July 28, 1964 G. C. IZENOUR 3,142,781

LIGHTING CONTROL CIRCUIT

Filed March 25, 1958 2 Sheets-Sheet 1

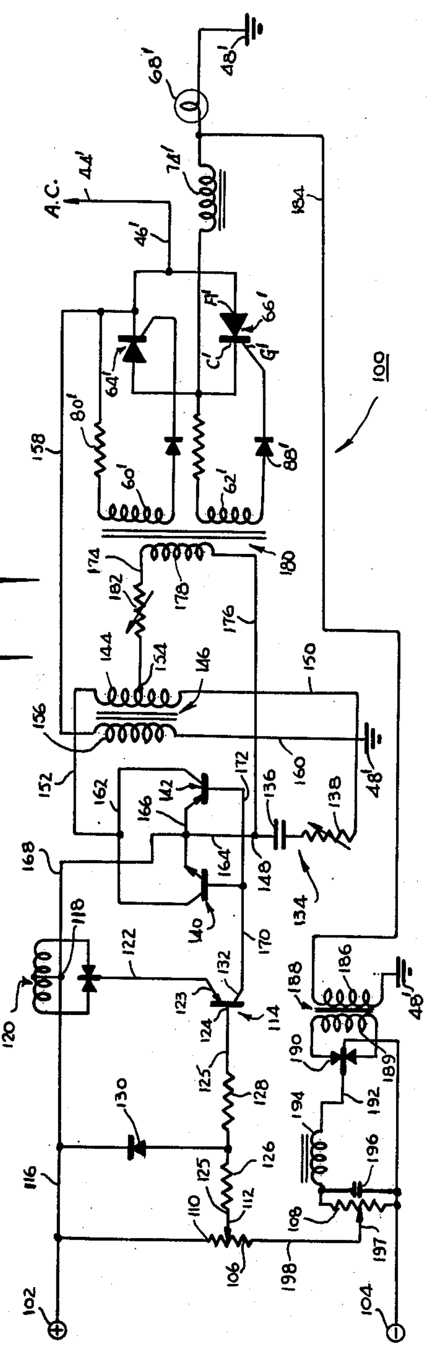

Fig. 2.

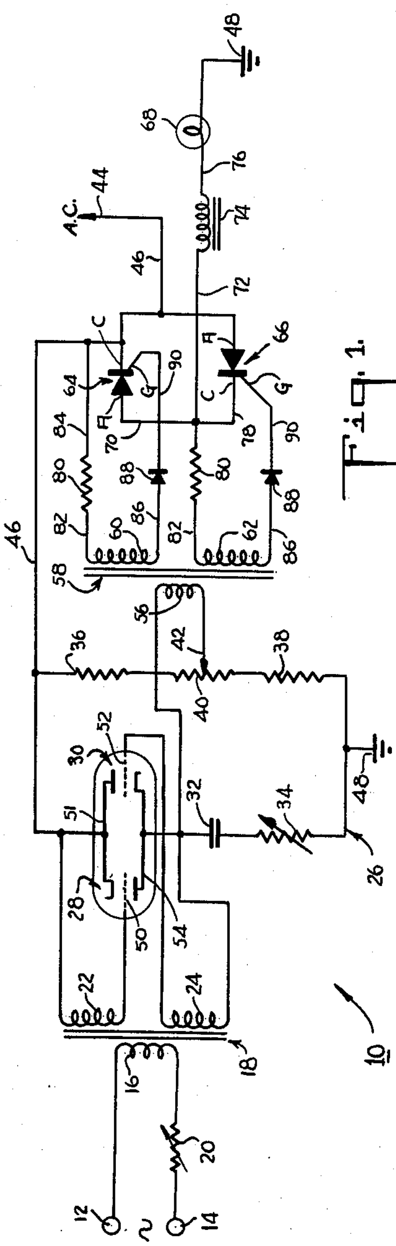

Fig. 1.

INVENTOR.
GEORGE C. IZENOUR
BY
Anderson, Luedeka [signature]
ATTORNEYS

July 28, 1964 G. C. IZENOUR 3,142,781

LIGHTING CONTROL CIRCUIT

Filed March 25, 1958 2 Sheets-Sheet 2

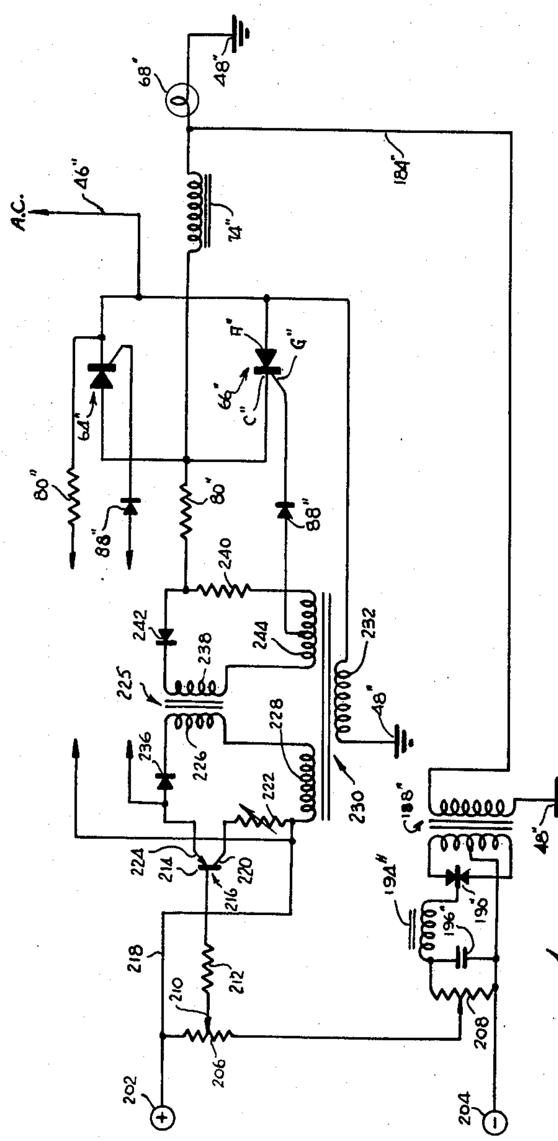

FIG. 3

INVENTOR.
GEORGE C. IZENOUR
BY
Kirschstein, Kirschstein & Ottinger
ATTORNEYS

United States Patent Office
3,142,781
Patented July 28, 1964

3,142,781
LIGHTING CONTROL CIRCUIT

George C. Izenour, New Haven, Conn., assignor to Century Lighting, Inc., New York, N.Y., a corporation of New York

Filed Mar. 25, 1958, Ser. No. 723,876
1 Claim. (Cl. 315—194)

This invention relates to electric lighting control circuits and, more particularly, to circuits of the type which find their greatest use in theatre and television lighting.

The present invention constitutes an improvement over the lighting control circuits shown, described and claimed in my earlier reissue United States Letters Patent No. Re. 23,575, reissued November 11, 1952, for Lighting Control Circuits, and my subsequent United States Letters Patent No. 2,798,984, issued July 9, 1957, for Lighting Control Circuits.

The circuits disclosed in my aforesaid patents, although widely used and extremely practical, reliable and efficient, are subject to certain drawbacks. For example, the equipment utilized in said circuits is comparatively large and heavy. Accordingly, until now it has been necessary to maintain the power units of said circuits physically separate from the loads, e.g., search lights, driven by said units. This necessitates the use of long individual power leads and the employment of patchboards, that is to say, switching equipment at which different loads are selectively connected to different power units. Moreover, the former circuits, although operating at high efficiencies which are commercially satisfactory, nevertheless experience noticeable power losses in the form of lost energy, voltage drops and heat radiation all of which represent additional expense and require ingenuity, special locations or additional equipment for handling or overcoming the loss of energy. Another difficulty experienced with the former circuits is the considerable noise developed in the sundry pieces of inductive equipment which are massive and handle high power, thereby creating a high level of sound which, unless successfully isolated or otherwise dampened, creates a nuisance factor.

It is an object of my present invention to provide a lighting control circuit having a power unit which avoids all of the foregoing drawbacks.

It is another object of my invention to provide a lighting control circuit in which the power unit is quite small, so small indeed that it is capable of being integrated within or on the casing of an ordinary piece of lighting equipment, such for instance, as a search light.

It is another object of my invention to provide a lighting control circuit which is of such nature that all of the major pieces of lighting equipment can be provided with their own power units, so that the patchboard connections which determine the pieces of equipment to be energized can be made at the low voltage control end of the circuit rather than at the power end of the circuit, thus eliminating the need for heavy complex patchboard equipment and the use of long individual power leads.

It is another object of my invention to provide a lighting control circuit in which the power unit is extremely efficient, having for example, so small a voltage drop that there is no necessity for the utilization of boosters to make up for voltage drop in passage through the power units.

It is another object of my invention to provide a lighting control circuit having a power unit which is so highly efficient that the heat radiated therefrom is negligible and needs very little, if any, special arrangements for its dissipation.

It is another object of my invention to provide a lighting control circuit having a power unit which substantially reduces the cost of the lighting, both through the lowering of voltage losses and the elimination of the ener-

gization of elements of many pieces of equipment forming part of the power unit.

It is another object of my invention to provide a lighting control circuit having a power unit which requires and uses far fewer pieces of electric equipment than the previous circuits, thereby substantially lowering the cost thereof, reducing the space required and simplifying and lessening the time needed for wiring.

It is another object of my invention to provide a lighting control circuit having a power unit in which the number and size of the pieces of inductive equipment is greatly reduced, thus both substantially lowering the cost of the circuit and substantially lessening the noise created thereby.

It is another object of my invention to provide a lighting control circuit having a power unit which, in addition to the many advantages pointed out above, is so constituted that the parts thereof rarely need replacement.

It is another object of my invention to provide a lighting control circuit having a power unit which comprises relatively few and simple parts and is inexpensive to manufacture.

Other objects of my invention in part will be obvious and in part will be pointed out hereinafter.

My invention accordingly consists in the features of construction, combinations of elements and arrangements of parts which will be exemplified in the lighting control circuits hereinafter described and of which the scope of application will be indicated in the appended claim.

In the accompanying drawings, in which are shown various possible embodiments of my invention,

FIG. 1 is a wiring diagram for a power unit of a lighting control circuit embodying one form of my invention, and

FIGS. 2 and 3 are diagrams similar to FIG. 1, but showing two modified forms of power circuits.

In the following description I only have detailed the power units of various lighting control circuits inasmuch as it is to these that my invention is specific. In other words, my invention does not relate to what is commonly referred to as the control section, or control end, or console section, this being the portion of the lighting control circuit which provides a variable electrical characteristic, specifically voltage, that is designed to control the variable intensity of illumination.

In each of the forms of my invention now to be described I have shown a pair of input terminals to which the variable control voltage is applied. In order to avoid undue complexity of circuitry and description, I have not illustrated here the standard control ends which are shown in the two aforesaid patents and it will be understood by those skilled in the art that in the practice of the present invention any of said control ends are to be employed to supply a control voltage to the input or control terminals of my power units, this voltage either being A.C., for instance as illustrated in my aforesaid reissue Letters Patent, or D.C. as is illustrated in my aforesaid Letters Patent No. 2,798,984. It further is to be understood, however, that I am not to be limited to these specific control ends for obtaining a variable amplitude control voltage.

Referring now in detail to the drawings, and more particularly to FIG. 1, I there have shown an A.C. power unit **10** such as I have described above in general terms. Said circuit includes a pair of input terminals **12**, **14** to which there is applied an A.C. voltage that is variable in amplitude, such for instance, as is derived at the output of the control end shown in my aforesaid reissue Letters Patent, this output being taken for example, at the poles of the double throw transfer switch **58** illustrated and described in my said reissue patent.

The control voltage applied to the terminals **12**, **14** is fed to the primary winding **16** of a high impedance line-to-grid transformer 18 for regulating a pair of back-to-back high vacuum triodes. A typical satisfactory impedance value for said transformer is in the order of 100,000 ohms. The input circuit for the primary 16 includes a low impedance variable resistor 20 the function of which will be described later herein. The twin secondaries 22, 24 of the transformer 18 are used to control a phase shifting network consisting of a bridge 26.

One leg of the bridge 26 includes a pair of back-to-back high vacuum triodes 28, 30 that are under the regulation of the transformer 18. Another leg of the bridge comprises a capacitor 32 in series with a variable trimming resistor 34. The remaining two legs of the bridge constitute, respectively, a first fixed resistor 36 and a second fixed resistor 38. In addition, said latter two legs include opposite sides of a potentiometer 40 having a variable tap 42. Power is applied to the bridge from any suitable in phase A.C. power source as, for instance, an A.C. line the hot side 44 of which is connected through a power lead 46 to the hot junction between the resistor 36 and the tube leg. The ground junction of the bridge between the resistor 38 and the capacitance leg is connected to the neutral side 48 of the A.C. line. The output of the bridge is taken from the potentiometer tap 42 and the junction between the tube leg and the capacitance leg.

The aforesaid bridge 26 is a phase shifting circuit which operates by virtue of the change of impedance afforded by the back-to-back high vacuum triodes in the manner described in my aforesaid reissue patent. More particularly, one of the secondary windings, e.g., the winding 22, is connected between the grid 50 of the triodes 28 and the cross-connection 51 between the cathode of said triode and the anode of the triode 30. The other secondary winding 24 is similarly connected between the grid 52 of the triode 30 and the cross-connection 51 between the cathode of the triode 30 and the anode of the triode 28. It will be seen that a variation in the amplitude of the signal applied to the terminals 12, 14 will cause a corresponding variation in the impedance afforded by the back-to-back high vacuum triodes, so that this leg of the bridge has, in effect, a variable resistance the value of which is a function of the amplitude input signal. Such variable resistance will vary the phase of the voltage appearing across the output of the bridge 26.

Although the twin triodes operate under very light loads, upon occasion they must be replaced and it will be appreciated by persons skilled in the art that despite the high uniformity of commercial high vacuum tubes, in this instance, 6SL7's, there is a variation from tube to tube. I have found that this variation influences the calibration of the lighting control circuit. In order, therefore, to enable the circuit to be readjusted when tubes are substituted, so that the initial calibration can be maintained, I have provided various trimming controls. These constitute the variable resistors 20 and 34 and the potentiometer 40. A change in the resistance afforded by the resistor 20 affects the grid drive of the twin triodes; a change in the values of the resistances afforded by the resistor 34 and the potentiometer 40 affects the plate voltage of the twin triodes. Moreover, the resistor 34 also varies the RC value and thus affects the capacity of the capacitance leg of the bridge.

The phase shiftable output of the bridge 26 energizes the primary winding 56 of an interstage transformer 58. Unlike the line-to-grid transformer 18, the transformer 58 is of low impedance in order, as soon will be seen, to permit current to be supplied thereby in an appreciable, albeit small, amount, i.e., in the range of milliamperes, e.g., about 20 milliamperes. The interstage transformer has twin secondary output windings 60, 62 which regulate the performance of a pair of back-to-back connected solid state rectifying devices, specifically semiconductor rectifiers, having control terminals. In particular I employ control breakdown avalanche rectifiers 64, 66 hereinafter referred to as "avalanche rectifiers" these constituting the output stage of the power unit. Such a rectifier, as is well known, constitutes PNPN triple junctions which act as a rectifier having a high forward impedance. Only upon the application of a potential to the last junction, usually called the gate, which potential is positive with respect to the cathode of the rectifier, the high forward impedance, in a matter of microseconds, drops to a normal low forward rectifier impedance and remains low as long as the anode is positive with respect to the cathode. In the circuit of FIG. 1, I have denoted the anode of each of the avalanche rectifiers by the reference character A, the cathode by the reference character C and the gate by the reference character G.

The avalanche rectifier 64 is series connected with a lamp load, here schematically indicated as a single lamp 68, between the neutral side 48 of the system and the hot side 44 of the A.C. line. The lead 46 connects the hot side of the line to the cathode of said avalanche rectifier while a second lead 70 connects the anode of said avalanche rectifier to a common return lead 72 running to a smoothing choke 74 series-connected by a lead 76 with the lamp load.

The other avalanche rectifier 66 likewise has its anode connected to the hot lead 46 and its cathode is connected by a lead 78 to the common return lead 72 and thence through the choke 74 to the lamp load so that the load will be energized during both halves of the A.C. cycle.

When either cathode is negative, one cathode being negative at one half of a 360° A.C. cycle and the other being negative during the other half of the cycle, the corresponding avalanche rectifier is ready to function for supplying energy to the lamp load. However, as long as no potential is applied to the gate of this rectifier which would make such gate positive with respect to the cathode and which would permit current to flow freely through the rectifier, the rectifier will maintain a high forward impedance. To break down the rectifiers, i.e. fire the same, the twin secondary outputs 60, 62 are employed.

The connections of the two secondaries are alike, although reverse, and therefore only that of one of them will be described. Referring to the secondary 60, one terminal thereof is connected to the cathode C of the avalanche rectifier 64 through a resistor 80 and a pair of leads 82, 84. Said resistor is of relatively small value, the only function thereof being to prevent too great a flow of current through the gate junction when the avalanche rectifier with which said gate is associated has fired. The other terminal of the secondary 60 is connected to the associated gate junction of the avalanche rectifier 64 through a lead 86, a rectifier 88 and a lead 90. The rectifier 88 may be of any conventional type, e.g., a dry disc rectifier or a semiconductor rectifier, and is connected in the direction indicated to prevent application of an overriding high negative voltage to the gate of the rectifier 64 when said rectifier is in its idle half of the cycle and the rectifier 66 is operative.

It will be seen that if, during the operation of the cycle described above when the cathode is negative with respect to the anode of the avalanche rectifier 64, the secondary winding 60 applies a potential to the gate which is positive with respect to the cathode, the rectifier 64 will break down and current will flow through the same to light the lamp load. My circuit varies the intensity of the illumination of the lamp load by varying the point in the conduction cycle of the said rectifier 64 when the gate becomes positive with respect to the cathode. This is accomplished by virtue of the phase shifting effected by the bridge 26. In other words, the power supplied by the secondaries of the transformer 58, although small, is sufficient to fire the avalanche rectifiers; however, the point in the conduction cycle when the gates are positive relative to the cathodes, will be varied by the amount of phase shift caused by varying the input signal on the terminals 12, 14 applied to the bridge network.

In FIG. 2, I have shown a power unit 100 embodying a modified form of my invention which is designed to employ a direct current signal, i.e., control voltage, for the power unit in contrast to the A.C. control voltage applied to the input terminals **12**, **14** of the power unit **10**. Essentially, the circuit of the power unit **100** is substantially like that of the power unit **10**, differing basically only for the purpose of accommodating the D.C. control voltage. In particular, the circuit of the power unit **100**, like that of the power unit **10**, employs back-to-back connected avalanche rectifiers in the output stage and an RC phase shifting bridge, the latter, however, being a modification of the bridge **26** shown in FIG. 1 in order to accommodate the D.C. signal.

Specifically, the power unit **100** includes a pair of input terminals **102**, **104** to which there is applied a D.C. signal voltage, such signal voltage being obtained, for example, from the control end of the circuit shown in FIG. 1 of my United States Letters Patent No. 2,798,984, being taken off, for instance, at the switch **48**. It may be noted that this voltage is not pure D.C. inasmuch as it includes a slight ripple which has been substantially smoothed by the various filtering components.

The D.C. signal voltage is applied across a gain control potentiometer **106** in series with a feedback potentiometer **108** the operation and connections of which will be described hereinafter. The signal derived between hot terminal **110** and the variable tap **112** of the gain potentiometer is applied to a low gain current amplifier such as a transistor **114**. More particularly, the terminal **110** of the potentiometer **106** is connected by a lead **116** to the negative terminal **118** of a full wave rectifier **120**, the positive terminal **122** of which is connected to the emitter **123** of the transistor **114**. The variable tap **112** of the gain control potentiometer is connected to the base **124** of said transistor by a lead **125**, this connection being made through a pair of series connecting limiting resistors **126**, **128**. The junction between the resistors is connected to the negative terminal of the full wave rectifier **120** through a half wave rectifier **130**. Said rectifier **130** and the resistor **128** serve to stabilize the operation of the transistor **114**.

The output from the transistor **114** appearing across the negative terminal **118** of the full wave rectifier **120** and the collector **132** of the transistor is applied to one leg of a phase shifting bridge **134**. Said bridge includes an RC leg consisting of a series connected capacitor **136** and trimmer resistor **138**. The bridge further includes one variable impedance leg consisting of a pair of oppositely symmetrical transistors **140**, **142**, the transistor **140** being, for instance, of the NPN type and the transistor **142** being of the PNP type. The remaining two legs of the bridge are inductive in nature and constitute a center tap secondary winding **144** of a step-down power transformer **146**. One terminal of the RC leg of the bridge is connected to the variable impedance leg including the twin oppositely symmetrical transistors at a junction **148**. The other terminal of the RC leg is connected by a lead **150** to one of the terminals of the transformer secondary **144**. Another lead **152** connects the variable impedance transistor leg to the other terminal of the transformer secondary **144**.

Power is fed to the bridge network by energization of the transformer secondary **144**, said power therefore being applied across the leads **150**, **152**. The primary **156** of the transformer **146** derives its energy by direct connection to A.C. power, the hot terminal of the primary being connected by a lead **158** to the hot side **44'** of the A.C. line. The ground side of the transformer primary is connected by a lead **160** to the neutral side **48'** of the line.

The collectors of the two transistors are connected in common by a cross-lead **162** to a terminal of the secondary **144** of the step-down transformer **146**, this constituting one output terminal of the twin oppositely symmetrical transistors. The other terminal of the pair of oppositely symmetrical transistors which is connected by a lead **164** to the junction **148**, runs from a cross-lead **166** that joins the emitters of the twin transistors.

The control of the twin transistors is derived from the output of the transistor current amplifier **114**, there being a lead **168** running from the negative output terminal of said low gain current amplifying stage to the cross-lead **166** between the twin transistor emitters, and another lead **170** running from the collector of the transistor **114** to a cross-lead **172** between the bases of the twin transistors. Thus, when the D.C. voltage signal applied to the terminals **102**, **104** varies, there will be a corresponding current variation in the output of the transistor stage **114** which in turn will be reflected as a variation in the two-way impedance of the twin transistors so that the effective impedance of this leg of the bridge network will be changed. A change in the impedance of said leg of the network is transduced into a shift in phase of the voltage appearing across the output terminals of the network.

The output terminals **148**, **154** of the phase shifting bridge are connected through leads **174**, **176** to the primary **178** of a low impedance interstage transformer **180** the secondaries of which control avalanche rectifiers **64'**, **66'** identical to those described with respect to FIG. 1 and therefore denoted by the same reference numerals primed. In addition, all circuit components associated with said avalanche rectifiers **64'**, **66'** are identical with the circuit components described with reference to FIG. 1 and likewise are identified by the same reference numerals primed. A variable resistor **182** is inserted in one of the output leads from the phase shifting network, e.g., the lead **174**. The function of said resistor is to vary the amplitude of the output from the phase shifting network, the resistor having been provided to adjust for variations in the electrical properties of the twin transistors. It also may be noted that the variable resistor **138** is employed to offset variations in the value of the capacitor **136**.

The operation of the power unit **100** is essentially similar to that of the power unit **10**, differing only in the particular functioning of the phase shifting network **134** and the transistor stage **114** which already have been described.

Due to the presence in the phase shifting network of the twin transistors which are essentially non-linear resistances, it is desirable to include a degenerative feedback to improve the linearity of response of the circuit. The feedback is taken from or adjacent the lamp load, the same including a return lead **184** initiating between the smoothing choke **74'** and the lamp load **68'**. Said return lead runs to one terminal of the primary **186** of a step-down transformer **188**, the other terminal of which is connected to the neutral side **48'** of the A.C. line. The secondary **189** of said transformer is connected in a full wave rectifying circuit **190** the output of which is connected by a lead **192** to an LC filter network including a choke **194** and capacitor **196**. The filter output then is applied across the potentiometer **108**. The variable tap **197** of the potentiometer is connected to the gain control potentiometer **112** by a lead **198**. The filtered feedback output is in polar opposition to the D.C. signal applied across the terminals **102**, **104** and greatly improves the linearity of response of the power unit **100**.

I wish it to be understood that the phase shifting bridges **26** and **134** described with reference to FIGS. 1 and 2 simply have been illustrated as examples of networks which can transduce a variation in the amplitude of the control voltage into a phase shift and therefore I am not to be limited to the utilization of any particular phase shifting network. To make the foregoing clear I have shown in FIG. 3 another embodiment of my invention showing a phase shifting network other than a bridge, the circuit of FIG. 3 in other respects being the same as that of FIG. 2 and similar parts therefore being denoted by the same reference numerals double primed.

More particularly, in FIG. 3 I have shown a power unit **200** having a pair of input terminals **202**, **204** to which is applied a D.C. signal of variable amplitude the same as the type of signal adapted to be applied to the terminals **102**, **104**. The terminals **202**, **204** feed a pair of series connected potentiometers including a gain control potentiometer **206** and a feed back control potentiometer **208** which are in all respects the same as the potentiometers **106**, **108** of the power unit shown in FIG. 2. The variable tap **210** of the potentiometer **206** is connected through a limiting resistor **212** to the base **214** of a transistor **216** connected to act as a low gain current amplifier and, incidentally, as a negative gain voltage amplifier, thus ensuring stability for the operation of this transistor stage. The hot terminal of the potentiometer is connected by a lead **218** to the collector **220** of the transistor **216**, the connection including a variable resistor **222**. The output of the transistor **216** appears across the emitter **224** thereof and the collector **220**.

The transistor **216** controls a magnetic reset amplifier **225** the primary **226** of which is powered by the secondary **228** of a transformer **230**. Said transformer includes a primary **232** connected between the hot side **46″** of the A.C. line and the neutral side **48″**. Said secondary **228** and the output of the transistor **216** are connected to buck one another and conjointly to feed the primary **226** of the magnetic reset amplifier. I also include in the circuit between the transistor **216** and the magnetic reset amplifier primary **226** a rectifier **236** to block said primary. The secondary **238** of the magnetic amplifier **225** has connected across it a load resistor **240**, there being provided a blocking rectifier **242** in the output circuit of the magnetic amplifier. The voltage across the load resistor **240** is applied to control one of the avalanche rectifiers **66″**. It may be noted that, as shown, I can if desired include a hold back biasing voltage for the gate junction G″ of said rectifier **66″**, as by including in the secondary circuit of the magnetic amplifier a series connected secondary winding **244** on the transformer **230**.

In the operation of the power unit **200** a variable D.C. voltage applied across the terminals **202**, **204** will engender what is, effectively, a variable impedance at the output of the transistor **216**, said impedance acting to change the time required to saturate the magnetic reset amplifier and thereby shifting the phase of the output voltage pulse appearing across the load resistor **240**. This acts therefore as a phase shifting network for the signal applied to the gate G″ of the avalanche rectifier **66″**. A similar magnetic amplifier with associated circuit components identical to those described in connection with the magnetic amplifier **225** is included to control the gate G″ of the avalanche rectifier **64″** and therefore has not been illustrated in FIG. 3 save for the input leads to and the output leads from the same. It will of course be understood by those skilled in the art that the secondary winding (not shown) for powering the second magnetic amplifier is connected in a reverse fashion to the winding **228** for powering the magnetic amplifier **225** that controls the rectifier **66″**.

The feedback circuit for the power unit **200** is in all respects identical to that for the power unit **100**.

It thus will be seen that I have provided lighting control circuits which achieve the various objects of my invention and are well adapted to meet the conditions of practical use.

As various possible embodiments might be made of the above invention and as various changes might be made in the embodiments above set forth, it is to be understood that all matter herein described or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

Having thus described my invention, I claim as new and desire to secure by Letters Patent:

An A.C. lighting load, an A.C. power unit for energizing said lighting load from an A.C. power line, said unit having input terminals and being of the type in which the intensity of lighting of said lighting load is variable as a definite function of a variable electrical characteristic applied to said input terminals, said A.C. unit comprising an output stage constituting a controlled breakdown semiconductor avalanche rectifier consisting of a multiple junction transistor having a normally high forward impedance, a gate terminal, an anode power terminal and a cathode power terminal, the impedance of said rectifier being lowered upon application to said gate terminal of a potential which is positive with respect to the cathode power terminal and said lowered impedance being maintained as long as the anode is positive with respect to the cathode, first circuit means connecting the A.C. power line to the anode and cathode terminals through said lighting load whereby alternately to reverse the voltages applied to said terminals, means for supplying a reference A.C. voltage of the same frequency as the A.C. power line, a phase shifting means constituting a magnetic reset amplifier circuit and a hold-back voltage biasing means, said phase shifting means being connected to said means for supplying a reference voltage and being responsive to the electrical characteristic applied to the input terminals of the power unit for supplying a phase shiftable A.C. control voltage of the same frequency as said A.C. power line, and second circuit means applying said control voltage between the gate terminal and the cathode terminal of the avalanche rectifier to intermittently render the gate positive with respect to the cathode and thus lower the impedance of the rectifier so that when said impedance is lowered upon application of the control voltage at such time as the anode is positive with respect to the cathode said impedance will remain lowered until the anode becomes negative with respect to the cathode.

References Cited in the file of this patent

UNITED STATES PATENTS

2,458,644	Ringer et al.	Jan. 11, 1949
2,463,463	Izenour	Mar. 1, 1949
2,474,886	Bovey	July 5, 1949
2,786,966	Taylor	Mar. 26, 1957
2,925,546	Berman	Feb. 16, 1960

FOREIGN PATENTS

747,996	France	June 27, 1933

OTHER REFERENCES

I.B.M. Technical Publication, "A New Transistor With Thyratron-Like Characteristics," by Berger and Rutz, published May 26, 1955.

Business Week Magazine, "New Way to Change A.C. to D.C.,'" a McGraw-Hill publication (Dec. 28, 1957, issue), reprint found in General Electric (The Silicon Control Rectifier, TK2798 $G4_s$).

Control Engineering, Phase-Controlling Kilowatts With Silicon Semiconductors by A. W. Gutzwiller, May 1959, reprint found in General Electric (The Silicon Control Rectifier, TK 2798 $G4_s$).