PATENT SPECIFICATION

(11) 1 570 972

(21) Application No. 40540/77 (22) Filed 29 Sept. 1977
(31) Convention Application No. 735 472
(32) Filed 26 Oct. 1976 in
(33) United States of America (US)
(44) Complete Specification published 9 July 1980
(51) INT CL³ F02P 3/04
(52) Index at acceptance F1B 2D11B
(72) Inventors ROBERT BENJAMIN JARRETT and DON WILLIAM ZOBEL

1 570 972

(19) THE PATENT OFFICE LONDON

(54) IGNITION SYSTEM INCLUDING THRESHOLD CIRCUIT

(71) We, MOTOROLA, INC., a corporation organised and existing under the laws of the State of Delaware, United States of America, of 1303 E. Algonquin Road, Schaumburg, Illinois 60196, United States of America, do hereby declare the invention, for which we pray that it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an ignition system including a threshold circuit to vary the dwell time of the system in response to changes in engine r.p.m.

In contemporary electronic ignition systems energy is stored in the primary winding of an ignition coil to develop, upon discharge of the coil, the necessary voltage across the secondary winding to provide a spark to operate the engine. The energy level is a function of the amount of current flowing through the primary and the duration thereof prior to the time when the current is interrupted to discharge the coil. It is the object of all such ignition systems to develop sufficient energy in the coil, at the highest operating engine speed, to provide the necessary voltage to cause high energy sparking. High energy spark causes the engine to operate more efficiently which reduces pollutant emissions from the vehicle.

One such ignition system provides a variable dwell time (ratio of current on time to off time) as the engine RPM is varied. Thus, at higher engine RPM the dwell time is regulated to be longer than at lower engine RPM which ensures sufficient energy storage in the coil to generate a high energy ignition spark. At lower engine RPM the dwell percent is reduced in order to minimize power dissipation in the ignition circuit.

As understood, a series of alternating ignition timing signals are generated across a sensor coil in timed relationship to the engine operation. For example, for an eight cylinder automobile, eight ignition timing signals are generated to complete one cycle of the engine operation. Each individual firing cycle comprises the negative half cycle portion and the positive half cycle portion of the timing signal. In the instant ignition system the ignition timing signals are symmetrically generated about an adjustable DC potential. By comparing the magnitude of the ignition signal generated to a fixed reference potential, a triggering signal can be produced when the magnitude of the ignition signal becomes greater than the reference potential to cause current to flow through the ignition coil to effect charging of the same. In response to the engine speed increasing, the level of the DC potential is increased which effectively causes the triggering signal to be generated earlier in the firing cycle to increase the dwell percent. In this fashion, at low engine RPM the dwell time can be maintained below 10 percent of the total firing cycle while at higher engine RPM the dwell time can be increased to approximately 75 percent of the firing cycle. Therefore, at higher engine RPM high energy ignition sparking is insured while at lower engine RPM minimum power dissipation is produced.

In order to generate the timing signal symmetrically about the aforesaid DC potential, the terminal of the sensor coil which is adapted to receive the DC potential must be terminated in a very low impedance. The larger in value that this termination impedance becomes, the more that the gain of the sensor coil is effectively reduced. Reduction of the gain of the sensor coil can cause a mis-spark condition at low engine RPM which is very undesirable. Moreover, if the generated ignition signal is not symmetrical about the DC potential, control of the initiation of current flow through the ignition coil cannot be provided.

The present invention overcomes the above problems in a unique manner by providing a high impedance termination to the source of DC potential while providing a low impedance termination to the sensor coil.

To provide a low impedance termination, the prior art system uses a low value resistor to terminate the senor coil. This allows excessive current drain to occur, as the DC potential is increased to a maximum value, at high engine RPM. However the high impedance termination of the present invention reduces current drain of the ignition system.

Moreover, because current drain is reduced by the present invention, under "load dump" conditions, which are specified by the automobile industry, power dissipation in the present ignition system can be greatly reduced which increases the reliability of the ignition system of the invention over the prior art as described hereinafter.

According to the present invention there is provided an ignition system including a threshold circuit to vary the dwell time of the system in response to changes in engine RPM, the ignition system including a sensing device having first and second terminals across which alternating timing signals are developed the magnitude of which varies in accordance with the engine RPM, an ignition coil for producing spark to operate the engine in response to being charged and then discharged, and current drive circuitry for charging the ignition coil in response to an applied control signal comprising a charge storage device being coupled to the first terminal of the sensing device for providing a direct current potential having a magnitude proportional to the magnitude of the ignition timing signals, a unity gain amplifier having an input coupled to said charge storage device and having an output coupled to the second terminal of the sensing device; said unity gain amplifier providing a low impedance termination at the second terminal of the sensing device and being responsive to changes in the magnitude of the potential applied thereto from said charge storage device for varying the direct current potential provided at the output thereof about which the ignition timing signals are developed, and a comparator circuit having an input coupled to the first terminal of the sensing device and an output coupled to the current drive circuitry for producing the control signal to render the current drive circuitry conductive when the voltage at the first terminal of the sensing device becomes equal to or greater than an established predetermined value.

In one embodiment of the invention there is provided a threshold circuit suitable to be fabricated in monolithic integrated circuit form which is utilized in a variable dwell ignition system. The threshold circuit comprises an adjustable voltage supply circuit and an output comparator-amplifier. The adjustable voltage supply circuit includes an unity gain amplifier adapted to receive an applied DC voltage at an input terminal of which the magnitude is varied to cause the output of the amplifier to vary accordingly. The amplifier provides a high impedance input to the source of the applied DC voltage and a low output impedance at the output thereof. The output comparator-amplifier develops a zero temperature coefficient reference potential and is adapted to be connected at an input terminal to one terminal of the sensor coil of the ignition system. The output of the unity gain amplifier is adapted to be connected to the other terminal of the senor coil such that as the output level from the unity gain amplifier is adjusted, by adjusting the applied input DC voltage level, the average value of the alternating ignition timing signal developed across the sensor coil is varied which varies the threshold level of the circuit. By varying the threshold level, the output comparator is caused to be rendered conductive sooner or later during the firing cycle, which causes the dwell time to be varied.

The invention will now be described by way of example only with particular reference to the accompanying drawings wherein:

Fig. 1 illustrates in partial schematic and block diagram form an electronic variable dwell ignition system of the present invention including the threshold circuit;

Fig. 2 illustrates waveforms useful for understanding the operation of the ignition system of Fig. 1; and

Fig. 3 illustrates in schematic form the threshold circuit of the ignition system of the present invention.

Referring to the drawings, Fig. 1 illustrates an electronic ignition system 10 which utilizes the threshold circuit 12. The portion of the ignition system 10 shown within dashed outline 14 is suitable to be fabricated in monolithic integrated circuit form. Ignition system 10 is a variable dwell ignition system, the function thereof being known in the art. Briefly, however, in response to ignition timing signals (Fig. 2) developed across sensor coil 16, current is caused to flow through the primary winding of ignition coil 18. By controlling the time that the current is initiated through the primary winding, the dwell time (ratio of current on to off time) is varied. Thus, power dissipation of system 10 may be maintained minimal by reducing the dwell time at low engine RPM and increasing the dwell time at high RPM. Moreover, by varying the dwell time at high engine RPM, sufficient energy can be developed in coil 18 to insure adequate spark to operate the engine.

More specifically, Fig. 1 illustrates in partial schematic and diagram form the components necessary for providing variable dwell operation. A magnetic pickup device (not shown) is positioned in the distributor of a vehicle engine which, as it rotates past sensor coil 16, develops an ignition timing signal illustrated in Fig. 2. Sensor coil 16 is connected between terminals S1 and S2 of threshold circuit 12, between amplifiers 20 and 22, respectively. The importance of this particular connection of sensor coil 16 will be discussed later. Generally, (Fig. 2A) as the magnitude of the timing signal, waveform 24, becomes greater than the magnitude of V_{REF} (generated internally to chip 14) comparator amplifier 22 is rendered conductive which in turn renders amplifiers 26 operative. When amplifier 26 is rendered operative, current is caused to flow into output amplifier stage 28 (which is provided off chip) which produces current flow through coil 18 and current sense resistor 30. Thus, energy is stored in the primary of coil 18. When the magnitude of the current from amplifier 28 to resistor 30 reaches a predetermined value, current sensor and regulator circuit 32 is activated to render transistor 34 conductive, (it otherwise being in a non-conductive state). Transistor 34 shunts input current away from amplifier 26 and reduces the output current therefrom such that current limiting occurs through output amplifier stage 28. As will be explained later, during current limiting when regulator circuit 32 is operative, discharge circuit 36 is caused to be operative which discharges capacitor 38. Previous to current limiting, capacitor 38 is charged to a predetermined value which produces a voltage, V_C, thereacross that is proportional to the magnitude of the ignition timing signal developed at terminal S_2. The resistor divider comprising resistors 40 and 42 provides a voltage which is proportionate to that developed at terminal S_2 at terminal 44. This voltage is utilized to charge capacitor 38 through resistor 46 and diode 48 during the positive half cycle of ignition timing signal 24 prior to current limiting.

Turning to Fig. 2, there is illustrated waveforms useful for explaining the variable dwell operation of ignition system 10. Figs. 2A and 2B correspond to low engine speeds, e.g., idling speeds, and Figs. 2C and 2D are representative of higher engine RPM. In all cases, V_{REF} is maintained substantially constant such that as the voltage at terminal S_1 is varied, the point at which amplifier 22 trips is caused to be varied. As is seen, the voltage developed across sensor coil 16 rides about the potential V_C, which is the magnitude of the voltage developed across capacitor 38. It is assumed that at low engine speeds V_C is nearly at ground potential.

Referring to Figs. 2A and 2B, a firing cycle is initiated at time T_1 when the timing signal goes negative. At T_2 waveform 24 reaches a peak negative value and begins going positive. At time T_3, the voltage developed across sensor coil 16 (which is applied at the input of amplifier 22) becomes equal to V_{REF} rendering amplifier 22 conductive. As amplifier 22 is rendered conductive output stage 28 is also turned on. Current then begins to ramp up through coil 18 (portion 52 of waveform 50). At time T_4 the current through the ignition coil has reached a value which causes limiting as is shown by portion 54 of waveform 50. At T_5, another firing cycle is initiated and the voltage developed across sensor coil 16 again goes negative. Output amplifier 28 remains conductive until the voltage at terminal S2 decreases below the value shown by point 56 (Fig. 2A) which renders amplifier 22 non-conductive and shuts off output amplifier 28. Ignition coil 18 is then caused to be discharged as current ceases to flow therethrough and spark is produced. At low engine RPM, the dwell time (T_5-T_3) of the system may be 10% or less of the total firing cycle.

As understood, at higher engine RPM it is desired to turn on output stage 28 sooner in the firing cycle so that current limiting will occur to insure adequate spark. From above, the ignition timing signal generated across sensor 16 is referenced to the voltage potential appearing at terminal S_1 and is developed symmetrically thereabout. By varying the value of V_C the average value of the generated ignition timing signal can be caused to vary with respect to the voltage reference potential V_{REF}. As observed in Figs. 2C and 2D, as V_C is increased with respect to V_{REF}, the particular value at which the ignition signal (waveform 58) becomes greater than V_{REF} occurs earlier in the firing cycle and causes current to flow through the ignition coil sooner. At T_3, the magnitude of waveform 58 becomes substantially equal to V_{REF} and amplifier 22 becomes conductive. By charging capacitor 38 to a higher value, V_C is increased which in turn causes amplifier 22 to be tripped sooner in the firing cycle. Subsequently, current limiting (portion 62 of waveform 60) occurs prior to the end of the firing cycle and a high energy voltage spark is provided upon discharge of the ignition coil (time T_5).

At higher engine speeds the magnitude of V_C is controlled by the closed feedback loop comprising discharge circuit 36, resistors 40, 42, 46 and diode 48. At higher RPM, larger voltage magnitudes are generated across sensor coil 16 and the higher magnitude of the voltage picked off by the resistor divider comprising resistors 40 and 42 produces a current through diode 48 to charge capacitor 38. Thus, capacitor 38 is charged to a higher value as engine RPM is increased which develops a higher voltage thereacross, conversely capacitor 38 is discharged to lower the voltage developed thereacross at lower engine RPM. Hence, as the frequency of the firing cycle increases, output stage 28 is rendered conductive proportionately sooner in the firing cycle time period. Subsequently, the dwell time is varied. In a steady state condition, i.e., constant engine RPM, the value of V_C is held constant such that the dwell time remains constant. This results by discharging capacitor 38 through discharge circuit 36 the same amount that it is charged through diode 48. Discharge circuit 36 is rendered operative only during the current limit portion of the firing cycle in response to a control signal developed from current sense and regulator circuit 32. At higher RPM the closed loop system insures that capacitor 38 is maintained at a desired state of charge. For instance, during steady state operation if for some reason capacitor 38 is charged to a higher value than normal, during the subsequent firing cycle output stage 28 will be rendered conductive sooner such that current limiting occurs sooner which in turn discharges capacitor 38 longer until the steady state value is once again obtained.

As will be explained, several significant advantages are provided by ignition system 10 over contemporary variable dwell ignition systems. One such advantage is provided by amplifier 20 of threshold circuit 12 which functions as a variable potential supply circuit. Amplifier 20 is a unity gain amplifier and provides both a high impedance termination to capacitor 38 and a low impedance termination to terminal S_1 of sensor coil 16.

As explained earlier, the dwell time is caused to vary in conjunction with the value of V_C developed across capacitor 38. As V_C increases, the point at which the value of the ignition timing signal (waveforms 24 and 58) becomes greater than V_{REF} occurs sooner in the firing cycle. Thus, any variation in V_C causes a corresponding variation in the dwell time. In the present invention, the voltage developed across capacitor 38 remains substantially constant until discharge because leakage current is maintained at a minimum due to the high input impedence developed at the input of amplifier circuit 20. Hence, the trip point of the ignition system of the present invention can be well defined.

Furthermore, by providing a low impedance termination to terminal S_1, the voltage derived across sensor coil 16 is caused to be symmetrically varied about the potential appearing at the output of amplifier 20 (illustrated as V_C in Fig. 2). If the termination impedance increases, the gain of the sensor coil is caused to be reduced which reduces the magnitude of voltage developed across the sensor coil. If the gain of the sensor coil is seriously reduced there is the possibility that at low engine RPM the generated ignition timing signal would not reach a peak value sufficient to trip amplifier 22 and misfiring would occur in the engine. Furthermore, the more asymmetrical the ignition timing signal becomes about the reference potential V_C, the less accurate is the point that amplifier 22 is rendered conductive during a firing cycle. Hence the dwell time of the ignition system cannot be well defined. Therefore, it is very important to maintain a low output impedance at terminal S_1.

Fig. 3 illustrates threshold circuit 12 of the present invention which provides the advantages discussed above. Threshold circuit 12 which in preferred form is a portion of of IC chip 14 is adapted to receive a power supply voltage V_{CC} supplied to power supply conductor 65. Amplifier 20 is illustrated as including input Darlington amplifier 66 comprised of transistors 68 and 70. The base electrode of transistors 68 is adapted to be connected to capacitor 38 at terminal 72 with the collectors of transistors 68 and 70 coupled to power supply conductor 65. The emitter of transistor 70 is coupled through resistor 74 to another power supply terminal 75 which may be at ground potential and also to the base of transistor 76, a PNP substrate transistor. Transistor 78 and 80 function as a push-pull output section. The base electrode of transistor 78 is coupled through current source 86 to power supply conductor 65 and to the emitter of transistor 76 through a pair of diodes 82 and 84. The base of transistor 80 is also connected to the emitter of transistor 76. The output of amplifier or voltage supply circuit 20 is coupled, via resistor 88, from the interconnected emitter electrodes of transistors 78 and 80 to terminal S_1 which is adapted to be connected thereat to sensor coil 16. The high input impedance provided to input terminal 72 is developed by "beta" multiplying the value of resistor 74, which in the preferred embodiment, is approximately equal to 3,000 ohms. This resistor also limits the current drain through Darlington amplifier 66 such that power dissipation is minimal. Similarly, a low output impedance is provided to terminal S_1 by dividing the value of resistor 74 by the betas of transistors 76 and 80 respectively.

In operation, the voltage potential appearing at terminal S_1 is nominally 2ϕ (where ϕ is the base-to-emitter voltage drop of the bipolar transistors) at all times when the magnitude of V_C is less than 2ϕ. If ϕ is approximately equal to 0.7 volts, then with V_C less than 1.4 volts, transistors 68 and 70 are nonconductive and no current flows therethrough to resistor 74. In this state the voltage appearing at the emitter of transistor 78 and to terminal S_1 is essentially 1.4 volts. However, when V_C becomes greater than 1.4 volts, the voltage appearing at terminal S_1 will thereafter be substantially equal to V_C. In this state the voltage at terminal S_1 tracks V_C for all values of V_C greater than 1.4 volts. This can be observed in Fig. 3 by considering that the base-to-emitter voltages of all the bipolar transistors are substantially equal. Then, when $V_C > 1.4$ volts, the voltage at terminal S_1 is;

$$V_{S1} = V_C - \phi_{68} - \phi_{70} + \phi_{76} + \phi_{84} + \phi_{82} - \phi_{78} \quad (1)$$

and

$$V_{S1} = V_C \quad (2)$$

Amplifier 22 of threshold circuit 12 is illustrated as comprising NPN transistor 90 serially connected to PNP substrate transistor 92. The base electrode of transistor 90 is coupled, via resistor 94, to terminal S_2 which is adapted to be connected to the other terminal of sensor coil 16. The collector of transistor 90 is coupled through current source 96 to power supply conductor 65 and also connected to output terminal 102. The collector of transistor 92 is connected to the ground reference line 75 with the base electrode thereof connected between the junction of current source 98 and resistor 100, the later two components being series connected between power supply conductor 65 and ground potential. It should be noted that resistor 100 is equal in value to the resistor 74.

In operation, current source 98 establishes the reference voltage, V_{REF}, across resistor 100 which is applied at the base of transistor 92. Transistor 92 remains non-conductive until such time that the voltage potential applied at terminal S_2 reaches a value which is $20 + V_{REF}$. Because sensor coil 16 is connected between terminals S_1 and S_2, when V_C is less than 1.4 volts, the voltage at terminal S_1 is equal to 1.4 volts and transistors 90 and 92 are rendered conductive when the voltage developed across sensor coil 16 becomes substantially equal to V_{REF}. This condition is illustrated in Fig. 2A. However, (Fig. 2C) when V_C becomes greater than 1.4 volts, the voltage at terminal S_1 is substantially equal to V_C such that the ignition timing signal rides thereabout and transistors 90 and 92 are rendered conductive sooner in the firing cycle. Therefore, as explained earlier, increasing the value of V_C (with V_{REF} being held constant) causes transistor 90 to be rendered conductive sooner. When transistor 90 is in the conductive state, amplifier 26, which is coupled thereto, is rendered conductive and energization current flows through ignition coil 18 as explained, supra.

By utilizing known techniques the voltage developed across resistor 100 can be made to have a zero temperature coefficient. Hence, if fabrication process variations are eliminated, the percentage dwell time at each respective engine RPM will remain substantially constant even though temperature conditions may vary.

The effect of process variations on the performance of threshold circuit 12 can be obviated by matching components of amplifiers 20 and 22. To eliminate such variations, substrate devices 76 and 92 as are current sources 86 and 96, are matched using known circuit techniques. Thus, the current supplied through diodes 82, 84 to transistor 76 is essentially equal in magnitude to the current through transistor 92. Because resistors 74 and 100 are identical in value, the relative values of the betas of transistors 76 and 92 are of no concern. Any voltage drop developed across resistor 74 due to the base current of transistor 76 will then be identical in value to the voltage developed across resistor 100 by base current from transistor 92. Hence, these variations are "common moded" between terminals S1 and S2 and do not affect the operation of the circuit.

In the operation of ignition system 10, threshold circuit 12 provides several significant advantages over contemporary variable dwell ignition systems. One such advantage is that the value of V_C is held essentially constant during each firing cycle because of the high input impedance appearing at terminal 72. Hence, very little leakage current is developed which otherwise would cause discharging of capacitor 38. Thus, for a given engine RPM, the dwell time remains constant.

Ignition system 10 requires lower power drain than similar variable dwell ignition systems. The relatively large value of resistor 74 limits the current during through Darlington amplifier 66 by an order of magnitude over prior art ignition systems. For example, the drain current of ignition system 10 is less typically than three milliamperes, whereas that of the prior art is 30 milliamperes. Since the current drain of the instant circuit is quite minimal, power dissipation under "load dump" conditions is significantly less than that of the prior art which increases the reliability of ignition system 10 thereover.

Thus, what has been described above is an improved variable dwell ignition system utilizing a novel threshold circuit. The threshold circuit comprises an input variable voltage supplied circuit and an output amplifier having hysteresis.

WHAT WE CLAIM IS:—

1. An ignition system including a threshold circuit to vary the dwell time of the system in response to changes in engine RPM, the ignition system including a sensing device having first and second terminals across which alternating timing signals are developed the magnitude of which in accordance with the engine RPM, an ignition coil for producing spark to operate the engine in response to being charged and then discharged, and current drive circuitry for charging the

ignition coil in response to an applied control signal comprising a charge storage device being coupled to the first terminal of the sensing device for providing a direct current potential having a magnitude proportional to the magnitude of the ignition timing signals, a unity gain amplifier having an input coupled to said charge storage device and having an output coupled to the second terminal of the sensing device; said unity gain amplifier providing a low impedance termination at the second terminal of the sensing device and being responsive to changes in the magnitude of the potential applied thereto from said charge storage device for varying the direct current potential provided at the output thereof about which the ignition timing signals are developed, and a comparator circuit having an input coupled to the first terminal of the sensing device and an output coupled to the current drive circuitry for producing the control signal to render the current drive circuitry conductive when the voltage at the first terminal of the sensing device becomes equal to or greater than an established predetermined value.

2. An ignition system as claimed in claim 1 wherein said unity gain amplifier includes a Darlington amplifier input stage having an input coupled to said charge storage device and an output, first resistive device coupled between said output of said Darlington amplifier and a reference potential, and an output amplifier circuit having an input coupled to said output of said Darlington amplifier and an output coupled to said output of the unity gain amplifier.

3. An ignition system as claimed in claim 2 wherein said output amplifier circuit includes a first transistor of a first polarity type having a base electrode coupled to said output of said Darlington amplifier, a collector electrode coupled to said reference potential and an emitter electrode, a second transistor of said first polarity type having a base electrode coupled to said emitter electrode of said first transistor, a collector electrode coupled to said reference potential and an emitter electrode coupled to the output of said output amplifier circuit, a third transistor of a second polarity type having a base electrode, a collector electrode coupled to a source of operating potential and an emitter electrode coupled to said emitter electrode of said second transistor, a current source coupled to said base of said third transistor and a voltage translation circuit coupled between said base electrode of said third transistor and said emitter electrode of said first transistor for translating the potential level appearing at said emitter electrode of said first transistor to another level at said base electrode of said third transistor.

4. An ignition system as claimed in claims 1 or 3 wherein said comparator circuit includes a first transistor of a second polarity type having a base electrode coupled to the first terminal of the sensing device, a collector electrode coupled to said output of said comparator circuit and an emitter electrode, a second transistor of a first polarity type having a base electrode, and an emitter electrode coupled to said emitter electrode of said first transistor of said comparator circuit and a collector electrode coupled to reference potential, threshold potential circuit for providing a threshold reference potential of said established predetermined value, said threshold potential circuit being coupled to said base electrode of said second transistor of said comparator circuit.

5. An ignition system as claimed in claim 4 wherein said threshold potential circuit includes a current source and a resistive device being coupled to said current source, the interconnection point between said resistive device and said current source being coupled to said base electrode of said second transistor of said comparator circuit.

6. An ignition system as claimed in claim 5 wherein said unity gain amplifier and said comparator circuit are monolithic integrated circuits, said first transistor of said output amplifier circuit and said second transistor of said comparator circuit being substrate devices and matched to each other to reduce process variations, and said respective resistive devices of said comparator circuit and said unity gain amplifier being of equal value.

7. An ignition system including a threshold circuit and substantially as hereinbefore described and as shown in the accompanying drawings.

For the Applicants:
F. J. CLEVELAND & COMPANY,
Chartered Patent Agents,
40—43 Chancery Lane,
London, WC2A 1JQ.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1980.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1570972 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

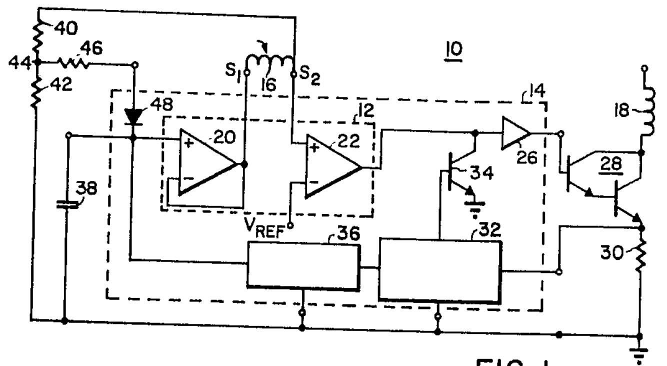

FIG. 1

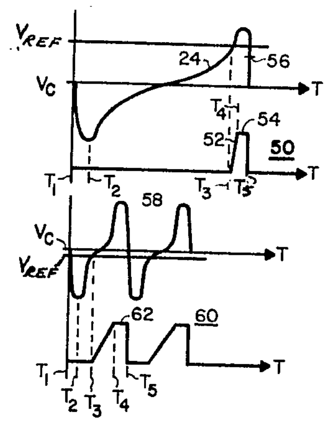

FIG. 2

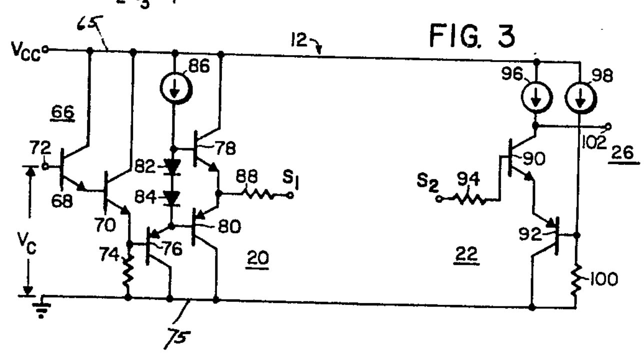

FIG. 3