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GAIN CONTROL MEANS

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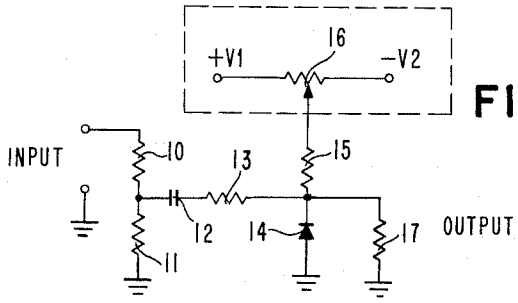
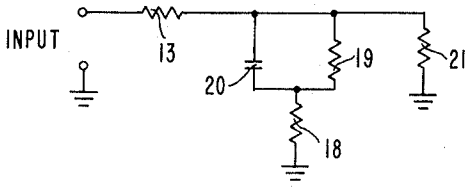


FIG. 1

FIG. 2



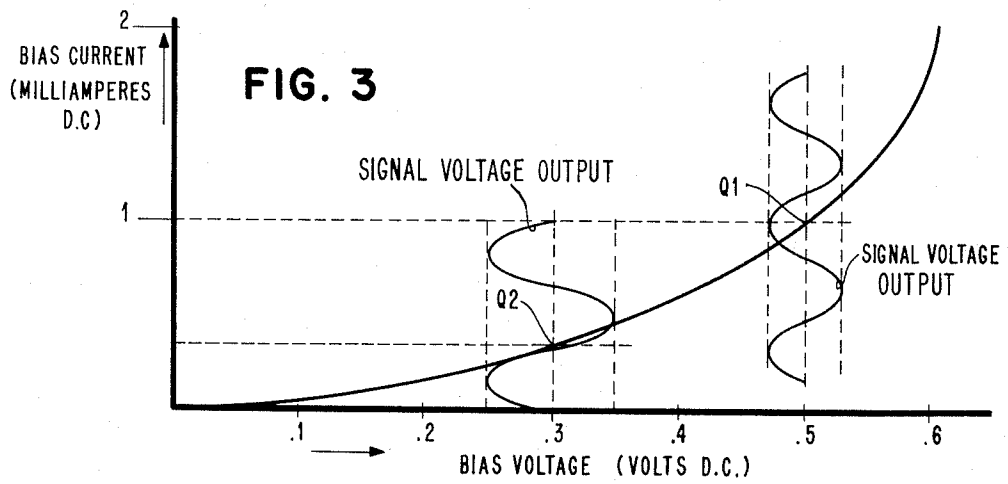


FIG. 3

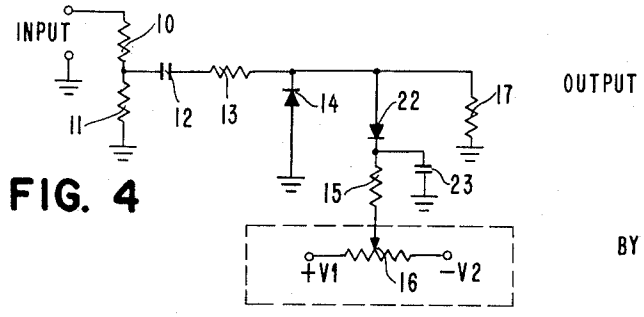


FIG. 4

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GAIN CONTROL MEANS

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The present invention relates generally to gain control of electric signals and in particular to a means for providing such control over signals of the high frequency type from a remote location.

In a number of different types of signal translating equipment there is a necessity for providing some means of selectively controlling the gain of a high frequency signal from a control station physically situated at a distance from the equipment itself. For example, it is conventional in radar systems to provide a cathode ray tube display device and its controls at one place and the rest of the radar apparatus some distance away. With this arrangement, it is frequently necessary to furnish a means at the display device for adjusting or controlling the gain of video-range electric signals originating remotely.

A fully satisfactory system for achieving this kind of regulation would provide a substantially distortion-free output throughout the complete range of control for the full span of signal frequencies to be encountered in the particular use. Heretofore, all such apparatus capable of accomplishing this difficult operation have required the use of extra equipment of a relatively expensive nature.

By way of explanation, if a signal in the video range is sent over transmission lines for even a comparatively short distance to a remote control location and back again, one undesirable influence which must be compensated for is the ground-to-transmission line capacitance. Of course, such compensation demands additional apparatus thereby increasing costs.

In an effort to obviate the difficulties brought about when video signals are transmitted over long lines, another conventional approach is to locate the actual gain control means in proximity to the main high frequency generation and handling equipment and regulate this means from the remote location by a servo system, for example. Obviously, this category of solutions is expensive even though high accuracy is obtainable. Additionally, in many uses this type of answer would be objectionable because of the required added weight.

The above-noted difficulties are further augmented by the fact that the magnitudes of the voltages being dealt with are small. Normally such voltages are in the millivolt range while the corresponding associated currents are to be measured as milliamperes.

It is, therefore, a fundamental object of the invention to provide a means for varying the amplitude of low level high frequency voltages from a remote location.

Another object is to provide such a means having frequency bandpass capabilities from about 200 cycles per second to about 8 megacycles per second.

A further object is the provision of such a means with a total voltage amplitude control ability extending at least to one hundred to one.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a circuit arrangement of one embodiment of the invention;

FIG. 2 is an equivalent circuit representation of the circuit arrangement of FIG. 1;

FIG. 3 is a graphical representation of the current-voltage characteristics of a typical diode; and

FIG. 4 is a circuit schematic of an alternate embodiment of the invention.

Referring now to the drawings and particularly to FIG. 1, the high frequency voltages to be amplitude controlled by the invention are introduced to the novel circuit at the pair of terminals indicated as INPUT. As noted above, although the present circuit, as well as an alternate embodiment described later herein, has been found particularly effective for use with voltage signals in the video range; it is fully applicable for use over a frequency spectrum extending from just a few cycles per second to above 8 megacycles per second.

The input impedance of the circuit is provided by a pair of serially connected resistances **10** and **11** arranged in shunting relation to the INPUT. The primary purpose of these resistances is to match the impedance of the line delivering the signal to the INPUT in a way well known in the electronic art. Accordingly, the relative values of these resistances will vary, for best results, with the average signal frequency to be passed.

It is to be noted that a certain amount of attenuation of the signal amplitude is effected by the resistance **10**; however, this is not of basic importance to the gain control function of the invention.

Connected to the common point of the resistances **10** and **11** is a series circuit comprised, in this order, of a capacitance **12** and a resistance **13**. The capacitance **12** furnishes isolation from D.C. voltages and currents of the preceding stage. The resistance **13** contributes a scaling function, i.e., to aid in proportioning the signal to a suitable magnitude so it can be readily acted upon by the remainder of the novel circuit.

The free end of the resistance **13** is connected to the cathode of a diode **14**, the anode of which is connected to ground. A selectively variable amount of D.C. bias voltage is provided to the common connection of the diode **14** and the resistance **13** through a series resistance **15** from the variable tap of a resistance potentiometer **16**. The extremities of the potentiometer are connected to positive and negative sources of D.C. voltage, denoted respectively, as +V1 and −V2.

As indicated by the broken line enclosure of the potentiometer **16** and the bias voltage sources, +V1 and −V2, these are capable of remote locations. Of course, although this feature is considered an important advantage of the described circuit, no impairment of operation results from placing this portion of the apparatus close to the rest of the circuit.

The output load of the novel circuit is illustrated as a resistance **17** in shunt across the diode **14** and for convenience has also been indicated generally as OUTPUT.

It is the theory of operation of the above-described gain control circuit to present a selectively variable resistance in shunt to the incoming alternating signal in the form of the diode **14**, the resistance of which is changed by varying the magnitude of the D.C. bias current passing through. For a fuller understanding of this, reference should be made to the current voltage characteristics curve illustrated in FIG. 3. This curve is representative of the general requirements necessary for the practice of the invention, namely, a suitable "knee" portion in which effective control is afforded. The necessary properties are to be found in a number of semiconductor diodes, particularly the class of diodes sometimes referred to as "switching" diodes.

Two diodes that have given especially good results for present purposes are the low conductive silicon switch-

ing diodes available under the commercial designations 1N251 and 1N252.

Turning again to the diode characteristic curve, with the potentiometer set to deliver a bias current to the diode of about 1 milliampere, a corresponding voltage point Q1 equal to approximately 0.50 volt is indicated. This point, termed a quiescent point, is the one about which an incoming signal can be considered to alternate as a reference base.

By way of example, with the diode biased to the quiescent point Q1 a given input voltage signal is seen to provide an output signal voltage having a total excursion of approximately 0.06 volt. Reducing the bias current of the diode to about 0.03 milliampere (providing a new quiescent point Q2) is seen to cause the output signal to increase to a peak-to-peak value of about 0.1 volt.

It is seen, therefore, that the variable resistance property of the diode provides an effective means for controlling the gain of an alternating signal. However, it is clear that for optimum results only a portion of the operating range of a diode can be utilized. Thus, for a diode having the current-voltage characteristics curve of FIG. 3, the best operation range would be on that portion of the curve extending from about 0.2 volt to about 0.6 volt. If these limits are exceeded, amplitude distortion occurs in an undesirable degree, as well as a variation in the duty cycle, either of which are to be avoided.

For detailed theoretical aspects of the novel circuit of FIG. 1, reference should now be made to the equivalent circuit schematic of FIG. 2. It is to be noted first that the input matching impedance network consisting of the resistances 10 and 11 are not represented there. This is easily understood since as commented on above, the network has no direct bearing on the main gain control function of the circuit, and, in fact, can change radically depending on the mean frequency of the signal being handled.

The resistance 12 is identical to the resistance of the same number in FIG. 1. The resistances 18 and 19 and the capacitance 20 collectively represent the impedance of the diode where specifically the resistance 18 is the series resistance of the diode, and the resistance 19 and capacitance 20 form the junction impedance of the diode. The resistance 21 is the combined or total load resistance which is presented to the diode.

Applying Laplace transform analysis to the equivalent circuit provides a mathematical expression for the output gain-controlled signal as follows:

$$V \text{ output} = \frac{E}{K}\left[e^{-t/H} + \frac{H}{G}(1-e^{-t/H})\right]$$

Where:

e=Napierian base

E=Peak Value of an Input Step Voltage

$$G = \frac{(R18)\,(R19)\,(C20)}{R18+R19}$$

$$H = \frac{(C20)\,(R19)\left[\frac{(R13)\,(R21)}{R13+R21}+R18\right]}{R19+\left[\frac{(R13)\,(21)}{R13+R21}+R18\right]}$$

It is seen from the above equation that a controlled alternating or pulse-like signal is obtained by summing two exponential terms, one increasing with time while the other decreases with time. Also, the rise time of an incoming signal pulse, i.e., the time required for the pulse to progress from 10% to 90% of its peak value, is dependent upon the values of the diode parameters (R18, R19 and C20). Still further, since the diode parameter values are themselves determined by the quiescent point at which the diode is operated, the output voltage is determined by the amount of bias current flowing through the diode which, in turn, depends upon the setting of the potentiometer 16.

Although it is indicated that no peaking takes place in the above equivalent circuit since H/G is less than 1, some peaking is experimentally observed. This is thought to be the result of a diode exhibiting an apparent increase in resistance when a rapid change in voltage increases the forward current of the diode, which increase is directly attributable to the inherent response time lag of diodes of this general character. Thus, the leading and trailing edges of a given pulse encounter different diode impedances. The condition where the leading edge of a pulse encounters a higher diode resistance than the trailing edge results in the type of peaking sometimes termed overshooting.

It is to minimize this problem of overshooting that the diode has been incorporated into the circuit in the particular way shown, that is, anode to ground and cathode presented to the signal. With this arrangement positive signals tend to shut off the diode. There still exists an undershooting at the trailing edge; however, this is of little significance generally since in most applications signal values below the reference base, i.e., negative here, are not utilized to provide an output indication. For example, in many video display systems only signal information on the positive side of the reference base is used. It is, of course, clear that the present circuit can be easily modified to accommodate negative pulses.

The primary factors affecting the range of gain control are the value of resistance 13, the available diode bias current and the value of the parallel resistance 21. The maximum value that resistance 13 can be given is set by the magnitude of the junction capacitance 20 of the diode, the desired range of frequency response, and somewhat by the stray capacitance of the circuit. Additionally, if a resistance matching network is incorporated into the circuit and signals of relative high frequency are being dealt with, resistance 13 must have a value substantially greater than that of resistance 11, otherwise severe distortion due to mismatch can result.

In cases where the D.C. isolation capacitance 12 is required, its use will act as a limiting factor on the low frequency response of the circuit, since it will present a high impedance to low frequencies while permitting high-frequency signals to pass through readily.

To give further understanding to the circuits just described, illustrative specific values for the circuit parameters will be mentioned. Using either of the semiconductor diodes 1N251 or 1N252 excellent results were obtained with the following circuit parameters:

R10	0.
R11	91 ohms.
C12	7 microfarads.
R13	1000 ohms.
R15	8,200 ohms.
R16	100,000 ohms.
R17	10,000 ohms.
+V1	+9 v. D.C.
−V2	−90 v. D.C.

With a circuit configuration as in FIG. 1 composed of the above elements and having a pulse-like input, a gain range exceeding 100 to 1 was obtained over the complete frequency range of about 200 cycles per second to 8 megacycles and an output was obtained which was substantially free of distortion.

An alternate embodiment of the invention which offers improved results, particularly in the area of amplitude linearity, is that illustrated by the circuit schematic of FIG. 4. The major distinction of this circuit from that of FIG. 1 is the insertion electrically of a second diode 22 in series relation between the first diode 14 and the bias potentiometer. For best results the second diode should have characteristics closely approximating those of the diode 14, otherwise the difference in the diodes will be reflected as differing gain factors for the positive and for the negative swings of a signal.

It is to be noted that the input resistance matching network, the D.C. isolating capacitance, the scaling resistance, the load resistance and the potentiometer and bias voltage supplies are identical to those of FIG. 1, and are so designated.

The principle of operation of this embodiment is basically the same as that of the first-described embodiment; however, there are certain important differences and advantages brought about by the addition of the second diode.

First of all, with the diodes connected in series the same bias current flows through each and since they have substantially the same characteristics, both diodes operate at the same point on their characteristics curves, or in other words, the diodes have the same quiescent impedance.

With respect to the alternating signal the two diodes are in parallel, but in opposite directions. Thus, as the signal voltage swings about a particular quiescent point, the impedance of one diode is increasing while the impedance of the other diode is simultaneously decreasing. This parallel linkage is provided by a capacitance **23** connected from the common point of the diode **22** and the resistance **15** to ground.

In the discussion of peaking as applied to the first-described embodiment, it was pointed out in that case that the leading and trailing edge of a pulse or half cycle encounters different impedances. However, in this circuit where the two diodes are arranged in parallel to the signal and each oppositely directed relative to the other, both the leading and trailing edges of a signal pulse are presented with substantially the same valued low impedance paths. From before it is seen that this serves to eliminate peaking and its undesirable effects.

It is important to note that the low frequency response of this circuit is primarily determined by the combined effect of the time constant of the capacitance **23** and the series impedance of the two diodes. It naturally follows that if a relatively small valued capacitance **23** is used and the circuit is operated at low gain settings of the control potentiometer, low frequencies will experience a greater gain relative to higher frequencies than would be the case at higher gain settings. For that reason and since the range of resistance variability of the diodes is fixed at the time of manufacture, a relatively large valued capacitance is used for the capacitance **23** so that a commensurately large time constant is obtained and the large frequency difficulty is overcome. With the other circuit parameters, bias voltage sources and diodes being identical to those given for the circuit of FIG. 1, a capacitance **23** of 20 microfarads gave fully satisfactory results.

With the exception of the specific differences and added features set forth above, those comments made in regard to the theoretical operation and advantages of the first-described embodiment are fully applicable to the alternate embodiment also.

Despite the fact that in the description of two embodiments of the invention the basic control element is exemplified as a semiconductor diode, it is considered within the contemplation of the invention that other non-linear resistance devices might be utilized in suitably modified circuits of the general type disclosed herein. Thus, for example, in special cases where the signals being handled are on the average of greater magnitude than those under particular examination here, vacuum tube diodes would be a fully satisfactory substitution for the semiconductor diodes.

Additionally, although the invention has been described in its specific aspects as relating to the control of video signals, it is not intended to confine its scope to this use alone. For example, the circuits described herein can easily be adapted for use in the fields of audio gain control, automatic-gain-control (AGC) or signal multiplication, to name but a few.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A voltage signal gain control circuit for use with low level alternating signals in the range of 200 cycles per second to 8 megacycles, comprising: an input consisting of a signal terminal and a common terminal adapted to receive said alternating signals; a scaling resistance connected to said signal terminal; first semiconducting diode means connected to the free end of said scaling resistance and said common terminal; second semiconducting diode means having one lead connected to said first diode means such that the forward direction of each diode means is opposed to the other; capacitance linking means connected from the free end of said second diode means to said common terminal; remotely located selectively variable current supply means adapted to provide bias current to said diode means for biasing said first diode means to operation in the knee region of its current-voltage characteristic curve; and output means for providing the controlled signal voltage as measured across said first diode means.

2. A signal voltage amplitude regulating device having an input and an output, each including separate signal terminals and a common terminal which serves as a voltage reference base, comprising: an impedance matching network shunted across the input; a series capacitance-resistance circuit connected to said network; a first low conductance silicon switching diode connected serially between the common terminal and said series circuit; a second low conductance silicon switching diode connected to the first diode and in opposition therewith; a parallel linking capacitance interconnecting the second diode and the common terminal; a remotely located selectively variable source of D.C. bias current; and a limiting resistance serially connecting said source to said second diode whereby said first diode is biased to operation within the knee region of its current-voltage characteristic curve with selective values of bias voltage presenting correspondingly controlled amounts of impedance to the incoming signal voltage.

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