Feb. 7, 1967 J. L. JENSEN 3,303,414

SEMICONDUCTOR APPARATUS

Filed May 15, 1963 5 Sheets-Sheet 1

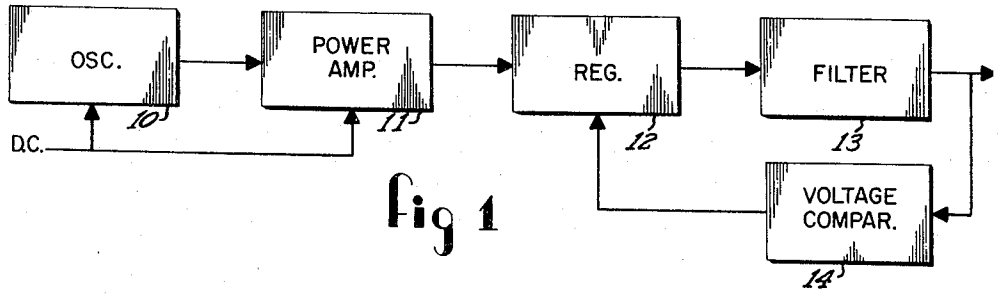


fig 1

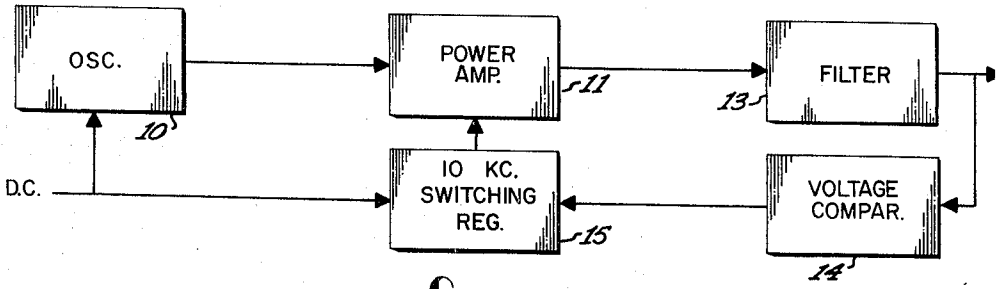


fig 2

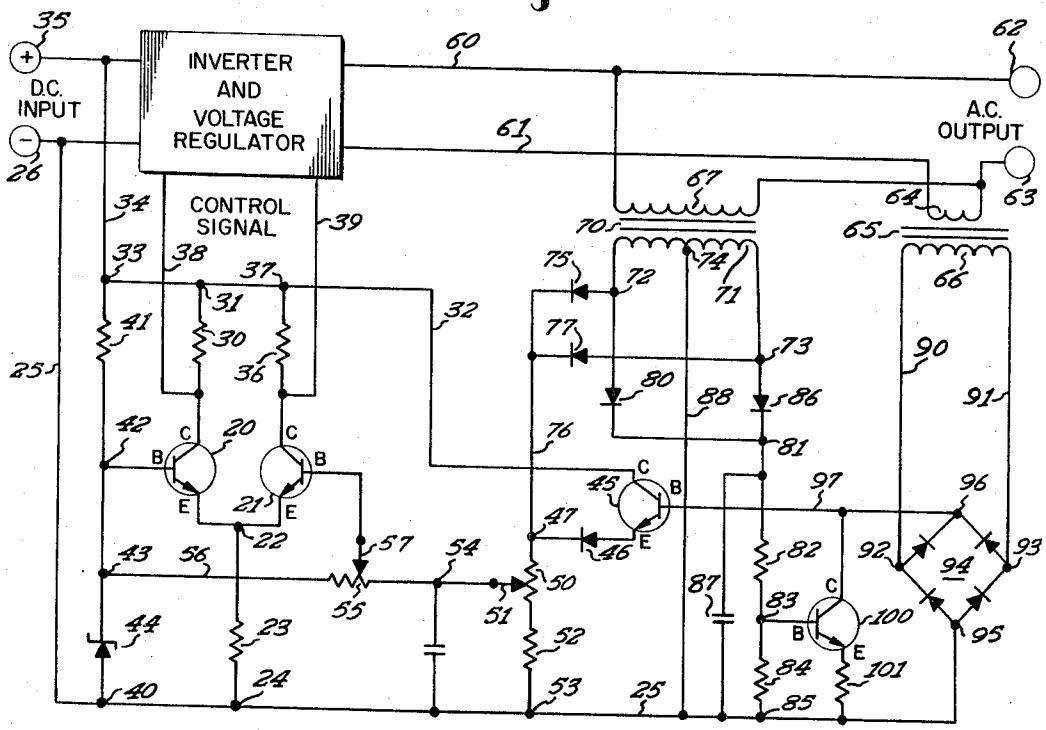


fig 3

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5 Sheets-Sheet 2

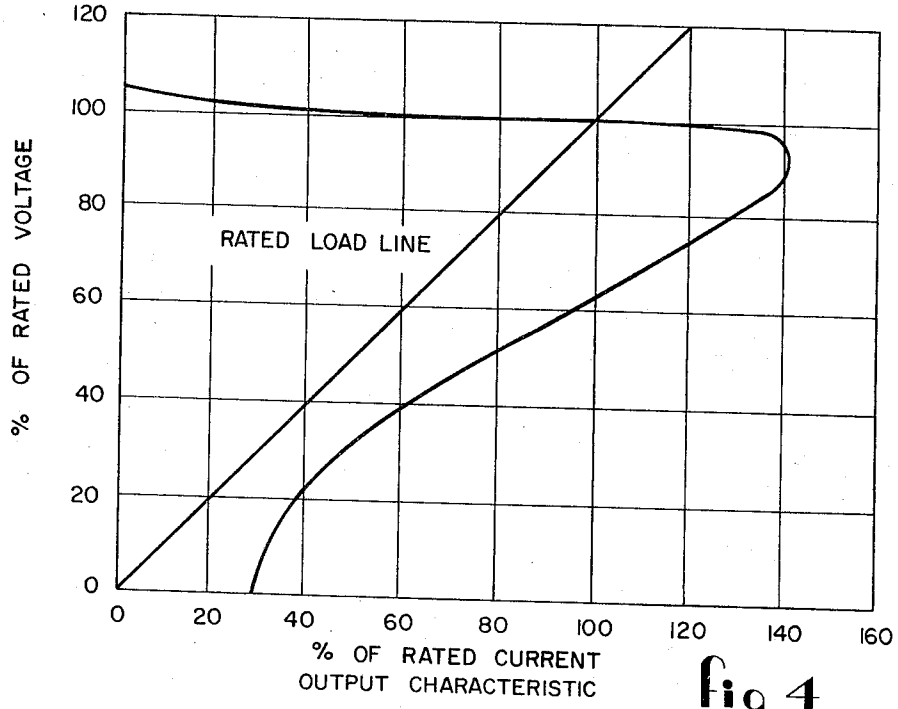


fig 4

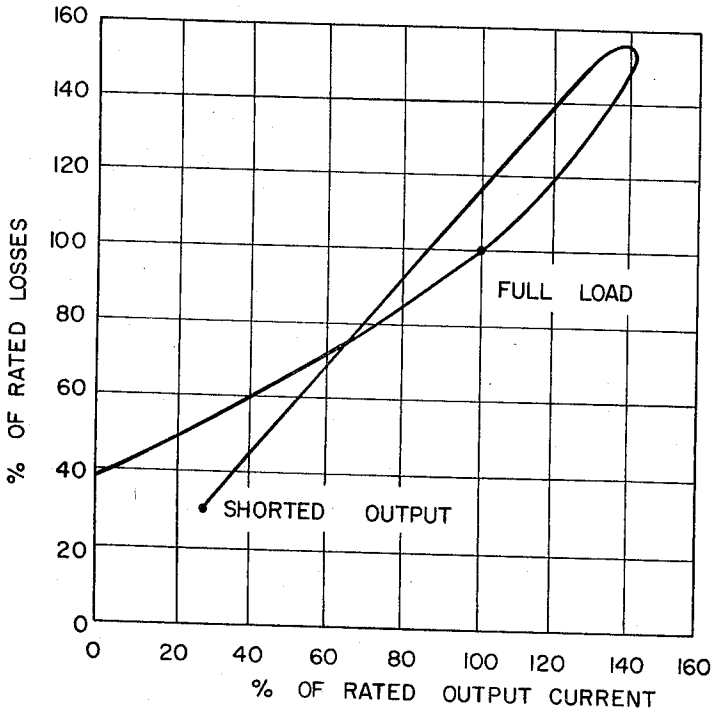


fig 5

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SEMICONDUCTOR APPARATUS

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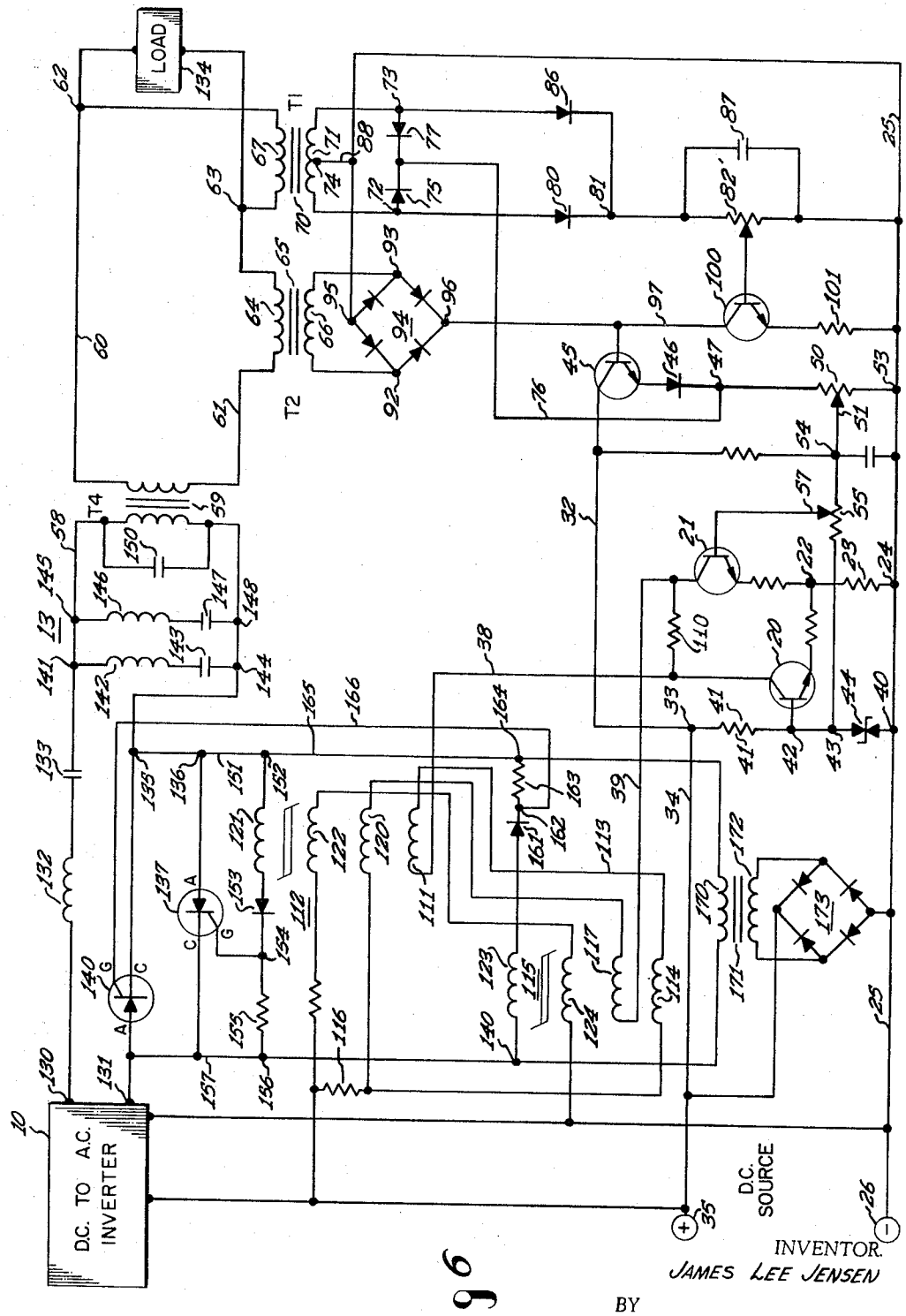


Fig. 3

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SEMICONDUCTOR APPARATUS

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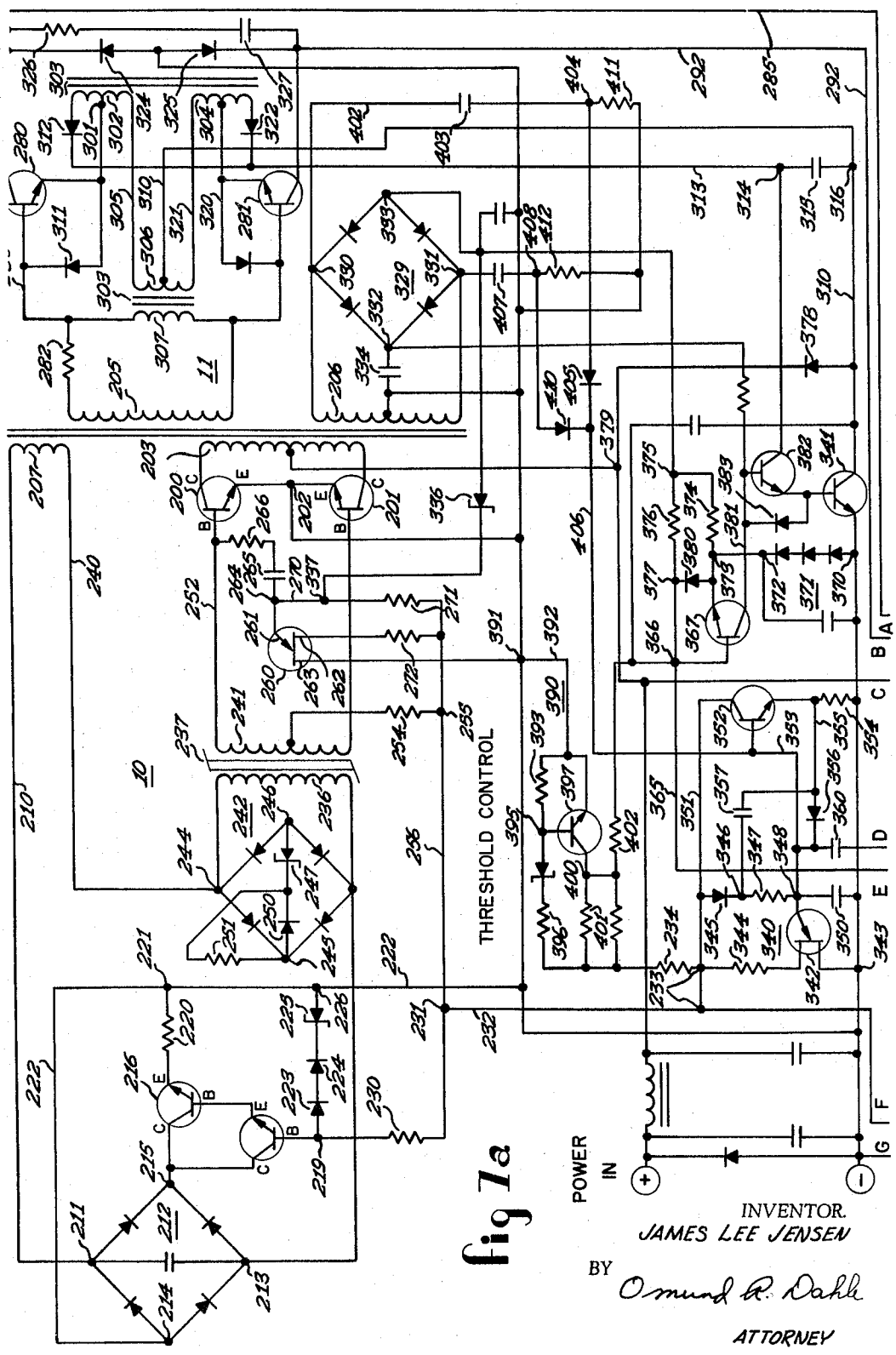


fig 1a

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SEMICONDUCTOR APPARATUS

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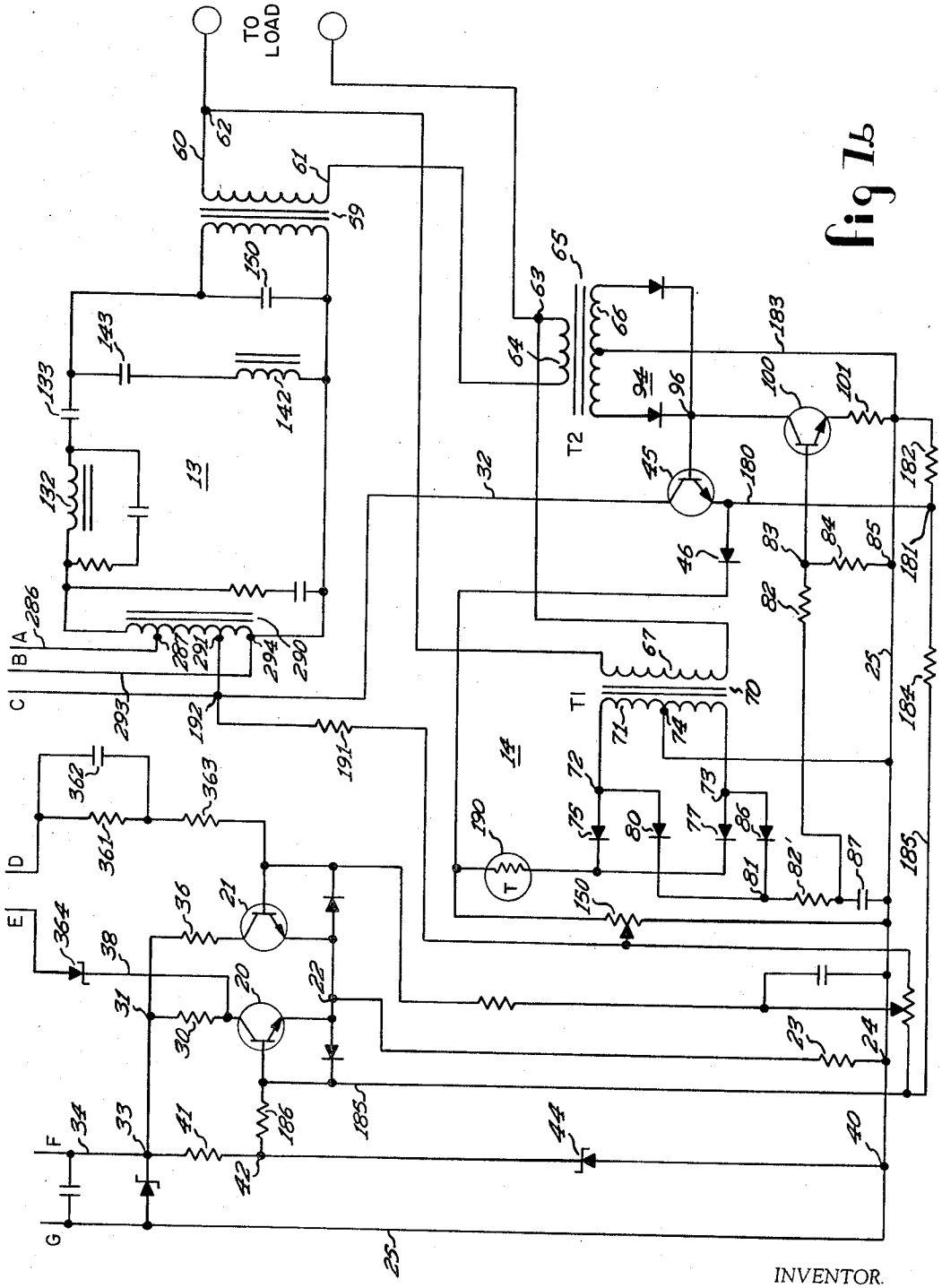


fig 1b

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United States Patent Office 3,303,414 Patented Feb. 7, 1967

3,303,414

SEMICONDUCTOR APPARATUS

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Filed May 15, 1963, Ser. No. 280,701
3 Claims. (Cl. 323—9)

This invention relates to new and improved semiconductor circuitry for use in power supplies and in particular relates to improved overload protection in semiconductor power supplies. The overload protection is intended to protect the power supply from damage due to overloads of any type, to minimize disturbances to the power source, and to minimize disturbances to the connected loads.

It is an object of this invention to provide an improved semiconductor overload regulator apparatus.

It is a further object of this invention to provide an improved semiconductor overload regulator which will automatically resume normal operation and regulation upon the removal of the overload condition.

These and other objects of the invention will become more apparent upon a consideration of the attached claims, specification and drawings of which

FIGURES 1 and 2 are block diagrams of two embodiments of the overload regulating systems of my invention;

FIGURE 3 is a schematic diagram of the voltage comparator section of FIGURES 1 and 2;

FIGURES 4 and 5 are graphical representations of the operating characteristics of my invention;

FIGURE 6 is a schematic diagram of the circuit of one embodiment of my invention generally corresponding to FIGURE 1; and

FIGURE 7 is a schematic diagram of the circuit of another embodiment of my invention generally corresponding to FIGURE 2.

Referring now to the drawing and especially to FIGURE 1, there is disclosed an oscillator-inverter **10** for converting a D.C. source to an alternating type potential, the alternating output of the inverter being connected to drive a power amplifier **11**. This oscillator may be of the general type disclosed in my Patent 2,774,878. Power amplifier **11** is also connected to be energized from a D.C. source. The output of amplifier **11** is connected through a regulator **12** and a filter network **13** to a load circuit, not shown. The output potential from the filter network **13** is connected to a voltage comparator circuit **14** which compares the output voltage against a reference and in turn controls the regulator as a function of the output potential.

The system disclosed in FIGURE 2 is somewhat similar in that the oscillator **10** drives the power amplifier **11**, the output of which passes through filter **13** to the load. The voltage comparator **14** now controls a regulator **15** which is in the supply line into power amplifier **11** rather than following the power amplifier as in FIGURE 1.

Before describing the voltage comparator **14** which is shown in more detail in FIGURE 3, the performance desired of the systems shown in FIGURES 1 and 2 will be further described. The inverter has a D.C. input and a single-phase sine wave output, with the inverter utilizing a square wave inverter, a pulse width voltage regulator and a harmonic reduction filter. The control characteristic obtained with this inverter is shown in FIGURE 4, with a substantially flat output voltage from no load to full load. Upon reaching approximately 140 percent of rated current a sharp but controlled decrease in voltage occurs causing the control characteristic to sweep back toward the origin. At short circuit condition, a current of about 30 percent of full load current is obtained. It

will be noted that after crossing the rated load line, the control characteristic does not recross the rated load line at any point and therefore, the inverter will start or recover from short circuit with any applied load.

A measure of self-protection is obtained in the amount of power lost within the inverter under various overload conditions, including short circuit. FIGURE 5 shows the percentage of loss at full load as a function of the percentage of rated output current. A normal increase in loss occurs with load increase until the output current is about 142 percent of rated current. At this point the overload control reduces the output current with a corresponding reduction in the internal losses until at short circuit conditions the internal loss of the inverter is less than that under no load conditions. The inverter will safely operate indefinitely under a short circuit.

Returning now to the voltage comparator **14** of FIGURE 3 which discloses the circuitary utilized to obtain this operating characteristic, there is disclosed a differential amplifier comprising a pair of npn type transistiors **20** and **21**, each having base, emitter and collector electrodes, the emitter electrodes being connected together at a junction **22** and connected through a common emitter resistor **23** to a junction **24** on a common negative supply conductor **25** which terminates at a negative input terminal **26**. The collector electrode **20***c* is connected through a resistor **30**, a junction **31** on a conductor **32** to a junction **33** on a positive supply conductor **34** which terminates at a positive power input terminal **35**. The collector electrode **21***c* is connected through a resistior **36** to a junction **37** on the conductor **32**. From the junction **33** to a junction **40** on the conductor **25** a current path may be traced which comprises a resistor **41**, junctions **42** and **43**, and a reference diode **44** such as a zener diode. The base electrode **20***b* is directly connected to the junction **42**.

The conductor **32** is further connected to the collector electrode **45***c* of an npn transistor **45**. The emitter electrode **45***e* is connected through a rectifying diode **46**, a junction **47**, a potentiometer **50** which also includes a wiper **51**, and through a resistor **52** to a junction **53** on the conductor **25**. The adjustable wiper **51** of potentiometer **50** is connected by a junction **54**, a potentiometer **55**, and a conductor **56** to the junction **43**. Potentiometer **55** has an adjustable wiper **57** thereon which is directly connected to base electrode **21***b*.

The D.C. input terminals **35** and **26** also provide power to the inverter and voltage regulator block. This block may comprise from FIGURE 1 the oscillator **10**, power amplifier **11**, regulator **12**, and filter **13**. Control signals to the inverter and voltage regulator are applied from collector electrodes **20***c* and **21***c* through the conductors **38** and **39**. The output of the inverter and voltage regulator is connected by a pair of conductors **60** and **61** to A.C. output terminals **62** and **63**. Conductor **61** has in series therewith a primary winding **64** of a current transformer **65**, which transformer also includes a secondary winding **66**. Connected across the A.C. output terminals **62** and **63** is the primary winiding **67** of an isolating transformer **70**, which transformer also includes a centertapped secondary winding **71**. Secondary winding **71** has a pair of end terminals **72** and **73** in addition to centertap **74**. The terminal **72** is connected by a rectifying diode **75** and a conductor **76** to the junction **47**, and the terminal **73** is connected by a rectifying diode **77** and the conductor **76** to the junction **47**. Terminal **72** is also connected by a rectifying diode **80**, a junction **81**, a resistor **82**, a junction **83**, and a resistor **84** to a junction **85** on the conductor **25**, and terminal **73** is also connected by a rectifying diode **86** to the junction **81**. A capacitor **87** is connected between the junction **81** and negative conductor **25**. The centertap **74** is directly connected by a conductor **88** to the negative conductor **25**.

The secondary winding **66** of the current transformer **65** has its terminals connected by a pair of conductors **90** and **91** to the A.C. terminals **92** and **93** of a full wave rectifier bridge **94**. The bridge type rectifier **94** has one D.C. terminal **95** directly connected to the conductor **25** and the other D.C. terminal directly connected by a conductor **97** to the base electrode **45***b*. The D.C. terminal **96** is also directly connected to the collector electrode **100***c* of an npn transistor **100**. The emitter **100***e* of transistor **100** is connected by means of an emitter resistor **101** to the negative conductor **25**. Base electrode **100***b* is directly connected to the junction **83**.

The differential amplifier comprising transistors **20** and **21** detects and amplifies the error signal between the reference diode voltage applied to base electrode **20***b* and a feedback voltage applied to base **21***b*. The average value of the resulting control signal applied from the differential amplifier through conductors **38** and **39** to the inverter and voltage regulator will determine the output voltage supplied to A.C. output terminals **62** and **63**. Under overload conditions, the current transformer **65** with variable loading creates a feedback signal to the emitter-follower transistor **45** which overrides the voltage feedback signal to control the voltage regulator. The bias and conduction of transistor **100** in the current transformer loading circuit are functions of both the output voltage and output current. The output current at which override is obtained decreases as the output voltage decreases. The control characteristic curves back toward the origin under overload as shown in FIGURE 4, until at short circuit the emitter follower **45** is the only loading on the current feedback circuit and is the determinant of short circuit output current.

Referring to the specific operation of the circuit of FIGURE 3, assume the A.C. output at terminals **62** and **63** is within the rated load. Under these normal operating conditions the alternating voltage induced on secondary winding **71**, which is a function of the output voltage, is rectified by diodes **80** and **86** and flows through resistors **82** and **84** to the conductors **25** and **88** and back to the winding centertap. The potential drop appearing across resistor **84** is sufficient to bias transistor **100** relatively fully conductive and current also flows from junction **83** through transistor **100** from base to emitter and through resistor **101** to conductor **25**.

The output from winding **66** is proportional to the load current and after being rectified by full wave rectifier **94** flows from terminal **96** through the conductive transistor **100** from collector to emitter and through resistor **101** and back to terminal **95**.

The alternating voltage induced on winding **71** is also rectified by the diodes **75** and **77** and flows through conductor **76**, junction **47**, potentiometer **50**, resistor **52**, and through the conductors **25** and **88** to the centertap of winding **71**. The potential at junction **47** and also at emitter **45***e* is thus a function of the output voltage. As long as normal operation continues with the load remaining within the rated value the potential at emitter **45***e* is held sufficiently positive with respect to base **45***b* to miantain the transistor **45** relatively non-conductive. The potential at wiper **51** of potentiometer **50** is also a function of the A.C. output at terminals **62** and **63** and this potential is applied by the potentiometer **55** through its wiper **57** to the base **21***b* for comparison with the reference potential on base **20***b* as determined by the zener diode **44** to provide voltage regulation.

As has been discussed, both current and voltage are sensed to provide both voltage regulation and current regulation. In addition, as noted before, it is desired to provide substantially proportional overload protection; that is, to detect voltage/current (V/I) at the output. This feature is desired so that if the output terminals become shorted, the very low output voltage will then cause the current regulator to limit at a much lower value. In order to provide the substantially proportional control of

current limiting, the bias for the normally conductive transistor **100** is a function of the output voltage as applied across the resistors **82** and **84**. At normal output voltage the transistor **100** is biased on to a maximum value and current limiting takes place at a relatively large current value. Thus, as the output voltage drops due to a short circuit or near short circuit, the conductivity of transistor **100** is lowered and current regulation or current limiting occurs at a much lower value.

Referring again to the current regulation, it has been stated that under normal conditions the output of current transformer **65** flows through the normally conductive transistor **100**. When the current reaches a critical value, the transistor **100** cannot carry more current and begins to come out of saturation whereupon transistor **45** begins to conduct also. This path may be traced from terminal **96** through conductor **97**, through transistor **45** from base to emitter, diode **46**, potentiometer **50**, resistor **52**, and conductor **25** back to terminal **95**. With transistor **45** beginning to turn on current also flows through the output circuit of the transistor **45** and a current path may be traced from terminal **35** through conductors **34** and **32**, through transistor **45** from collector to emitter, diode **46**, potentiometer **50**, resistor **52**, and conductor **25** back to negative supply terminal **26**. The voltage across resistors **50** and **52** increases as a result of this current, this increase being reflected into the voltage regulator by way of the differential amplifier. As the output voltage begins to drop due to the overload, the voltage at base **100***b* drops substantially proportionally thereto so that the transistor **100** is biased less conductive and substantially proportional control of the current limiting point is obtained. In other words, as the output voltage drops, the potential on winding **71** is lowered, the potential across resistors **82** and **84** is lowered, the conductivity of transistor **100** is lowered, and current limiting occurs at a lower magnitude of output current. Another way of expressing the operation of the current sensing transistor **100** is that it is not biased to a reference, but instead is biased as a function of the output voltage to the load. At such time as the output is completely shorted so that there is zero voltage across the load, the regulator cuts back or reduces the current supplied to the load terminals to a very low value, a fraction of the normal current limit. Upon a removal of the short circuit, the regulator automatically resets.

Referring now to FIGURE 6, there is shown a schematic of a system of an embodiment of my invention it will be noted that the voltage comparator portion of the drawing is substantially the same as described above in reference to FIGURE 3 and carries the same reference numerals. Several minor differences are evident; a pair of relatively low resistance resistors have been added in series, respectively, with emitter electrodes **20***e* and **21***e* and a resistor **110** has been connected between collector electrodes **20***c* and **21***c*.

The conductor **38** from collector **20***c* is connected through a control winding **111** of a magnetic amplifier **112**, a conductor **113**, a control winding **114** of a further magnetic amplifier **115**, and a common resistor **116** to the positive source terminal. Collector electrode **21***c* is connected through the conductor **39**, a second control winding **117** on magnetic amplifier **115**, a second control winding **120** and through the resistor **116** to the positive source terminal. Magnetic amplifier **112** also includes a power output winding **121** and a bias winding **122** and magnetic amplifier **115** also includes a power output winding **123** and a bias winding **124**. The bias windings are disclosed as being connected in series and in series with a resistor current limiting across the D.C. source.

The D.C. to A.C. inverter **10** of FIGURE 6 which may also include the power amplifier **11** if desired, has a pair of A.C. output terminals **130** and **131**. Terminal **130** is connected through a choke coil **132**, a capacitor **133**, and a conductor **58** to the primary winding of transformer

59. The secondary winding thereof is connected by the conductor 60 to the output terminal 62. Terminal 62 is connected to one end of the load device 134, the other end of which is connected to the output terminal 63.

As in FIGURE 3, the voltage transformer primary winding 67 is connected across the output terminals 62 and 63. A current path may be traced from the terminal 63 through the current transformer primary winding 64, and the conductor 61 to the other end of the secondary winding of transformer 59. The lower terminal of the primary winding of transformer 59 is connected to junctions 135 and 136, through a controlled rectifier 137, here disclosed as a silicon controlled rectifier (SCR), from anode to cathode, and then directly to the inverter terminal 131. Another controlled rectifier 140 is connected in parallel with but in polarity opposition to the SCR 137. This circuit may be traced from the inverter terminal 131 through SCR 140 from anode to cathode, which cathode is directly connected to junction 135 and thus also to the anode of SCR 137. The choke coil 132 and the capacitor 133 are tuned to the fundamental frequency of the inverter. Additional filtering is shown connected in the circuit and from a junction 141 on the conductor 60 a series connected inductive coil 142 and capacitor 143 connect to a junction 144 on the conductor 61. This network is tuned and operates as a 3rd harmonic shunt. Also connected from a junction 145 on the conductor 60 is another series connected coil 146 and a capacitor 147 to a junction 148 on the conductor 61, this portion of the filter being tuned to shunt the 5th harmonic. A capacitor 150 is also connected in parallel with the primary winding of transformer 59 to form a tuned circuit so that the output approaches sine wave form.

A firing circuit for the SCR 137 is connected in parallel with the anode cathode circuit and may be traced from the junction 136 through a conductor 151, a junction 152, the output winding 121 of magnetic amplifier 112, a rectifying diode 153, a junction 154, a resistor 155, a junction 156, and then by a conductor 157 directly to the terminal 131. The junction 154 is directly connected to the gate or control electrode G of SCR 137. A firing circuit for the SCR 140 may be traced from terminal 131 through conductor 157 to a junction 160, through the output winding 123 of magnetic amplifier 115, rectifying diode 161, junction 162, resistor 163, junction 164, and conductor 165 to the cathode of SCR 140. The junction 162 is directly connected by a conductor 166 to the gate or control electrode G of SCR 140.

In considering the operation of FIGURE 6 it will be apparent that the SCR's 140 and 137 must be rendered conductive in order that the output of the inverter be applied to the load 134. Since the SCR's are switching devices the amount of power delivered to the load is dependent upon the ratio of the "on" time to "off" time of the SCR's. The firing or gating circuit for SCR 137 includes the output winding 121 of magnetic amplifier 112, and this A.C. circuit may be traced from terminal 130 through coil 132, capacitor 133, transformer 59, junctions 148, 144, 135, 136, and 152, output winding 121, rectifying diode 153, junction 154, resistor 155, and conductor 157 to terminal 131. It will be evident that when current flows in this path a potential will be developed across resistor 155 which is applied between gate electrode G and cathode C of SCR 137. When this potential reaches a predetermined magnitude, the SCR is switched on. Until saturation is reached in the core of magnetic amplifier 112, however, the impedance of winding 121 is sufficiently high to limit the current therethrough to a low value and thus the voltage across resistor 155 is not sufficient to fire SCR 137. The bias current flowing in bias winding 120 provides a predetermined reset of the flux of the core of magnetic amplifier 112 such that the SCR fires at an intermediate portion of the half cycle.

The switching circuit for SCR 140 is substantially identical in nature with control being accomplished by magnetic amplifier 115. As has been described, the collector electrodes of the differential amplifier are connected to the control windings 120, 111, 117, and 114 to modify the current therethrough as a function of conditions sensed and thus vary the firing angle of the SCR's.

The firing angle of the SCR's is normally under the control of the output voltage sensed by transformer 70, the voltage on secondary winding 71 being rectified and applied across voltage divider potentiometer to control the differential amplifier. As the output voltage increases above the desired value, the firing angle of the SCR's is retarded and vice versa. When the load current becomes too high the normally nonconductive transistor 45 is rendered conductive causing additional current to flow through the potentiometer and thus retarding the firing angle of the SCR's. If simultaneously the output voltage drops, the bias voltage applied to transistor 100 is reduced and as a result transistor 45 begins to conduct at a lower load current than when transistor 100 is biased full on.

The filter network accepts the nearly square wave signal from the inverter and provides an output waveform which more closely approximates a sine wave. Voltage transients appearing across the SCR's in excess of a predetermined magnitude flow through the primary winding 170 of step-down transformer 171, the secondary winding 172 thereof being connected to a full wave bridge rectifier 173, the D.C. output terminals of which are connected back to the D.C. supply line. Whenever the potential across the SCR's rises to the point that the voltage induced on secondary winding 172 exceeds the D.C. supply potential, current flows in the transformer, is rectified and fed back into the D.C. source thereby limiting the voltages which may appear across the SCR's.

Turning now to FIGURE 7 and particularly to FIGURE 7*b*, it will be seen that the voltage comparator is in most respects similar to that described in FIGURE 3 and carries like reference numerals. The voltage responsive output of transformer 70 is rectified by diodes 80 and 86 and flows through the resistors 82', 82 and 84 to render the transistor 100 conductive. Under normal conditions the majority of the current from the current sensing transformer 65, which is rectified by diodes 94' flows through this normally conductive transistor 100 and resistor 101. A smaller amount flows through the base-emitter circuit of transistor 45 and through a conductor 180, a junction 181, a resistor 182, and a conductor 183 to the centertap on the secondary winding 66' of transformer 65'. In the normal operating range the current through resistor 182 provides a load compensation potential which is fed to the differential amplifier. This compensation is connected by a circuit from the junction 181 through a resistor 184 and a conductor 185 to the base electrode 20*b* of the differential amplifier. A resistor 186 is connected between the junction 42 and base 20*b*. As the current limiting point is reached the increasing current through the transistor 45 flows through the diode 46 and the potentiometer 50 to provide a regulating signal to the differential amplifier. In addition, if the output voltage drops due to overloading or short circuit condition, the bias to transistor 100 is reduced and the current regulating occurs at a lower value than would otherwise be the case. A temperature compensating resistive element 190 is connected between the rectifiers 75 and 77 and the potentiometer 50. A line voltage compensation is also applied to the differential amplifier by a resistor 191 connected between a junction 192 on the conductor 32 and the wiper of potentiometer 50.

Turning now to FIGURE 7*a*, there is disclosed in more detail an embodiment of the oscillator-inverter 10. The inverter has a pair of npn transistors 200 and 201, each having collector, emitter, and control electrodes. The emitter electrodes 200*e* and 201*e* are connected together at a junction 202 which is directly connected to negative

power input terminal. The collector electrodes 200*c* and 201*c* are connected to opposite ends of a centertapped primary winding 203 of a transformer 204. Transformer 204 also includes a secondary winding 205, a centertapped secondary winding 206, and a feedback winding 207. The upper terminal of feedback winding 207 is connected by a conductor 210 to a terminal 211 of a bridge type rectifier 212. The rectifier 212 has a pair of AC terminals 211 and 213 and a pair of DC terminals 214 and 215. Terminal 215 is connected to the collector electrodes of a pair of npn transistors 216 and 217, each of which also has an emitter electrode and a base electrode. Base electrode 216*b* is directly connected to emitter 217*e*. The emitter electrode 216*e* is connected through a resistor 220, a junction 221, and a conductor 222 to the bridge rectifier terminal 214. The junction 221 is also directly connected by a conductor 223 to the negative DC source terminal 26. The base electrode 217*b* is connected through a junction 219, a pair of diodes 223 and 224, and a zener diode 225 to a junction 226 on the conductor 222. The junction 219 is connected by a resistor 230, a junction 231, a conductor 232, a junction 233, and a resistor 234 to the positive supply conductor and terminal 35. The zener diode 225 and transistors 217 and 216 operate as a constant current source to maintain the feedback signal current from winding 207 at a constant value.

Terminal 213 is connected through a conductor 235, the primary winding 236 of a saturable transformer 237, and a conductor 240 to the lower terminal of feedback winding 207 thus completing the feedback current loop. The saturable transformer 237, which has a substantially rectangular hysteresis loop core material, also has a centertapped secondary winding 241. Connected in parallel with the primary winding 236 is a voltage regulator circuit, generally designated by the numeral 242, which maintains constant the voltage across winding 236. This voltage regulator circuit is in the form of a four diode bridge rectifier having A.C. terminals 243 and 244 on conductors 235 and 240, respectively, D.C. terminals 245 and 246 and having a zener diode 247 connected across the D.C. terminals of the bridge. Also in series with the zener diode 247 is a rectifying diode 250 paralleled by a resistor 251. The use of the zener diode in conjunction with the bridge circuit allows the use of a single zener or reference diode for both polarities of voltage across the winding 236 and eliminates the need for matching of reference diodes. The diode 250 provides temperature compensation for the zener diode.

The base electrodes 200*b* and 201*b* are connected by conductors 252 and 253 to the extremities of secondary winding 241, the centertap thereof being connected by a resistor 254, a junction 255, and a conductor 256 to the junction 231. This connection provides a bias to render both transistors 200 and 201 normally conductive even though the system is not oscillating.

A relaxation oscillator comprising a unijunction transistor 260 and associated components to be described operates as a starting circuit for the oscillator. The unijunction has an emitter 261, and two base electrodes 262 and 263, the emitter 261 being connected by a junction 264, a capacitor 265, and a resistor 266 to the base electrode 200*b*. The junction 264 is also connected by a conductor 270 and a resistor 271 to the conductor 256. The base electrode 262 is connected by a resistor 272 to the conductor 256. The base electrode 263 is directly connected to the negative supply conductor and terminal 26.

When the oscillator 10 is operating, the AC signal induced on feedback winding 207 flows through the primary winding 236 of the saturable transformer 237, to the full wave rectifier 212, through the constant current regulator transistor 216 and back to the opposite terminal of winding 207. The need for current regulation and for voltage regulation to the primary winding of the saturable transformer 237 is to maintain the frequency stability of the oscillator very precise. In order to prevent output loading of the oscillator from affecting the frequency, the biasing current which flows through resistor 254 is chosen to be a substantially constant current so that the load presented by the secondary winding 241 of the saturable transformer 237 is relatively constant. Transistors 200 and 201 are "on" alternately, with switching occurring each time the core of transformer 237 saturates. The frequency of oscillation of the inverter 10 is, of course, determined by the time taken for the flux of the saturating transformer 237 to be changed from negative saturation to positive saturation and back to negative saturation.

The A.C. square wave output of the oscillator 10 on secondary winding 205 is connected to alternately bias a pair of amplifying transistors 280 and 281 to a conductive condition. The upper terminal of winding 205 is connected through a resistor 282 and a conductor 283 to base electrode 280*b*, and the lower terminal of winding 205 is connected by a conductor 284 to the base electrode 281*b*. The collector electrode 280*c* is connected by a conductor 285 and by terminal A to a conductor 286 on FIGURE 7*b*, to terminal 287 on an autotransformer 290; the intermediate tap 291 on transformer 290 being connected to the junction 192 which connects back through terminal C to FIGURE 7*a*, and then by way of the positive supply conductor to source terminal 35.

The collector electrode 281*c* is connected by a conductor 292 to the terminal B, to a conductor 293 on FIGURE 7*b* which terminates at a terminal 294 on the transformer 290. The collector electrodes 280*c* and 281*c* are thus connected to the positive power terminal source terminal 35 by means of the autotransformer 290.

The emitter electrode 280*e* is connected by a conductor 300 to an intermediate tap 301 on a transformer winding 302 of a transformer 303 which also includes windings 304, 306, and 307. The lower terminal of winding 302 is connected by a conductor 305 to the centertapped winding 306. The centertap of winding 306 is connected by a conductor 310 to the collector electrode of a switching transistor regulator, to be discussed in detail below. A rectifying diode 311 interconnects the emitter 280*e* with the base electrode 280*b*. The upper terminal of winding 302 is connected through a rectifying diode 312 and a conductor 313, a junction 314, and a capacitor 315 to a junction 316 on the conductor 310. The emitter electrode 281*e* is connected by a conductor 320 to the midtap on the winding 304, through the winding and from the upper terminal through a conductor 321 to the lower extremity and through primary winding 306 of the transformer 303. The lower extremity of winding 304 is connected through a rectifying diode 322 to a junction on the conductor 313. A rectifying diode 323 interconnects the emitter electrode 281*e* to the base electrode 281*b*.

A pair of rectifying diodes 324 and 325 are connected in back-to-back relation, their anodes being tied together and directly connected to the negative source conductor and terminal 26. The cathodes of rectifier 324 is connected to the conductor 285 and thus to collector 280*c*; the cathode of rectifier 325 is connected to the conductor 292 and thus to the collector 281*c*. Also connected between the collector electrodes of transistors 280 and 281 is a series RC network comprising a resistor 326 and a capacitor 327.

The secondary winding of the 206 of the transformer 204 has its centertap directly connected to the negative supply conductor and terminal 26. The upper and lower extremities of winding 206 are connected to the A.C. terminals 330 and 331 of a conventional bridge-type rectifier, which rectifier also includes a pair of D.C. output terminals 332 and 333. The positive D.C. output of terminal 332 is coupled by a capacitor 334 to a winding 306. The negative D.C. output terminal 333 is connected by a conductor 335 and a Zener diode 336 to a junction

337 on the conductor 270 in the starting circuit for oscillator 10.

A switching voltage regulator operating at a 10 kilocycle switching rate controls the magnitude of the voltage applied to the power amplifier 11 comprising the transistors 280 and 281. This switching voltage regulator basically comprises a unijunction transistor oscillator circuit 340, which operates at a 10 kc. rate to switch a regulating transistor 341 through a network to be described in more detail hereafter. Turning now to the unijunction relaxation oscillator circuit 340, there is disclosed a unijunction transistor 342 having the conventional emitter electrode and two base electrodes. One of the base electrodes is directly connected to the negative supply line at a junction 343. The other base electrode is connected through a current limiting resistor 344, the junction 233, and the resistor 234 to the positive supply conductor and power terminal 235. From the junction 233 a current path may be traced through a rectifying diode 345, a junction 346, a resistor 347, a junction 348 which is directly connected to the emitter of the unijunction transistor, and through a capacitor 350 to the negative supply conductor.

The junction 233 is connected by a conductor 351 to the collector electrode of an npn transistor 352, which transistor also includes a base electrode and an emitter electrode. The base electrode 352*b* is directly connected to the junction 348 and the emitter of the unijunction transistor 342. The emitter electrode 352*e* is connected through an emitter resistor 354 to the negative supply conductor, and the emitter is also connected by a conductor 355 and a rectifying diode 356 to the junction 348. A capacitor 357 interconnects the junction 346 and the conductor 355. The transistor 352 operates together with the unijunction transistor 342 to provide a more linear operation of the relaxation oscillator.

The output of the unijunction oscillator at junction 348 is connected through a capacitor 360, the terminal D, and continues on FIGURE 7*b* through a resistor 361 paralleled by a capacitor 362, and through a further resistor 363 to the base electrode 21*b* of the differential amplifier. The output of the differential amplifier is connected from the collector electrode 20*c* through the conductor 38, a Zener diode 364 to the terminal E and then back to FIGURE 7*a* and through a conductor 365 and a junction 366 to the emitter to the base of an npn transistor 367, which transistor 367 also includes an emitter and a collector electrode. A current path may be traced from a junction 370 on the negative supply conductor through a series of rectifying diodes 371, and junctions 372 and 373 to the emitter electrode 367*e*. The junction 373 is further connected through a resistor 374, a junction 375, and the conductor 335 to the negative bridge rectifier terminal 333. The junction 375 is connected by a resistor 376 and a conductor 377 to the junction 366. A rectifying diode 380 connects the emitter electrode 367*e* to the conductor 377.

The collector electrode 367*c* is connected by a conductor 381 to the base electrode of an npn transistor 382. The emitter electrode 382*b* is directly connected to the base electrode of the switching transistor 341. A rectifying diode 383 connects the emitter electrode 382*e* with the conductor 381. This diode is connected with its forward direction opposite to the base-emitter junction of transistor 382 which it shunts. The collector electrode 382*c* is directly connected by a conductor 384 to the junction 314. The base electrode 382*b* is further connected through a resistor 385 and a conductor 386 to the terminal 332 of the bridge rectifier. A rectifying diode 378 is connected between the conductor 310 and a junction 379 on the positive supply conductor.

A threshold control circuit generally designated by the numeral 390, is utilized to maintain inoperative the switching regulator including the transistors 367, 382, and 341 until the supply of voltage at terminals 35 and 26 reaches a predetermined magnitude. This threshold control comprises a voltage divider network connected from the negative supply conductor at junction 391 through a conductor 392, a resistor 393, a junction 394, a zener diode 395, and a resistor 396 to the positive supply conductor. The junction 394 is directly connected to a base electrode of an npn transistor 397, the emitter electrode of transistor 397 being directly connected to the conductor 392, and the collector electrode being connected through a junction 400 and a resistor 401 to the positive supply conductor. The junction 400 is also connected through a resistor 402 and the junction 366 to the base electrode 367*b*.

Synchronizing signals are fed from the oscillator 10, which in one practical embodiment was operated at 400 c.p.s., to the 10 kc. unijunction oscillator 340 by an A.C. circuit which may be traced from the secondary winding 206 of transformer 204. From the A.C. rectifier terminal 330, a circuit may be traced through a conductor 402, a capacitor 403, a junction 404, a rectifying diode 405, and a conductor 406 to the base electrode 352*b* Another path may be traced from the lower extremity of winding 206 through a junction 311, a capacitor 407, a junction 408, and a rectifying diode 410 to the conductor 406 and thus to the base electrode 352*b* to provide a pulse every half cycle of oscillator 10. The junction 404 is connected by a resistor 411 to the negative supply conductor, and the junction 408 is connected by a resistor 412 to the negative supply conductor. The synchronizing signal from the relatively low frequency oscillator 10 is effective to adjust the relaxation oscillator so that the 10 kc. switching regulator transistor 341 "turn on" point is maintained consistent from cycle to cycle with respect to the leading edge of each half cycle of the oscillator 10.

In the overall operation of the system of FIGURE 7, the oscillator 10 converts the D.C. input voltage to a square wave A.C. output at transformer 204 which is further amplified by transistors 280 and 281, the amplified output being increased in voltage by autotransformer 290 and filtered by the components 13 to approach a sine waveform whereby it is coupled to the load device. The comparator circuit 14 senses the output and applies a signal by means of the differential amplifier to pulse-width modulate the switching regulator transistor 341 which in turn controls the amount of electrical power supplied to the amplifier 11 and thus regulates the output.

The unijunction transistor oscillator circuit 340 operates at a 10 kc. rate. Current flows from the positive terminal through the resistor 234, the diode 345, and the resistor 347 to charge the capacitor 350. As soon as a predetermined voltage is reached on capacitor 350, the unijunction transistor 342 fires to discharge the capacitor and initiates a new cycle. The ramp voltage appearing on the capacitor 350 is coupled through coupling capacitor 360, terminal D, and the network including resistors 361 and 363 and capacitor 362 to the differential amplifier. This ramp voltage is summed with the signal from the comparator circuit and provides an output from the differential amplifier which is a function of the summed signal. The positive going ramp voltage tends to increase the conduction of transistor 21 which decreases the conduction of transistor 20 so that a positive going signal appears at the collector electrode 20*c* that at some level causes zener diode 364 to conduct which turns on transistor 367 and turns off the regulating transistors 382 and 341. At the termination of each cycle of oscillation of the unijunction circuit 340, the ramp voltage drops suddenly, the zener diode 364 becomes nonconductive, the transistor 367 becomes nonconductive, and the transistors 382 and 341 again become conductive. This switching occurs at the 10 kc. rate and the percentage "time on" of the transistors 382 and 341 is determined by the magnitude of the D.C. control voltage from the voltage comparator 14 which is summed with the ramp voltage from the unijunction oscillator 340.

The A.C. voltage on winding 206 is converted to D.C. by the bridge rectifier 329 to provide a turn-on bias for

the transistors 382 and 341, and a positive curent flows from the positive terminal 332 through the conductor 385, resistor 385, from the base to emitter of transistor 382, from base to emitter of transistor 341, through the rectifying diode 371, the resistor 374, and the conductor 335 to the negative D.C. terminal 333 of the rectifier.

The transistors 382 and 341 are thus normally rendered conductive by the bias developed from rectifier 329 when the oscillator 10 is operating.

As long as transistors 382 and 341 are conductive, a current path is established betwen the emitter electrodes 280*e* and 281*e* and the negative terminal 26. In other words, the voltage regulator transistors 341 and 382 operate as a switch in the negative supply conductor. The complete supply circuit for the amplifier from power terminal 35 may be traced through the transformer 290 to the collector electrodes 280*c* and 281*c* and from the emitter electrodes 280*e* and 281*e* through current transformer 303, conductor 310, the switching regulator transistor 341 and the negative conductor to terminal 26. More specifically the current from emitter 280*e* flows through conductor 300 windings 302 and 306 of current transformer 303, and conductor 310 to transistor 341. A potential is also induced in the upper portion of winding 302 which causes a current to flow through rectifier 312 and conductors 313 and 384 to the collector 382*c*. This additional potential derived from winding 302 is sufficient to supply a collector-to-emitter potential for the transistor 382 so that the composite transistor means comprising transistors 341 and 382 can be made fully efficient as a switching device. In other words, the additional bias potential permits both transistors 382 and 341 to be driven into a fully saturated condition reducing the losses in and thus increasing the efficiency of the composite transistor. On the other half cycle when transistor 281 is rendered conductive current flows from the emitter 281*e* through conductor 320, windings 304 and 306, and through conductor 310 to transistor 341. The bias potential induced on the lower portion of winding 304 causes a current to flow through rectifier 322 and conductors 313 and 384 to collector 382*c*. The capacitor 315 operates as a smoothing filter on the pulsating bias applied to transistor 382.

As has been described, the switching regulator operates at a 10 kc. rate in supplying power to the transistors 280 and 281. These transistors are loaded with an inductive load, however, and during the periods when the switching transistors 341 and 382 are "off," current flows from conductor 310 up through diode 378 due to the energy stored in the inductance. A substantially continuous current flows through the conductive transistor 280 or 281, therefore, with the average current being a function of the ratio of "on" time to "off" time of transistor 341.

It will be noted that the bias applied to the collector electrode 382*c* is a current derived feedback and is proportional to the load current flowing in the amplifier 11. In other words, the drive to the composite transistor means of transitsors 341 and 382 is not a constant although a portion of the bias current is so. The bias derived from winding 206 which when rectified flows from junction 332, conductor 386, resistor 385, base to emitter of 382, base to emitter of 341, diode 371, resistor 374, and back to junction 333 is a voltage derived bias and is relatively constant. The bias derived from windings 302 and 304 is current derived, however, and provides an increasing base current for transistor 341 through transistor 382 as the load requirements increase.

Many changes and modifications of this invention will undoubtedly occur to those who are skilled in the art and I therefore wish it to be understood that I intend to be limited by the scope of the appended claims and not by the specific embodiments of my invention which is disclosed herein for the purpose of illustration only.

I claim:

1. Overload voltage and current regulating apparatus of the type in which under overload conditions the current regulator limits at a magnitude which is a function of output voltage comprising:

means for providing an alternating current potential to load apparatus;

voltage sensing means connected to sense the magnitude of said output alternating potential and having a direct current output signal indicative of said potential;

current sensing means connected to sense the magnitude of the alternating current to said load apparatus and having a direct current output substantially proportional to the magnitude of said alternating current;

normally conductive current comparator means having a bias circuit, an input circuit, and an output circuit;

means connecting the output of said voltage sensing means to said bias circuit whereby said current comparator means is biased conductive with a signal substantially proportional to said output potential so that under normal conditions a maximum bias is applied to said bias circuit;

means connecting the output of said current sensing means to said comparator means input circuit, said comparator means being designed such that no output signal is obtained from said output circuit until a predetermined magnitude of current is sensed, however, under overload conditions wherein said output voltage is decreased the signal to said bias circuit is decreased substantially in proportion thereto whereby lower magnitude of signal to said input circuit is effective to provide an output signal from said comparator means.

2. Overload potential and current regulating apparatus of the type in which under short circuit or near short circuit overload conditions wherein the output potential decreases, the current regulator limits at a lower magnitude which is a direct function of output potential comprising:

regulating means for connecting electrical power to load apparatus;

potential sensing means connected to sense the magnitude of the output potential at said load apparatus and having an output signal dependent upon said potential;

current sensing means connected to sense the magnitude of the current to said load apparatus and having an output substantially proportional to said current;

current comparator means comprising semiconductor current control means having a control electrode, an emitter electrode, and a collector electrode, the output signal from said comparator means being connected in controlling relation to said regulating means;

means connecting the output of said voltage sensing means to said control electrode whereby said semiconductor means is biased with a signal substantially proportional to said output potential so that under normal conditions a maximum bias is supplied to said control electrode;

means connecting the output of said current sensing means to the emitter-collector circuit, said semi-conductor circuit being designed such that it operates in a normally conductive saturated condition and no output signal potential is obtained from said collector electrode until a predetermined magnitude of current is sensed; however, under overload conditions wherein said output voltage is decreased the signal to said control electrode is decreased substantially in proportion thereto whereby lower magnitude of signal to said emitter-collector circuit is effective to provide an output signal potential from said comparator means.

3. Overload regulating apparatus of the type in which under overload conditions the current limiting point is

varied as a function of the output voltage comprising:

regulating means for controlling an alternating current potential supplied to load apparatus;

voltage responsive means connected to sense the magnitude of said potential and providing an output signal proportional to said potential;

current responsive means connected to sense the magnitude of the current to said load apparatus and providing an output substantially proportional to said current;

transistor means comprising control and current carrying electrodes forming control circuit and output circuit, respectively;

means connecting the output of said voltage responsive means to said control circuit whereby said transistor means is biased to conduction with a signal substantially proportional to said output potential so that under normal conditions a relatively large bias is applied to said control circuit;

means connecting the output of said current responsive means to said transistor means current carrying electrodes said transistor means being normally biased

to saturation such that no output signal potential is obtained from said output circuit until a predetermined magnitude of current is sensed; however, under overload conditions wherein said output voltage is decreased the signal to said control circuit is decreased substantially in proportion thereto whereby lower magnitude of signal to said current carrying electrodes is effective to bring said tranisstor out of saturation to provide an output signal from said output circuit and means connecting the output of said transistor means in controlling relation to said regulating means.

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