June 17, 1969 A. L. BETTON 3,450,980

OSCILLATING SWITCH REGULATOR

Filed Dec. 2, 1966 Sheet 1 of 4

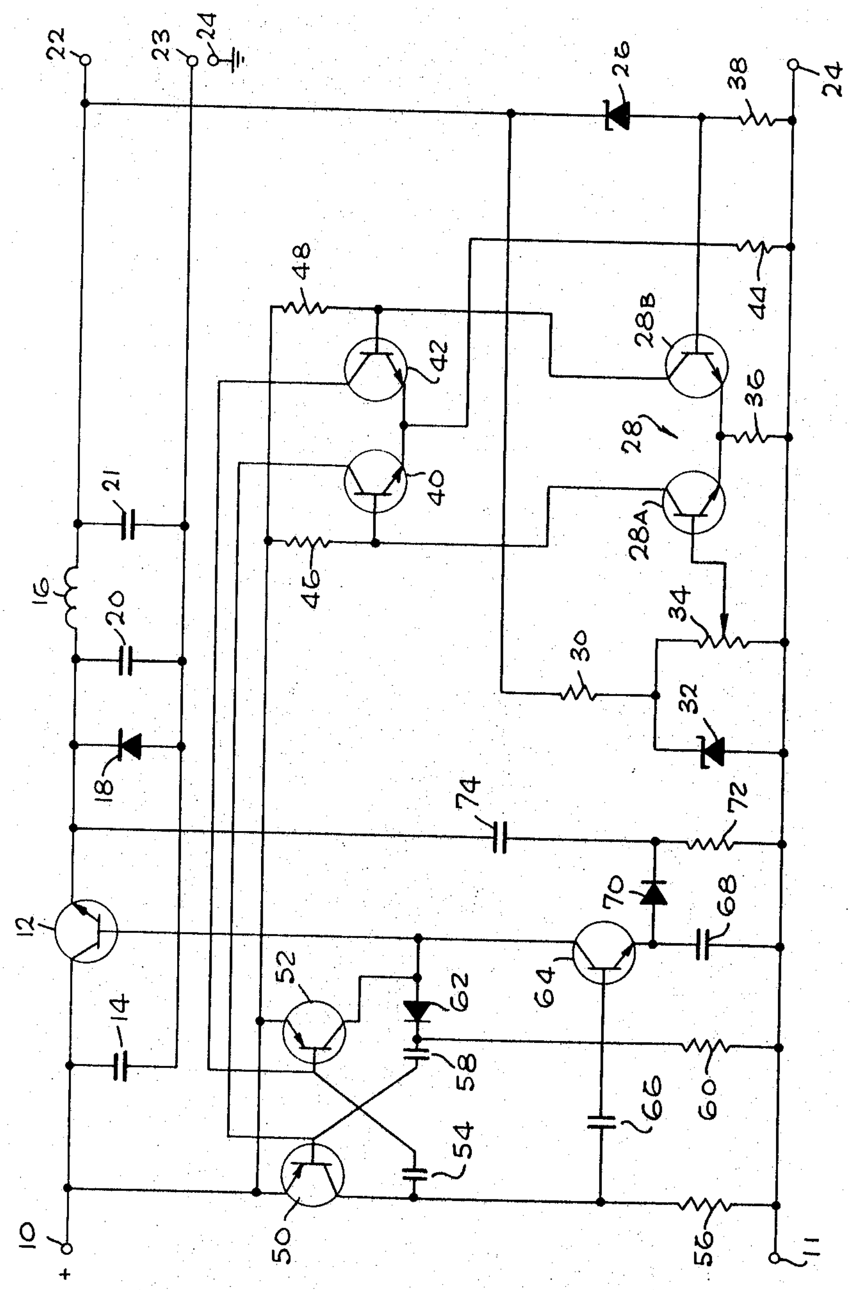

Fig. 1

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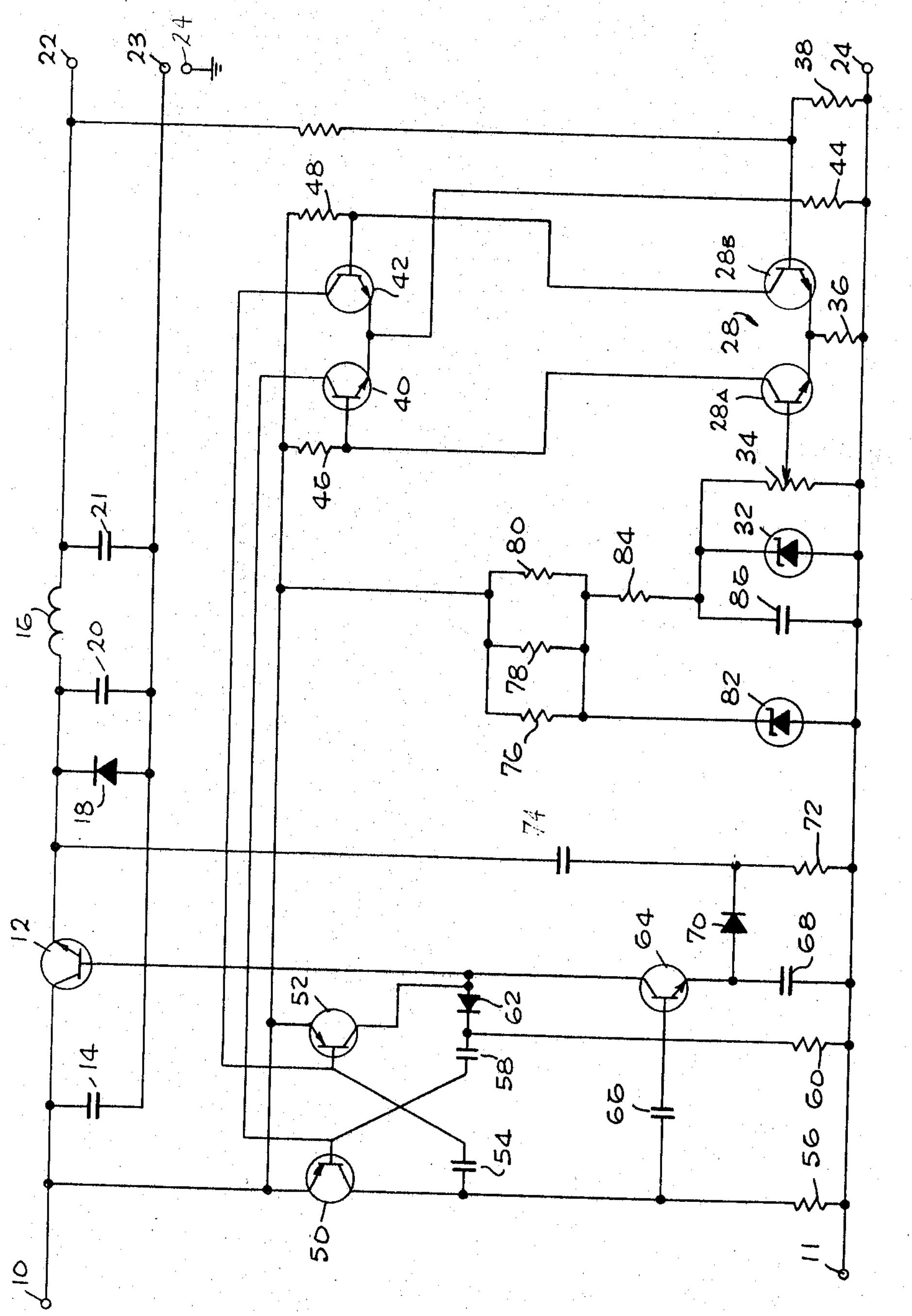

Fig. 2

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Fig. 3

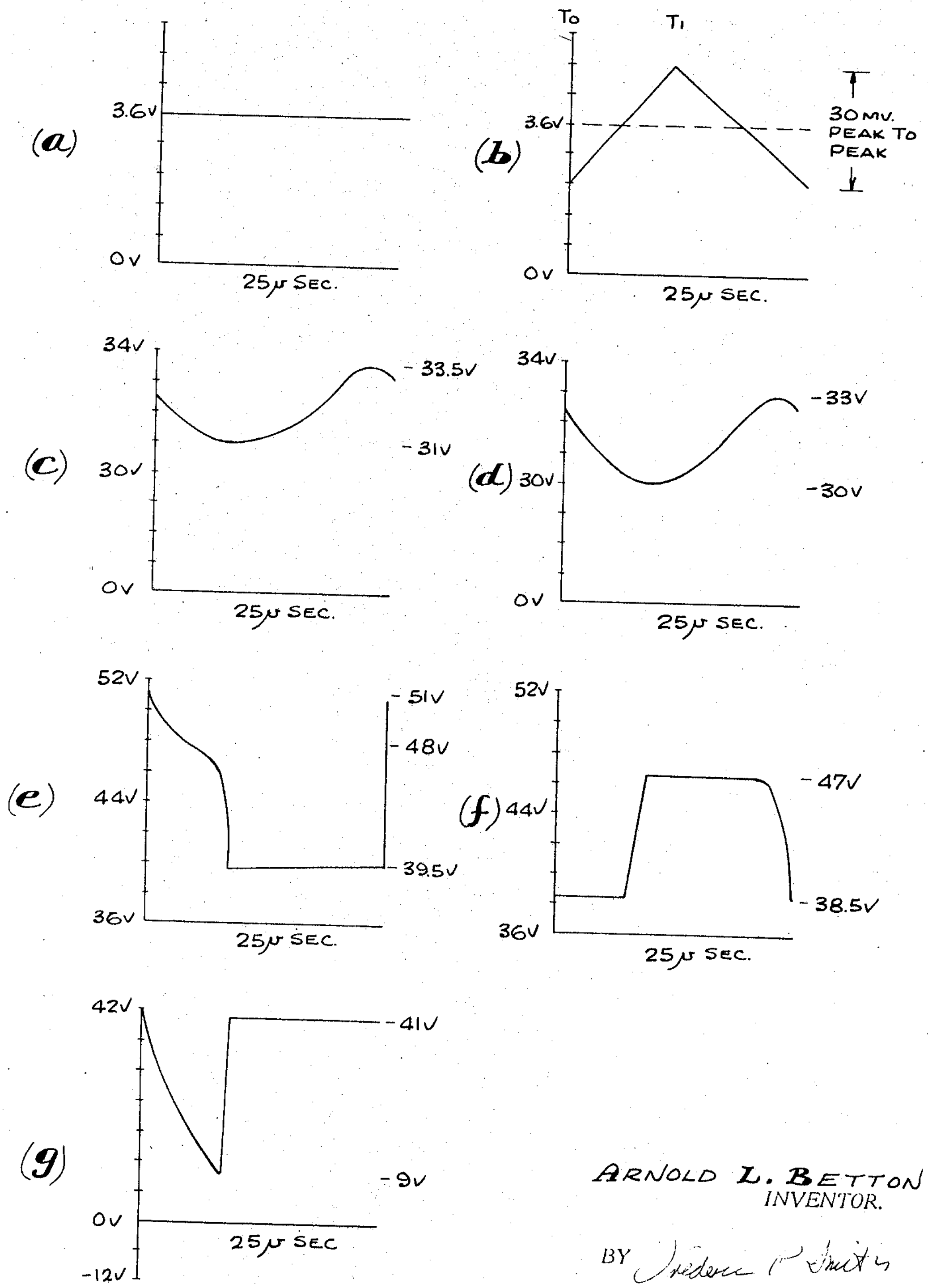

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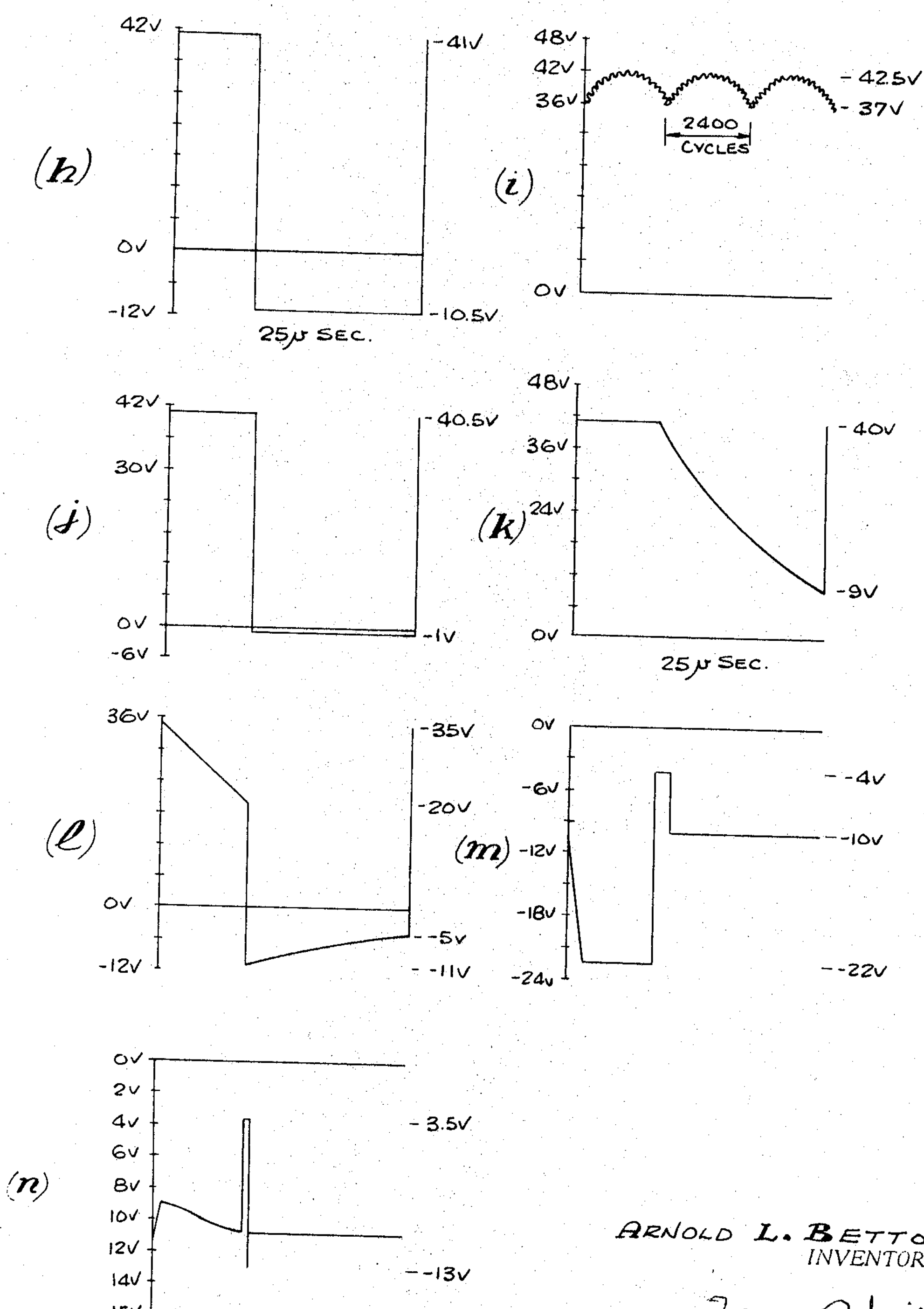
Fig. 3



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3,450,980
OSCILLATING SWITCH REGULATOR

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U.S. Cl. 323—18 8 Claims

ABSTRACT OF THE DISCLOSURE

A regulating power supply for regulating an input source voltage to provide a DC output voltage of a predetermined level including a transistor switch and a filter connected between the input and output with an error signal being generated by comparing output voltage variations with a reference voltage, the error signal actuating a bistable device to a first or second stable state to generate a first or second control signal depending upon the output voltage being above or below the predetermined level, the control signals so generated controlling the transistor switch conductivity or non-conductivity to maintain the predetermined voltage level.

This invention relates to a regulating power supply and more particularly to a step-down DC to DC switch regulator.

In the prior art, numerous types of power supplies have been utilized to provide a regulated DC voltage. Pulse-width modulated switching regulators which operate on the principal of time-ratio control are one such type known in the prior art. In a time-ratio control power supply a constant output voltage is obtained by varying the duration of the conducting time of a series switching transistor connected between the load and the source voltage to produce a pulse train with a constant average valve. The conducting time of the series switch transistor is controlled by an error signal which is developed by sampling the output voltage. The error signal is a measure of the difference between the actual output voltage and a desired output voltage level. In typical applications. the error signal is developed in a difference amplifier and is utilized to control a bistable multivibrator which gates the series switching transistor in and out of conduction in response to changes of state in the multivibrator. As the output voltage rises above the desired value, the error voltage causes the multivibrator to change its state of conduction thereby gating the series switch out of conduction. Likewise when the output voltage falls below the desired value, the error voltage causes the multivibrator to change its state of conduction which gates the series switching transistor into conduction. This switching cycle, which is of short duration, is rapidly repeated to produce a pulse train having a constant average value, and thus, the load is supplied with a regulated DC voltage.

One undesirable characteristic of power supplies in the prior art has been the loss of power which occurs in the series switching transistor when it is gated in or out of conduction. The power loss in the transistor is a function of the time required to change the state of its conduction which is, in turn, dependent upon the shape of the gating pulse from the control circuitry. Pulses from multivibrator circuits, for example, have rise ties which are functions of the values of circuit components in the multivibrators. Thus, the efficiency of this type of regulated power supply is a function of the switching time of the control circuitry which commutates the series switching transistor. In many applications of the prior art, the rise time of the gating pulses from the commutating circuitry is longer than the minimum interval needed to drive the

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series transistor switch out of its state of saturated conduction, thus limiting the maximum efficiency of this type of power supply.

The present invention overcomes the above and other disadvantages of the pulse-width modulated switching regulators of the prior art by providing a series switching transistor and commutating circuitry which, according to the basic concept of the invention, operate at a higher efficency since pulses are provided by the commutating circuitry which have a shortened rise time and thus gate the series switching transistor out of conduction in a minimal time. More specifically, the regulated power supplies of the invention employ an inverting amplifier which is coupled between the output of a first transistor in a bistable multivibrator and the series switching transistor and which is operative to gate the series switching transistor out of conduction when the first transistor of the multivibrator goes into conduction. By gating the series switching transistor with the inverted output of the first transistor as it goes into conduction, rather than gating it with the output pulse of the second transistor as that transistor goes out of conduction, the rise time of the trigger pulse is shortened because its minimum duration is no longer limited by the time constant of the cross-coupling network of the second transistor.

It is therefore, on object of the invention to provide a power supply for transforming an unregulated voltage into a regulated voltage of a predetermined magnitude.

Another object of the invention is to provide a regulated power supply which filters a variable width pulse train from a commutated series switch to provide an output voltage proportional to the average amplitude of the pulse train.

A further object of the invention is to provide a regulated power supply capable of maintaining a substantially constant output voltage with minimum internal power dissipation.

Still another object of the invention is to provide a switching regulator which has control circuitry for commutating the series switch with a minimal power loss in the series switch.

Yet another object of the invention is to provide a switching regulator which is rapidly caused to change its state of conduction by control circuitry having a minimal power loss.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof will be better understood from the following description considered in connection with the accompanying drawings in which two embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

FIG. 1 is a circuit diagram of a first embodiment of the invention.

FIG. 2 is a circuit diagram of a second embodiment of the invention.

FIG. 3 illustrates waveforms attendant during the cycle of regulation.

With reference now to the drawings, wherein like or corresponding parts are designated by the same reference characteristics throughout the several views, there is shown in FIG. 1 a schematic diagram of the regulating power supply of the present invention. An unregulated voltage source, not shown, is connected to a pair of signal input terminals **10** and **11**. Connection to the source voltage is made so that terminal **10** is positive. The regulated output voltage is supplied either to output terminals **22** and **24** as a positive potential or to terminals **23** and **24** as a negative potential. The load, not shown, may be connected to either pair of terminals. In order to provide a positive regulated output voltage to the load a current path is completed by connecting output terminal **24** to input terminal **11** and by connecting output terminal **22** through inductance **16** in series with switching transistor **12** to input terminal **10**.

A constant output voltage is produced in two stages. In a first stage transistor switch **12** is actuable to provide constant amplitude pulses of controlled width. In a second stage a filter comprising inductance **16**, capacitor **21** and diode **18**, operates to smooth the pulse train. The positive unregulated potential at input terminal **10** is applied to the collector of transistor switch **12**. Transistor switch **12** is driven in and out of conduction by gating pluses applied to its base emitter junction, thereby alternately forward biasing and reverse biasing the junction. The transistor conducts when the base-emitter junction is forwarded biased and the collector-base junction is reverse biased. When both junctions are reverse biased, no conduction takes place except for leakage current. Transistor switch **12** is gated in response to an error signal which is, in turn, responsive to variations in the output voltage. The output from the switch, a pulsating DC voltage, is applied to inductance **16**. Diode **18** is connected to the emitter of transistor **12** and to inductance **16** with a polarity as shown in FIG. 1. Capacitor **21** is connected to the other terminal of inductance **16** and to output terminal **23**. A positive output potential is obtained at terminal **22** by shunting output terminal **23** to ground terminal **24**. A negative output voltage at terminal **23** may be had by connecting terminal **22** to ground terminal **24**. During the interval that transistor switch **12** is conducting the positive potential appearing at its emitter is applied to inductance **16**. During this period of conduction, inductance **16** and capacitor **21** store energy, the inductance in the form of a magnetic field and the capacitor in its static charge. After transistors switch **12** is gated off, the collapsing magnetic field of inductance **16** and the charge of capacitor **21** supply energy to maintain the flow of current constant. Diode **18** completes the path for the load current during the period when transistor switch **12** is non-conducting. Capacitor **14** is connected between input terminal **10** and output terminal **23** to prevent transient pulses from transistor switch **12** from being reflected back to unregulated voltage source. Such pulses are created by commutating switching transistor **12**. capacitor **20** is connected from the emitter of transistor **12** to output terminal **23** to reduce RFI by decreasing the reverse recovery current through diode **18** .

Complementary error signals proportional to deviations in the output voltage from a desired level are developed by dual transistor amplifier **28** and are amplified in a second difference amplifier comprising transistors **40** and **42**. A reference potential, which is independent of variations in the output voltage, is supplied to the base of transistor **28A** by a reference voltage network comprising resistors **30**, Zener diode **32** and variable resistor **34**. Resistor **30** and variable resistor **34** are connected in series from output terminal **22** to output terminal **24**. Zener diode **32** is connected between the junction of resistor **30** and variable resistor **34** to output terminal **24**. The voltage across variable resistor **24** is a constant value, independent of fluctuations in the output voltage, because of the characteristics of Zener diode **32**. The voltage at the adjustable tap of variable resistor **34**, a reference voltage variable over particular range, is applied to the base of difference amplifier **28A**. Resistor **36** is connected between the common emitters of difference amplifier **28** and output terminal **24**. The amount of emitter-base current in transistor **28** is a function of the resistance of resistor **36**. A signal responsive to variations in the output voltage is applied to the base of difference amplifier **28B** through a sensing network comprising Zener diode **26** and resistor **38**. Zener diode **26** and resistor **38** are connected in series between output terminal **22** and output terminal **24**. The junction of Zener diode **26** and resistor **38** is connected to the base of difference amplifier **28B**. Zener diode **26** serves two functions; it provides a drop in potential from the output voltage to the value useable on the second base of amplifier **28** and it permits the full variations in output potential to be applied to the base of amplifier **28B**. Because the voltage drop across diode **26** remains constant all variations appear across resistor **38**. Complimentary error signals, which are proportional to the difference between the output voltage and the predetermined value selected by the adjustment of resistor **34**, appear at the collectors of difference amplifiers **28A** and **28B**.

The output signals from difference amplifier **28**, a pair of complimentary error signals, are applied to a linear amplifier comprising transistors **40** and **42**. The collector of the amplifier **28A** is connected to the base of transistor **40**; the collector of amplifier **28B** to the base of transistor **42**. The emitters of transistors **40** and **42** are connected in common. Resistor **44** is connected between the common emitters of transistors **40** and **42** and output terminal **24**. The amount of emitter-base current in transistors **40** and **42** is a function of the resistance of resistor **44**. Resistor **46** is connected between input terminal **10** and the base of transistor **40**. Recall that the unregulated DC source voltage is applied to input terminal **10**. This unregulated source voltage less the voltage drop across resistor **46** is applied to the collector of amplifier **28A**. Variations in current flow through resistor **46** caused by fluctuations in the base-collector current of difference amplifier **28A** drive the base of transistor **40**. Resistor **46** also sets the collector-base bias current for transistor **40**. Resistor **48** is connected between the unregulated DC source voltage at input terminal **10** and the base of transistor **48**. Its functions are similar to those of resistor **46**. Thus a pair of complimentary amplified error signals are provided at the collectors of transistors **40** and **42**.

Amplifier **64** and a bistable multivibrator, comprising transistors **50** and **52**, control conduction through transistor switch **12** in response to the pair of error signals received from transistors **40** and **42**. The error signals are transmitted from the collectors of transistors **40** and **42** by connections to the bases of transistors **50** and **52** respectively. The emitters of transistors **50** and **52** are connected to the source voltage at input terminal **10**. The base to emitter junctions of transistors **50** and **52** supply current paths to the source for the collector currents of transistors **40** and **42** respectively. In an RC coupled multivibrator, each stage is alternately conducting and is in an opposite state of conduction from the other stage. Transistors **50** and **52** are alternately driven into conduction by the error signals applied to their bases. Resistor **56** provides a current path to the negative input terminal **11** for the collector current of transistor **50**. Likewise, diode **62** and resistor **60** complete the circuit for the collector current of transistor **52**. Capacitor **54** is connected from the collector of transistor **50** to the base of **52**. Capacitor **58** is connected from the junction of resistor **60** and diode **62** to the base of transistor **50**. Capacitors **54** and **58** provide the cross coupling between transistors **50** and **52** which is necessary to cutoff one stage when the other starts conducting. For example, when transistor **50** begins conducting capacitor **54** discharges into the base of transistor **52**. This current flow reverse biases the base-emitter junction of transistor **52** thereby driving transistor **52** out of conduction. Likewise, capacitor **58** discharges into the base of transistor **50** thereby driving transistor **50** out of conduction as a result of transistor **52** beginning to conduct. The frequency at which the multivibrator changes stage is a function of the charging time of the capacitors **54** and **58**. This frequency is primarily determined by the amount of collector current in transistors **40** and **42**. Because these collector currents vary as a function of the fluctuations in the output voltage at output terminal **22**, the conducting time of transistors **50** and

52 will also be a function of the output voltage. The collector of transistor 52 is connected to the base of transistor switch 12. Each time that the error signal at the base of transistor 52 drives transistor 52 into conduction, the potential at the collector of transistor 52 approaches the positive potential at input terminal 10. This fast rising positive potential is applied at the base of transistor switch 12 for actuating transistor switch 12 into conduction.

In accordance with the concept of the invention, switching amplifier 64 drives transistor switch 12 out of conduction each time that transistor 50 is driven into conduction by the error signal appearing at the base of transistor 50. Capacitor 66 is connected between the base of switching amplifier 64 and the collector of transistor 50. The collector of transistor 64 is coupled to the base of transistor switch 12. The emitter of transistor 64 is connected to a bias network comprising capacitor 68, diode 70, resistor 72, and capacitor 74. The sharp positive rise in voltage appearing at the collector of transistor 50 when transistor 50 begins to conduct is transmitted by capacitor 66 to the base of transistor amplifier 64. This fast rising positive pulse drives transistor amplifier 64 into conduction. Recall that transistor 52 will be driven out of conduction when transistor 50 goes into conduction. Diode 62 isolates the collector of transistor 52 from capacitor 58. This has the effect of making the time required to actuate transistor switch 12 out of conduction a function of the sharp negative pulse appearing at the collector of transistor 64 rather than a function of the rate at which capacitor 58 discharges.

The network comprising capacitor 68, diode 70, resistor 72 and capacitor 74 is a bias circuit for transistor 64. Capacitor 68 is connected from the emitter of transistor 64 to input terminal 11. Capacitor 68 rapidly discharges when amplifier 64 conducts. Resistor 72 and capacitor 74 are connected in series from input terminal 11 to the emitter of transistor switch 12. Diode 70 is connected between the emitter of transistor 64 and the common connection between resistor 72 and capacitor 74. It will be recalled that transistor 64 was driven into conduction in order to cut-off transistor switch 12 sharply. When transistor switch 12 ceases to conduct capacitor 74 negatively charges into capacitor 68. Charging capacitor 68 with a negative voltage drives transistor switching amplifier 64 out of conduction thereby readying it for the next cycle.

Turning now to FIG. 2, in another embodiment of the invention the reference voltage supplied to the base of difference amplifier 28 is obtained from the unregulated DC source potential at input terminal 10. A voltage divider network is connected between input terminals 10 and 11. This voltage divider comprises the resistive network of resistors 76, 78 and 80 connected in series with Zener diode 82. Because of the characteristics of Zener diode 82 the voltage at the junction of the diode and the resistors remains constant. This constant voltage supplies a second voltage divider network connected between this junction and input terminal 11. This second voltage divider network comprises resistor 84 connected in series with the parallel network of capacitor 86, Zener diode 32 and variable resistor 34. As in FIG. 1, a constant voltage which is variable over a certain range is available at the top of variable resistor 34. This embodiment of the invention is used when the desired output voltage is too low to supply the reference voltage needed for proper operation of difference amplifier 28.

Consider now the motivating concept of the regulated power supply of the invention and the manner in which high efficiency of operation is achieved with the use of a minimum number of circuit components. A stepdown DC to DC voltage conversion is accomplished by rapidly opening and closing switch 12 which is connected to a source voltage. The output of switch 12 is a pulsating DC voltage that is nearly equal to the source voltage when the switch is on and zero when the switch is off. The average value of the output voltage of switch 12 is proportional to the input voltage and to the ratio of conducting time of switch 12 to total operating time. The use of a diode 18 shunting the switch and an inductance 16 in series with the switch provides a path for the load current when switch 12 is opened and thus permits continuous current flow. The output voltage to the load is maintained at a predetermined level by actuating switch 12 in response to an error signal which is a measure of the deviation of the output voltage from the predetermined level. The error signal is produced by comparing the output voltage with a reference voltage in differential amplifier 28. If the output voltage drops below the desired value, the error signal will turn switch 12 on; and, likewise, if the output voltage rises above the desired value, the error signal will turn switch 12 off. Thus the average value of the output voltage at output terminal 22 remains constant. The switching action cannot occur at the instant the output voltage deviates above or below the desired value because of the delay in actuating circuitry and in the transistor switch itself. The time delay in the switching action results in a slight overshoot or undershoot of the output voltage. Thus, the output voltage varies in a small bandwidth about the desired level. The principal of actuation utilized in the various embodiments of the invention is pulse-width modulation. Switch 12 will conduct only so long as the output voltage is less than the desired value and, conversely, it will remain off as long as the output voltage is greater than the desired value. Important factors which determine the efficiency of the power supply include the power consumed by the switch in changing state and the power consumed by the circuitry which performs the commutating action. The power lost in switching is a function of the time required to perform the switching action. According to the concept of the invention commutating circuitry is employed which requires minimum power to turn the switch off in a minimum time.

A step-down time-ratio control converter is capable of controlling a load voltage from a low value to a level nearly as high as that of the supply voltage. The minimum input voltage necessary to operate a supply such as that shown in FIG. 1 is equal to the sum of the voltage drops across the load, inductance 16 and transistor switch 12. However, in order to achieve efficient operation of the switch, the input voltage should be from two to six times higher than the output voltage. The vlaue of input voltage which results in the most efficient operation of the supply may be determined by experimentation. The average load voltage E load over a repetitive time interval is related to the source voltage E in as follows:

$$E_{\text{load}}=E_{\text{in}}\frac{T_{\text{on}}}{T_{\text{on}}+T_{\text{off}}}$$

where T_{on} is a total conducting time of the switch and T_{off} is the total non-conducting time of the switch.

Diode 18, as shown in FIG. 1, provides a path for the load current when transistor switch 12 is non-conducting. This permits inductance 16 to sustain the DC load current during the half-cycle transistor switch 12 is off. When transistor switch 12 is conducting, the current flow creates a magnetic field in inductance 16 and charges capacitor 21. When transistor switch 12 is off the collapsing magnetic field of inductance 16 and the charge stored in capacitor 21 sustain current flow through the load, inductance 16 and diode 18. Because the average voltage across inductance 16 is zero, the voltage drop across inductance 16 is not a factor in the expression for the average output voltage at terminal 22. Diode 18 must be connected with the proper polarity to permit current flow during the off half-cycle and block flow during the on half-cycle. Thus, there is available at terminal 22 an output voltage with a magnitude dependent upon the level of the source voltage and the duty cycle of transistor switch 12.

Inductance 16 and capacitor 21 produce a steady DC output voltage from a pulsating input voltage. Note that the output voltage at terminal 22 is a function of the voltage drop across inductance **16**, is in turn, a function of the rate of change of current through inductance **16**. This means that the output voltage at terminal **22** will vary because of the changing current in inductance **16**. For example, suppose that transistor switch **12** were switched on for a period of continuous operation. The division of the source voltage across the load and inductance **16** would be determined by the initial flow of current. After a length of time determined by the time constant of inductance **16**, the current flow would have created a magnetic field, charged capacitor **21** and reached a steady state value. At this time the voltage drop across inductance **16** is zero because the rate of change of current flow is zero. This means that the output voltage at terminal **22** must have risen to the level of the source voltage less any drop across transistor switch **12**. Now assume that transistor switch **12** is switched out of conduction. The current supplied by the collapsing magnetic field of inductance **16** will decrease at a rate also determined by the time constant of inductance **16**. After the magnetic field has collapsed, capacitor **21** will supply the load current until it discharges. Decreasing current flow means, of course, that the output voltage at terminal **22** will also decrease. Ultimately, it would fall to zero. In operation, the switch is commutated in cycles having a period much shorter than the time constant of inductance **16** and capacitor **21**. Choice of a duty cycle of short duration with respect to this time constant has the effect of causing the output voltage to rise in and fall in a narrow bandwidth about some average value.

Regulation is accomplished by actuating switch **12** so that the output voltage varies in a narrow bandwidth about a predetermined level. Actuation is conventionally accomplished by comparing the output voltage and the reference voltage in a difference amplifier to develop an error voltage, applying the error voltage to a bistable multivibrator to change its state when the output voltage rises above and falls below the reference voltage, and gating the series switch with the output of one stage of the multivibrator. Of course, the transistor switch cannot be made to instantly change its state of conduction when the output voltages rise above or fall below the desired value. Time delays occur in the commutating circuitry and in the time required to turn the series switch on or off. According to the concept of the invention, diode **62** and amplifier **64** operate to decrease the time required by the bistable multivibrator, which comprises transistors **50** and **52**, to switch transistor switch **12** out of conduction in response to an error signal.

Comparison of a reference voltage and the output voltage in difference amplifier **28** generates an error signal proportional to the deviation of the output voltage from a desired value. In one embodiment of the invention, shown in FIG. 1, a reference voltage is developed by applying the output voltage across resistor **30** and Zener diode **32**. The breakdown characteristics of the Zener diode are such that the voltage across the diode **32** is constant and independent of the variations in the output voltage. A voltage which fluctuates in proportion to the output voltage at terminal **22** is developed by connecting Zener diode **26** and resistor **38** across the output terminals **22** and **24**. Again the voltage drop across the Zener diode remains constant. Zener diode **26** functions to provide an offset voltage so that the output voltage may be very variable down to zero volts. Without the offset voltage, the minimum output voltage would be the reference voltage. The inputs to the bases of difference amplifier **28** are the constant voltage available at resistor **34** and the fluctuating voltage across resistor **38**. A pair of complementary error signals, which represent the difference between the output voltage and the reference voltage, appear at the collectors of difference amplifier **28**. These signals provide inputs to the bases of a second differential amplifier comprising transistors **40** and **42**. The linearly amplified, inverted pair of error signals appear at the collectors of transistors **40** and **42**.

Consider now the operation of the bistable multivibrator comprising transistors **50** and **52** and of amplifier **64**. The pair of inverted error signals at the collectors of transistors **40** and **42** drive the bases of transistors **50** and **52**. In a bistable multivibrator one stage is conducting while the other is cut off. The states of conduction in transistors **50** and **52** will reverse in response to a negative going error signal to the base of the PNP transistor which is non-conducting. Assume, for example, transistor **40** is non-conducting and transistor **52** is conducting. As transistor **50** conducts, its collector voltage approaches the source voltage at its emitter. The positive going pulse which appears at the collector of transistor **50** as it begins to conduct is coupled to the base of transistor **52**. Transistor **52** had been conducting. Coupling the positive going pulse to the base of the outer stage cuts it off. Thus, the bistable multivibrator has reversed its states of conduction. Conventionally, the output pulses from one state of a bistable multivibrator are coupled to a series switch to gate the switch on and off. In the present invention the positive going signal which appears at the collector of transistor **52** when transistor **52** begins to conduct is used to drive transistor switch **12** into conduction. Transistor **52** will quickly go into conduction in response to an error signal at its base. However, when transistor **52** is cut off by a signal coupled from transistor **50** the fall time of the negative going signal at the collector of transistor **52** is determined by the time constant of coupling capacitor **58**. In order to turn off transistor switch **12** it is necessary to remove energy from the base-emitter junction. The power lost in switching transistor **12** out of conduction is proportional to the amount of time required to accomplish this. According to the concept of the invention the negative going voltages at the collector of transistor **52** are isolated from capacitor **58** by diode **62**. The diode isolates the collector of transistor **52** from the capacitor during the half-cycle when transistor **52** goes out of conduction but does not effect the half-cycle when transistor **52** conducts. Positive pulses from the collector of transistor **52** are coupled through diode **62** and capacitor **58** to the base of transistor **50**. A negative going signal to rapidly switch transistor **12** out of conduction is provided by amplifier **64**. Amplifier **64** is driven by the fast rising positive going pulse from the collector of transistor **50** which exists when transistor **50** goes into conduction. The pulse is amplified and inverted in amplifier **64**. The drive signal appearing at the collector of amplifier **64** more quickly gates transistor switch **12** out of conduction than would a signal from transistor **52** because it has a shorter fall time and reaches a more negative voltage level.

The operation of the regulated power supply of the invention may be better understood by consideration of the waveform shown as an example in FIGURE 3. All illustrations of FIG. 3 are based on a time scale of twenty-five microseconds for one cycle of operation. FIG. 3*a* illustrates the constant reference voltage which is applied to one base of differential amplifier **28**. Assume that transistor switch **12** is conducting. FIG. 3*b* depicts voltage variations at the base of transistor **28B**. The voltage variations at this base junction are the output voltage at terminal **22**. During the time that transistor switch **12** is conducting the output voltage rises in magnitude. Note that FIG. 3*b* shows the sample voltage rising above the level of the reference voltage. The sample voltage continues to rise throughout the time required to gate transistor switch **12** and plus the time required for transistor **12** to cease conduction. Consider now the effect resulting from the sample voltage rising above the reference voltage. FIGS. 3*c* and 3*d* portray difference voltages which appear at the collectors of amplifiers **28A** and **28B**, respectively, and at the base connections of amplifiers **40** and **42**, respectively. These signals are amplified by transistors **40** and **42**. The pair of complementary error signals which appear at the collectors of transistors **40** and **42** are shown in FIGS. 3*e* and 3*f*, respectively. Note that the error signals vary from a high state to a low state and vice versa in response to the sample voltage, as shown in FIG. 3*b*, rising above and falling below the level of the error voltage. At this time the collector voltage of amplifier **40**, as shown in FIG. 3*e*, falls to a less positive value. This voltage is applied to the base of transistor **50** which is cut off during the time transistor switch **12** is conducting. The negative going signal from transistor **40** will cause the bistable multivibrator to reverse its state in the following manner. The negative going signal from transistor **40** charges capacitor **58**. Transistor **50** begins to conduct as the base-emitter junction becomes forward biased. Refer to FIG. 3*g* for the waveform of the collector voltage of transistor **50**. During the time transistor **50** was off capacitor **54** was charged. As transistor **50** rapidly begins to conduct, capacitor **54** discharges into the base emitter junction of transistor **52**, thereby turning transistor **52** off. The positive going pulse at the collector of transistor **50** is also applied to the base of amplifier **64**, as seen in FIG. 3*m*. This pulse drives the base of amplifier **64** to a less negative potential. It may be seen in FIG. 3*n* that the emitter of amplifier **64** is held at a negative value by capacitor **68**. As amplifier **64** begins to conduct in response to the positive going pulse at its base, capacitor **68** discharges through amplifier **64**. FIG. 3*h* shows that the common connection of the collector of amplifier **64**, the collector of transistor **52** and the base of switch **12** falls to a negative potential. During the period switch **12** was conducting the base voltage had been at a level very close to the value of the input voltage at terminal **10**. Amplifier **64** conducts for a very short period to remove energy from the base junction of transistor switch **12**, thereby rapidly gating transistor switch **12** out of conduction. As shown in FIG. 3*j* the emitter voltage of switch **12** falls from a high value to a slightly negative one. In FIG. 3*l* it may be seen that capacitor **74** held a positive charge during the interval the sample voltage was rising because transistor switch **12** was conducting. As the emitter of transistor switch **12** falls to a slightly negative value, a negative pulse is transmitted by capacitor **74** through forward-biased diode **70** to charge capacitor **68** negatively. Thus, the bias network comprising capacitor **74**, resistor **72**, and diode **70** has readied capacitor **68** for the next cycle of operation. The sample voltage shown in FIG. 3*b* peaks and begins to decrease because transistor switch **12** has now ceased to conduct.

Continuing now to the sequence of events through which the falling of the sample voltage below the level of the reference voltage, as seen in FIG. 3*b*, actuates transistor switch **12** back into conduction. As seen in FIG. 3*e* and FIG. 3*f*, the pair of error signals at the collectors of transistors **40** and **42** reverse as the polarity of the reference voltage with respect to the sample voltage changes. During this half-cycle the negative going voltage shown in FIG. 3*f* changes the bias on the base-emitter junction of transistor **52** by charging capacitor **54**. As transistor **52** begins to conduct, its collector voltage approaches the level of the emitter voltage as shown in FIG. 3*i*. A positive going voltage is coupled from the collector of transistor **52** through forward bias diode **62** and capacitor **58** to switch transistor **50** out of conduction. The voltage at the junction of diode **62** and capacitor **58** is shown in FIG. 3*k*. The positive going voltage at the collector of transistor **52** carries the base of transistor switch **12** to a positive value thereby gating it back into conduction. As may be seen in FIG. 3*j*, the emitter voltage of switch **12** increases from a slightly negative value to a value approaching that of the source voltage as switch **12** goes back into conduction. At this point the cycle starts anew. The sample voltage as shown in FIG. 3*b* rises during the interval that transistor switch **12** conducts.

What is claimed is:

1. A regulating power supply for regulating an input

source voltage to provide a DC output voltage of predetermined voltage level, said regulating power supply comprising:

an output terminal;

an input terminal for receiving the input source voltage;

switch means connected between said input and said output terminal and selectively actuable for establishing either a conductive or non-conductive connection therebetween;

a bistable device coupled to said output terminal and responsive to the output voltage thereon for switching to a first stable state whenever the output voltage rises above the predetermined voltage level and for switching to a second stable state whenever the output voltage falls below the predetermined voltage level, said bistable device producing a first fast rising output signal whenever it switches to one of its stable states and producing a second separate fast rising output signal whenever it switches to the other of its stable states;

first means responsive to the first output signal for actuating said switch means to establish a conductive connection; and

second means responsive to the second output signal for actuating said switch means to establish a non-conductive connection.

2. The combination as defined in claim **1** wherein said second means for actuating said switch means includes an inverting amplifier for inverting the second output signal and for actuating said switch means with the inverted second output signal to establish a non-conductive connection.

3. A regulating power supply for regulating an input voltage to provide a DC output voltage of predetermined voltage level, said regulating power supply comprising:

an output terminal;

an input terminal for receiving the input source voltage;

switch means for selectively applying the source voltage to said output terminal, said switch means being connected between said input terminal and said output terminal, and being selectively conductive or non-conductive therebetween in response to application to said switch of predetermined first and second gating signals;

means for producing a reference voltage;

comparing means coupled to receive the reference voltage and the output voltage, for producing a signal proportional to the difference between the reference voltage and the output voltage;

a bistable device having a first and second stage, said first and second stages being connected to said comparing means to receive the difference signal, said first stage being responsive to the difference signal for producing a first fast rising output signal whenever the output voltage falls below the predetermined voltage level and said second stage being responsive to the difference signal for producing a second separate fast rising output signal whenever the output voltage rises above the predetermined voltage level;

first means connected between said first stage of said bistable device and said switch means for coupling the first output signal to said switch means to serve as the first gating signal; and

inverting means connected between said second stage of said bistable device and said switch means and responsive to the second output signal for producing the second gating signal and applying the second gating signal to said switch means.

4. A regulating power supply for regulating an input source voltage to provide a DC output voltage of predetermined voltage level, said regulating power supply comprising:

an output terminal;

an input terminal for receiving the input source voltage;

a switching transistor for producing unidirectional voltage pulses, said switching transistor being connected to said input terminal and being selectively conductive or non-conductive in response to application to said switching transistor of predetermined first and second gating signals;

a filter for smoothing the unidirectional voltage pulses, said filter being connected between said switching transistor and said output terminal;

means for producing a reference voltage;

a difference amplifier coupled to receive the reference voltage and the output voltage for producing a signal proportional to the difference between the reference voltage and the output voltage;

a bistable multivibrator having a first and second stage, said first and second stages being connected to said difference amplifier to receive the difference signal, said first stage being responsive to the difference signal for producing a first fast rising output signal whenever the output voltage falls below the predetermined voltage level and said second stage being responsive to the difference signal for producing a second separate fast rising output signal whenever the output voltage rises above the predetermined voltage level;

first means connected said first stage of said bistable multivibrator and said switching transistor for coupling the first output signal to said switching transistor to serve as the first gating signal; and

a transistor amplifier connected between said second stage of said bistable multivibrator and said switching transistor and responsive to the second output signal for inverting the second output signal and applying the inverted second output signal to said switching transistor as the second gating signal.

5. The combination as defined in claim **4** wherein said bistable multivibrator includes a diode connected between said first and second stages of said bistable multivibrator for isolating said first stage from said second stage.

6. The combination as defined in claim **5** wherein said transistor amplifier includes a capacitor for normally biasing said transistor amplifier out of conduction until said transistor amplifier receives said second output signal.

7. The combination as defined in claim **6** wherein said transistor amplifier includes an RC network for charging said capacitor, said network being connected between the output of said switching transistor and said capacitor.

8. The combination as defined in claim **4** wherein said means for producing a reference voltage includes a network comprising a resistor and Zener diode, said resistor being connected to said input terminal and said Zener diode being connected to said resistor.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,450,980 Dated June 17, 1969

Inventor(s) A. L. BETTON

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the specification, Column 1, Line 39 delete "valve" and insert therefor --value--.

In the specification, Column 1, Line 43, delete "." at end of line after the word applications and insert thereor --,--.

In the specification, Column 1, Line 65, after the word rise delete "ties" and insert therefor --times--.

In the specification, Column 1, Line 71 delete "pulses" and insert therefor --pulse--.

In the specification, Column 3, Line 63 delete "24" and insert therefor --34--.

In the specification, Column 8, Line 18, delete "outer" and insert therefor --other--.

In the claims, Column 11, Line 26, after the word connecte insert --between--.

SIGNED AND SEALED
MAR 24 1970

(SEAL)
Attest:

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