

[54] **INTERNAL COMBUSTION ENGINE
IGNITION SYSTEM**

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[56] **References Cited**

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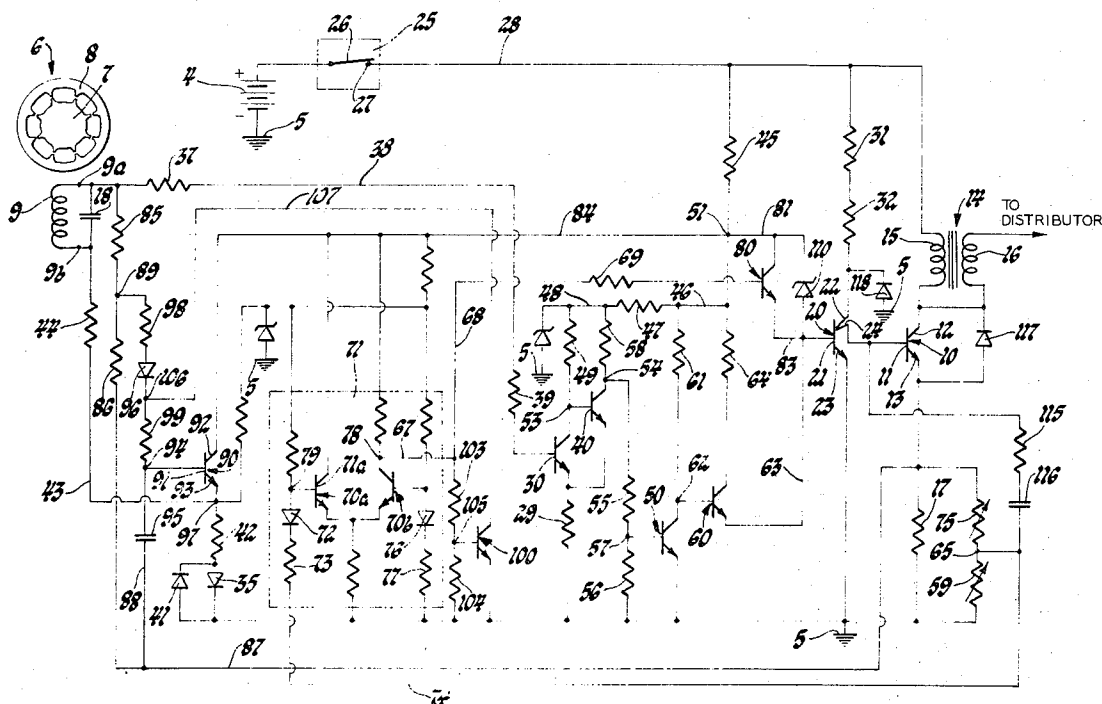
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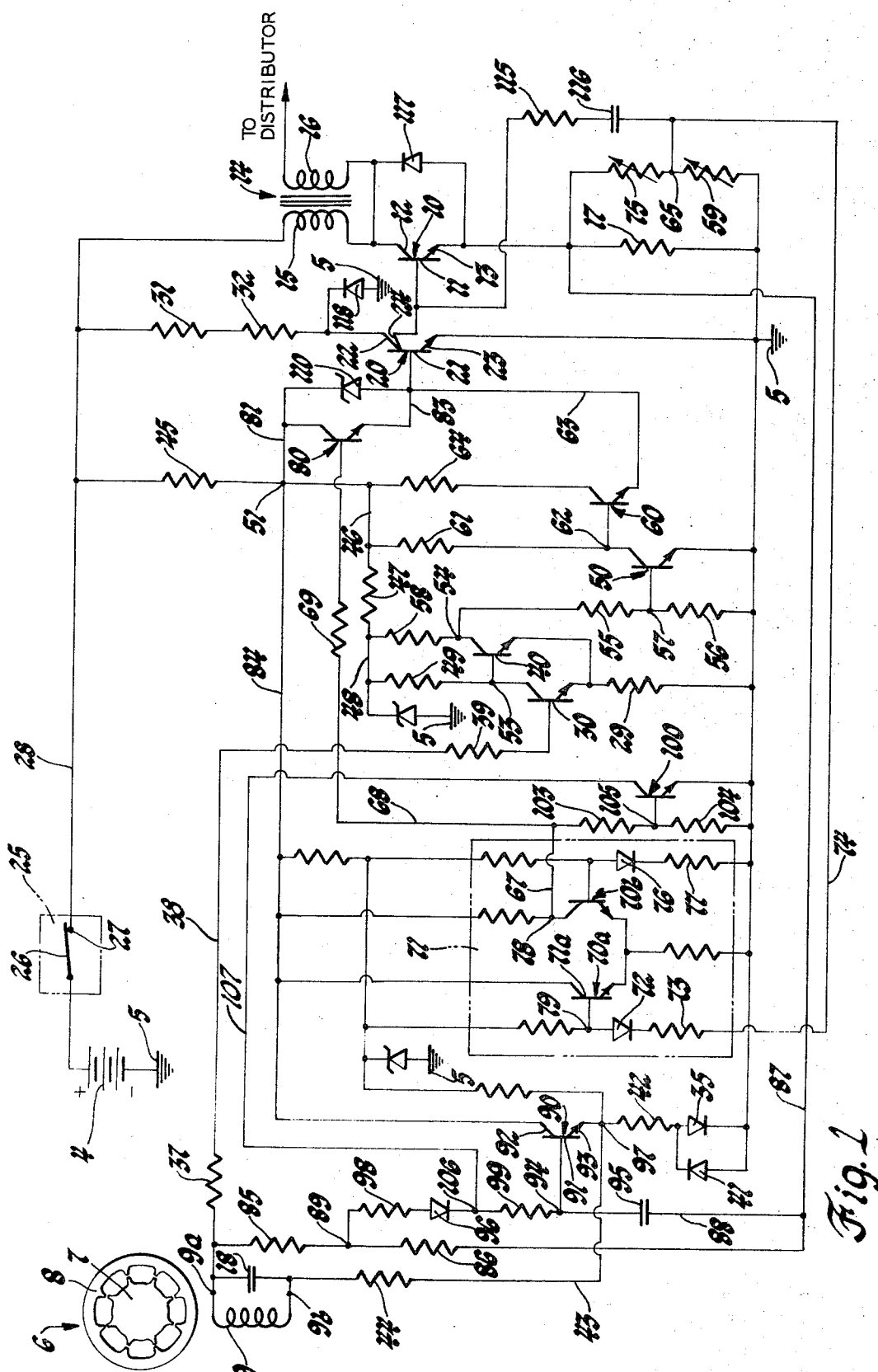
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[57] **ABSTRACT**

An internal combustion engine system having the ignition coil primary winding, the current carrying electrodes of a switching transistor, operated conductive and not conductive in timed relationship with the engine in response to alternating current ignition signals, and a control resistor connected in series across the battery. A differential amplifier circuit produces an output control signal in response to and proportional to the potential developed across the control resistor while the switching transistor is conductive. Separate circuits responsive to this control signal are provided for limiting the ignition coil primary winding energizing current to a predetermined magnitude by adjusting the base drive current supplied to the switching transistor and for establishing the length of time energizing current flows through the ignition coil primary winding by establishing the electrical angle of each cycle of the alternating current ignition signals at which the switching transistor is operated conductive.

5 Claims, 4 Drawing Figures





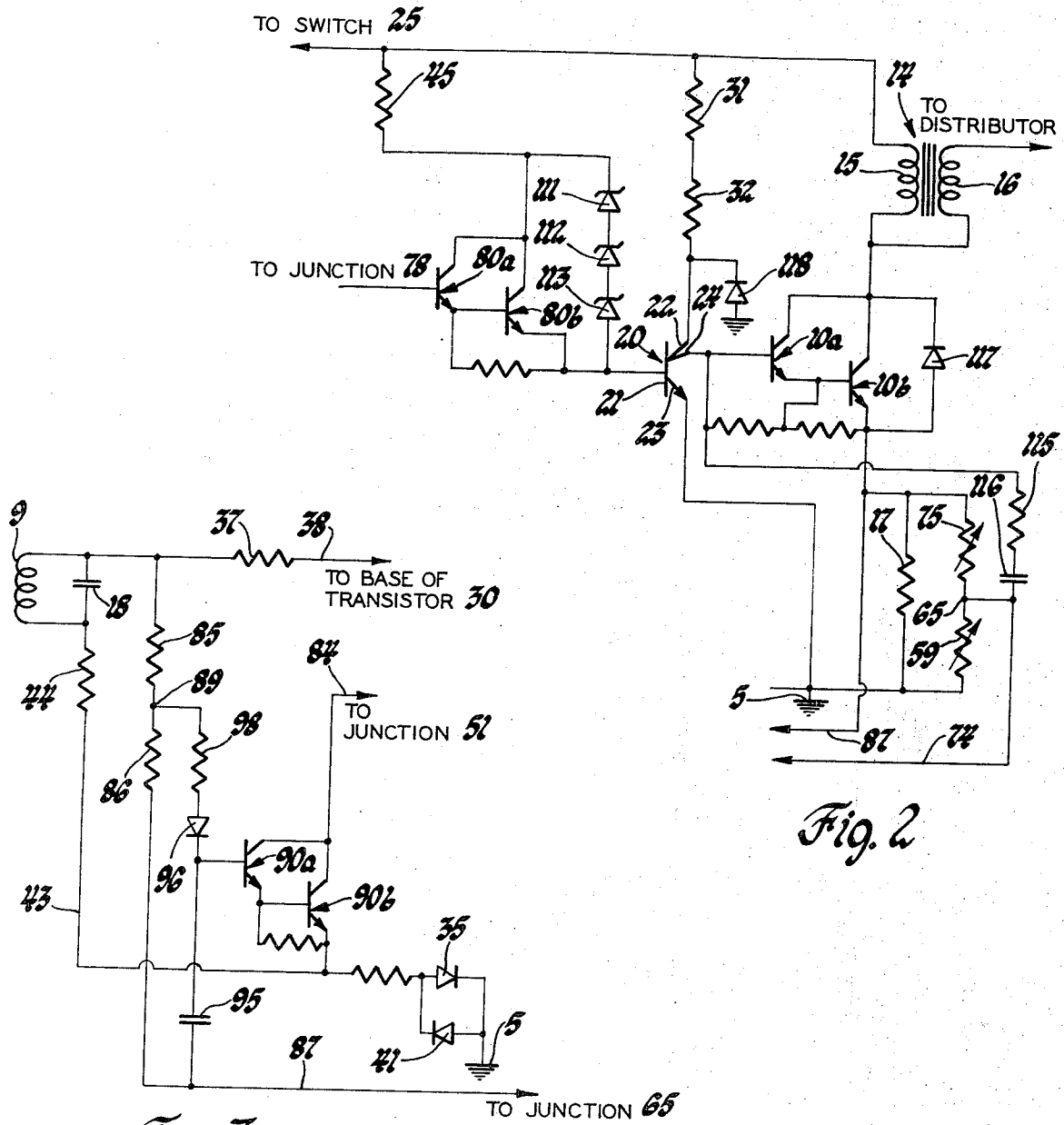


Fig. 2

Fig. 3

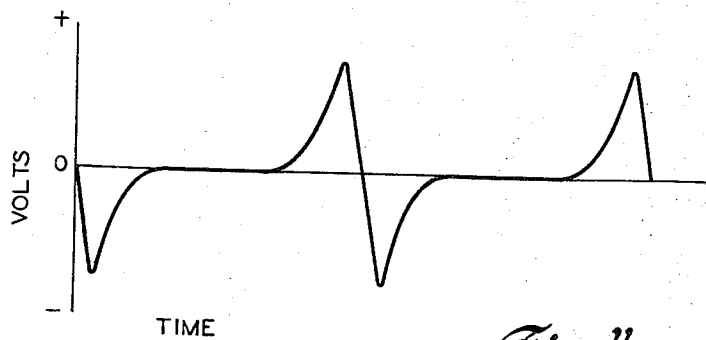


Fig. 4

INTERNAL COMBUSTION ENGINE IGNITION SYSTEM

This invention relates to internal combustion engine ignition systems and, more particularly, to a solid state internal combustion engine ignition system which provides for the limiting of ignition coil primary winding energizing current to a predetermined magnitude and establishes the length of time energizing current flows through the ignition coil primary winding.

To provide an adequate ignition sparking potential to the spark plugs of an internal combustion engine, it is necessary that the ignition coil primary winding energizing current reach a predetermined magnitude. However, should the ignition coil primary winding energizing current reach a magnitude greater than is necessary to provide an adequate sparking potential or should the ignition coil primary winding energizing current flow through the ignition coil primary winding for a period of time longer than is necessary, a significant waste of battery power results.

It is, therefore, an object of this invention to provide an improved internal combustion engine ignition system.

It is another object of this invention to provide an improved solid state internal combustion engine ignition system.

It is an additional object of this invention to provide an improved solid state internal combustion engine ignition system which limits the magnitude of energizing current flow through the ignition coil primary winding to a predetermined magnitude and determines the length of time during which energizing current flows through the ignition coil primary winding.

In accordance with this invention, an internal combustion engine ignition system is provided wherein an ignition coil primary winding switching transistor is operated conductive and not conductive in timed relationship with the engine, in response to alternating current ignition signals, and includes a differential amplifier circuit for producing an output control signal in response to and proportional to the potential drop across a control resistor, connected in series with the ignition coil primary winding and the switching transistor, which is applied to separate circuits which, respectively, limit the ignition coil primary winding energizing current to a predetermined magnitude and determine the length of time energizing current flows through the ignition coil primary winding.

For a better understanding of the present invention, together with additional objects, advantages and features thereof, reference is made to the following description and accompanying drawings in which:

FIG. 1 sets forth the internal combustion engine ignition system of this invention in schematic form;

FIG. 2 sets forth an alternate embodiment of a portion of the ignition system of FIG. 1 in schematic form;

FIG. 3 sets forth another alternate embodiment of a portion of the ignition system of this invention in schematic form; and

FIG. 4 illustrates the alternating current ignition signal waveform to which the internal combustion engine ignition system of this invention is responsive.

In FIGS. 1, 2 and 3 of the drawings, like elements have been assigned like characters of reference and the point of reference or ground potential has been schematically illustrated by the accepted symbol and reference by the numeral 5.

FIG. 1 of the drawings, the internal combustion engine ignition system of this invention is set forth in schematic form in combination with a source of alternating current ignition signals produced in timed relationship with the engine, referenced by the numeral 6; a direct current potential source, which may be a conventional storage battery 4, and an ignition coil 14, which may be a conventional automotive type ignition coil well known in the art having a primary winding 15 and a secondary winding 16 in which the high sparking potential is induced upon the interruption of the energizing circuit of primary winding 15.

The source of alternating current ignition signals 6 may be any one of the several conventional magnetic distributors well known in the automotive art. One example of a distributor well known in the automotive art suitable for use with the ignition system circuit of this invention is of the variable reluctance type disclosed and described in U.S. Pat. No. 3,254,247, Falge, which issued May 31, 1966 and is assigned to the same assignee as that of the present invention. In the interest of reducing drawing complexity, the variable reluctance type ignition distributor disclosed and described in U.S. Pat. No. 3,254,247 has been set forth in schematic form in the drawing. A rotor member 7 is rotated in timed relationship with the engine by the engine in a manner well known in the automotive art within the bore of pole piece 8. Equally spaced about the outer periphery of rotor 7 and about the bore of pole piece 8 are a series of projections equal in number to the number of cylinders of the engine with which the distributor and ignition system is being used. Pole piece 8 may be made up of a stack of a number of laminations of magnetic material secured in stacked relationship by rivets or bolts or other fastening methods and the magnetic flux may be provided by a permanent magnet, not shown, which may be secured to the lower face surface thereof. As each projection on rotor member 7 approaches a projection on pole piece 8, the reluctance of the magnetic path between pole piece 8 and rotor 7 decreases and as each projection on rotor 7 moves away from a projection on pole piece 8, the reluctance of the magnetic circuit between pole piece 8 and rotor 7 increases. Consequently, the magnetic field produced by the permanent magnet increases and decreases as each projection on rotor 7 approaches and passes a projection on pole piece 8, a condition which induces an alternating current potential in pickup coil 9, which is magnetically coupled to pole piece 8, of a waveform as shown in FIG. 3. Pickup coil capacitor 18 filters electromagnetic noise which may be coupled into the ignition system circuit from an external source.

The ignition coil primary winding 15, the current carrying electrodes of an ignition coil primary winding switching transistor, collector electrode 12 and emitter electrode 13 of NPN transistor 10, and a control impedance element, which may be a resistor 17, are connected in series across the direct current potential source through a circuit which may be traced from the positive polarity output terminal of battery 4, through movable contact 26 and stationary contact 27 of switch 25, lead 28, ignition coil primary winding 15, the collector-emitter electrodes of ignition coil primary winding switching transistor 10, control impedance element 17 and point of reference or ground potential 5 to the

negative polarity terminal of battery 4. Switch 25 of this circuit may be the ignition switch of a type well known in the art. The circuit just described is the ignition coil primary winding energizing circuit through which ignition coil primary winding energizing current flows while switching transistor 10 is conductive.

Control impedance element 17 has been illustrated in the drawing as a resistor. It is to be specifically understood, however, that any other suitable electrical impedance element which will provide a potential drop thereacross with current flow therethrough may be substituted therefor without departing from the spirit of the invention.

As with conventional automotive type ignition systems, the ignition coil primary winding energizing circuit is established to build up energizing current flow through primary winding 15 to produce a magnetic field and interrupted to collapse the magnetic field which induces a high ignition potential in secondary winding 16, in timed relationship with the engine. Consequently, circuitry responsive to each cycle of the alternating current ignition signals is provided for operating ignition coil primary winding switching transistor 10 conductive and not conductive through the current carrying electrodes thereof in timed relationship with the engine. This circuitry includes a normally not conducting control transistor 20 of the NPN type but having an additional quasi-collector electrode and type NPN transistors 30, 40, 50 and 60 and the associated circuitry.

Control transistor 20 is a silicon planar transistor comprised of an epitaxial layer of N-type conductivity silicon on a foundation wafer of P-type conductivity silicon with an N+ diffused buried layer in the foundation wafer at its interface with the epitaxial layer. The epitaxial layer serves as a transistor collector region. Over the buried layer there is an island-like P-type base region diffused into the surface of the N-type epitaxial layer, an island-like N-type emitter region diffused into the base region island and a diffused N+ surface enhancement island region inset in the surface of the epitaxial layer collector region on each of opposite sides of the base region island. A discrete ohmic contact of evaporated aluminum is laid down upon each of the emitter region, the base region and the two N+ collector surface enhancement regions to provide separate electrodes serving as the emitter electrode 23, the base electrode 21, the collector electrode 22 and quasi-collector electrode 24, respectively. With the collector emitter electrodes connected across the positive and negative polarity terminals, respectively, of a direct current potential source, a control potential applied across the base-emitter electrodes of a positive polarity upon the base electrode with respect to the emitter electrode will produce base-emitter current flow and, consequently, a current flow between collector electrode 22 and emitter electrode 23. With the quasi-collector electrode 24 connected to an external point of reference or ground potential directly or through an external electrical circuit, while the device is not conducting through the collector-emitter electrodes, current flows through the collector region between collector electrode 22 and quasi-collector electrode 24. While the device is conducting through the collector-emitter electrodes, substantially no current flows through the quasi-collector electrode 24. The reason for the low or substantially zero current flow through the quasi-

collector electrode while the device is conducting through the collector-emitter electrodes is that the quasi-collector electrode, which is at a positive polarity potential with respect to the emitter electrode, the base electrode and the emitter electrode comprise a lateral NPN transistor at the surface of the device which conducts to provide a low impedance circuit to ground around the quasi-collector electrode.

The collector electrode 22 and emitter electrode 23 of control transistor 20 are connected across the direct current potential source, battery 4, through a circuit which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistors 31 and 32, the collector-emitter electrodes of control transistor 20 and point of reference or ground potential 5 to the negative polarity terminal of battery 4. The quasi-collector electrode 24 of control transistor 20 is connected to the control electrode, base electrode 11, of switching transistor 10. Forward control electrode drive current is supplied to the control electrode 11 of switching transistor 10 through quasi-collector electrode 24 while control transistor 20 is not conducting through the current carrying electrodes for producing conduction through the current carrying electrodes of the switching transistor 10 to complete the ignition coil primary winding energizing circuit for the flow of ignition coil primary winding energizing current through ignition coil primary winding 15, the current carrying electrodes of switching transistor 10 and control impedance element 17.

While the engine is in the running mode, rotor 7 of source of alternating current ignition signals 6 is rotated in timed relationship therewith to produce an alternating current ignition signal in pickup coil 9 of a waveform as illustrated in FIG. 3 in a manner previously described.

With each half cycle of the alternating current ignition signals during which the potential of terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b, this potential signal is applied across the base-emitter electrodes of NPN transistor 30 in the proper polarity relationship to produce base-emitter drive current through a type NPN transistor through a circuit which may be traced from terminal end 9a of pickup coil 9, through current limiting resistor 37, lead 38, resistor 39, the base-emitter electrodes of NPN transistor 30, emitter resistor 29, point of reference or ground potential 5, diode 41, resistor 42, lead 43 and resistor 44 to terminal end 9b of pickup coil 9. This base-emitter drive current renders NPN transistor 30 conductive through collector-emitter electrodes thereof through a circuit through which they are connected across the direct current potential source which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistor 45, lead 46, resistor 47, lead 48, resistor 49, the collector-emitter electrodes of transistor 30, emitter resistor 29 and point of reference or ground potential 5 to the negative polarity terminal of battery 4. While transistor 30 is conductive through the collector-emitter electrodes thereof, the potential upon junction 53, through which the base electrode of NPN transistor 40 is connected to the collector electrode of transistor 30, is of an insufficient magnitude to produce base-emitter drive current through NPN transistor 40, consequently, transistor 40 is not conductive. While transistor 40 is not conductive, the potential upon junction 54 is of a positive po-

larity with respect to ground 5. This potential is applied across the voltage divider comprising series resistors 55 and 56 which are so proportioned that, with transistor 40 not conductive, the magnitude of the potential upon junction 57 is of a sufficient magnitude to produce base-emitter drive current through NPN transistor 50, the base electrode of which is connected to the collector electrode of transistor 40 through junction 57, resistor 55 and junction 54. This base-emitter drive current renders NPN transistor 50 conductive through the collector-emitter electrodes thereof through a circuit through which they are connected across the direct current potential source which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistor 45, lead 46, resistor 61, the collector-emitter electrodes of transistor 50 and point of reference or ground potential 5 to the negative polarity terminal of battery 4. While transistor 50 is conducting through the collector-emitter electrodes, junction 62, through which the base electrode of NPN transistor 60 is connected to collector electrode of transistor 50 is substantially ground potential, consequently, transistor 60 is not conductive. While transistor 60 is not conductive, base-emitter drive current is not supplied to control transistor 20, consequently, this device is also not conductive. While control transistor 20 is not conductive, base-emitter drive current is supplied through the quasi-collector electrode 24 thereof to the base electrode 11 of switching transistor 10 to render this device conductive through the collector-emitter electrodes. Conducting switching transistor 10 establishes the ignition coil primary winding energizing circuit, previously described, for the flow of energizing current through primary winding 15 and control impedance element 17. The buildup of energizing current through primary winding 15 produces a magnetic field in a manner well known in the art.

With each half cycle of the alternating current ignition signals during which the potential of terminal end 9a of pickup coil 9 is of a negative polarity with respect to terminal end 9b, this potential signal is applied across the base-emitter electrodes of NPN transistor 30 in a reverse polarity relationship, consequently, transistor 30 extinguishes. While transistor 30 is extinguished, the potential upon junction 53 is of a positive polarity with respect to ground 5 and of a sufficient magnitude to produce base-emitter drive current through NPN transistor 40. This base-emitter drive current renders NPN transistor 40 conductive through the collector-emitter electrodes thereof through a circuit through which they are connected across the direct current potential source which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistor 45, lead 46, resistors 47 and 58, the collector-emitter electrodes of transistor 40, emitter resistor 29 and point of reference or ground potential 5 to the negative polarity terminal of battery 4. While transistor 40 is conductive, through the collector-emitter electrodes, the potential upon junction 54 is of a positive polarity with respect to ground 5 of a magnitude equal to the drop across transistor 40 and emitter resistor 29. This potential is applied across a voltage divider comprising series resistors 55 and 56 which are so proportioned that, with transistor 40 conductive, the magnitude of the potential upon junction 57 is of an insufficient magnitude to produce base-emitter drive current through NPN transistor 50, consequently, this device is

not conductive through the collector-emitter electrodes. While transistor 50 is not conductive, the potential upon junction 62 is of a positive polarity with respect to ground 5 and of a sufficient magnitude to produce base-emitter drive current through NPN transistor 60. This base-emitter drive current renders NPN transistor 60 conductive through the collector-emitter electrodes through a circuit through which they are connected in series with the base electrode 21 and emitter electrode 23 of control transistor 20 across the direct current potential source which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistor 45, resistor 64, the collector-emitter electrodes of transistor 60, lead 63, the base-emitter electrodes of control transistor 20 and point of reference or ground potential 5 to the negative polarity terminal of battery 4. As the collector-emitter electrodes of NPN transistor 60 and the base-emitter electrodes of control transistor 20 are connected in series across battery 4, conducting transistor 60 supplies base-emitter drive current to control transistor 20 to render this device conductive through the collector-emitter electrodes. With control transistor 20 conducting through the collector-emitter electrodes, quasi-collector electrode 24 does not conduct, consequently, base-emitter drive current is removed from switching transistor 10 to extinguish this device. When switching transistor 10 extinguishes, the ignition coil primary winding energizing circuit is interrupted, the magnetic field of ignition coil primary winding 15 collapses to induce a high ignition potential in ignition coil secondary winding 16 which is directed to the proper spark plug of the engine through a conventional distributor, not shown, in a manner well known in the automotive art.

From this description, it is apparent that NPN transistors 30, 40, 50 and 60 and control transistor 20 are responsive to each cycle of the alternating current ignition signals for operating NPN switching transistor 10 conductive and not conductive through the current carrying electrodes in timed relationship with the engine and NPN transistors 30, 40, 50 and 60 are responsive to each cycle of the alternating current ignition signals for operating control transistor 20 not conductive and conductive through the current carrying electrodes thereof in timed relationship with the engine.

A differential amplifier circuit 71 comprised of two NPN transistors 70a and 70b and the associated circuitry, is provided for producing a direct current control signal in response to and of a magnitude proportional to the potential developed across control impedance element 17 while switching transistor 10 is conducting primary winding energizing current through the current carrying electrodes thereof. The input circuit of differential amplifier circuit 71, base electrode 71a of transistor 70a, is connected to junction 65 between variable resistors 75 and 59 through diode 72, resistor 73 and lead 74. The potential drop across control impedance element 17 is divided by the variable resistor 75 and 59 voltage divider network, consequently, the potential upon junction 65 is proportional thereto. The magnitude of this potential may be adjusted down by varying the ohmic value of variable resistor 75 and up by varying the ohmic value of variable resistor 59. With this connection, the potential appearing across diode 72 and resistor 73, which changes with changes of ignition coil primary winding energizing

current, is compared with the potential appearing across diode 76 and resistor 77. As the potential developed across control impedance element 17 increases and decreases with an increase or decrease of ignition coil primary winding energizing current flow, the collector-emitter conduction through NPN transistor 70a of differential amplifier circuit 71 increases and decreases. As collector-emitter conduction through transistor 70a increases and decreases, there occurs a corresponding decrease and increase of collector-emitter conduction through NPN transistor 70b. As collector-emitter conduction through transistor 70b decreases and increases, the magnitude of the direct current control signal upon junction 78, the output circuit of differential amplifier circuit 71, correspondingly increases and decreases. That is, differential amplifier circuit 71 produces a direct current output signal upon the output circuit thereof in response to and of a magnitude proportional to the potential developed across control impedance element 17 while switching transistor 10 is conducting primary winding energizing current through the collector-emitter electrodes thereof. This control signal is of a positive polarity upon junction 78 with respect to point of reference or ground potential 5.

The control signal produced by differential amplifier circuit 71 is applied to the control electrode of control transistor 20 through leads 67 and 68 and resistor 69 and through the collector-emitter electrodes of NPN transistor 80. That is, the control signal appearing upon the output circuit of differential amplifier circuit, junction 78, is applied across the base-emitter electrodes of NPN transistor 80 through leads 67 and 68 and resistor 69 to render this device conductive through the collector-emitter electrodes thereof. While NPN transistor 80 is conducting through the collector-emitter electrodes, base-emitter drive current is supplied to control transistor 20 through a circuit through which the collector-emitter electrodes of transistor 80 and the base-emitter electrodes of control transistor 20 are connected in series across the source of direct current potential which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistor 45, lead 81, the collector-emitter electrodes of NPN transistor 80, lead 83, the base-emitter electrodes of control transistor 20 and point of reference or ground potential 5 to the negative polarity terminal of battery 4. NPN transistor 80 is included in the circuit through which the control signal produced by differential amplifier circuit 71 is applied across the base-emitter electrodes of control transistor 20 for providing current amplification. If desired, a transistor Darlington pair may be substituted for NPN transistor 80, as illustrated by NPN Darlington pair 80a and 80b of FIG. 2, without departing from the spirit of the invention.

With a flow of energizing current less than the predetermined magnitude through the ignition coil primary winding energizing circuit, transistor 70b of differential amplifier circuit 71 conducts through the collector-emitter electrodes in a substantially saturated condition and transistor 70a is substantially cut off. With these conditions, the potential upon junction 78 is of an insufficient magnitude to produce base-emitter drive current through NPN transistor 80, consequently, this device is not conductive. When the flow of energizing current through the ignition coil primary winding energizing circuit approaches and reaches the predeter-

mined magnitude, the potential drop produced thereby across control impedance element 17 causes the potential upon junction 79 to increase in a positive direction to a magnitude at which it produces base-emitter drive current through NPN transistor 70a to render this device conductive through the collector-emitter electrodes. An increase in collector-emitter conduction through NPN transistor 70a results in a corresponding decrease of collector-emitter conduction through NPN transistor 70b, consequently, the control signal upon the output circuit of differential amplifier 71 begins to go positive upon junction 78 with respect to point of reference or ground potential 5. This control signal is applied across the base-emitter electrodes of NPN transistor 80, through circuitry previously described, to produce base-emitter drive current and, consequently, collector-emitter conduction therethrough. The collector-emitter conduction through transistor 80 supplies base-emitter drive current to control transistor 20, through circuitry previously described, a condition which increases the degree of collector-emitter conduction therethrough. With an increase of collector-emitter conduction through control transistor 20, quasi-collector electrode 24 thereof supplies less base-emitter drive current to switching transistor 10. With reduced-emitter drive current supplied to switching transistor 10, collector-emitter conduction therethrough correspondingly decreases to limit the flow of ignition coil primary winding energizing current to the predetermined magnitude. From this description, it is apparent that the circuitry responsive to the control signal produced by differential amplifier circuit 71 for limiting the flow of primary winding energizing current through the current carrying electrodes of switching transistor 10 to a predetermined magnitude includes NPN transistor 80 and control transistor 20.

Because of distributed collector to base capacitance in the NPN switching transistor 10, significant phase shift between current and voltage may occur at the base terminal of switching transistor 10 on some devices. Resistor 115 and capacitor 116 provide feedback to the control circuitry in differential amplifier 71 through resistor 73 and diode 72 to correct the phase shift at the base of NPN switching transistor 10.

To determine the length of time ignition coil primary winding switching transistor 10 is conductive through the current carrying electrodes during each alternating current ignition signal cycle, circuitry responsive to the control signal produced by differential amplifier circuit 71 for establishing the electrical angle of each cycle of the alternating current ignition signals at which control transistor 20 is extinguished is provided.

As has been brought out earlier in this specification, control transistor 20 is not conductive the collector-emitter electrodes to supply forward base-emitter drive current to ignition coil primary winding switching transistor 10 through quasi-collector electrode 24 while transistor 30 is conductive through the collector-emitter electrodes and is conductive through the collector-emitter electrodes thereof to drain forward base-emitter drive current from ignition coil primary winding switching transistor 10 while transistor 30 is not conductive through the collector-emitter electrode. Consequently, the electrical angle of each cycle of the alternating current ignition signals at which control transistor 20 is extinguished through the emitter electrodes is determined by the electrical angle of each

cycle of the alternating current ignition signals at which transistor 30 conducts through the collector-emitter electrodes. Transistor 30 conducts through the collector-emitter electrodes thereof while the potential of the half cycles of the alternating current ignition signals during which terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b is of a sufficient magnitude to produce base-emitter drive current therethrough and does not conduct through the collector-emitter electrodes thereof with the alternate half cycles of the alternating current ignition signals. The electrical angle of the half cycles of the alternating current ignition signals during which the potential of terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b at which transistor 30 conducts through the collector-emitter electrodes is the electrical angle at which the potential appearing across pickup coil 9 is of a sufficient magnitude to produce base-emitter drive current through NPN transistor 30. Consequently, this electrical angle may be controlled or selected or adjusted, or changed by inserting a source of bias potential in series with pickup coil 9 and poled to aid the ignition signal potential induced in pickup coil 9 with the half cycles of the alternating current ignition signals during which terminal end 9a is of positive polarity with respect to terminal end 9b, the greater the magnitude of this bias potential, the earlier during these half cycles that the alternating current ignition signals are of a sufficient magnitude to produce base-emitter drive current through NPN transistor 30. To supply this bias potential, type NPN transistor 90 and capacitor 95 are provided.

The collector 92 and emitter 93 electrodes of NPN transistor 90 and emitter follower resistor 42 are connected in series across the direct current potential source through a circuit which may be traced from the positive polarity terminal of battery 4, through switch 25, lead 28, resistor 45, lead 84, the collector-emitter electrodes of transistor 90, emitter resistor 42, diode 34 and point of reference or ground potential 5 to the negative polarity terminal of battery 4.

one terminal end 9a of pickup 9 is connected to the base electrode of NPN transistor 30 through current limiting resistor 37, lead 38 and base resistor 39 and the other terminal end 9b is connected to the junction 97 between the emitter electrode of NPN transistor 90 and emitter resistor 42 through resistor 44 and lead 43. Connected across terminal ends 9a and 9b of pickup coil 9 is a voltage divider network comprising series resistors 85 and 86 through a circuit which may be traced from terminal end 9a of pickup coil 9, through series resistors 85 and 86, lead 87, control impedance element 17, point of reference or ground potential 5, diode 41, resistor 42, lead 43 and resistor 44 to terminal end 9b. The potential upon junction 89 between series resistors 85 and 86 of this voltage divider network is half-wave rectified by diode 96 and charges capacitor 95 through a charging circuit which may be traced from junction 89, through current limiting resistor 98, diode 96, resistor 99, capacitor 95, lead 87, control impedance element 17, point of reference or ground potential 5, diode 41, resistor 42, lead 43, resistor 44, pickup coil 9 and resistor 85 to junction 89. The base electrode 91 of NPN transistor 90 is connected to junction 94 between resistor 99 and capacitor 95. Consequently, the charge upon capacitor 95 which is of a positive polarity upon the plate connected to junction

94 with respect to point of reference or ground potential 5 is applied across the base-emitter electrodes of type NPN transistor 90 in the proper polarity relationship to produce base-emitter drive current through a type NPN transistor through a circuit which may be traced from junction 94, through the base-emitter electrodes of transistor 90, resistor 42, diode 35, point of reference or ground potential 5, control impedance element 17 and leads 87 and 88 to the other plate of capacitor 95. As the collector electrode 92 of transistor 90 is connected to the positive polarity terminal of battery 4 through lead 84, resistor 45, lead 28 and switch 25 and the emitter electrode 93 is connected to the negative polarity terminal of battery 4 through emitter resistor 42, diode 35 and point of reference or ground potential 5, the collector-emitter electrodes of NPN transistor 90 are poled for forward conduction therethrough. With transistor 90 conducting through the collector-emitter electrodes, the potential drop developed across emitter resistor 42 of a positive polarity upon junction 97 with respect to point of reference or ground potential 5 is the bias potential for pickup coil 9, the greater the degree of collector-emitter conduction through transistor 90, the greater the magnitude of this bias potential. As terminal end 9b of pickup coil 9 is connected to junction 97, the bias potential developed across emitter resistor 42 is in series aiding relationship with those half cycles of the alternating current ignition signals during which terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b. With the half cycles of the alternating current ignition signals during which the potential upon terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b, capacitor 95 charges through the charging circuit previously described and is of a positive polarity upon the plate thereof connected to junction 94 with respect to the opposite plate and is prevented from being drained off through resistor 85 during the alternate half cycles of the alternating current ignition signals by diode 96 which is reverse biased thereby. The degree of collector-emitter conduction through transistor 90 is established by the magnitude of the charge upon capacitor 95, the greater the magnitude of this charge, the greater the degree of base-emitter current and, consequently, the greater the degree of collector-emitter conduction through transistor 90. As the bias potential developed across emitter resistor 42 is in series aiding relationship with the potential of the half cycles of the alternating current ignition signals induced in pickup coil 9 during which the potential of terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b, the sum of the bias potential magnitude and the ignition signal potential magnitude during these half cycles is the magnitude of the ignition signal potential applied across the base-emitter electrodes of transistor 30, the greater the magnitude of bias potential, the smaller the magnitude of the ignition signal potential required to initiate base-emitter conduction through transistor 30, consequently, the earlier during these half cycles that ignition coil primary winding switching transistor 10 is rendered conductive through the collector-emitter electrodes thereof to establish the ignition coil primary winding energizing circuit. Should the ignition coil primary winding energizing current reach the predetermined magnitude, the potential developed across control impedance element 17 reaches the magnitude

which will initiate base-emitter drive current through transistor 70a of differential amplifier 71 which, consequently, initiates collector-emitter conduction there-through. As has been previously brought out, any collector-emitter conduction through NPN transistor 70a results in a corresponding decrease of collector-emitter conduction through NPN transistor 70b and, consequently, an increase of the control potential appearing across junction 78 and point of reference or ground potential 5. This control potential is applied across a voltage divider network comprising series resistor 103 and 104 which are so proportioned that when the control potential signal present across junction 78 and point of reference or ground potential 5 is of a magnitude corresponding to that produced when the ignition coil primary winding energizing current is of a predetermined magnitude, the potential upon junction 105 is of a positive polarity with respect to point of reference or ground potential 5 and of a sufficient magnitude to produce base-emitter drive current through the base-emitter electrodes of NPN transistor 100 to initiate collector-emitter conduction through this device. The collector-emitter electrodes of NPN transistor 100 are connected across junction 106 between diode 96 and capacitor 95 and point of reference or ground potential 5 through lead 107. The potential across capacitor 95, therefore, is applied across the collector-emitter electrodes of transistor 100 through a circuit which may be traced from junction 94, through resistor 99, lead 107, the collector-emitter electrodes of transistor 100, point of reference or ground potential 5, control impedance element 17 and leads 87 and 88 to the opposite plate of capacitor 95.

When the ignition coil primary winding energizing current reaches the predetermined magnitude, therefore, the control signal produced by differential amplifier circuit 71, in a manner previously explained, is of a magnitude which will produce base-emitter drive current through both NPN transistors 80 and 100 which renders both of these devices conductive through the respective collector-emitter electrodes. The collector-emitter current flow through transistor 80 results in a reduction of collector-emitter current flow through ignition coil primary winding switching transistor 10 in a manner previously explained. The collector-emitter current flow through transistor 100 drains a portion of the charge from capacitor 95 through resistor 99, lead 107 and the collector-emitter electrodes of transistor 100, to point of reference or ground potential 5 to reduce the magnitude of charge thereon. The reduced magnitude of charge upon capacitor 95 reduces the degree of base-emitter current flow and, consequently, collector-emitter conduction through transistor 90 to reduce the magnitude of bias potential produced across emitter resistor 42. Therefore, a greater ignition signal potential magnitude of the half cycles of the alternating current ignition signals during which the potential of terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b is required to produce base-emitter drive current through NPN transistor 30. As this required greater ignition signal potential magnitude is reached later during each cycle of the alternating current ignition signals, transistor 30 conducts through the collector-emitter electrodes later during each cycle and, consequently, ignition coil primary winding switching transistor 10 is operated conductive through the collector-emitter electrodes later during

each cycle thereby reducing the length of time for the build-up of ignition coil primary winding energizing current. Should the ignition coil primary winding energizing current not reach the predetermined magnitude, transistor 100 would not conduct to drain away a portion of the charge upon capacitor 95. Therefore, this greater charge upon capacitor 95 increases base-emitter current flow and, consequently, collector-emitter conduction through type NPN transistor 90 to increase the magnitude of bias potential produced across emitter resistor 42. Therefore, a smaller ignition signal potential magnitude of the half cycles of the alternating current ignition signals during which the potential of terminal end 9a of pickup coil 9 is of a positive polarity with respect to terminal end 9b is required to produce base-emitter drive current through NPN transistor 30. As this required smaller ignition signal potential magnitude is reached earlier during each cycle of the alternating current ignition signals, transistor 30 conducts through the collector-emitter electrodes earlier during each cycle and, consequently, ignition coil primary winding switching transistor 10 is operated conductive through the collector-emitter electrodes earlier during each cycle, thereby increasing the length of time for the build-up of ignition coil primary winding energizing current. This circuitry, of course, reaches a steady condition at which ignition coil primary winding switching transistor 10 conducts for a period of time just long enough for the ignition coil primary winding energizing current to build up to the predetermined magnitude.

To provide overvoltage protection, a Zener diode 110 having an inverse breakdown potential of a value equal to the supply potential magnitude at which overvoltage shutdown is required may be connected between resistor 45 and the base electrode 21 of control transistor 20. When the supply potential magnitude reaches the inverse breakdown potential of Zener diode 110, this device conducts in a reverse direction to supply base-emitter drive current to control transistor 20. This base-emitter drive current renders control transistor 20 conductive through the collector-emitter electrodes which prevents quasi-collector electrode 24 from supplying base-emitter drive current to switching transistor 10. Zener diode 110 may be replaced by two or more Zener diodes having a combined inverse breakdown potential equal to the magnitude of supply potential at which overvoltage protection is desired as indicated by Zener diodes 111, 112 and 113 of FIG. 2. Protection against damage from reverse battery polarity is provided by diodes 117 and 118.

In FIG. 1 of the drawings, the ignition coil primary winding switch is illustrated as a single NPN transistor 10 and the transistor through which emitter follower resistor 42 is energized is illustrated as a single NPN transistor 90. It is to be specifically understood that each of these transistors may be replaced by two transistors connected in Darlington pair and connected as shown in respective FIGS. 2 and 3. In each of FIGS. 2 and 3, the like elements of FIG. 1 have been given like characters of reference.

Throughout this specification, specific transistor types and electrical polarities have been set forth. It is to be specifically understood, however, that alternate transistor types and compatible electrical polarities may be employed without departing from the spirit of the invention.

While the preferred embodiment of the present invention has been shown and described, it will be obvious to those skilled in the art that various modifications and substitutions may be made without departing from the spirit of the invention which is to be limited only within the scope of the appended claims.

What is claimed is:

1. An internal combustion engine ignition system comprising in combination with a source of alternating current ignition signals produced in timed relationship with the engine, a direct current potential source and an ignition coil having at least a primary winding: at least one ignition coil primary winding switching transistor having two current carrying electrodes and a control electrode; a control impedance element; means for connecting said ignition coil primary winding, said current carrying electrodes of said switching transistor and said control impedance element in series across said direct current potential source; means responsive to each cycle of said alternating current ignition signals for operating said switching transistor conductive and not conductive through said current carrying electrodes in timed relationship with said engine; a differential amplifier circuit for producing a direct current control signal in response to and of a magnitude proportional to the potential developed across said control impedance element while said switching transistor is conducting primary winding energizing current through said current carrying electrodes thereof; first circuit means responsive to said control signal for limiting the flow of primary winding energizing current through said current carrying electrodes of said switching transistor to a predetermined magnitude; and second circuit means responsive to said control signal for determining the length of time said switching transistor is conductive through said current carrying electrodes during each said alternating current ignition signal cycle.

2. An internal combustion engine ignition system comprising in combination with a source of alternating current ignition signals produced in timed relationship with the engine, a direct current potential source and an ignition coil having at least a primary winding: at least one ignition coil primary winding switching transistor having two current electrodes and a control electrode; a control impedance element, means for connecting said ignition coil primary winding, said current carrying electrodes of said switching transistor and said control impedance element in series across said direct current potential source; a normally not conducting control transistor of the type having a control electrode, two current carrying electrodes and a quasi-collector electrode through which forward control electrode drive current is supplied to said control electrode of said switching transistor while said control transistor is not conducting through said current carrying electrodes for producing conduction through said current carrying electrodes of said switching transistor to complete an ignition coil primary winding energizing circuit for the flow of ignition coil primary winding energizing current through said current carrying electrodes of said switching transistor, said ignition coil primary winding and said control impedance element; means responsive to each cycle of said alternating current ignition signals for operating said control transistor conductive through said current carrying electrodes thereof to extinguish said switching transistor whereby said switching transistor is operated conductive and not

conductive through said current carrying electrodes thereof in timed relationship with said engine; a differential amplifier circuit for producing a direct current control signal in response to and of a magnitude proportional to the potential developed across said control impedance element while said switching transistor is conducting primary winding energizing current through said current carrying electrodes thereof; means for applying said control signal to said control electrode of said control transistor for limiting the flow of primary winding energizing current through said current carrying electrodes of said switching transistor to a predetermined magnitude; and circuit means responsive to said control signal for establishing the electrical angle of each cycle of said alternating current ignition signals at which said control transistor is extinguished.

3. An internal combustion engine ignition system comprising in combination with a magnetic distributor of the type which produces alternating current ignition signals in a pickup coil in timed relationship with the engine, a direct current potential source having positive and negative polarity output terminals and an ignition coil having at least a primary winding: at least one ignition coil primary winding switching transistor having collector-emitter electrodes and a base electrode; a control element impedance element; means for connecting said ignition coil primary winding, said collector-emitter electrodes of said switching transistor and said control impedance element in series across said direct current potential source; a control transistor of the type having a base electrode, a collector electrode, an emitter electrode and a quasi-collector electrode; means for connecting said collector-emitter electrodes of said control transistor across said direct current potential source; means for connecting said quasi-collector electrode of said control transistor to said base electrode of said switching transistor through which base-emitter drive current is supplied to said switching transistor while said control transistor is not conducting; means responsive to each cycle of said alternating current ignition signals for operating said control transistor not conductive and conductive in timed relationship with said engine; a differential amplifier circuit having an input circuit and an output circuit for producing a control signal upon said output circuit; means for connecting said input circuit of said differential amplifier circuit to the junction between said current carrying electrodes of said switching transistor and said control impedance element, means for applying the signal appearing upon said output circuit of said differential amplifier circuit across said base-emitter electrodes of said control transistor; a first transistor having collector-emitter electrodes and a base electrode; a resistor; means for connecting said collector-emitter electrodes of said first transistor and said resistor in series across said direct current potential source; means for connecting one terminal end of said pickup coil to the junction between said collector-emitter electrodes of said first transistor and said resistor; a capacitor; a diode; a charging circuit including said diode through which said capacitor is charged by said alternating current ignition signals produced in said pickup coil; means for applying the charge upon said capacitor across said base-emitter electrode of said first transistor; a second transistor having collector-emitter electrodes and a base electrode; means for connecting said

collector-emitter electrodes of said second transistor across the junction between said diode and said capacitor and said negative polarity output terminal of said direct current potential source; and means for applying the signal upon said output circuit of said differential amplifier circuit across said base-emitter electrodes of said second transistor.

4. An internal combustion engine ignition system comprising in combination with a magnetic distributor of the type which produces alternating current ignition signals in a pickup coil in timed relationship with the engine, a direct current potential source having positive and negative polarity output terminals and an ignition coil having at least a primary winding; at least one ignition coil primary winding switching transistor having collector-emitter electrodes and a base electrode; a control impedance element; means for connecting said ignition coil primary winding, said collector-emitter electrodes of said switching transistor and said control impedance element in series across said direct current potential source; a control transistor of the type having a base electrode, a collector electrode, an emitter electrode and a quasi-collector electrode; means for connecting said collector-emitter electrodes of said control transistor across said direct current potential source; means for connecting said quasi-collector electrode of said control transistor to said base electrode of said switching transistor through which base-emitter drive current is supplied to said switching transistor while said control transistor is not conducting; means responsive to each cycle of said alternating current ignition signals for operating said control transistor not conductive and conductive in timed relationship with said engine; a differential amplifier circuit having an input circuit and an output circuit for producing a control signal upon said output circuit; means for connecting said input circuit of said differential amplifier circuit to the junction between said circuit carrying electrodes of said switching transistor and said control impedance element, means for applying the signal appearing upon said output circuit of said differential amplifier circuit across said base-emitter electrodes of said control transistor; a first transistor having collector-emitter electrodes and a base electrode; a first resistor; means for connecting said collector-emitter electrodes of said first transistor and said first resistor in series across said direct current potential source; means for connecting one terminal end of said pickup coil to the junction between said collector-emitter electrodes of said first transistor and said first resistor; a diode; a second resistor; a capacitor; means for connecting said diode, said second resistor and said capacitor in series across said pickup coil in that order whereby said capacitor is charged by said alternating current ignition signals produced in said pickup coil; means for connecting said base electrode of said first transistor to the junction between said second resistor and said capacitor; a second transistor having collector-emitter electrodes and a base electrode; means for connecting said collector-emitter electrodes of said second transistor across the junction between said diode and said capacitor and said negative polarity output terminal of said direct current potential source; and means for applying the signal upon said output circuit of said differential amplifier circuit across said base-emitter electrodes of said second transistor.

5. An internal combustion engine ignition system comprising in combination with a magnetic distributor of the type which produces alternating current ignition signals in a pickup coil in timed relationship with the engine, a direct current potential source having positive and negative polarity output terminals and an ignition coil having at least a primary winding; at least one ignition coil primary winding switching transistor having collector-emitter electrodes and a base electrode; a control impedance element; means for connecting said ignition coil primary winding, said collector-emitter electrodes of said switching transistor and said control impedance element in series across said direct current potential source; a control transistor of the type having a base electrode, a collector electrode, an emitter electrode and a quasi-collector electrode; means for connecting said collector-emitter electrodes of said control transistor across said direct current potential source; means for connecting said quasi-collector electrode of said control transistor to said base electrode of said switching transistor; first, second, third and fourth transistors each having collector-emitter electrodes and a base electrode; means for connecting said collector-emitter electrodes of said first, second and third transistors across said direct current potential source; means for connecting said collector-emitter electrodes of said fourth transistor and said base-emitter electrodes of said control transistor in series across said direct current potential source; means for connecting said base electrodes of said second transistor to said collector electrode of said first transistor, said base electrode of said third transistor to said collector electrode of said second transistor and said base electrode of said fourth transistor to said collector electrode of said third transistor; a differential amplifier circuit having an input circuit and an output circuit for producing a control signal upon said output circuit; means for connecting said input circuit of said differential amplifier circuit to the junction between said current carrying electrodes of said switching transistor and said control impedance element, means for applying the signal appearing upon said output circuit of said differential amplifier circuit across said base-emitter electrodes of said control transistor; a fifth transistor having collector-emitter electrodes and a base electrode; a resistor; means for connecting said collector-emitter electrodes of said fifth transistor and said resistor in series across said direct current potential source; means for connecting one terminal end of said pickup coil to said base electrode of said first transistor; means for connecting the other terminal end of said pick-up coil to the junction between said collector-emitter electrodes of said fifth transistor and said resistor; a capacitor; a diode; a charging circuit including said diode through which said capacitor is charged by said alternating current ignition signals produced in said pickup coil; means for applying the charge upon said capacitor across said base-emitter electrode of said fifth transistor; a sixth transistor having collector-emitter electrodes and a base electrode, means for connecting said collector-emitter electrodes of said sixth transistor across the junction between said diode and said capacitor and said negative polarity output terminal of said direct current potential source; and means for applying the signal upon said output circuit of said differential amplifier circuit across said base-emitter electrodes of said sixth transistor.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,838,672

Dated October 1, 1974

Inventor(s) Roy C. Richards et al

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

In the Abstract, line 1, after "engine" insert -- ignition --. Column 3, line 18, "magneitc" should read -- magnetic --; line 22, "oerat-" should read -- operat- --; line 54, "bae" should read -- base --. Column 7, line 7, "increasea" should read -- increases --; line 12, "decreasea" should read --decreases --. Column 8, line 54, after "conductive" insert -- through --. Column 10, line 17, "ar" should read -- are --; line 22, "groung" should read -- ground --. Column 15, line 39, "circuit" should read -- current --. Column 16, line 30, "electrodes" should read -- electrode --.

Signed and sealed this 28th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents