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ANALOG MULTIPLIER USING RADIATION RESPONSIVE IMPEDANCE
MEANS IN ITS FEEDBACK ARRANGEMENT

Filed June 15, 1962

2 Sheets-Sheet 1

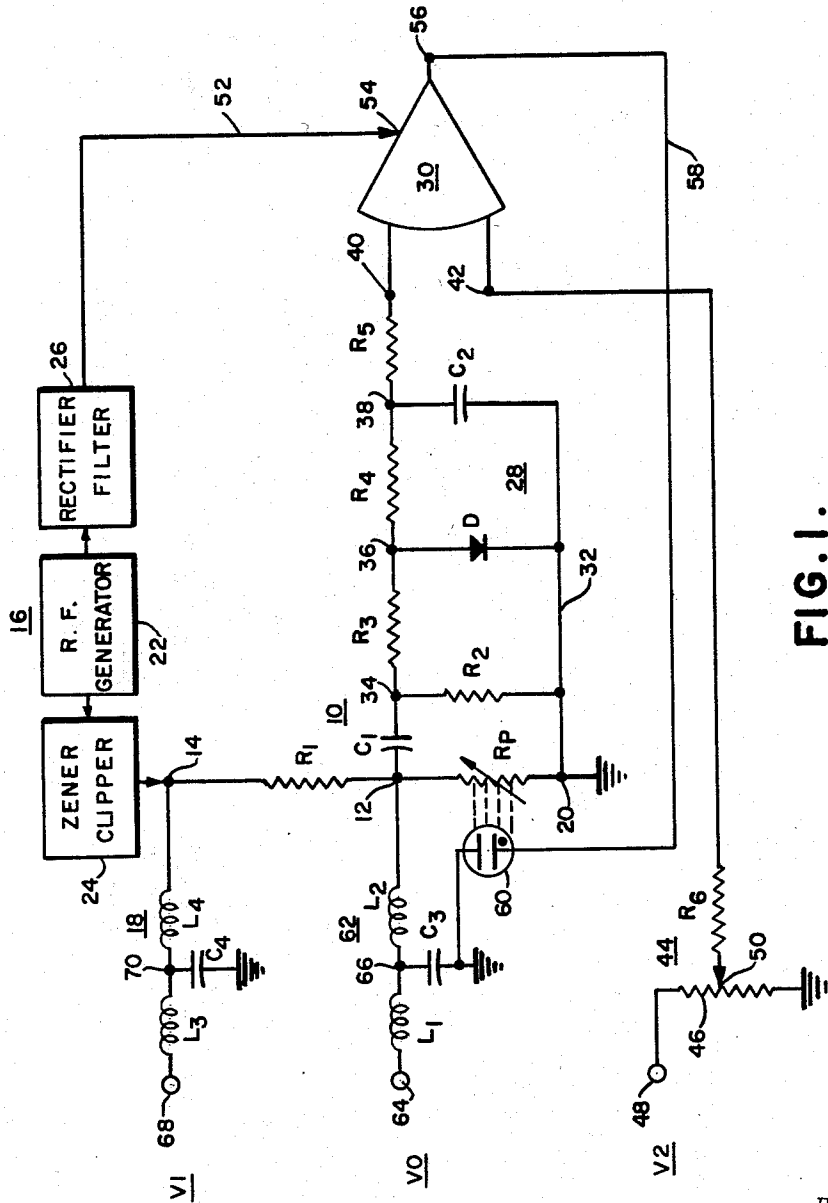


FIG. 1.

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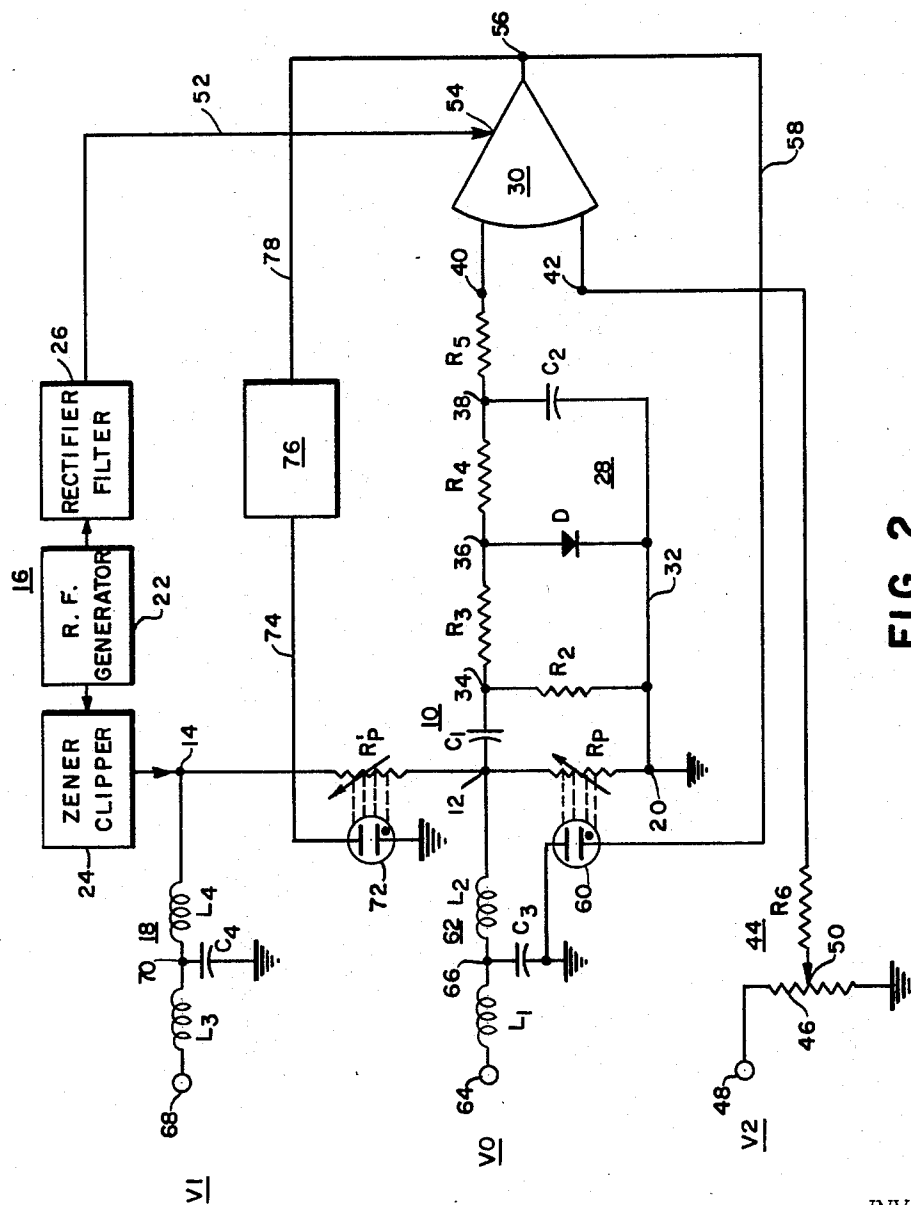


FIG. 2.

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ANALOG MULTIPLIER USING RADIATION RESPONSIVE IMPEDANCE MEANS IN ITS FEED-BACK ARRANGEMENT

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This invention relates to electronic multiplier circuits and more particularly to multiplier circuits of the analog type.

Analog multiplier circuits generally comprise means capable of receiving two or more variables as inputs and deriving an output proportional to the product of the inputs. In the simple case of two input variables, one of the inputs serves as a multiplicand and the other as a multiplier.

A basic well-known analog multiplier device is the three terminal variable voltage divider or potentiometer. If applied voltage to the potentiometer is used as one input variable and the position of the variable tap or slider thereon is used as the second variable, the output voltage at the slider is proportional to the product of the variables represented by the applied voltage and slider position.

Multipliers of the potentiometer type are very accurate and therefore, desirable, but in use they are not practical until the slider thereon is made automatically adjustable in response to the respective input variable which is to be represented by the slider position. The more obvious expedient in the past has been the use of an electric motor to position the slider as a function of some selected variable. This variable is usually fed to the motor via an amplifier which provides sufficient amplification to provide proportional energization of the motor with respect to the said variable.

It is an object of this invention to provide analog multiplier means equivalent to motor driven potentiometer types wherein all moving parts are eliminated.

Another object of this invention is to provide analog multiplier means of the self-adjusting potentiometer type having greater frequency response than those presently known.

Another object of this invention is to provide analog multiplier means of the self-adjusting potentiometer type wherein the potentiometer means includes radiation responsive variable impedance means.

Still another object of this invention is to provide analog multiplier means of the self-adjusting potentiometer type which is inexpensive and has a long operating life.

These and other objects of this invention will become apparent with reference to the following specification and drawings which relate to preferred embodiments of the invention.

In the drawings:

FIGURE 1 is a schematic of one embodiment of the invention; and

FIGURE 2 is a schematic of another embodiment of the invention.

Basically, the analog multiplier of the present invention comprises a variable voltage divider or potentiometer having at least one of the impedances therein responsive to the intensity of radiation impinged thereon from a controlled source of radiation, whereby the impedance ratio of the voltage divider may be varied. The source of radiation is controlled as to intensity in response to one input variable and the applied voltage to the potentiometer is controlled by, or is in actuality, the other input variable. The resulting output at the central junction of the poten-

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tiometer is a function of the product of the two input variables.

Referring in detail to the drawings and more particularly to FIGURE 1, one embodiment of the invention will now be described.

A voltage divider generally indicated at 10, is shown as comprising a fixed resistor R_1 and a photosensitive resistor R_p connected in series at a common central junction 12. The fixed resistor R_1 is connected at its outer end to an input terminal junction 14 which is a common connection for a fixed-frequency power supply 16 and first input network 18 for a first input variable V_1 . The photosensitive resistor R_p is connected at its outer end to a ground terminal 20.

The power supply 16 comprises a radio frequency oscillator 22 having one output feeding a Zener diode clipper 24 and another output feeding a rectifier-filter circuit 26.

The clipper circuit 24 feeds a constant amplitude square wave signal to the input terminal 14 of the voltage divider 10. The square wave signal is capacitively coupled from the central junction 12 of the voltage divider 10 to a second input network 28 of a high gain D.C. amplifier 30 by means of a coupling capacitor C_1 connected on one side thereof to the junction 12.

The input network 28 includes a common ground lead 32 connected to the ground terminal 20 of the voltage divider 10. An input resistor R_2 is connected from the other side of the coupling capacitor C_1 to the ground lead 32 whereby that portion of the square wave signal voltage appearing across the photosensitive resistor R_p in the voltage divider 10 is reflected thereacross. A rectifier means comprising a resistor R_3 , connected from the junction 34 between the coupling capacitor C_1 and the input resistor R_2 to a terminal junction 36 and a diode D connected from the junction 36 to ground lead 32 is provided to rectify the square wave input appearing across the input resistor R_2 .

An integrating means comprising a resistor R_4 connected between the junction 36 and a terminal junction 38 and a capacitor C_2 connected from the junction 38 to the ground lead 32 is provided to integrate the rectified voltage from the rectifier means. Finally, the direct current signal derived from the integrating means at the junction 38 is fed to a first input terminal 40 of the amplifier 30 via a resistor R_5 connected from the said junction 38 to the first input terminal 40.

The amplifier 30 is provided with a second input terminal 42. This second input terminal receives what will hereinafter be referred to as the second input variable V_2 from a third signal input network 44. The third signal input network 44 may comprise, for example, a potentiometer comprising a fixed resistor 46 extending from an input terminal 48 to ground and a variable tap 50 connected through a resistor R_6 to the second amplifier input 42.

The output of the rectifier-filter means 26 is connected via a lead 52 to a bias supply terminal 54 of the amplifier 30 whereby the necessary operating power is supplied to the said amplifier.

The output of the amplifier 30 is taken from an output terminal 56 and fed through a lead 58 to a neon bulb 60 connected between the amplifier output terminal 58 and ground. The neon bulb is positioned adjacent the photosensitive resistor R_p whereby it will irradiate the

The output of the amplifier 30 is taken from an output of the amplifier 30.

The output VO of the multiplier is taken from the central junction 12 of the voltage divider 10 via an output network 62 having an output terminal 64. The output network 62 is a radio frequency filter comprising two

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series connected inductances L_1 and L_2 connected between the junction 12 of the divider 10 and the output terminal 64 and a shunt capacitor C_3 connected from the common junction 66 between the inductances L_1 and L_2 to ground.

The first signal input network 18 is a radio frequency filter of the same configuration and comprises series connected inductances L_3 and L_4 connected between the input terminal 68 of the network 18 and the terminal junction 14 of the voltage divider 10 and a shunt capacitor C_4 connected from the common junction 70 between the inductances L_3 and L_4 to ground.

Referring now to FIGURE 2, all of the input and output circuits described with reference to FIGURE 1 remain the same with the exception of the output from the amplifier 30. All of the circuit elements equivalent to those of FIGURE 1 bear the same corresponding numerals.

In this embodiment, the fixed resistor R_1 (FIGURE 1) of the voltage divider 10 is replaced by a second photo-sensitive resistor R_p' . A second neon bulb 72 is connected from the output terminal 56 of the amplifier 30 to ground via a lead 74, transfer network 76 which illuminates the second neon bulb 72 in inverse proportion to the amplifier output, and a lead 78. Of course, it should be understood that the transfer network 76 could be incorporated internally of the amplifier 30 and a separate output terminal provided for the purpose of energizing the said second neon bulb 72.

In the transfer network 76, for example, a photoconductive resistance may be utilized in series with the second neon bulb 72 and a constant voltage source, the said photoconductive resistance being energized by a suitable light source modulated in intensity in direct proportion to the magnitude of the output signal at the amplifier terminal 56. Since the resistance of the photoconductive resistance is inversely proportional to the intensity of illumination the magnitude of current flow therethrough and through the second neon bulb 72 will be inversely proportional to the magnitude of the output signal at the amplifier terminal 56 and will effect an intensity modulation of the light output of the second neon bulb 72 in the same inversely proportionate manner.

The operation of the embodiment of FIGURE 1 will first be described.

The square wave input from the clipper 24 applied to the terminal 14 of the voltage divider 10 is fed to the first input terminal 40 of the D.C. amplifier 30 via the rectifying and integrating input coupling network 28, whereby the input at the terminal 40 is a direct current representation of the voltage drop across the resistor R_p of the voltage divider 10 resulting from the square wave signal input at the voltage divider terminal 14.

This input signal to the first input terminal 40 of the amplifier 30 results in an output signal at the amplifier output 56 which energizes the neon bulb 60. The light from the neon bulb 60 irradiates the photo-sensitive resistor R_p and thus causes the resistance thereof to vary in inverse proportion to the intensity of the light impinged thereon by the bulb 60.

The square wave signal is used as a reference for the analog multiplier and provides maximum illumination of the neon bulb 60 and hence, minimum resistance in the photo-sensitive resistor R_p .

If now, an external signal voltage comprising the previously defined second input variable V_2 is applied to the second input terminal 42 of the amplifier 30, via the input terminal 48 of the third input coupling network 44, and the polarity of the said second input variable is such as to oppose the reference voltage applied to the first amplifier input terminal 40, the amplifier 30 will modulate the output signal at the output terminal 56. Thus, the intensity of the neon bulb 60 will be varied until the value of the photosensitive resistor R_p has been adjusted to the point wherein the voltage drop there-

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across, as provided by the square wave input, results in a reference voltage at the first amplifier input terminal 40, as derived by the input coupling network 28, which is equal and opposite to that applied to the second amplifier input terminal 42 as a function of the second input variable V_2 .

This self-adjusting action of the reference input to the first terminal 40 of the amplifier 30 is of the closed loop negative feedback type causing R_p to be adjusted such that the ratio

$$\frac{R_p}{R_1 + R_p}$$

is a direct function of the second input variable applied to the input terminal 48 of the analog multiplier.

If now, a first input variable V_1 , as previously defined, is applied to the input terminal 68 of the first input network 18, and therefore, to the input terminal 14 of the voltage divider 10, this first variable V_1 will be multiplied by the ratio

$$\frac{R_p}{R_1 + R_p}$$

and the resulting voltage VO representative of the product will be taken from the central junction 12 of the voltage divider 10 and reflected at the output terminal 64 of the output network 62.

The reason for the radio frequency filters in the first input network 18 and the output network 62 and the coupling capacitor C_1 in the second input coupling network 28 will now become apparent. The square wave radio frequency reference signal is prevented from interfering with either the first input network 18 or the output network 62 by means of the LC filters therein and the direct current voltage representing the first input variable V_1 will be prevented from entering the second coupling network 28 and reaching the first input terminal of the amplifier 30 by the coupling capacitor C_1 . Thus the D.C. and A.C. signal components in the voltage divider 10 are effectively isolated from the standpoint of operational interference.

The first input variable V_1 has thus been multiplied by an impedance ratio which is the direct function of a second input variable V_2 , the resulting product being represented by an output voltage VO which is a direct function of the said product of the first and second input variables.

Referring now to FIGURE 2, the operation of the second disclosed embodiment will now be described.

The square wave reference signal, applied as a direct current input voltage to the first input terminal 40 of the amplifier 30 results in a maximum output of the amplifier 30 at the output terminal 56 thereof. The first neon bulb 60 is thus energized to maximum illumination via lead 58.

The second neon bulb 72 is also energized by the amplifier output via the lead 74, transfer network 76 and lead 78. Since the transfer circuit provides an output to the second neon bulb 72 which is inversely proportional to the output from the amplifier 30 at the said output terminal 56, the second neon bulb 72 is energized to a minimum illumination corresponding to the maximum illumination of the first bulb 60.

Thus, the intensity of illumination in the first and second neon bulbs 60 and 72, respectively, may be said to vary in opposition in response to input variations at the amplifier 30.

Since the first bulb 60 will be intensity modulated with respect to the second input variable V_2 applied to the second input terminal 42 of the amplifier 30 as hereinbefore described in the description of operation of the embodiment of FIGURE 1, the second bulb 72 will also be intensity modulated thereby in the opposite sense from the first bulb 60.

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Since the change in resistance of the photosensitive resistors R_p and R_p' is inversely proportional to the intensity of illumination impinged thereon, an increase in illumination of the first bulb 60, in response to an increase in the output of the amplifier 30, will cause a decrease in the resistance R_p and the corresponding decrease in the illumination of the second bulb 72 will cause an increase in the resistance R_p' . Thus, the effect is identical to that of a slide wire potentiometer wherein the slide or variable tap has just traversed downwardly along the voltage divider 10 as shown.

The effect of the embodiment of FIGURE 2 on the equation of the multiplier is to change the sensitivity of the circuit but not the theoretical relationships. The first input variable V1 applied via the input terminals 68 and 14, will still be multiplied by a ratio

$$\frac{R_p}{R_p' + R_p}$$

where R_p' now replaces R_1 in the ratio derived for the embodiment of FIGURE 1. Since there are now two variables in the denominator, instead of the single variable of the embodiment of FIGURE 1, the analog multiplier circuit is provided with a greater sensitivity to changes in the second input variable V2.

As can be seen from the foregoing specification and drawings, this invention provides a novel, highly stable analog multiplier circuit providing the operating characteristics of an automatically driven slide wire potentiometer type multiplier without the necessity of any moving parts.

It is to be understood that the embodiments of the invention shown and described herein are for the purpose of example only and are not intended to limit the scope of the appended claims.

What is claimed is:

1. An analog multiplier for deriving the product of a first input variable and a second input variable, comprising a voltage divider having an input terminal, an output terminal, a reference terminal, first impedance means between said input and output terminals and second impedance means between said output and reference terminals, said impedance means each including radiant energy responsive variable impedance means, radiant energy for emitting radiations located adjacent said variable impedance means, and means for energizing said radiant energy means as a function of said second input variable to thereby vary said variable impedance means as a function thereof, whereby application of said first input variable to said input terminal results in an output at said output terminal which is directly proportional to the product of said first and second input variables; wherein said radiant energy responsive variable impedance means comprise first and second photosensitive resistors in said first and second impedance means, respectively, and said radiant energy means comprise first and second light sources, respectively, said first light source being intensity modulated as an inverse function of said second input variable and said second light source being intensity modulated as a direct function of said second input variable.

2. An analog multiplier for deriving the product of a first input variable and a second input variable, comprising a voltage divider having an input terminal, an output terminal, a reference terminal, first impedance means between said input and output terminals and second impedance means between said output and reference terminals, said impedance means each including radiant energy responsive variable impedance means, radiant energy means for emitting radiations located adjacent said variable impedance means, and means for energizing said radiant energy means as a function of said second input variable to thereby vary said variable impedance means as a function thereof, whereby application of said first input variable to said input terminal

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results in an output at said output terminal which is directly proportional to the product of said first and second input variables; wherein said means for energizing said radiant energy means as a function of said second input variable comprises a power source for providing an alternating current reference signal, means for connecting said power source to said input terminal of said voltage divider, an amplifier having first and second signal inputs and an output, a coupling network between said output terminal of said voltage divider and said first signal input of said amplifier, said coupling network comprising means for deriving a direct current representation of the alternating voltage drop produced across said second impedance means of said voltage divider by said reference signal and applying said direct current representation to said first signal input of said amplifier, and means for coupling said second input variable to said second signal input of said amplifier with a polarity opposed to said representation of said reference signal at said first signal input, said amplifier providing an output signal at its output as a function of the difference in said reference signal and said second input variable.

3. The invention defined in claim 2, wherein said coupling network further includes means for admitting said reference signal to said coupling network and simultaneously excluding said first input variable therefrom.

4. The invention defined in claim 2, wherein said means for deriving a direct current representation of the alternating voltage drop produced across said second impedance of said voltage divider by said reference signal comprises a half-wave rectifier for said alternating voltage drop and an integrating circuit for deriving a constant direct current reference voltage from the output of said rectifier, said integrating circuit being connected between said rectifier and said first signal input of said amplifier.

5. An analog multiplier, for deriving the product of a first input variable and a second input variable, comprising a voltage divider including first and second series connected impedance means having an input terminal for said first input variable, an output terminal for said product and a reference terminal, a direct current amplifier having first and second signal inputs and an output, said second input being adapted to receive said second input variable, a power source for providing an alternating current reference signal, means for connecting said power source to said input terminal of said voltage divider, an input coupling network connected from said output terminal of said voltage divider, across said second impedance means, to said first signal input of said amplifier, said coupling network including means for converting the alternating voltage drop provided across said second impedance means by said reference signal to a direct current representation thereof at said first signal input of said amplifier, means for coupling said second input variable to said second signal input of said amplifier with a polarity opposed to said representation of said reference signal at said first signal input, said amplifier providing an output signal at its output as a function of the difference in said reference signal and said second input variable, and radiant energy means, connected to said output and located adjacent said second impedance means, energized to emit radiations intensity modulated as a function of said amplifier output signal, said second impedance means comprising a radiant energy responsive variable impedance varied as a function of intensity of the radiant energy impinged thereon, whereby said second impedance means is varied as a function of said second input variable, and whereby simultaneous application of said first input variable to said input terminal of said voltage divider results in an output at the output terminal thereof which is directly proportional to the product of said first and second input variables as a function of the ratio of said first and second impedance means.

6. The invention defined in claim 5, wherein said

radiant energy responsive variable impedance comprising said second impedance means includes a photosensitive resistor and said radiant energy means comprises a light source.

7. The invention defined in claim 5, wherein said coupling network further includes means for admitting said reference signal to said coupling network and simultaneously excluding said first input variable therefrom.

8. The invention defined in claim 5, wherein said means for converting the alternating voltage drop provided across said second impedance means by said reference signal to a direct current representation thereof comprises a half wave rectifier for said alternating voltage drop and an integrating circuit for deriving a constant direct current reference voltage from the output of said rectifier, said integrating circuit being connected between said rectifier and said first signal input of said amplifier.

9. An analog multiplier, for deriving the product of a first input variable and a second input variable, comprising a voltage divider including first and second series connected impedance means having an input terminal for said first input variable, an output terminal for said product and a reference terminal, a direct current amplifier having first and second signal inputs and an output, said second input being adapted to receive said second input variable, a power source for providing an alternating current reference signal, means for connecting said power source to said input terminal of said voltage divider, an input coupling network connected from said output terminal of said voltage divider, across said second impedance means, to said first signal input of said amplifier, said coupling network including means for converting the alternating voltage drop provided across said second impedance means by said reference signal to a direct current representation thereof at said first signal input of said amplifier, means for coupling said second input variable to said second signal input of said amplifier with a polarity opposed to said representation of said reference signal at said first signal input, said amplifier providing an output signal at its output as a function of the difference in said reference signal and said second input variable, and first and second radiant energy emitting means, connected to said output and located adjacent said first and second impedance means, respectively, said first radiant energy means being energized to emit radiations intensity modulated as an inverse function of said amplifier output signal and said second radiant energy means being energized to emit radiations intensity modulated as a direct function of said amplifier output signal, said first and second impedance means comprising, respectively, first and second radiant energy responsive variable impedances varied as a function of the intensity of the radiant energy impinged thereon, whereby said first and second impedance means

are varied as inverse and direct functions, respectively, of said second input variable, and whereby simultaneous application of said first input variable to said input terminal of said voltage divider results in an output at the output terminal thereof which is directly proportional to the product of said first and second input variables as a function of the ratio of said first and second impedance means.

10. The invention defined in claim 9, wherein said first and second radiant energy responsive variable impedances comprise, respectively, first and second photosensitive resistors, and said first and second radiant energy means comprise first and second light sources, respectively.

11. The invention defined in claim 9, wherein said input coupling network further includes means for admitting said reference signal to said coupling network and simultaneously excluding said first input variable therefrom.

12. The invention defined in claim 9, wherein said means for converting the alternating voltage drop provided across said second impedance means by said reference signal to a direct current representation thereof comprises a half wave rectifier for said alternating voltage drop and an integrating circuit for deriving a constant direct current reference voltage from the output of said rectifier, said integrating circuit being connected between said rectifier and said first signal input of said amplifier.

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