to electrically charge said capacitor with a voltage when said light source is in a condition of illumination other than said first condition, the voltage on said capacitor being discharged through said resistor with the signals from the source fall below said predetermined amplitude.

5. The control device of claim 4 wherein said resistor is variable to thereby vary the time constant of the voltage discharge of the capacitor.

6. A signal magnitude control device for use with a circuit utilizing signals from an audio signal source, said control device comprising: light-responsive variable impedance means for electrical connection between the output of the signal source and the input of said circuit for controlling the magnitude of the audio signals applied to said circuit, a light source positioned to illuminate said light responsive means, means electrically connected to said light source and responsive to the audio signals from the signal source for energizing said light source from a first toward a second condition of illumination as the level of said audio signals from said signal source increases from a first toward a second amplitude level, and means electrically connected to said energizing means and responsive to the audio signals from the source below a predetermined amplitude level for controlling the operation of said energizing means to energize said light source toward said first condition of illumination at a predetermined time after the audio signals from the source fall below said predetermined amplitude level.

7. A control device as in claim 6 wherein said predetermined amplitude level at which said controlling means operates is said first amplitude level.

8. A control device as in claim 6 further comprising means electrically connected to said energizing means for selecting the first amplitude level at which said energizing means becomes effective to change the illumination condition of the light source in response to the audio signals.

9. In a signal magnitude control device for use with a circuit utilizing audio signals from an audio signal source the combination comprising: light responsive variable impedance means adapted for connection between the output of the signal source and the input to said circuit, a light source arranged to illuminate said light responsive variable impedance means, amplifier means adapted to be connected to the output of the signal source, means connecting said amplifier means to said light source for supplying electrical energy thereto, control means electrically connected to said amplifier means and responsive to the amplitude of the audio signals from the source to normally hold said amplifier in a condition to apply a predetermined amount of electrical energy to said light source, said control means being responsive to an increase in the audio signals above a predetermined amplitude level to operate said amplifier means to supply an amount of electrical energy greater than said predetermined amount to said light source to increase its light output, and means connected to said control means and responsive to a decrease in the audio signals from an amplitude exceeding said predetermined level to said predetermined level to gradually change the operation of the amplifier means over a period of time to reduce the amount of electrical energy supplied to the light source back to said predetermined amount to reduce the light output of the light source.

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