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[54] **VARIABLE CONTROL, CURRENT SENSING BALLAST**

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[73] Assignee: **IceCap, Inc.**, Hamilton, N.J.

[21] Appl. No.: **601,906**

[22] Filed: **Feb. 15, 1996**

Related U.S. Patent Documents

Reissue of:

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Issued: **Feb. 15, 1994**
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Filed: **Jul. 6, 1992**

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[52] **U.S. Cl.** **315/291**; 315/307; 315/278; 315/224; 315/219; 315/324; 315/205; 315/119

[58] **Field of Search** .... 315/291, 307, 315/278, 224, 219, 324, 205, 119, 306, 209 R

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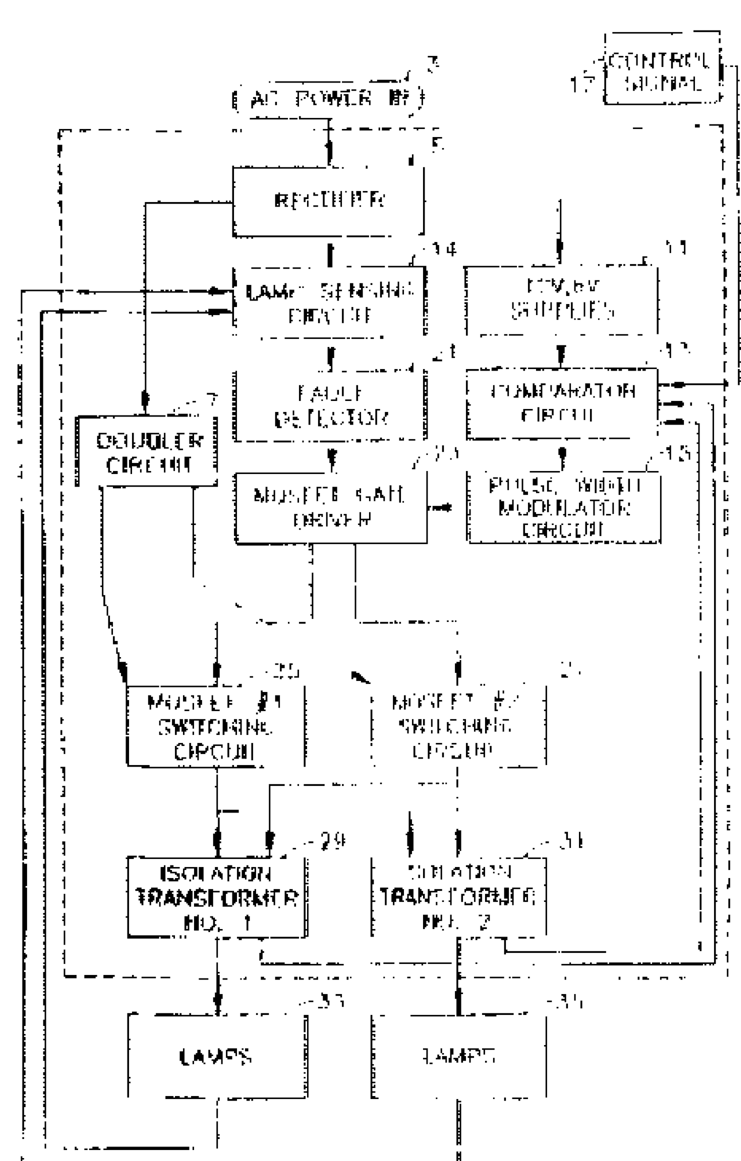
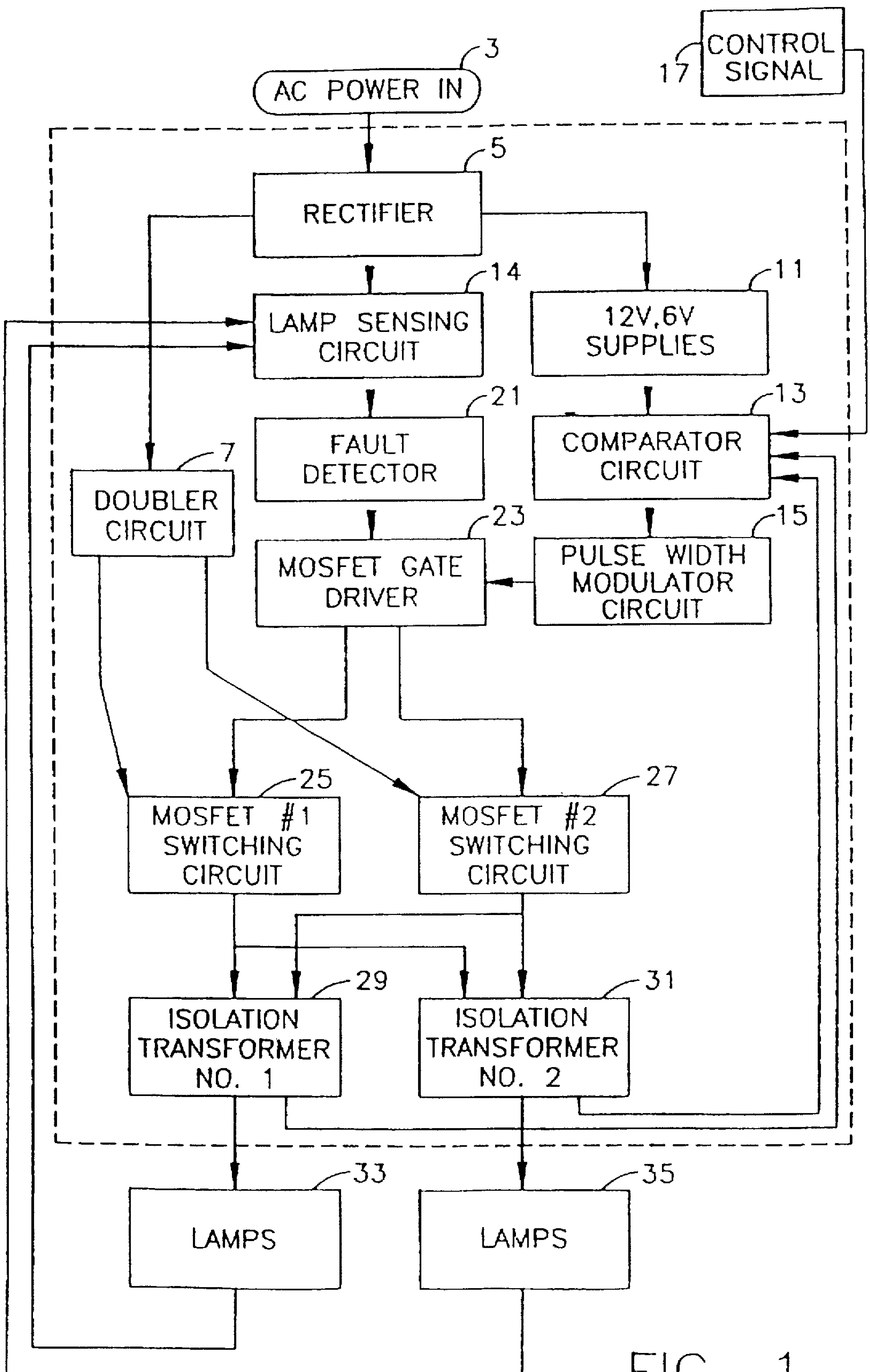
[57] **ABSTRACT**

The present invention is directed to an electronic ballast device for the control of gas discharge lamps. The device is comprised of a housing unit with electronic circuitry and related components. The device accepts a.c. power and rectifies it into various low d.c. voltages to power the electronic circuitry, and to one or more high d.c. voltages to supply power for the lamps. Both the low d.c. voltages and the high d.c. voltages can be supplied directly, eliminating the need to rectify a.c. power. The device switches a d.c. voltage such that a high frequency signal is generated. Because of the choice of output transformers matched to the high frequency (about 38 kHz) and the ability to change frequency slightly to achieve proper current, the device can accept various lamp sizes without modification. The ballast can also dim the lamps by increasing the frequency. The device can be remotely controlled.

20 Claims, 5 Drawing Sheets





AC POWER IN
3
CONTROL SIGNAL
17
RECTIFIER
5
LAMP SENSING CIRCUIT
14
12V,6V SUPPLIES
11
FAULT DETECTOR
21
COMPARATOR CIRCUIT
13
DOUBLER CIRCUIT
7
MOSFET GATE DRIVER
23
PULSE WIDTH MODULATOR CIRCUIT
15
MOSFET #1 SWITCHING CIRCUIT
25
MOSFET #2 SWITCHING CIRCUIT
27
ISOLATION TRANSFORMER NO. 1
29
ISOLATION TRANSFORMER NO. 2
31
LAMPS
33
LAMPS
35

FIG. 1

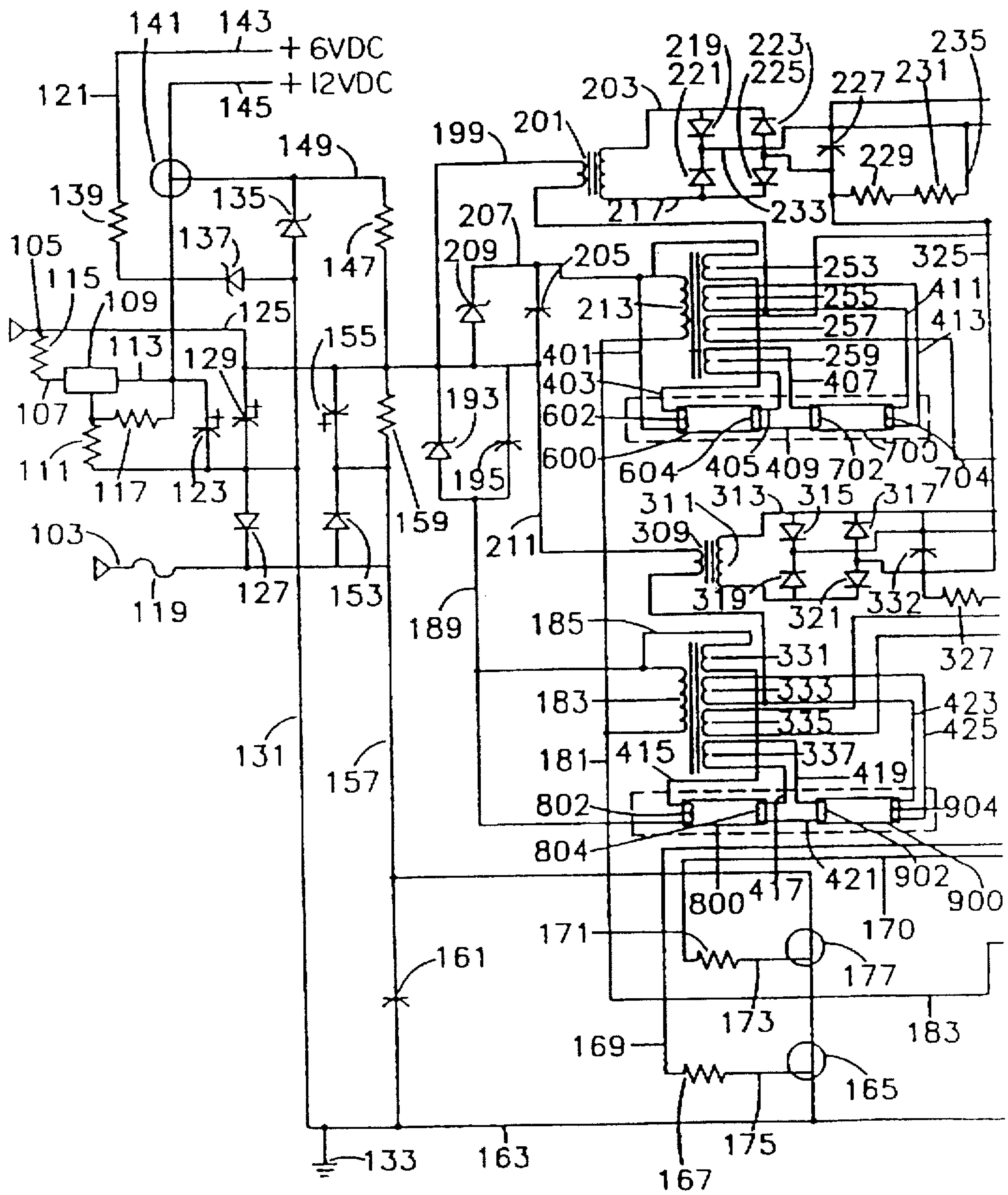


FIG. 2

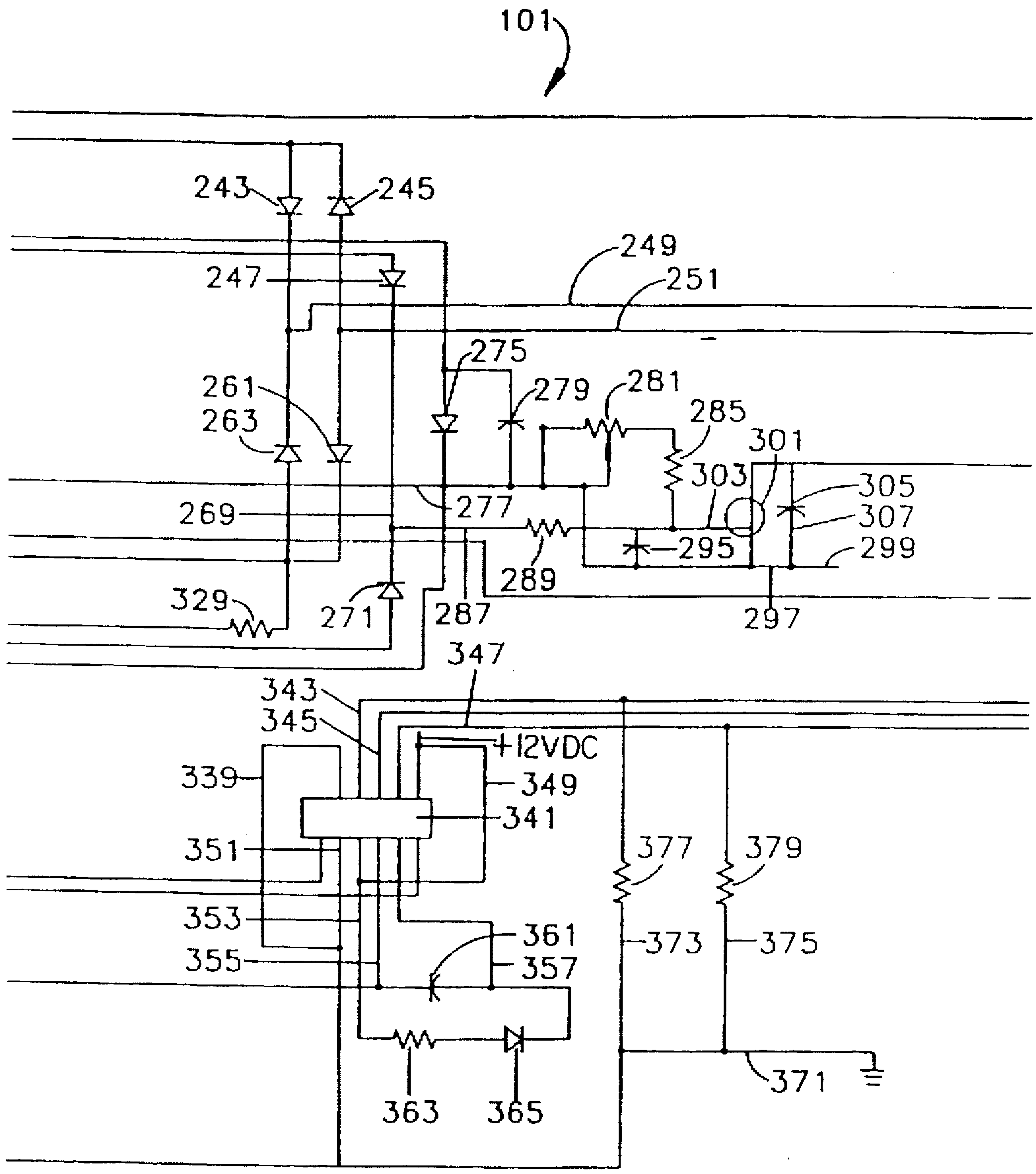

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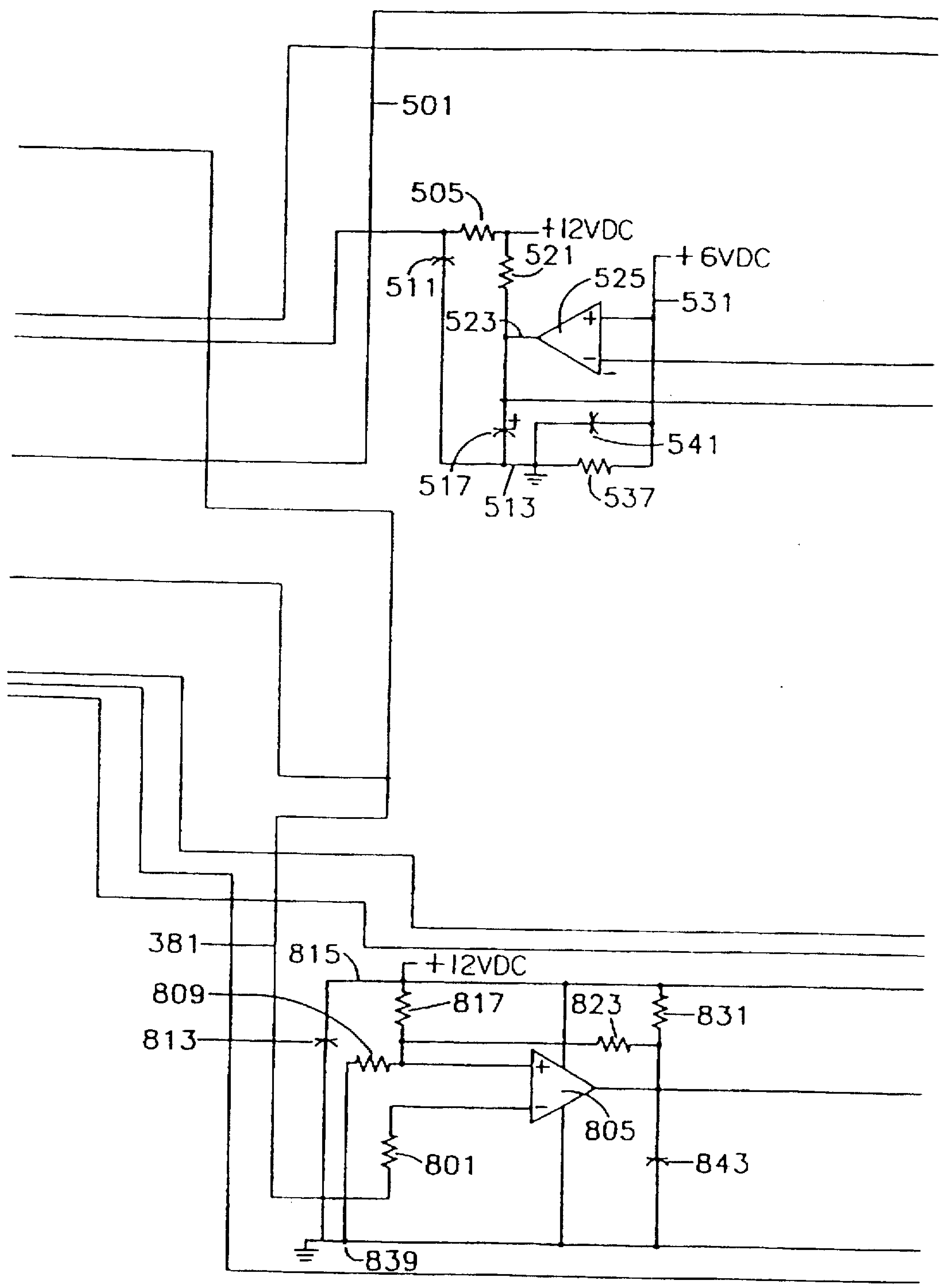
FIG. 2



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+6VDC
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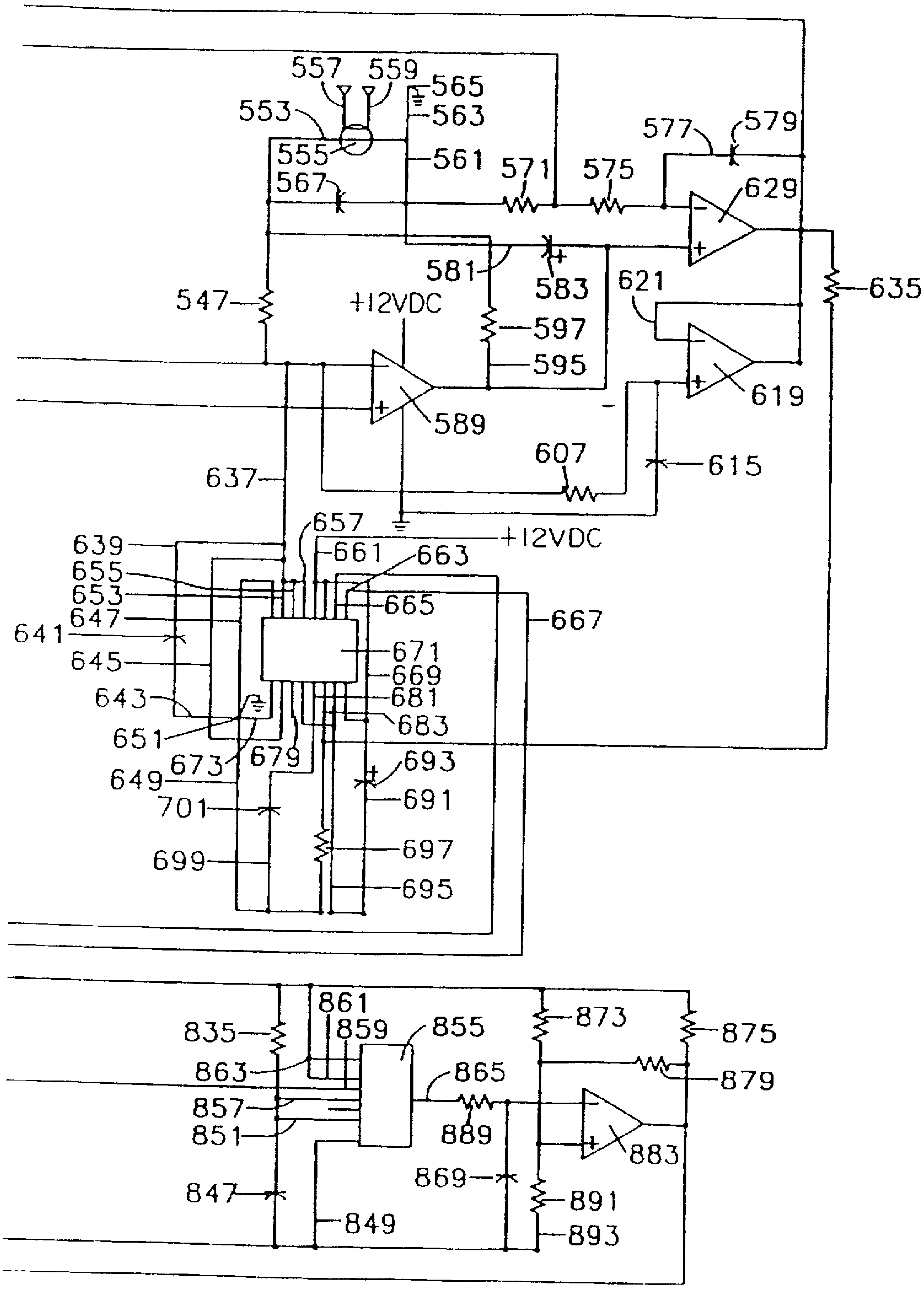
FIG. 2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847
849
893

FIG. 2

VARIABLE CONTROL, CURRENT SENSING BALLAST

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is an electronic ballast device for controlling the power to one or more gas discharge lamps, specifically, fluorescent lamps. It is directed to the problems of present ballasts used for fluorescent lamps which waste energy through excess heat generation and which also lack control options.

The present invention is able to power any of the conventional fluorescent lamps without modification. This includes, but is not limited to standard fluorescent lamps, HO, VHO, T8, T10, and T12 lamps ranging from a two foot standard lamp to an eight foot T12.

2. Prior Art Statement

Fluorescent lamps are used extensively throughout office buildings, schools, hospitals, industrial plants for lighting, as plant grow lights for outdoor lighting, and for many other uses. The power to these lamps are controlled by ballasts which have inherent problems. While fluorescent lamps with standard ballasts and less sophisticated electronic ballasts offer some benefits over other lighting techniques, such as lower energy use for comparable light output, these ballasts still waste energy through excessive heat generation and they lack the features available with the present invention. Standard ballasts use bulky energy wasting transformers to create a high voltage, low frequency signal to excite the lamp filaments. The present invention uses a low voltage, high frequency signal to excite the filaments. Existing ballasts require specific impedance matching to a specific lamp design. The present invention can power a wide range of lamp sizes without modification.

Using the present invention, lamps will burn cooler, last longer and produce a brighter light while using less electricity. The present invention also has a more sophisticated level of control then is available from the present state of the art. It can dim the lamps, delay power-up to improve lamp life, sense when a lamp is missing or burnt out and respond accordingly by reducing power or shutting down completely, and it can be controlled remotely or by a programmable unit.

The present invention does not require that the lamp be individually matched to the ballast design. The present design can power a standard 425 ma lamp, an 800 ma HO lamp, a 1500 ma VHO lamp a T8, a T10 or a T12 lamp without modification. Prior Art requires the impedance of each lamp to be matched to the ballast in order that lamp current be limited. The present device uses the performance characteristics of the transformer at the operating frequency (typically about 38 kHz) that allows the impedance of the lamps in combination with the reactance of the transformer windings and a slight frequency change to limit lamp current.

International Patent No. WO 83/02537 uses a much lower frequency (20 kHz). While it uses the frequency characteristics of the output transformer to dim the lamp by increasing the frequency, its steady state operation is in the frequency mid-band of the transformer. This coupled with the lower

frequency (transformer reactance is proportional to frequency) means that during steady state operation, the lamp load must be matched to the ballast. Each additional lamp requires an additional output transformer. Further, this design requires an additional transformer in the timing circuit.

U.S. Pat. No. 4,853,598 discloses a higher frequency device (30 kHz), but one that operates in the frequency mid-band of the output transformer. This design dims by lowering voltage and must also be tailored to match the load of each lamp.

U.S. Pat. No. 4,998,045 discloses a device which operates in the frequency mid-band of the output transformer, and dims by varying the pulse width (duty cycle) and frequency of the timing circuit. This ballast must also be matched to the load.

U.S. Pat No. 4,998,046 discloses a complex device with separate transformers for arc voltage and filament voltage. Additional lamps require extra transformer winding and additional ballast capacitors to match the new load.

While Prior Art is extensive, none of the patents disclose an electronic ballast which takes full advantage of the characteristics of the output transformer such that any size lamp can be powered without impedance matching by adding or changing components.

SUMMARY OF THE INVENTION

The present invention is directed to an electronic ballast device for the control of gas discharge lamps such as fluorescent lamps. The device is comprised of a housing unit with electronic circuitry and related components. The device accepts a.c. power and rectifies it into various low d.c. voltages to power the electronic circuitry, and by use of a doubler circuit, to one or more high d.c. voltages to supply power for the lamps.

Both the low d.c. voltages and the high d.c. voltages can be supplied directly, eliminating the need to rectify a.c. power.

The high voltage d.c. power is applied to a plurality of MOSFET's [Metal Oxide Semiconductor Field Effect Transistors] which are controlled by a Pulse Width Modulation [P.W.M.] circuit which outputs two pulse trains 180 electrical degrees out of phase with each other. The PWM circuit controls switching circuitry which switches the MOSFET's such that a high frequency output is fed into a plurality of output transformers. Power from the output side of the transformers is fed to one or more fluorescent lamps. The PWM circuit thus controls the frequency which is supplied to the lamps.

The electrical characteristics of the transformers and the impedance of the circuit are chosen so that two important features are derived. The transformer operates in its "high frequency zone" where an increase in frequency, with voltage held nearly constant, will cause a decrease in output current. This allows for the ballast to dim the lamps by increasing the frequency range. Secondly, in this region of operation the reactance values of the transformer primary windings and the transformer secondary windings become significant. Because reactance is proportional to frequency, with a steady state operating frequency of about 38 kHz, these values are large. When different lamps are installed, the impedance of the lamp becomes part of the overall impedance reflected back to the MOSFET's. As lamp current increases, the resistance of the lamp decreases allowing for a further current increase. The overall impedance of the output transformers coupled with the impedance of the lamp with a slight frequency change acts to limit the lamp current. For any of the lamp sizes installed, a different, steady-state operating point for current and frequency is achieved when voltage is held nearly constant. It is the phenomenon of the transformer characteristics at the design nominal operating frequency which allow different lamp loads to be powered without rewiring or component change.

The high frequency of the voltage applied to the lamps striking the filaments, causes the lamps to light. The present invention can din the lamps by increasing the frequency inputted to the transformers thereby causing the output current to lower while the voltage is held constant As the current decreases, the lamps dim. Thus, it can be seen that the selection of the operating frequency and corresponding frequency response of the output transformer are critical in the design of the present device.

If one or more lamps is burned out or removed, the device will sense this and either shut down completely or decrease output power to the remaining lamps as required.

The present device operates with a higher efficiency than conventional ballasts and higher than most electronic ballasts in large part because of the higher frequency and correspondingly smaller output transformers required.

The lamps operated by this device will also last longer. The combination of small constant voltage on the filaments, lower voltage between filaments and higher operating frequency cut down on filament sputtering, and lower the voltage potential at the levels of the lamp so that the phosphorus in the lamp is depleted evenly from end to end. This will increase lamp life by as much as six times.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more fully understood when the present specification is taken in conjunction with the appended drawings.

FIG. 1 illustrates a flow diagram of the electrical process of preferred embodiments of the present invention; and,

FIGS. 2 (1–4) illustrate electrical schematic diagrams of one preferred embodiment ballast of the present invention showing the detailed interrelationships of the various components.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

The present invention involves an electronic ballast device for controlling one or more gas discharge lamps such as a fluorescent lamp. The flow chart in FIG. 1 presents one embodiment of the present invention shown generally as frame 1.

In this configuration there is an input of a.c. power 3 by means of a neutral lead and a hot lead (120 volts in the present embodiment). The device has the means to connect to the a.c. power 3. The a.c. power is input to the rectifier section 5. The rectifier 5 performs several functions. It rectifies the a.c. power 3 into various low d.c. voltages 11 as required to power the electronic circuitry of the device 1.

The rectifier section 5 also converts the a.c. power 3 into a high voltage d.c. power. This power is converted by the rectifier 5 and doubler circuit 7 from the a.c. voltage 3 into the d.c. power voltage 7. (In the present embodiment this results in 375 volts d.c. relative to ground.)

The doubler circuit 7 supplies d.c. power and ground to two MOSFET's 25 and 27. The switching of the MOSFET's is controlled by gate driver circuitry 23 which in turn is controlled by the Pulse Width Modulated [PWM] circuit 15 in the control section described below. The MOSFET's 25 and 27 are fired alternatively between the high voltage and ground, at 180 electrical degrees apart such that a high frequency output is fed into the inputs of the two isolation transformers 29 and 31, which see a high frequency symmetrical, alternating signal relative to the neutral lead which, with filtering, approaches a sinusoidal wave.

The outputs of the isolation transformers 29 and 31 are fed to the means to connect to the fluorescent lamps 33 and 35. One or more lamps may be connected to each transformer.

There is also an output of each of the transformers, 29 and 31 which is connected to the comparator circuit 13 described below.

The comparator circuit receives an externally generated control signal 17 and compares this signal to feedback signals from the outputs of the transformers 29 and 31. The control signal can turn the device on and off or can control dimming of the lamps. The comparator circuit 13 inputs timing signals to the PWM circuit 15. This PWM circuit 15 sends the timing signals to the MOSFET gate driver 23 as described above. By controlling the firing of the MOSFET's 25 and 27, the output of the MOSFET's 25 and 27 will be a voltage wave form of variable frequency. The high frequency voltage excites the filaments of the fluorescent lamps causing them to light. By changing the frequency slightly, proper operating conditions will be achieved. By increasing the frequency, the lamps can be dimmed. By preventing the firing of the MOSFET's 25 and 27, the lamps are shut off completely.

There is a lamp sensing circuit 19 which can detect a fault. A power signal from the rectifier 5 and feedback signals from the lamps 33 and 35 are input to the lamp sensing circuit 19 which senses the current draw of the lamps. The lamp sensing circuit 19 feeds into the fault detector circuit 21 which detects when a fault occurs. A fault occurs when one or more lamps burn out or when one or more lamps are missing causing a load change thereby changing the current draw of the load. If such a fault is detected, the fault detector 21 causes the MOSFET gate driver 23 to change the signals to the MOSFET switching circuits 25 and 27 so that power to the lamps is decreased or completely shut off.

Referring now to FIG. 2, a schematic diagram 101 shows details of a preferred embodiment of the present invention. Segments 103 and 105 show the 120 V a.c. mains input. This a.c. signal is used in three ways: To supply high voltage bias to a power switching network, to be used in a 12 V power supply, and to be used as an offset voltage in the transformer network. Fuse 119 serves as an over current protection device.

The a.c. voltage is rectified by 1000 μF power capacitors 129, 155, and diodes 127 and 153. A byproduct of the rectification process is that the output voltage is doubled to approximately 325 V across wire 131 to wire 157. When 103 is positive, 153 conducts and charges 155. When 103 is negative, 105 is positive and charges 129. When 103 returns positive, 129 discharges and make the negative reference of 155 approximately 180 V d.c. Capacitor 155 charges and adds another 180 V to the negative reference, resulting in approximately 360 to 375 volts at the junction of 153 and 155 relative to the junction of 127 and 129. This voltage serves as the working voltage for the switching network to be described later. The junction of diode 127 and capacitor 129 is connected by wire 131 to ground 133 for the system. Resistor 159 (16.2 kΩ) serves as a drain device to bleed off the high voltage stored in the power capacitors 129 and 155.

The rectified voltage is stepped down through 2.5 kΩ power resistor 115 and used to derive the 12 V power supply voltage. Resistor **115**, connects to voltage regulator **109** by wire **107**, which regulates its output voltage to approximately 30 V using reference resistors **117** (82 Ω) and **111** (1.8 kΩ). The output voltage of **109** on wire **113** is filtered by 470 μF capacitor **123** to remove any ripple voltage. The regulator output, taken at the junction of the output pin of **109** and capacitor **123** (wire **113**) is then used as bias voltage for the switching FET **141**. The gate of FET **141** is connected to wire **149** which connects to 150 kΩ resistor **147** from the a.c. line **125**. This drain voltage is regulated at 24 V by the zener diode **135**, the zener diode **137**, and 30.1 kΩ resistor **139** which steps the 24 V down to 6 V on wire **143** for use in the comparator network to be described later. The source voltage is regulated at 12 V on wire **145** for use as the voltage supply for the electronic components.

TRANSFORMERS

One side of an **85** turn primary winding **213** is oscillated in parallel with an **85** turn winding **183** of a second transformer by the switching signal at the junction of the source of MOSFET **177** and the drain of MOSFET **165**. The other side of **213** is connected to the one turn scondary winding **253**, the waveshaping network of .033 μF capacitor **205** and varistor **209** by wire **207**, and also to filament **602** of lamp **600** by wire **401**. The switching signal generated by the MOSFET network is essentially a square wave, and this signal must be conditioned before it is connected to the lamps. Capacitor **205** smooths the signal and varistor **209** protects against any overvoltage spikes, resulting in a symmetrical wave approximating a sinusoidal waveform. The secondary winding **253** on one side is connected to the primary, while the other side is connected by wire **403** to the other side of filament **602** of lamp **600**. This creates a small differential voltage across filament **602**. On the other side of **600**, one side of the filament **604** is tied to one side of a two turn secondary winding **259**. The other side of filament **602** is connected to one side of filament **702** of lamp **700**. The other side of winding **259** is connected by wire **407** to the opposite side of filament **702**. Secondary winding **255** (one turn) has each side connected to opposite sides of filament **704** of lamp **700** by wires **411** and **413** respectively. Thus all filaments have a small voltage across them. The side of **255** connected to **411** is also connected to the a.c. bus **125** connected by wire **199** through the center of toroid **201**. This gives winding **255** an offset voltage with which to excite the lamps, so that there is a voltage between the filaments of each lamp, which is about equal to the voltage across primary winding **213**.

Secondary winding **257** (one turn) acts as a current sensing device and is used as an input to one of the auxiliary lamp sensing circuits to be described later. One side of **257** passes through diode **247**, while the other is connected to the ground **299** by wire **277**.

The function of the second transformer mirrors the first, as they are operated in parallel. The primary winding **183** is excited by the same MOSFET switching signal as the first transformer from wire **181**. Capacitor **195** (0.033 μF and Varistor **193** shape the square wave into a sinusoidal wave to wire **189** connected to winding **183**.

The secondary winding **331** (one turn) on one side is connected to the primary by wire **185**, while the other side is connected to the filament **802** of lamp **800** by wire **415**. The primary is connected to the other side of the filament **802**, which creates a small differential voltage difference across filament **802**. On the other side of **800**, one side of filament **804** is tied to one side of secondary winding **337** (two turn) by wire **417**. The other filament is connected to filament **902** of lamp **900** by wire **421**. The other side of filament **902** is connected to the ramming side of secondary winding **337** by wire **419**. Secondary winding **333** has (one turn) one side connected to filament **904** of lamp **900** by wire **425** and the other connected to the other side of filament **904** by wire **423**. The side of **333** connected to **425** is also connected to the rectified a.c. bus **125** connected through a jumper wire through the center of toroid **309**. This gives winding **335** an offset voltage with which to excite the lamps so that there is a voltage between the filaments of each lamp, which is about equal to the voltage across primary winding **183**.

Secondary **535** (one turn) acts as a current sensing device and is used as an input to one of the auxiliary lamp sensing circuits to be described later. One side of **335** passes through diode **271**, while the other is connected to the ground **299** by wire **277**.

FAULT DETECTOR

In the absence of a lamp load, or the presence of an excessive load, the MOSFET switching network operates in a severe overcurrent mode. This condition will persist in the initial steady state, as there are only filaments acting as a load, since the lamps are not yet ionized. Therefore, a fault detector circuit is required. The operation of the circuit is as follows.

A reference voltage is established at the high input of comparator **805** by the resistive network of 20 kΩ resistor **817** and 10 kΩ resistor **809**. These resistors form the reference with a simple voltage divider using 12 V supply **815**, which has been filtered by 1 μF capacitor **813** connected between 12 V **815** and ground **839**. The sensing input from wire **381** passes through series 10 kΩ resistor **801** and terminates at the low input of **805**. When this input is below the reference level at the high input (ie, as during a fault condition), the output of **805** is high. When the input is above the reference value (normal operating conditions), the output of **805** is low. Resistor **823** (3.3 MΩ) is used to stabilize the output of **805** against oscillation and is connected between the output pin and high input of **805**. Resistor **831** (10 kΩ) serves as a pull up resistor between the output pin of **805** and the 12 V supply line. Any noise at this output is removed by the 1 μF capacitor to ground **843**. Under normal operating conditions, the output of **805** will first be high, and then drop to low. This is because as the lamps are first started, they appear similar to a fault condition, and then after they are lit settle down and appear as a normal load. If the lamps fail to strike, as in a fault condition, the output of **805** will remain high.

The output of **805** is fed into the trigger input **859** of a timer chip **855**. This timer chip is configured to act as a time delay one-shot circuit. The length of the delay is determined by the combination of 2.2 MΩ resistor **835** and 1 μF capacitor **847**. The junction of **835** and **847** is connected to both timing pins of **855** by wires **857** and **851**. The supply **863** and reset **861** pins of **855** are shortened together and tied directly to the 12 V **815** supply line. The ground pin of **855** is tied to the ground bus by wire **849**.

When the output of **805** falls low, the falling edge triggers the timer of **855** to start operating. After the delay, determined by **835** and **847**, the output of **855** goes high and remains high. If the output of **805** remains high, there is no falling edge, and the output of **855** remains low.

The output is buffered from the next comparator stage by the series 1 MΩ resistor **889**, and any noise is removed by

1 μF capacitor **869**. A reference voltage is established by equivalent 2.2 MΩ resistors **873** and **891** connected between 12 V d.c. and ground, and their junction connected to the high input of **883**. The low input to **883** is taken from the junction of **889** and **869**. When the input **855** is low, the output of **833** remains high, only going low when the input rises above the level determined by **873** and **891**. This output is stabilized by 3.3 MΩ resistor **879** connected between the output pin and the junction of **873** and **891** which connects to the high input of **883**. The last component of this section is the 499 kΩ pull up resistor **875** connected between the output of **883** and the 12 V supply line.

The output of **883** is then connected to the shutdown pin of the MOSFET driver **341** by wire **345**. When this signal is high, no oscillation occurs. When the shutdown signal is low, oscillation is allowed as normal.

MOSFET GATE DRIVER

The MOSFET gate driver circuit is used to ensure proper turn on at the gates of MOSFETs **177** and **165**, ie, no reverse currents and proper gate voltage.

The 12 V supply line provides power to, the gate driver **341** by wire **349**. The grounding for **341** is at wire **351** which is also connected to wire **339**. Wire **351** connects to wire **163** which ties to ground **133**. Wires **667** and **343** are the inputs to **341** for the oscillating square wave from the pulse width modulation. In effect, **347** and **343** are two of the three control signals. As long as wire **345** (the shutdown input) remains low, these inputs will allow gate driver **341** to control the switching outputs. When a voltage is applied to wire **345** from the fault detector circuit, the outputs of gate driver **341** are disabled until the voltage at wire **345** falls to zero.

The switching outputs of gate driver **341** are found at wires **169** and **170** with wire **169** being the low side voltage switch and wire **170** being the high side voltage switch. The high side voltage is established by taking the high voltage at the source of **177** and feeding it through a bootstrap circuit consisting of 20 Ω resistor **363**, diode **365**, and 0.1 μF capacitor **361**. The 12 V at wire **353** causes diode **365** to conduct after passing through **363**. This section acts as the charging scheme for capacitor **361**. Capacitor **361** is connected between wire **355** and wire **357**. Capacitor **361** stores the voltage at the source of **177** and uses it as the high side switching voltage. The junction between capacitor **361** and diode **365** is connected to gate driver **341** by wire **357**.

MOSFET SWITCHING CIRCUIT

MOSFETs **177** and **165** are connected in a half bridge configuration and provide the high voltage switching to operate the transformers and drive the lamps. The high voltage supply at the drain of **177** is taken from the output of the doubler circuit at the junction of **153** and **155** by wire **157**. Any ripple present at this point is removed by the 0.68 μF filter capacitor **161**, which is connected between the high voltage supply and ground. The gate of **177** is turned on by the high voltage output of the gate driver circuit, with 20 Ω resistor **171**, connected by wire **173**, acting as a buffer to reduce the gate voltage level slightly.

When the gate is turned on, the high voltage supply is switched through to the source of **177**, which is connected to the drain of **165**, the bootstrap circuit connected by wire **183**, and the primary of transformer **213**. This is the high power oscillating signal used to drive the lamps. The switching signals from **341** on wires **169** and **170** alternate 180 electrical degrees out of phase so that when **177** is on, **165**

is off, so at the junction of the source of **177** and the drain of **165**, the voltage is 325 V. When the gate of **177** is off, **165** turns on, making the potential at the junction equal to ground. The gate of **165** is turned on in the same fashion as **177**, with 20 Ω resistor **167**, connected by wire **175**, acting to soften the gate turn on voltage.

PULSE WIDTH MODULATOR CIRCUIT

The pulse width modulator (PWM) circuit uses a PWM chip **671** to supply the timing signals to the MOSFET gate driver circuit, and ultimately control the frequency of MOSFET oscillation. These timing signals may be generated by other means but in this embodiment this PWM circuit supplies the alternating, high frequency timing signals.

Power for PWM **671** comes from the 12 V supply line connected by wire **661**. Capacitor **693** (10 μF) acts as a local filter from the 12 V line to ground by wire **691**. The 12 V supply is also connected by wires **669** and **663** to the collectors of the chip's output transistors, and this voltage simply serves as the bias voltage for them. Grounding **651** for PWM **671** is supplied by **695**, which is also connected to the dead time control pin by **679**, non-inverting input #1 by **673**, and non-inverting input #2 by **647**. The regulated reference output is connected by **655** to **657**, **653**, and **645**. A 0.1 μF capacitor **641** is connected from **653** by **639** to ground **651** by wire **643** to smooth the d.c. voltage. This d.c. voltage serves as the inverting input for the error amplifiers of PWM **671**, as well as the output control voltage. The timing for **671** is determined by the combination of 22.6 kΩ resistor **697** and 1000 pF capacitor **701** connected to ground by wire **699**. Resistor **697** is connected to PWM **671** by **683** and **649** to ground, while capacitor **701** is connected from wire **681** to ground. At the junction of **697** and wire **683** is attached one side of 16.2 kΩ series resistor **635**, which affects the frequency of oscillation based on the dimming signal to be described later.

The outputs of PWM **671** are taken from the emitters of the output transistors, at wires **665** and **667**. These outputs are then connected to inputs of gate driver **341**. Resistors **377** and **379** (10 kΩ each) are shunted across each output line respectively by wires **373** and **375**, to ground **371** to stabilize the outputs locally.

LAMP SENSING CIRCUIT

The output of the toroid at **203** and **217**, represent the current passing through the secondary winding **255**. This is an a.c. voltage and must be rectified to d.c. Diodes **219**, **221**, **223** and **225** are configured in a full wave bridge rectifier formation. The full wave rectified signal is then filtered through 0.1 μF capacitor **227** to remove the ripple voltage. Capacitor **227** is connected on one side to the junction of **219** and **221**, and on the other side to the junction of **223** and **225**. The input to the shutdown circuit is also taken from this point, and is connected to resistor **801** by wire **381**. Resistors **229** and **231** (182 Ω each) serve as a bleeder for capacitor **227** connected by wire **235**. These resistors are equivalent and can be replace by one resistor equal to the sum of two. It is not critical to this embodiment that the two resistors be in series. Diode **275** and 0.1 μF capacitor **279** couple the junction of **227** and **229** to ground.

The operation of the second lamp sensing circuit mirrors the first, much as the transformer operation is the same. The outputs of the toroids, across **311**, represent the current passing through the secondary winding **333**. This is an a.c. voltage and must be rectified to d.c. Diodes **315**, **319**, **321** and **317** are configured in a full wave bridge rectifier formation. The full wave rectified signal is then filtered through 0.1 μF capacitor **332** to remove the ripple voltage. Capacitor **332** is connected on one side to the junction of **315** and **319**, and on the other side to the junction of **317** and **321**. This junction is connected to the junction of diodes **223** and **225** by wire **325**. The input to the shutdown circuit is taken from the junction of **315** and **317** and is connected to resistor **801** by wire **381**. Resistors **327** and **329** (182 Ω each) serve as a bleeder for capacitor **322**. These resistors are equivalent and can be replaced by one resistor equal to the sum of two. It is not critical to this embodiment that the two resistors be in series.

The circuitry that remains in the lamp sensing circuit is not critical to the operation of the ballast. However, the extra circuitry provides alternate means to implement current sensing, fault detection, and dimming modules. The present embodiment leaves these circuits intact for development of future embodiments.

Diodes **243**, **245**, **262**, and **263** are used to sum together the outputs of the dual toroidal full wave bridge circuits. Essentially, they act as another full wave bridge stage. The junction of **261** and **243** is connected by wire **249** to the junction of resistors **571** and **575** in the comparator network, to be described later. The junction of **245** and **263** is connected by wire **251** to the junction of resistor **505** and capacitor **511** in the comparator network.

Diode **247** passes only the positive portion of the lamp sensing signal from winding **257**. This positive portion is then summed with the positive portion of winding **335**, which has also passed through diode **271**. The junction of **271** and **247**, wire **269**, which is always a positive voltage, is applied to the gate of FET **301**, first passing through 16.2 kΩ resistor **289**, resistor **289** being connected to the diode junction by wire **287** and so to the gate by wire **303**. The voltage at the gate is divided by the resistive network of **289**, 3.8 kΩ **285** and 5 k potentiometer **281**. This network is used to set the turn on voltage for the gate of the FET **301** by adjusting the value of **281**. Capacitor **295** (22 μF) filters out between wire **303** and ground on wire **297**, which may have infiltrated the signal coming from the windings **257** and **335**. Capacitor **305** (0.1 μF) serves simply to couple the drain voltage of FET **301** by wire **307**, to the voltage coming from pin 1 of comparator **629** through wire **501**. The source of FET **301** is connected to ground **299** by wire **297**.

COMPARATOR CIRCUIT

The 6 V supply **531** derived in the power supply section here acts as a reference voltage at the high input of comparator **525**. The 6 V supply **531** is filtered by 0.1 μF capacitor **541** from **531** to ground **513** and stabilized locally by 9.91 kΩ resistor **537** shunted from **531** to the ground **513**. The low input gets its level from the regulated 5 V output from wire **637** in the PWM circuit. Since this comparator is in the inverting mode, the output to wire **523** will be high. The output rises slowly, as it charges 22 μF capacitor **517** connected between the output and ground **513**. The speed at which the output rises is controlled by the pull up resistor **521** (45 k). The smaller the value of **521**, the faster **517** will charge. Resistor **521** is connected on one side to the output of **525** and on the other side to the junction of the 12 V supply line, and to 10.7 kΩ resistor **505**. Resistor **505** here works as a pull up resistor for the junction of diodes **245** and **263**, whose potential is nearly ground. Capacitor **511** (0.1 μF) is connected between wire **251** and ground **513**.

The output of **525** is also connected to the high input of comparator **589**. The low input of **589** is taken from the regulated 5 V output of **621**. The high input of **589** ramps up until it is at a higher potential than the low input. At this point, the output rises slowly, since it is charging 1 μF capacitor **583**, whose positive side is connected to the output of **589** and high input of comparator **629** The negative side of capacitor **583** is connected to the ground. The output of **589** is also attached to 100 kΩ resistor **597**, which connects to 10 kΩ resistor **547**, 1 μF capacitor **567**, and the opto isolator chip **555**. These resistors are used in the dimming mode which will be discussed later.

Comparator **629** gets a high input from the output of **589**. The low input comes from the junction of diodes **243** and **261**, which comes into the junction of the resistors **575** (32.7 kΩ) and **571** (100 kΩ). Resistor **571** goes between the junction of diodes **243** and **261** and the ground for stability, while resistor **575** goes from this junction to the low input of **629**. Also meeting at the low input of **629** is one side of 0.047 μF capacitor **579**, connected by wire **577**, which is connected as a feedback capacitor from the output of **629**. This input is taken from the lamp sensing circuit. When the lamps are not yet lit, the signal is low, but once the lamps light, the voltage here goes high. The low input goes high faster than the high input, which is more of a slow ramp. When the voltage at the high input finally exceeds the voltage at the low input, the output of **629** goes high.

The output of **629** is connected to the output of **619**, the low input of **619** by wire **621**, the feedback capacitor **579**, and the series resistor **635**.

The high input of **619** comes from the low input of **589** through the 100 kΩ buffer resistor **607**. To take out noise at this pin, 0.1 μF capacitor **615** is shunted from the high input to ground. The low input of **619** is connected to the output of **629**. Comparator **619** is used to reduce the voltage present over resistor **635** at startup. When the input at the low input finally goes high as a result of comparator **629**, the output of **619** then goes high also.

CONTROL SIGNAL

The control signal is supplied by an external device which outputs information to input pins of the optical isolator **555** between wires **557** and **559**. This information can be used to dim the ballast, or remotely turn the device on or off. When no control signal is present, the voltage at the collector of **555** is 5 V at wire **553**, since it is connected to the regulated output voltage of **671** though resistor **547**. The emitter of **555** is connected to the ground **565** by wire **561**. Capacitor **567**, connected from the collector of **555** to the ground **563**, serves as a noise filter. The control signal, in this case a dimmer signal, causes a PWM signal to appear at the collector of **555**, and the pulse width of this signal varies with dimmer input. As the duty cycle decreases, and the dead time increases at the collector of **555**, the lower average voltage at this point causes the voltage at the output of comparator **589** to lower, allowing **583** to drain off. As **583** drains off, the voltage at the high input of **629** decreases, which causes the voltage at the output of **629** to drop off. Resistor **635** is the timing interface device between the comparator section and the PWM section. When voltage is applied over **635**, it changes the effective resistance seen at the resistive timing of **671**. As this effective resistance changes, the frequency of oscillation increases and the lamps dim.

For a remote on-off controller, the input to **555** is a d.c. voltage, and this causes the collector of **555** to fall to zero volts. At this point, the same characteristics are displayed as when dimming, except instead of dimming, the ballast shuts off.

The present invention can be used to power fluorescent lamps in a wide variety of applications. It can power fluorescent lamps to provide light to aquariums, controlled by a timer. It can power lamps used to provide light for houseplants, controlled by a photocell monitoring system.

The present invention can achieve great energy savings in office buildings, schools, hospitals and industrial plants or any other location where there are large banks of lights. Not only does this type of application where there are so many lamps benefit from great energy savings, but it benefits from the ability to remotely and precisely control the output of the lamps. Also, since not all lamps in such a location will necessarily be of the same type, the user will benefit from the ability to interchange bulb types without rewiring or modification.

The present invention is also ideal for outdoor applications, lighting either areas or billboards. Because of the need to provide light for long periods in remote locations, the applications will benefit both from the energy savings of the present invention and from its ability to control the output of lamps.

Obviously, numerous modifications and variations of the present invention arc possible in light of the above teachings. It is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

What is claimed is:

1. An electronic ballast device for controlling the power to one or more gas discharge lamps, comprising:
- (a) a housing unit to mount electronic circuitry and related components;
- (b) electronic circuitry mounted on said housing unit, which includes:
  - (i) means for connecting and applying a.c. power input to said circuitry;
  - (ii) means for switching lamps on and off controlling said circuitry;
  - (ii) rectifying circuitry to convert a.c. power input to a plurality of d.c. outputs, including one or more low voltage outputs;
  - (iv) comparator circuitry which receives an external control signal and compares it to feedback from the output of the device, and thereby controls a Pulse Width Modulation [PWM] circuitry;
  - (v) said PWM circuitry which sends at least one timing signal to MOSFET gate driver circuit;
  - (vi) said MOSFET gate driver circuit which receives said timing signal from PWM circuitry and supplies switching control to two MOSFET's;
  - (vii) said MOSFET's which receive d.c. power from doubling rectifying circuitry and which are controlled by said MOSFET gate driver circuitry such that a high frequency voltage is output;
  - (viii) means to create an initial delay of MOSFET switching during initial power-up to improve lamp life and effectiveness;
  - (ix) two isolation transformers, with the outputs of said MOSFET's connected to the inputs of said transformers;
  - (x) lamp sensing circuitry receiving input from rectifier to detect lamp outage, and connected to shut down circuitry;
  - (xii) said shut down circuitry to at least partially decrease power when at least one lamp is missing, and;
  - (xii) means to connect power output from isolation transformers to lamps.

2. The electronic device of claim 1, further comprising the means to be remotely controlled, for switching on and off.

3. The electronic device of claim 1, further comprising the means to remotely control the device such that the lights may be dimmed by controlling the PWM circuitry.

4. The electronic device of claim 1, further comprising the means to control the device by a programmable timer and dimmer.

5. An electronic ballast device for controlling the power to one or more gas discharge lamps, such device comprising:
- (a) a housing unit to mount electronic circuitry and related components;
- (b) electronic circuitry which includes:
  - (i) means for connecting and applying d.c. input power;
  - (ii) means for switching lamps on and off;
  - (iii) means for connecting and applying low voltage d.c. power to the electronic components;
  - (iv) comparator circuitry which receives an external control signal and compares it to feedback from the output of the device, and thereby controls a Pulse Width Modulation [P.W.M.] circuitry.
  - (v) said P.W.M. circuitry which sends at least one timing signal to the MOSFET gate driver circuit;
  - (vi) said MOSFET gate driver circuit, which receives said timing signal from PWM circuitry and supplies switching control to two MOSFETs;
  - (vii) said MOSFET's which receive high voltage d.c. power, and which are controlled by said MOSFET gate driver circuit such that a high frequency voltage is output;
  - (viii) means to create an initial delay of MOSFET switching during power-up to improve lamp life and effectiveness;
  - (ix) two isolation transformers, with the outputs of said MOSFET's connected to the inputs of said transformers;
  - (x) lamp sensing circuitry receiving input from rectifier to detect lamp, outage and connected to shut down circuitry;
  - (xi) shutdown circuitry to at least partially decrease power when at least one lamp is missing, and;
  - (xii) means to connect power output from isolation transformers, to lamps.

6. The electronic device of claim 5 further comprising the means to be remotely controlled, for switching on and off.

7. The electronic device of claim 5 further comprising the means to remotely control the device such that the lights may be dimmed by controlling the PWM circuitry.

8. The electronic device of claim 5 further comprising the means to control the device by a programmable timer and dimmer.

9. An electronic ballast for controlling the power to a set of one or more gas discharge lamps, comprising:
- *(a) a switching circuit for generating a high frequency a.c. voltage;*
- *(b) a waveshaping circuit for smoothing the high frequency a.c. voltage;*
- *(c) at least one transformer having a primary winding and at least one secondary winding, each of the primary and secondary windings having a first end and a second end;*
- *(d) wherein the switching circuit, waveshaping circuit and Primary winding are connected together in series; and*
- *(e) the set of one or more gas discharge lamps and the at least one secondary winding is connected in parallel with the waveshaping circuit such that the first end of*

said at least one secondary winding is connected to a node between the primary winding and the waveshaping circuit.

10. The electronic ballast of claim 9, wherein the set of one or more gas discharge lamps comprises one lamp.

11. The electronic ballast of claim 9, wherein the set of one or more gas discharge lamps comprises two or more lamps and connections between lamps in the set of two or more gas discharge lamps is serial and each connection is provided by one of said at least one secondary winding.

12. The electronic ballast of claim 9, wherein the waveshaping circuit comprises a capacitor in parallel with a varistor.

13. The electronic ballast of claim 11, wherein the primary winding has approximately 85 turns and each secondary winding that provides a serial connection between lamps in the set of one or more gas discharge lamps has approximately two turns.

14. The electronic ballast of claim 9, wherein the switching circuit comprises:

(a) means for connecting to an a.c. power supply at an input;

(b) a rectifying circuit to convert an a.c. voltage received from the a.c. power supply to a d.c. voltage; and

(c) a converting circuit connected to an output of the rectifying circuit for converting the d.c. voltage into a high frequency a.c. voltage.

15. The electronic ballast of claim 14, wherein the converting circuit comprises:

(a) a pulse width modulator;

(b) a gate driver connected to the pulse width modulator;

(c) a switch controlled by the gate driver for converting the d.c. voltage from the rectifying circuit into the high frequency a.c. voltage;

(d) wherein the pulse width modulator provides timing signals to the gate driver.

16. The electronic ballast of claim 15, wherein the switch comprises one or more MOSFETs.

17. The electronic ballast of claim 9, further comprising dimming means for controlling the frequency of the high frequency a.c. voltage.

18. The electronic ballast of claim 14, further comprising a lamp sensing circuit connected to one of the at least one secondary winding for detecting a current passing through the one of the at least one secondary winding.

19. The electronic ballast of claim 18, further comprising a shutdown circuit connected to the lamp sensing circuit for decreasing power to the set of one or more gas discharge lamps when the detected current is indicative of a lamp fault.

20. The electronic ballast of claim 18, further comprising a comparator circuit connected to the lamp sensing circuit, the comparator circuit receiving an external control signal and comparing the control signal to the signal received from the lamp sensing circuit and thereby controlling the pulse width modulator.

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