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Switsen

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[54] **PHASE CONTROLLED FIRING CIRCUIT**

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[21] Appl. No.: **143,881**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 874,098, Nov. 5, 1969, Pat. No. 3,600,996.

[52] **U.S. Cl.** ..... **315/200 R,** 315/227, 315/241 R

[51] **Int. Cl.** **H05b 37/00**

[58] **Field of Search** ..... 315/200, 227, 241 R, 315/241 P, 241 S

[56] **References Cited**

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Assistant Examiner—Lawrence J. Dahl
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[57] **ABSTRACT**

A very simple circuit for generating a pulse at a particular phase of an A.C. source, including a silicon controlled rectifier (SCR), an initiating capacitor connected to the cathode of the SCR through a load such as a pulse transformer, and a large resistor that connects the gate of the SCR to a location on the power supply to slowly charge or discharge the capacitor by SCR cathode-to-gate current until the cathode is of low enough potential to again fire the SCR and strike the lamp. In one circuit which assures striking of a stroboscopic lamp near the positive peak of the A.C. source, the gate resistor is connected to a point of the power source that cyclically varies from a level somewhat below the anode voltage to a much lower voltage, so that the gate reaches a voltage exceeding the cathode voltage near the peak of the A.C. source. In another circuit which assures firing during the negative portion of the A.C. cycle, the resistor is connected to a point of constant low voltage (with respect to the SCR anode) to obtain a largely exponential reduction of cathode voltage. In this circuit, a ripple-producing capacitor is also provided which connects the cathode of the SCR to a terminal of the A.C. source to provide a ripple component that assures that the cathode potential will be lowest during the negative portion of the A.C. cycle and therefore that the gate-to-cathode firing voltage will be attained during a negative phase of the A.C. cycle.

14 Claims, 12 Drawing Figures

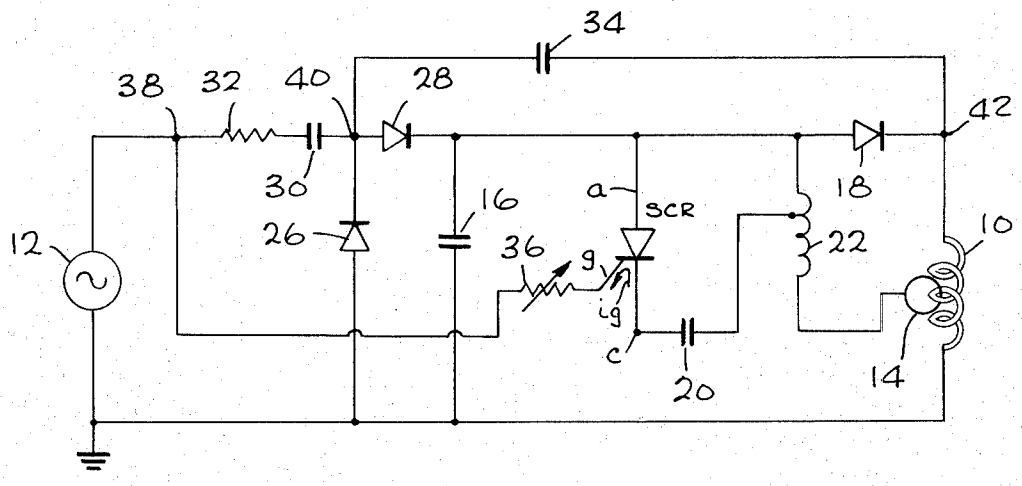
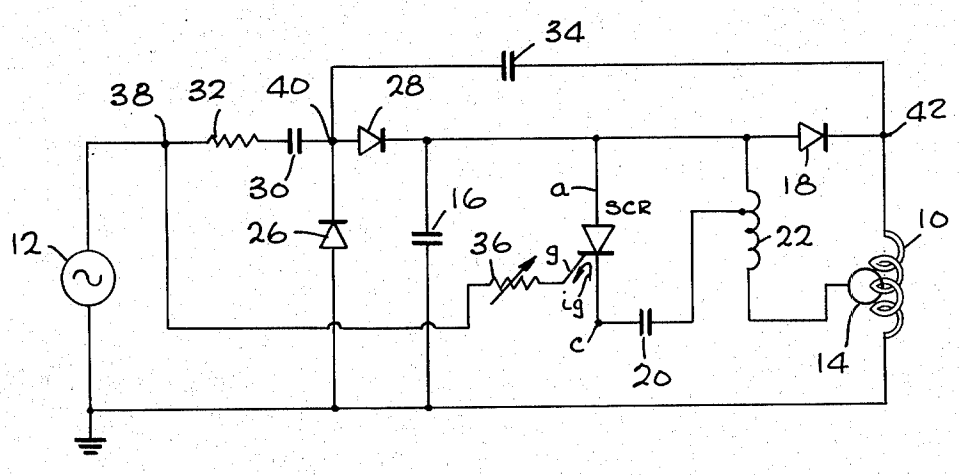


Fig. 1



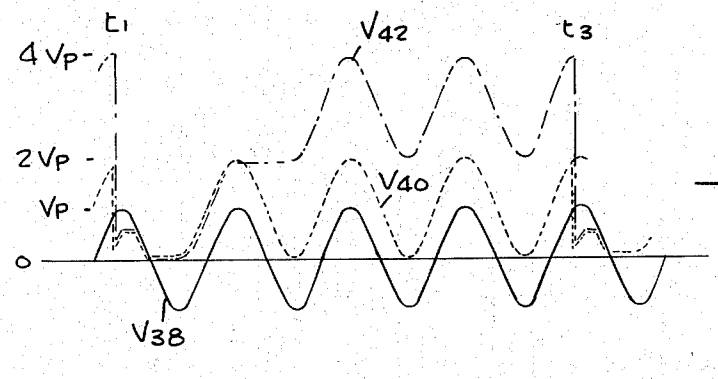


Fig. 2

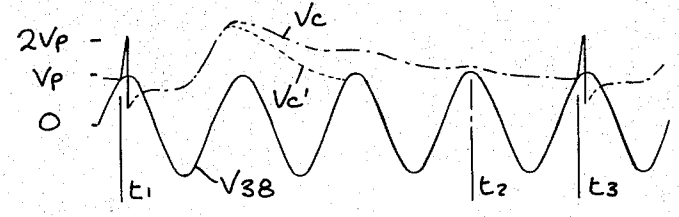


Fig. 3

Fig. 3A

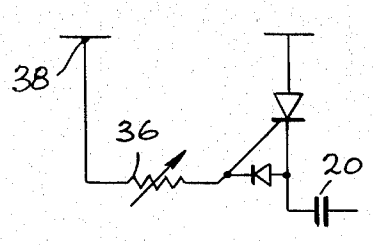
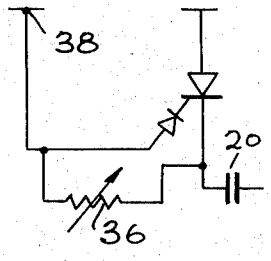


Fig. 3B



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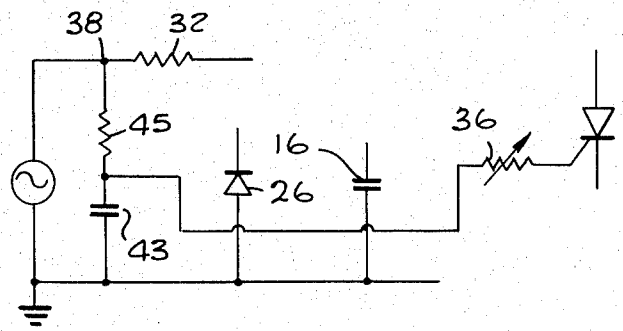


Fig. 3c

Fig. 5

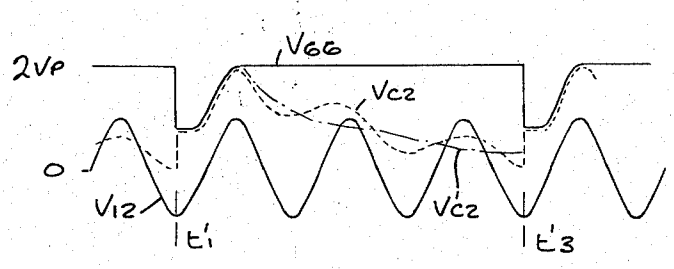
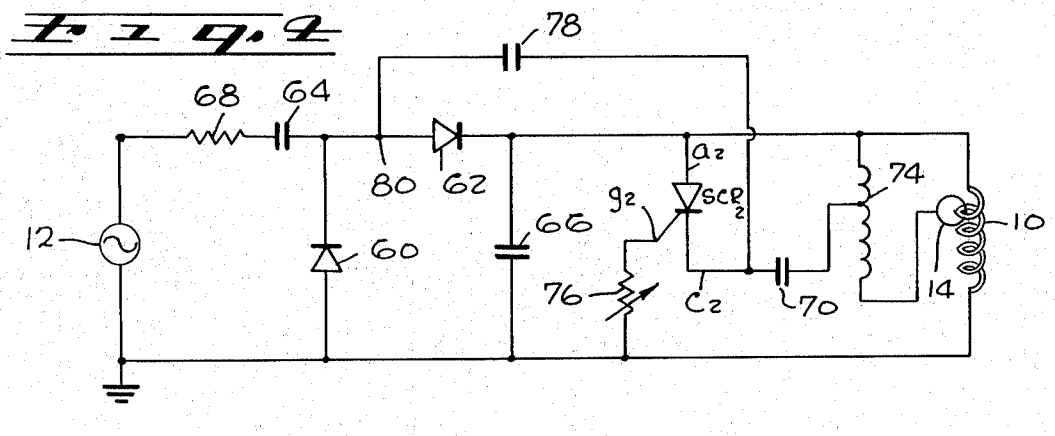


Fig. 4



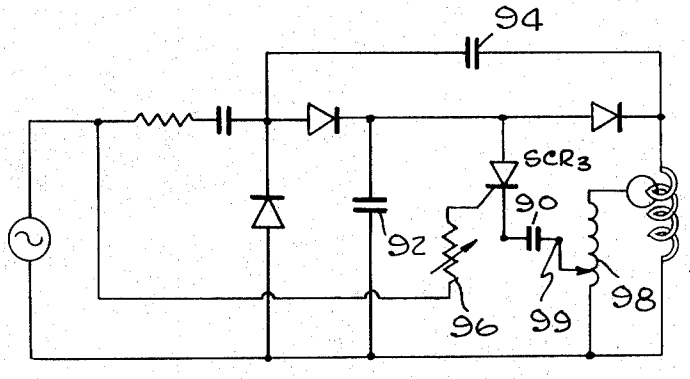


Fig. 6

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Fig. 7

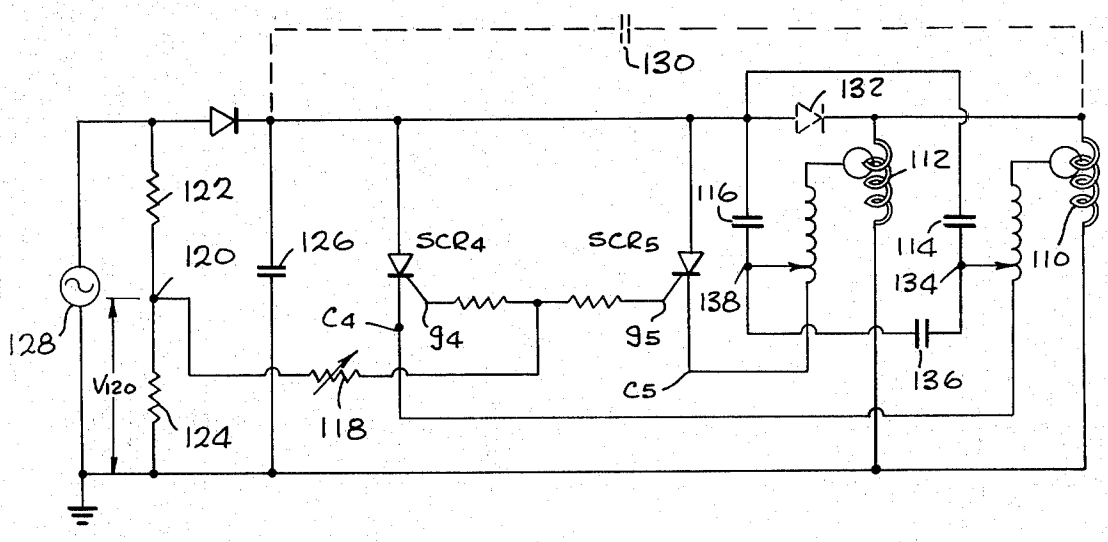
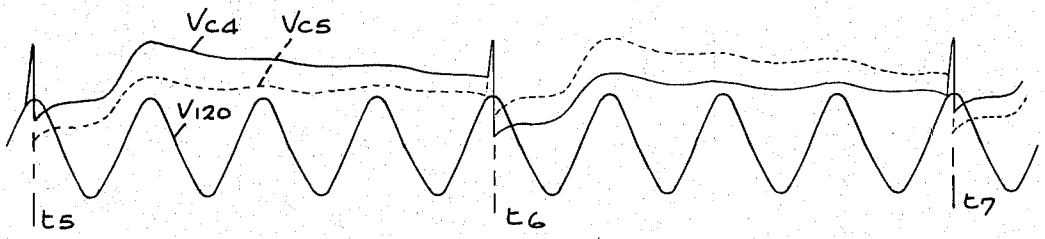


Fig. 8



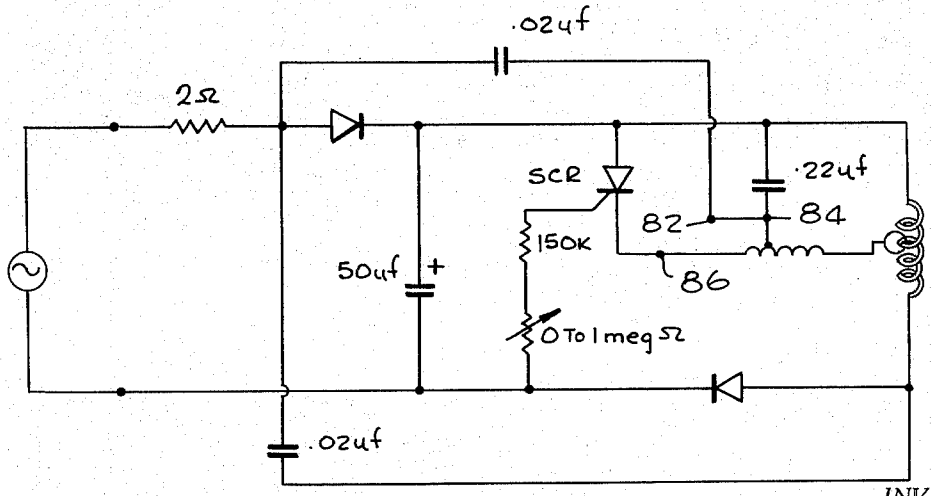


Fig. 9

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PHASE CONTROLLED FIRING CIRCUIT

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of patent application Ser. No. 874,098 filed Nov. 5, 1969, now U.S. Pat. No. 3,600,996.

BACKGROUND OF THE INVENTION

This invention relates to circuits for generating firing pulses and, while not limited thereby, is especially suited to stroboscopic lamp firing circuits when the load is a pulse transformer.

Certain types of electrical apparatus, such as lamps used in stroboscopic lighting, are periodically struck or fired by a current pulse that is obtained by suddenly discharging a capacitor. Where an A.C. power supply is employed, it is often desirable to assure lamp firing at a particular phase of the A.C. cycle. For example, stroboscopic lamps used for obtaining psychedelic lighting effects are often energized by a simple circuit that includes a power capacitor charged to a constant voltage to supply most of the current that lights the lamp, but a special A.C. booster supply may be added to the capacitor voltage. If the lamp is struck at an instant when the special booster supply is near a peak, then a large initial voltage will be applied to the lamp which assure that it fires even if its condition has decayed or the A.C. source provides a lower than expected voltage. In this type of circuit, it is desirable that the striking current from the striking capacitor be applied near the peak of the A.C. booster supply.

In another type of circuit which is used for energizing stroboscopic lamps in psychedelic lighting applications, lamp lighting current is obtained from a power capacitor (with or without a special booster) that is charged from an A.C. source through a diode and current-limiting resistor. If the lamp should fire during certain positive portions of the A.C. cycle, then the lamp could draw a large current directly from the A.C. power source through the current-limiting resistor. Normally, a large current-limiting resistor is required to limit such a current. However, if the circuit were constructed to assure that firing does not occur during the positive portion of the A.C. source, then a much smaller current-limiting resistor could be utilized and heating of the circuit could be reduced. Reduction of such heating is of great importance because heating can cause many malfunctions, so that steps taken to reduce heating have resulted in undesirable limitations in circuit design.

Of course, many circuits are available which can sense the peak of an A.C. voltage and trigger a device. However, it is desirable to provide an extremely simple circuit that can be a simple lamp firing circuit or the like to control the phase of firing, in order that the entire circuit may be sold at low cost.

OBJECTS AND SUMMARY OF THE INVENTION

An object of the present invention is to provide a very simple circuit that generates a firing pulse at a predetermined phase of an alternating current source.

Another object is to provide a power circuit for a stroboscopic lamp, wbich assures firing of the lamp near a peak (either positive or negative) of a varying supply voltage to the lamp.

Still another object is to provide a power circuit for a stroboscopic lamp, which minimizes the cost of the circuit components and minimizes heating of the circuit.

In accordance with the invention, firing circuits are provided of the type wherein a striking, or initiating capacitor rapidly discharges or charges through a silicon controlled rectifier (SCR) or the like, to provide a firing pulse. Control of the phase at which the SCR is turned on is accomplished by connecting the gate of the SCR to a point of the power supply that is usually of lower potential than the anode of the SCR, and connecting one side of the initiating capacitor to the cathode of the SCR. This allows current to flow between the cathode and reversed biased gate of the SCR to slowly charge or discharge the capacitor, and thereby slowly decrease the voltage at the cathode. As the cathode voltage decreases, it approaches a level that can be exceeded by the gate voltage to fire the SCR and therefore suddenly discharge or charge the initiating capacitor through it. This is accomplished by providing a ripple current that adds to the exponential gate current. The ripple current is in phase with the A.C. source, and it assures that the SCR fires at a particular phase of the A.C. source.

In one circuit utilized to power a stroboscopic lamp used in psychedelic lighting, most of the lamp current can be supplied by a power capacitor that is charged to a constant high voltage, but an additional booster supply can also be utilized. The booster supply adds a varying voltage to the constant voltage of the power capacitor. If the lamp is struck when the booster voltage is at a maximum, then a very high voltage is initially available to the lamp to assure that it will light even if its condition has decayed somewhat or if the A.C. voltage supply is somewhat lower than normal. The lamp is struck by a pulse obtained when the initiating capacitor is discharged through the SCR. To assure firing near a peak of the variable voltage, the gate of the SCR is connected by a resistor to a terminal of the A.C. source to provide a variable gate voltage. The initiating capacitor, which is connected between the cathode and anode of the SCR, is slowly charged by current that flows between the cathode and the reversed biased gate of the SCR and, therefore, the cathode slowly falls in voltage. When the cathode finally falls to a voltage slightly below the peak voltage being periodically applied to the gate, then at the next cycle when the gate voltage is near its peak, the SCR fires.

In another circuit utilizing a stroboscopic lamp for psychedelic lighting, the lamp can be powered as before, from a power capacitor that supplies a constant voltage prior to lamp firing (with or without a special booster for the lamp). The power capacitor is charged through a diode and current-limiting resistor, (or through additional capacitors and diodes and/or transformers that may be provided to step up the voltage), and it is important to assure that firing will occur substantially only during negative portions of the A.C. cycle to assure that the lamp will not draw a large current directly through the power supply components. In this circuit, the gate of the SCR is connected to a point of constant low voltage so that the initiating capacitor is exponentially charged by a current that flows from the cathode to the gate of the SCR. In order to assure firing during the negative portion of the A.C. cycle, a small capacitor connects a terminal of the A.C. source

to the cathode of the SCR to provide a small ripple voltage that adds to the exponentially declining voltage. The ripple voltage assures that the cathode of the SCR will acquire a voltage less than the constant gate voltage during a negative portion of the A.C. cycle, so that the SCR will fire during a negative portion of the A.C. cycle.

The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of a circuit constructed in accordance with the invention, which assures firing of a stroboscopic lamp near a positive peak of an A.C. source;

FIG. **2** illustrates waveforms of voltages in the circuit of FIG. **1**;

FIG. **3** illustrates the relationship between the SCR cathode voltage and the A.C. source voltage in the circuit of FIG. **1**;

FIGS. **3A** and **3B** illustrate modifications of a portion of the circuit of FIG. **1** to provide capacitor-charging current that bypasses the gate of the SCR;

FIG. **3C** illustrates another modification of the circuit of FIG. **1**, to provide a controlled phase shift of the firing time with respect to the A.C. source;

FIG. **4** is a schematic diagram of a circuit constructed in accordance with another embodiment of the invention, which assures firing during substantially a negative portion of the A.C. source voltage;

FIG. **5** illustrates the waveforms of various voltages in the circuit of FIG. **4**; and

FIG. **6** is a schematic diagram of a circuit constructed in accordance with a further embodiment of the invention, which operates in a manner similar to that of FIG. **1**;

FIG. **7** is a schematic diagram of a circuit constructed in accordance with yet another embodiment of the invention, for alternately firing two stroboscopic lamps, with all firings occurring near a positive peak of an A.C. source;

FIG. **8** illustrates waveforms of the circuit of FIG. **7**; and

FIG. **9** is a schematic diagram of still another embodiment of the invention, which utilizes a negative booster voltage and which assures firing near a negative peak of the A.C. source.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates a circuit for striking and energizing a stroboscopic lamp **10** from an alternating current source **12**, in a manner that assures firing even if the lamp has decayed so that it requires a higher voltage across it to start it or if the voltage supply **12** supplies less than normal voltage. The lamp **10** has a striking member **14** which is supplied with a high voltage to create an arc that ionizes gas within the lamp, to start it. The resistance of the lamp then drops from a very high level to a very low level so that a large current can flow from a power capacitor **16** through a diode **18** and through the lamp to create a brief high intensity flash of light. The high voltage pulse at the striking member **14** of the lamp is obtained by suddenly discharging an initiating capacitor **20** through primary windings of a transformer **22**. The initiating capacitor **20** is connected, in series with some windings of the transformer, between the cathode *c* and the anode *a* of the SCR. (If desired, the locations of the initiating capacitor **20** and primary windings of the transformer **22** can be reversed so that a terminal of the primary transformer windings connects directly to the cathode c while a terminal of the capacitor **20** connects directly to the anode *a*.) When the voltage at the gate *g* of the SCR exceeds the voltage at the cathode *c* by a predetermined small amount such as 0.7 volts, then the SCR fires and there is a very low resistance between its anode *a* and cathode *c*.

The power capacitor **16** is charged by a voltage doubling circuit which includes two diodes **26, 28,** a capacitor **30** and a current-limiting resistor **32.** The capacitor **30** and diode **26** serve in conjunction with source **12** as an alternating current source that provides a voltage at location **40** that varies between ground and twice the peak voltage of the supply **12.** The diode **28** provides current that charges the power capacitor **16** to a voltage $2V_p$ which is twice the peak voltage V_p of the supply **12.** Thus, for a household outlet at **12** that may supply a nominal 110 volts with a peak of 150 volts, the doubler circuit portion can supply approximately **300** volts across the power capacitor **16.** In order to provide an even higher voltage across the lamp at the instant when it is fired, a booster capacitor **34** is provided to serve in conjunction with the diode **18.** The booster capacitor **34** provides a variable voltage in phase with the A.C. source **12** that adds to the voltage supplied by the power capacitor **16,** to provide a maximum voltage of $4V_p$. Thus, instead of only the 300 volts of the power capacitor **16** being applied across the lamp **10** prior to the time when it is struck, a variable voltage is applied which may vary between about 300 and 600 volts. This variable voltage is in phase with the A.C. source **12** and is synchronized with it so that the peak (e.g. 600 volts) of the variable voltage coincides with the peak of the A.C. source **12.** After the lamp **10** is struck, most of the current through it may be supplied by the power capacitor **16.** However, the fact that there is initially a very high voltage at the instant of striking makes it more probable that the lamp will light. Typically, the lamp draws a heavy current during a period which may be a fraction of a millisecond, until the voltage across the lamp drops to a value such as on the order of 50 volts and the lamp is then extinguished.

In order to obtain the maximum advantage of the booster capacitor **34,** the SCR should fire only at a time near the peak of the A.C. source **12,** when the booster capacitor **34** is supplying nearly its maximum voltage (of about $4V_p$) to the lamp **10.** In psychedelic lighting, it is generally desirable to provide for such a firing of the lamp **10** on the order of several times per second. Thus, for an A.C. source **12** that may alternate at a rate of 60 cycles per second, the lamp **10** may be fired only once in every several cycles, although the instant of firing should occur near a peak. In order to assure firing near a peak of the A.C. source **12,** a resistor **36** is provided that couples the gate g of the SCR to a point **38** of the power supply. The reason for coupling the gate g through the resistor **36** to the point **38,** is to provide a gate current through the SCR that can recharge the initiating capacitor **20** until the SCR next fires, and also to vary the voltage at the gate g in unison with the volt-

age of the A.C. source **12** so that the gate reaches a high voltage and can fire the SCR near a peak of the A.C. source **12.**

The SCR defines a diode between its gate g and cathode c. The diode tends to allow current flow only from the gate to the cathode, and such current flow which may occur at a low voltage such as 0.7 volts turns on the SCR. However, this gate to cathode diode breaks down in an avalanche mode when it is reversed biased by a higher voltage such as 7 volts, so that it acts like a Zener diode. An instant after the SCR fires and the initiating capacitor **20** has been discharged, there is substantially no voltage across the capacitor **20.** When the anode *a* of the SCR has again reached a high constant voltage at the next A.C. cycle, the low voltage across the capacitor **20** results in the cathode *c* also being at a high voltage nearly equal to that at the anode. The gate *g* which is connected through the resistor **36** to the A.C. source, experiences a voltage which varies periodically, but which is always below the voltage of the anode a and therefore below the cathode voltage until the initiating capacitor **20** has been charged. For example, where the anode a is maintained at 300 volts, the point **38** may vary between +150 volts and −150 volts. A reverse current can flow from the cathode to the gate of the SCR to charge the capacitor **20,** which lowers the voltage at cathode *c*. Such charging continues until the cathode c has dropped to a voltage slightly below the peak voltage which can occur at the voltage source point **38.** At the peak of the next cycle, when the voltage at the gate g exceeds the voltage at the cathode *c*, the SCR **24** fires. The initiating capacitor **20** then discharges to again strike the lamp and the process begins all over.

FIG. **2** illustrates the voltages that appear at three points, **38, 40** and **42** of the circuit of FIG. **1,** these voltages being labeled V_{38}, V_{40}, and V_{42}. A comparison of these voltages shows the desirability of striking the lamp near a peak of the A.C. voltage source. FIG. **3** compares the voltages at the cathode *c* of the SCR and at the point **38,** these voltages being designated V_c and V_{38}. All voltages are taken with respect to the ground indicated in FIG. **1.**

As shown in FIGS. **2** and **3,** a firing of the SCR and lamp occurs at a time t_1. The voltage across the initiating capacitor **29** quickly drops to zero, so that the voltage V_c quickly becomes equal to the voltage at the anode of the SCR. The voltage across the lamp, which equals the voltage V_{42}, quickly drops to a low level such as 50 volts which is the level at which the lamp is extinguished. By the peak of the next cycle of the A.C. source **12,** the power capacitor **16** is nearly fully charged to twice the peak voltage of the A.C. source **12,**(if resistor **32** and capacitor **30** are so chosen) and therefore the anode a of the SCR is at this voltage. Thus, at the peak of the A.C. source cycle following the cycle in which firing occurred, the anode a has reached a substantially constant high voltage (which equals $2V_p$). As the initiating capacitor **20** begins charging, the voltage V_c at the cathode of the SCR begins to decrease, as shown in FIG. **3.** The decrease is in a somewhat exponential manner, except that it has a ripple factor to it. This ripple is due to the fact that the gate is not connected to a constant voltage, but is connected to point **38** that constantly varies. The initiating capacitor **20** therefore charges most rapidly during a negative portion of each cycle of the A.C. source. During such charging, a gate current indicated at i_g in FIG. **1** flows from the cathode to the gate of the SCR. Such flow will occur so long as the required Zener breakdown voltage, which may be about 7 volts, can be maintained between the cathode and gate.

After three cycles (for values of capacitor **20** and resistor **36** chosen to cause this) at the time t_2, the cathode voltage V_c is only slightly above the peak of the voltage V_{38}. When the cathode to gate voltage is less than the Zener breakdown voltage of the gate to cathode diode, no appreciable gate current flows. Thus, near the peak of the cycle at time t_2, no additional capacitor charging occurs. However, a short time later when the voltage V_{38} again decreases towards the negative portion of the A.C. cycle, the initiating capacitor again continues to charge and the voltage at V_c drops further, to a level that is below the peak V_p of the A.C. source V_{38}. When the voltage V_{38} next approaches its peak, there will be a time when the voltage at the gate g of the SCR exceeds the voltage V_c at the cathode (by an amount such as 0.7 volts). The SCR will then be suddenly turned on, the initiating capacitor **20** will suddenly discharge, and the lamp will be struck again. This striking will again occur near the peak of the A.C. cycle and therefore at a time when the voltage V_{42} across the main terminals of the lamp is at nearly a maximum. As previously mentioned, in the operation of the circuit of FIG. **1** the resistor **36** may be thought of as serving two functions. One function is to provide a current that discharges the initiating capacitor **20** so as to slowly lower the voltage at the cathode of the SCR; a resistance is used to provide a net change in voltage across the capacitor and therefore a net change of cathode voltage of each cycle of the A.C. source. Another function of the resistor **36** is to provide a voltage at the gate g of the SCR that varies in synchronism with the A.C. source **12.** This variation of gate voltage, combined with a slowly decreasing cathode voltage, assures that the gate will exceed the cathode voltage at a time near the peak of the A.C. source. The fact that the cathode voltage V_c decreases most rapidly during the negative portion of the source A.C. cycle may not be of major importance in those cases where firing occurs after a limited number of cycles of the A.C. source. However, it can help to assure firing at a constant number of A.C. source cycles in those cases where there is a large number of A.C. cycles between firings.

The number of cycles required for the cathode voltage V_c to reach the gate voltage depends upon the impedance of the resistor **36** in relation to the size of the initiating capacitor **20.** The resistor **36** is made variable to allow for a choice of lamp flashing frequency. If the value of the resistance **36** is increased, then lamp flashing will occur less often, while if the resistance **36** is decreased lamp flashing will occur more often. It is possible to make the resistance at **36** so low that lamp flashing occurs at every cycle of the A.C. source. However, this prevents taking advantage of the voltage boost provided by the capacitor **34,** and in fact, could cause lamp striking prior to substantially full charging of the power capacitor **16.** If operation at every cycle should be desired, then special attention should be given to the setting of resistor **36,** or additional phase shifting elements may have to be added to the circuit. It is generally desirable that the resistance **36** be large enough to prevent firing until at least the second cycle of the A.C. source following a lamp striking. Where more cycles of

the A.C. source are allowed to pass between firings, the firings automatically occur closer to the peak of the boost supply. The variable resistor **36** can be constructed so it can be reduced to a low enough level to create a cathode voltage decay that follows the line shown at V_c' in FIG. **3**, so that the lamp can fire every other cycle but it still fires near the peak of the boost supply. In such a case, however, the resistance and capacitance values must be held within moderate tolerances to assure firing near the peak. The user can increase the resistance to reduce the frequency of lamp firing, and at a time between firings above about four A.C. source cycles, firing always occurs very close to the voltage peak.

The power circuit of FIG. **1** can be utilized for other applications than stroboscopic lamp firing. In situations wherein the load does not completely drain the power capacitor or other supply, firing can even occur every cycle, and by proper choice of the gate resistor in relation to the initiating capacitor, firing can be controlled to occur near a peak of the A.C. source. In FIG. **1**, the gate resistance **36** is shown connected to a terminal of the A.C. voltage source **12.** Where only a gate resistance is used, it is necessary that the resistance be connected to a point of the circuit which has a voltage that varies in synchronism with the A.C. source to which firing is to be synchronized, that the maximum voltage of such a point be below the anode voltage of the SCR, and that the peak-to-peak voltage of the point vary by more than the reverse breakdown voltage, or Zener voltage, of the gate to cathode diode of the SCR (which is typically about 7 volts). Of course, if it is desired to fire the initiating capacitor at some time during a cycle other than the positive peak, a point of varying voltage can be made available by the addition of reactive networks that provide a peak at the desired firing time, and the gate resistor then can be connected to such a point.

In the operation of the circuit, the gate to cathode diode of the SCR is utilized to provide current to charge the capacitor. If it is desired to avoid this, an external diode can be added across the gate and cathode leads as illustrated in FIG. 3A, or a blocking diode can be added in series with the gate and the resistor connected between the cathode and point **38** as illustrated in FIG. 3B, or between the cathode and ground, or some other suitable point, which may even be reactive to shift the firing phase. Of course, other switching devices such as a thyratron tube can be used instead of an SCR, although in the case of a thyratron this would require circuitry mentioned above, such as an external diode between the gate and cathode or a resistor connecting the cathode to some suitable point. Any of such devices or circuitry which functions in this manner may be considered as silicon controlled rectifier means.

In many applications, it is desirable to provide a firing pulse at the peak of the A.C. source. However, any desired shift can be accomplished to provide a pulse at a different time during the A.C. cycle by the use of a phase shifting network. FIG. 3C shows a network formed by a capacitor **43** and resistor **45** that provide a delay phase shift, by coupling the control resistor **36** to the A.C. source through this phase shift network.

FIG. **4** illustrates a stroboscopic lamp firing circuit which does not utilize a variable positive booster voltage, and which, therefore, does not have to fire at the positive peak of the A.C. source. Instead, the circuit is designed for minimum heating of the voltage doubling circuitry, and this is achieved by assuring firing at an instant during an A.C. source cycle when the source is in the negative portion of its cycle or when it is at only a small positive voltage. The circuit includes a pair of diodes **60, 62,** a pair of capacitors **64, 66,** and a current-limiting resistor **68** connected to the alternating voltage source **12,** which may be a household outlet. The circuitry serves as a voltage doubler to provide a voltage across the power capacitor **66** which is twice the peak voltage of the source **12.** When the striker member **14** of the lamp **10** receives a high voltage pulse, current from the power capacitor **66** passes through the lamp to briefly light it.

When the lamp **10** is ignited, it has a very low resistance and quickly discharges the power capacitor **66** from an initial high voltage such as 300 volts to a maintenance voltage such as 50 volts at which time the lamp cannot be kept on. If the A.C. source **12** should be at a voltage above the maintenance voltage at the instant when the lamp flashes, then current could flow through the limiting resistor **68,** capacitor **64** and diode **62** through the lamp **10.** Unless the resistor **68** is of a relatively high value, a large current will be drawn through it, which can unduly heat resistor **68,** the capacitor **64** and the lamp **10.** Such current can be minimized by increasing the current limiting resistance at **68,** but this can interfere with rapid recharging of the power capacitor **66.** Generally, a compromise has been resorted to which involved using a higher resistance at **68** abd accepting a considerable amount of excess heating. Such a compromise would not have to be resorted to if the lamp were fired only when the A.C. source **12** had a negative voltage (with respect to the indicated ground) or a low positive voltage that was less than the lamp maintenance voltage. The circuit of FIG. **4** is constructed to assure firing only during the negative portion of THE A.C. source **12.** Firing of the lamp **10** in the circuit of FIG. **4** occurs when an initiating capacitor **70** is discharged through SCR_2, so that the pulse passes through an autotransformer **74** to provide a high voltage at the starter member **14** of the lamp. After discharge of the initiating capacitor **70,** it begins to charge again by reason of current that passes between the cathode c_2 and gate g_2 of SCR_2. Such gate current flows through a gate resistor **76** that is connected to a terminal of the power capacitor **66** (which is connected to a terminal of the A.C. source **12** that is assumed to be at ground potential). In addition, a ripple capacitor **78** is provided which is connected between a point **80** of the power circuitry or supply which is at a variable voltage and the cathode c_2. In the absence of the ripple capacitor **78,** the initiating capacitor **70** would charge exponentially until the cathode c_2 of SCR_2 reached a voltage slightly above ground potential. Thereafter, no further current would flow between the gate and cathode, and SCR_2 would not fire. The ripple capacitor **78** can supply a sufficient negative voltage to the cathode c_2 at such a time to lower its voltage beneath the gate potential so that firing does occur. The ripple capacitor **78** also assures that such firing occurs during a negative portion of the A.C. cycle.

FIG. **5** shows the voltage applied by the capacitor **66** to the lamp **20,** the voltage at the cathode c_2 and the voltage supplied by the A.C. source **12,** these voltages being indicated at V_{66}, V_{c2}, and V_{12}, respectively. In addition, a voltage V'_{c2} is shown that indicates the voltage

that would be present at the cathode in the absence of the ripple capacitor **78.** At a time t'_1 when the lamp fires, the voltage V_{66} across the power capacitor and lamp drops to the lamp maintenance voltage. The initiating capacitor **70** quickly discharges so that the voltage V_{c2} at the cathode follows the voltage at the positive terminal of the power capacitor. At the next cycle of the A.C. source, the power capacitor voltage V_{66} rises to substantially a maximum and thereafter remains substantially constant. The cathode voltage V_{c2} follows it but then begins decreasing in a somewhat exponential manner, as SCR cathode to gate current flows to recharge the initiating capacitor **70.**

In the absence of the ripple capacitor **78,** a simple exponential discharge indicated at $V_{c2'}$ would occur which would cause the cathode voltage to approach ground voltage. Actually, the cathode voltage would stop decreasing when a voltage such as 7 volts were reached which was too small to cause reverse breakdown of the gate to cathode diode of SCR_2. In the presence of the ripple capacitor **78,** a ripple voltage is applied to the cathode c_2 of SCR_2, which is in phase with the A.C. source voltage V_{12}. When the initiating capacitor has charged sufficiently so that the cathode voltage is relatively low, then the negative portion of the ripple voltage supplied by the ripple capacitor **78** can lower the voltage of the cathode c_2 to a level below ground and therefore below the gate g_2. When the cathode reaches a level such as 0.7 volts below the gate, SCR_2 can again fire. This is shown as occurring at the time t'_3, and the process then repeats.

The ripple capacitor **78** can supply a negative voltage to fire SCR_2 only during a negative portion of the A.C. source **12.** Accordingly, SCR_2 will fire and the lamp **10** will ignite only during a negative portion of the A.C. source, and there is no danger that a current will be drawn through the current-limiting resistor **68** and capacitor **64** directly through the lamp **10.** This enables a small resistance to be used at **68** to assure rapid charging of the power capacitor **66.** In addition, there are no cycles when lamp current flows directly through the capacitor **64** of the voltage doubler and, therefore, there is minimum heating of this capacitor as well as of the resistor **68.** Accordingly, resistor and capacitor components can be employed which have a lower wattage rating and there is less heating of the circuit. There is also an advantage of greater efficiency, which can be especially important where a portable battery powered A.C. supply is employed instead of a household outlet.

The capacitance of the ripple capacitor **78** is chosen to provide a high enough peak ripple voltage at the cathode c_2 to assure that the cathode will fall to a level beneath ground potential when there can be no further gate current. For an SCR with a gate-to-cathode diode portion that breaks down at about 7 volts, a ripple voltage of at least on the order of 10 volts is required. The ripple capacitor **78** should not provide such a large ripple voltage that the gate resistor **76** cannot exert major control over the time of firing. In a typical case wherein the source **12** is a nominal **110** voltage supply that charges the power capacitor **66** to a voltage of about 300 volts, a ripple voltage that supplies excursions of about 30 volts above and below the exponential cathode voltage decay V'_{c2} is satisfactory. It may be noted that instead of utilizing a capacitor **78** to provide ripple voltage, other types of impedance devices such as a resistor or a reactive network can be utilized.

The gate resistor **76** is preferably a variable type to enable control of the frequency of lamp flashing. When the gate resistance is increased, flashing occurs less often. A very small gate resistance can be employed to permit lamp flashing even at every cycle, although the resistance should be large enough to limit the gate current through SCR_2 to prevent damage. Of course, various devices described earlier, can be used to vary the use of the reverse biased gate and to provide other silicon controlled rectifier means.

In the operation of the circuit of FIG. **4,** firing actually occurs near the negative peak of the A.C. supply. This is useful where the circuit is used with a negative boost supply, similar to the positive boost of FIG. **1** but which lowers the "ground" terminal of the lamp below ground with a variable negative voltage. The fact that the circuit fires near the negative peak allows maximum negative voltage to be applied, where the negative boost supply is in phase with the A.C. source. FIG. **9** illustrates a circuit which provides such a negative boost voltage, to assure striking of the lamp without the need to charge the 50 microfarad power capacitor to double the A.C. source voltage. This circuit also assures that lamp current will not be drawn directly through the 2 ohm current-limiting resistor. The actual component values of one circuit constructed in accordance with this invention are given in the figure to show how it can be constructed using low cost standard value components. It may be noted that the point **82** in the circuit can be connected to point **86** instead of point **84** without changing the operation.

In the circuits of FIGS. **1, 4,** and **9,** the initiating capacitor **20** or **70** is charged prior to a lamp flash and rapidly discharged to strike the lamp. FIG. **6** illustrates a circuit which employs an initiating capacitor **90** that is slowly discharged prior to a lamp firing and that is rapidly charged from a second capacitor, here a power capacitor **92** to strike the lamp. The circuit is somewhat similar to that of FIG. **1,** in that a booster capacitor **94** is employed to provide a variable booster voltage at the lamp, so that firing should occur near the peak of the A.C. source. At the end of a cycle following firing, the initiating capacitor **90** has been charged to the voltage across the power capacitor **92,** so the cathode of SCR_3 is at this voltage. Relatively slow discharge of the initiating capacitor **90** occurs by current flowing between the cathode and gate of SCR_3, and from the gate through resistor **96** to an A.C. source terminal. When the initiating capacitor **90** has discharged sufficiently, then at the peak of the next A.C. source cycle, the gate of SCR_3 reaches a voltage that is higher than at the cathode and SCR_3 fires. When SCR_3 fires, the initiating capacitor **90** is rapidly charged from the power capacitor **92** (so that the power capacitor suddenly discharges, but only partially), so that a current pulse flows through transformer **98** to strike the lamp. Thus, instead of coupling the capacitor terminal **99** to the anode of the SCR directly through turns of the auto-transformer, this terminal **99** is coupled through the power capacitor **92** (as well as through turns of the auto-transformer) to the anode to create a sudden charging instead of a sudden discharging of capacitor **90** when the SCR is turned on.

In some psychedelic lighting displays, it is desirable to alternately strike two lamps. FIG. **7** illustrates a circuit somewhat similar to that of FIG. **1,** for providing

firing pulses near the peak of the A.C. source and after every predetermined number of A.C. cycles, but which alternately strikes two lamps **110** and **112.** The circuit includes two SCR, SCR_4 and SCR_5, that can respectively dischrage two capacitors **114, 116,** to strike the two lamps **110, 112.** The gates g_4 and g_5 of the SCR's are connected through gate resistors to a variable resistor **118.** The resistor **118** is connected to a point **120** of a voltage divider formed by two resistors **122, 124.** The voltage divider is used here because there is no voltage doubler so the power capacitor **126** has a voltage equal to the peak voltage of the supply **128,** and the voltage divider assures that the gate of the SCR's has a voltage below the anode when firing is to occur. The voltage divider can be used in other circuits such as that of FIG. **1,** to adjust the triggering level. The circuit may be used with a booster formed by a boost capacitor **130** and a diode **132,** which are shown in phantom lines. If no booster is used, the fact that firing occurs at a peak is not an advantage, and the purpose of the circuit then is primarily to assure alternate firings of the lamp and to space the firings by several cycles of the A. C. supply **128.**

FIG. **8** illustrates the voltages Vc_4, Vc_5 and V_{120}, respectively, at the cathodes c_4 and c_5 and at point V_{120}. When SCR_4 fires at time t_5, the voltage at its cathode c_4 rises thereby raising the voltage at point **134.** An intercircuit capacitor **136** transmits this voltage rise to point **138,** which therefore raises the voltage Vc_5. When Vc_5 rises, the initiating capacitor partially discharges so that firing of SCR_5 is delayed until time t_6. Where it is desired to provide a constant delay between firings, capacitors **114** and **116** may be made equal and an intercircuit capacitance for **136** is used which has twice the capacitance of **114** or **116.** It may be noted that a dual lamp circuit can be constructed which assures alternate firings of two lamps during negative peaks of the A.C. source, by the use of circuits of the type shown in FIGS. **4** or **9.**

Thus, the invention provides circuits that assure the delivery of a firing pulse at a controlled phase of an A.C. voltage source. In one application, firing is assured at a positive peak of the A.C. source by connecting the gate through a resistor to a point on the circuit that varies in voltage in synchronism with the A.C. source, but which is always at a voltage less than the anode of the SCR. In another application, firing is assured during a negative portion of the A.C. cycle by connecting the gate of the SCR through a resistor to a circuit point which is always lower than the anode of the SCR to provide a substantially exponential decay in the SCR cathode voltage; in addition, a ripple voltage that is substantially synchronized with the A.C. source is supplied to the cathode of the SCR to cause firing after the cathode voltage has exponentially decayed, and to assure that such firing occurs during the negative portion of the A.C. cycle. The circuit is shown utilized to fire a stroboscopic lamp, but it can be employed in a variety of other applications where a pulse is to be generated at a controlled time of an A.C. source. It should be realized that not only is phase control achieved, but it is achieved in a very simple manner requiring a minimum of inexpensive components to be added to the power circuit. Furthermore, even where the phase of firing is not considered, a very economical and reliable frequency divider, or oscillator, is provided. The achievement of phase control in an extremely economical manner enables its application in a variety of circuits that must be sold at low cost.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art and consequently it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. Apparatus for use with an alternating current source to provide an output pulse at a predetermined phase of the alternating source comprising:

silicon controlled rectifier means having anode, cathode, and gate terminals, which rapidly turns on to decrease in anode to cathode resistance when there is a predetermined gate to cathode voltage;

an initiating capacitor having a first terminal coupled to said cathode terminal and a second terminal;

means coupling said second terminal of said capacitor to said anode of said silicon controlled rectifier means, so that the voltage across said capacitor changes by the flow of a current pulse through it and through said rectifier means when said rectifier means is turned on;

impedance means coupled to said alternating current source for supplying current to said capacitor that changes the voltage across it and to provide a controlled gate voltage, said impeance means including a resistor and means coupling one side of said resistor to said current source and the other side of said resistor to said capacitor to provide a net change in capacitor voltage over each cycle of said alternating current source that lowers the potential of said first capacitor terminal and cathode terminal with respect to said gate terminal.

2. The apparatus described in claim **1** wherein:

said means coupling said second terminal of said capacitor to said anode of said silicon controlled rectifier means includes a second capacitor; and including

means for charging said second capacitor, so that said initiating capacitor is rapidly charged from said second capacitor when said rectifier means is turned on.

3. The apparatus described in claim **1** wherein:

said alternating current source has a ground terminal and a second source terminal and defines an alternating voltage therebetween; and including

second capacitor means for maintaining the anode terminal of said silicon controlled rectifier means at a voltage above said ground terminal during a period prior to said rectifier means turning on; and wherein

said resistor of said impedance means couples said gate terminal to said second source terminal of said alternating current source, whereby to fire said silicon controlled rectifier means and provide an output pulse, near a positive peak of the alternating current source.

4. The apparatus described in claim **1** wherein:

said alternating current source has a ground terminal and a second source terminal and defines an alternating voltage therebetween; and including

second capacitor means for maintaining the anode terminal of said silicon controlled rectifier means at a voltage above said ground terminal during a

period prior to said rectifier means turning on; and wherein

said resistor of said impedance means couples said gate terminal to said ground terminal, and said impedance means also includes ripple-producing means of predetermined impedance coupling said first capacitor terminal to said second terminal of said alternating current source, whereby to fire said silicon controlled rectifier means during a negative portion of the alternating current voltage.

5. The apparatus described in claim **1** including:

phase shift means for connection to said alternating current source to provide a varying voltage which varies as said current source varies but with a phase shift; and

said impedance means is coupled to said alternating current source through said phase shift means to provide a gate voltage that varies out of phase with said alternating current source.

6. The apparatus described in claim **1** including:

a second silicon controlled rectifier means having a second anode, cathode and gate terminals, and which rapidly decreases in anode to cathode resistance when there is a predetermined gate to cathode voltage;

a second initiating capacitor having a first terminal coupled to said second cathode terminal and a second terminal;

second means coupling said second terminal of said second capacitor to said second anode;

second impedance means coupled to said alternating current source for supplying current to said second capacitor that changes the voltage across it and to provide a controlled gate voltage; and

an intercircuit capacitance coupling said first-named initiating capacitor and said second initiating capacitor.

7. In a power supply which includes an alternating voltage source, storage means for providing a voltage of constant polarity, silicon controlled rectifier means having an anode connected to a positive terminal of said storage means, a cathode, and a gate, striking circuit means, an initiating capacitor, and means coupling the cathode to the anode by way of the striking circuit means, so that when the gate voltage is above the cathode voltage the silicon controlled rectifier means fires to provide a sudden current flow through the capacitor for activating the striking means, the combination comprising:

a resistor with first and second terminals;

means for coupling said first resistor terminal to said voltage source; and

means for coupling said second resistor terminal to said gate of said silicon controlled rectifier means, to provide a gate voltage that varies in constant phase relationship to said voltage source and a current for flow substantially between said gate of said rectifier means and said cathode thereof to change the charge on said initiating capacitor in a direction that lowers the voltage of the initiating capacitor terminal which is coupled to the cathode of the silicon controlled rectifier means.

8. In a power supply which includes a point of substantially constant voltage, an alternating voltage source for supplying a voltage which alternates in polarity with respect to said point of constant voltage, storage means for providing a voltage of constant polarity, silicon controlled rectifier means having an anode connected to a positive terminal of said storage means, a cathode, and a gate, striking circuit means, an initiating capacitor, and means coupling the cathode to the anode through windings by way of the striking circuit means, so that when the gate voltage is above the cathode voltage the silicon controlled rectifier means fires to provide a sudden current flow through the capacitor for activating the striking means, the combination comprising:

a resistor coupling said gate of said silicon controlled rectifier means to said point of substantially constant voltage, and

an impedance having one terminal coupled to a point on said voltage source which varies in voltage at the same frequency as said alternating voltage source and at a constant phase relationship therewith and a second terminal; and

means coupling said second terminal of said impedance to said cathode of said silicon controlled rectifier means, to provide a ripple voltage thereon.

9. In a stroboscopic lamp initiating circuit which includes a power supply having a predetermined location with a varying voltage thereon, means for coupling said power supply to a stroboscopic lamp to supply a voltage across the lamp that varies in amplitude in phase with variations in voltage at said predetermined location but which supplies a higher peak voltage at the lamp than the peak voltage at said location, and lamp striker means, the combination comprising:

silicon controlled rectifier means having an anode, a cathode, and a gate, said rectifier means turning on when there is a predetermined gate to cathode firing voltage and said rectifier means defining a gate-to-cathode diode which can conduct a reverse current;

initiating means including an initiating capacitor and means responsive to a current pulse through said capacitor for operating said striker means, said initiating means coupling said cathode to said anode; and

impedance means coupling said gate to said predetermined location of said power supply, to provide a reverse current through said diode of said rectifier means that changes the charge on said capacitor at each cycle of said varying voltage of said power supply, and to provide a voltage at said gate that turns on said rectifier means when the charge on said capacitor has been sufficiently changed, said impedance means having an impedance high enough to change the voltage across said capacitor to a voltage that enables turning on of said rectifier means only after a plurality of cycles of said A.C. source, whereby to assure striking of the lamp at close to a peak of the varying voltage across the lamp.

10. In a stroboscopic lamp initiating circuit including an A.C. voltage source and striking means, the combination comprising:

voltage storage means including a power capacitor for supplying current to light said lamp and a circuit portion for charging said power capacitor from said A.C. voltage source to establish a first terminal of said power capacitor positive with respect to a second terminal thereof, said circuit portion capable of supplying current directly to said lamp during at least a portion of a positive A.C. cycle if the

lamp is struck during said portion, but not during a negative portion of an A.C. cycle;

silicon controlled rectifier means having an anode coupled to said first power capacitor terminal, a cathode, and a gate, said rectifier means turning on when there is a positive gate-to-cathode voltage to permit a large anode to cathode current flow;

initiating means including an initiating capacitor coupling said cathode to said anode and means responsive to a current pulse through said capacitor for operating said striking means; and

impedance means coupled to said voltage source for establishing a voltage at said gate, and for carrying a ripple current to said capacitor that varies in constant phase relationship with said A.C. source so that the voltage at the cathode decreases at every cycle of the A.C. voltage source with a ripple component that is in constant phase relationship with the A.C. voltage source, to lower the cathode voltage below the gate voltage and thereby cause lamp striking only during a negative portion of the A.C. cycle, thereby to prevent the flow of lamp current directly through said circuit portion that charges the power capacitor.

11. The combination described in claim **10** wherein:

said silicon controlled rectifier means is constructed so that it can carry a reversed biased cathode-to-gate current; and

said impedance means includes a resistor coupling said gate to a location on said circuit portion of constant potential, to provide an exponential charging current, and a ripple-producing impedance coupling a terminal of said initiating capacitor to a location on said circuit portion which varies in voltage in phase with said A.C. source to provide a ripple charging current that adds to said exponential charging current.

12. A lamp firing circuit for striking and energizing a stroboscopic lamp that has a predetermined maintenance voltage below which the lamp becomes extinguished, from an A.C. source with first and second source terminals that alternate in relative polarity at every half cycle and which obtain a peak voltage exceeding said maintenance voltage of said lamp, comprising:

a power capacitor with first and second capacitor terminals;

a diode;

means for coupling said diode and capacitor in series to said A.C. source to charge said capacitor, so that said first capacitor terminal becomes positive with respect to said second capacitor terminal and so that the charge on said capacitor can increase only during portions of the A.C. source half cycle when said first source terminal is positive with respect to said second source terminal;

means for connecting said capacitor across said stroboscopic lamp, so that said capacitor can provide lamp energizing current when the lamp is struck; and

means responsive to said A.C. source for striking said lamp only during those times of each A.C. source cycle when the voltage at said first source terminal minus the voltage at said second source terminal is less than said lamp maintenance voltage, whereby to prevent the flow of lamp current directly from said A.C. source.

13. The circuit described in claim **12** wherein:

said means for connecting said capacitor across said lamp includes a diode coupling said second capacitor terminal to a second of said lamp terminals, to prevent current flow in a direction from said second capacitor terminal to said second lamp terminal; and including

means for applying a varying voltage to said lamp that reduces the voltage at said second lamp terminal below the voltage at said second capacitor terminal in phase with said A.C. source; and wherein

said means for striking is constructed to fire said lamp at times when the potential at said second lamp terminal is near a negative peak with respect to the voltage at said second capacitor terminal.

14. A stroboscopic lamp firing circuit for striking and firing a stroboscopic lamp from an A.C. source comprising:

a capacitor with first and second capacitor terminals;

a diode;

first and second circuit terminals for connecting to first and second terminals of said A.C. source;

means for coupling said capacitor and diode in series to said circuit terminals, with said diode allowing current flow only in a direction from said first circuit terminal to said first capacitor terminal, for charging said capacitor so that said first capacitor terminal becomes positive with respect to said second capacitor terminal;

means for coupling said capacitor across said lamp, so that said capacitor can provide lamp energizing current when the lamp is struck; and

means coupled to said circuit terminals for striking said lamp only during times when said first circuit terminal is negative with respect to said second circuit terminal whereby to prevent the flow of lamp current directly from said A.C. source.

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