United States Patent

Nomura et al.

[15] **3,649,869**

[45] **Mar. 14, 1972**

[54] APPARATUS FOR LIGHTING DISCHARGE LAMPS

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[30] **Foreign Application Priority Data**

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June 20, 1969	Japan	44/48558
June 20, 1969	Japan	44/48561
July 30, 1969	Japan	44/59772
Sept. 12, 1969	Japan	44/72174

[52] **U.S. Cl.** **315/205,** 315/100, 315/258, 315/283

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

[58] **Field of Search** 315/94, 97, 98, 100, 101, 102, 315/103, 105, 205, 258, 283

[56] **References Cited**

UNITED STATES PATENTS

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Primary Examiner—Roy Lake
Assistant Examiner—Lawrence J. Dahl
Attorney—Flynn & Frishauf

[57] **ABSTRACT**

An apparatus for operating one or more electric discharge lamps from an AC source with an inductive element, in which a semiconductor switching element is Both preheating and pulse generating circuits included in a preheating circuit and a pulse generating circuit for starting and operating a discharge lamp. circuits are operated for the common switching element, so that the discharge lamp is preheated and then kept in a stable lighting condition.

20 Claims, 34 Drawing Figures

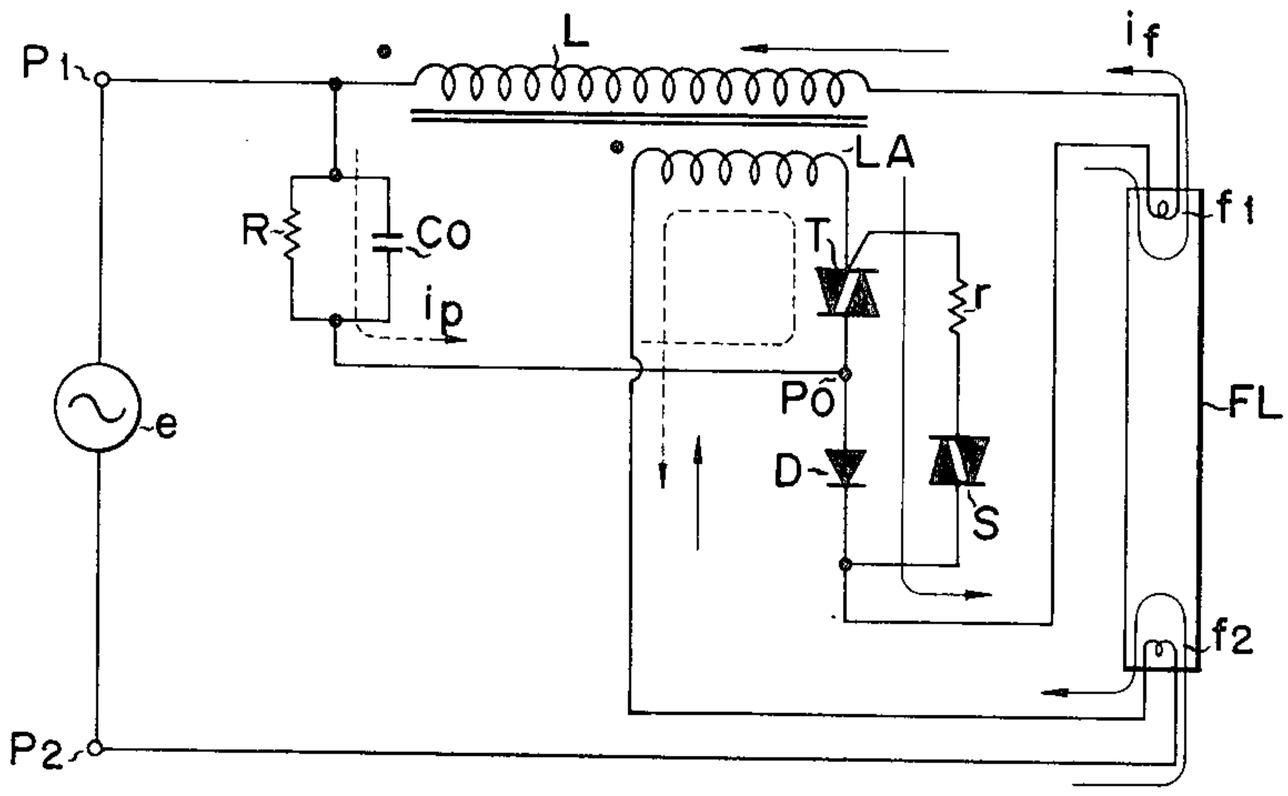


FIG. 1

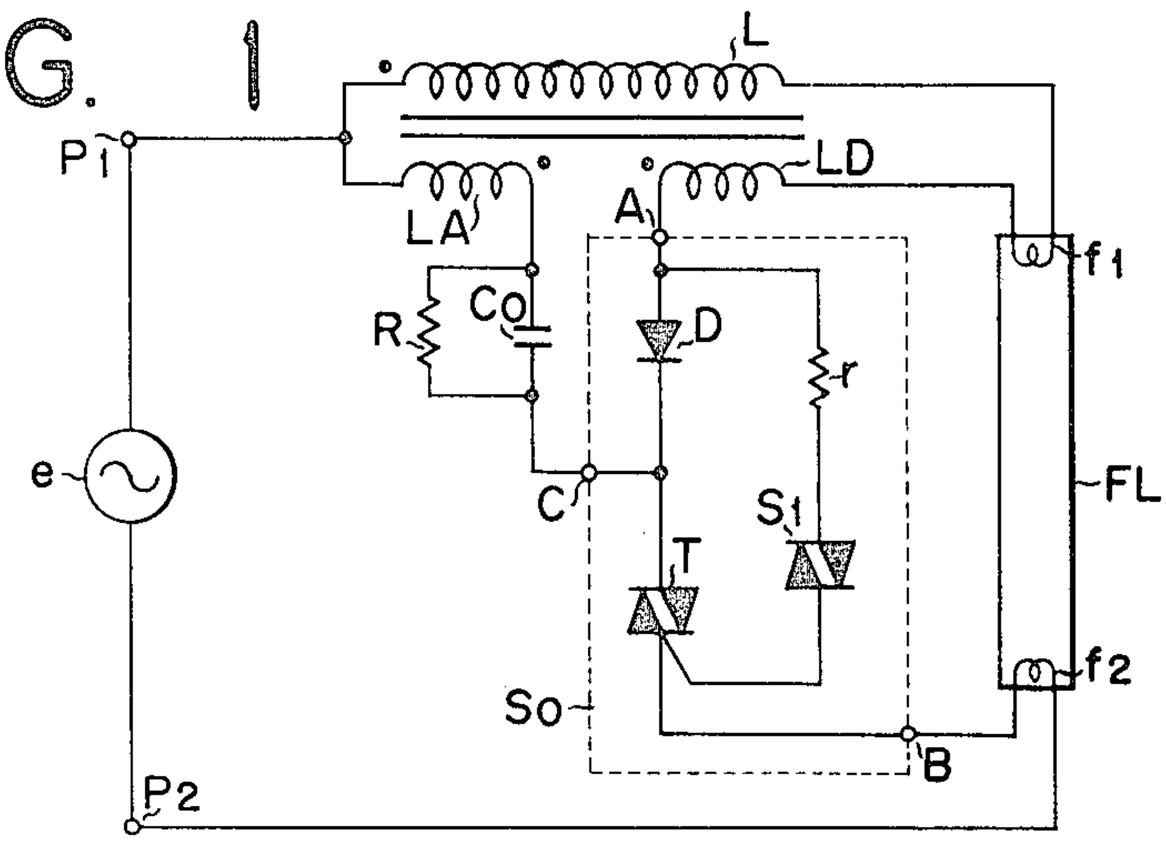


FIG. 2

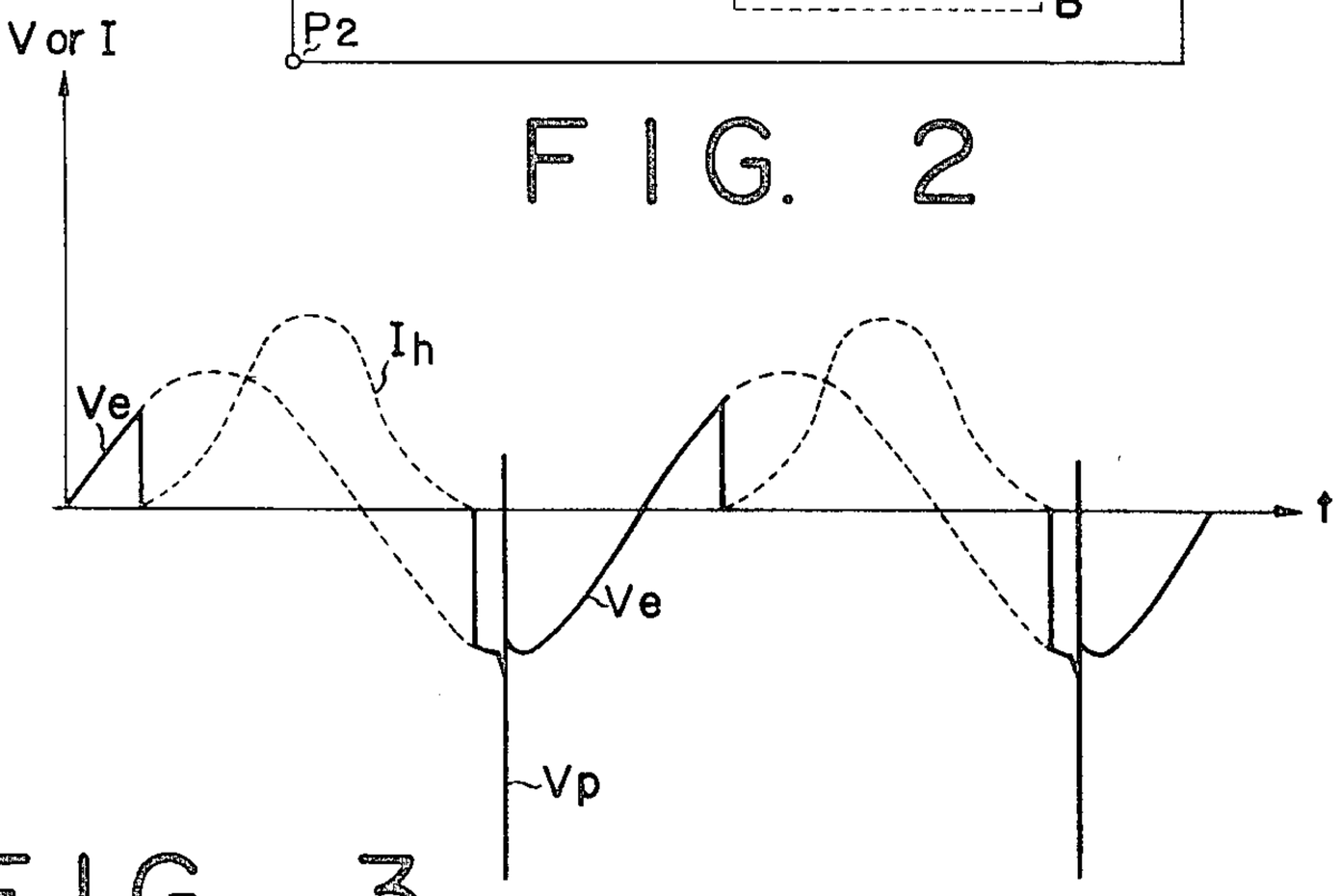


FIG. 3

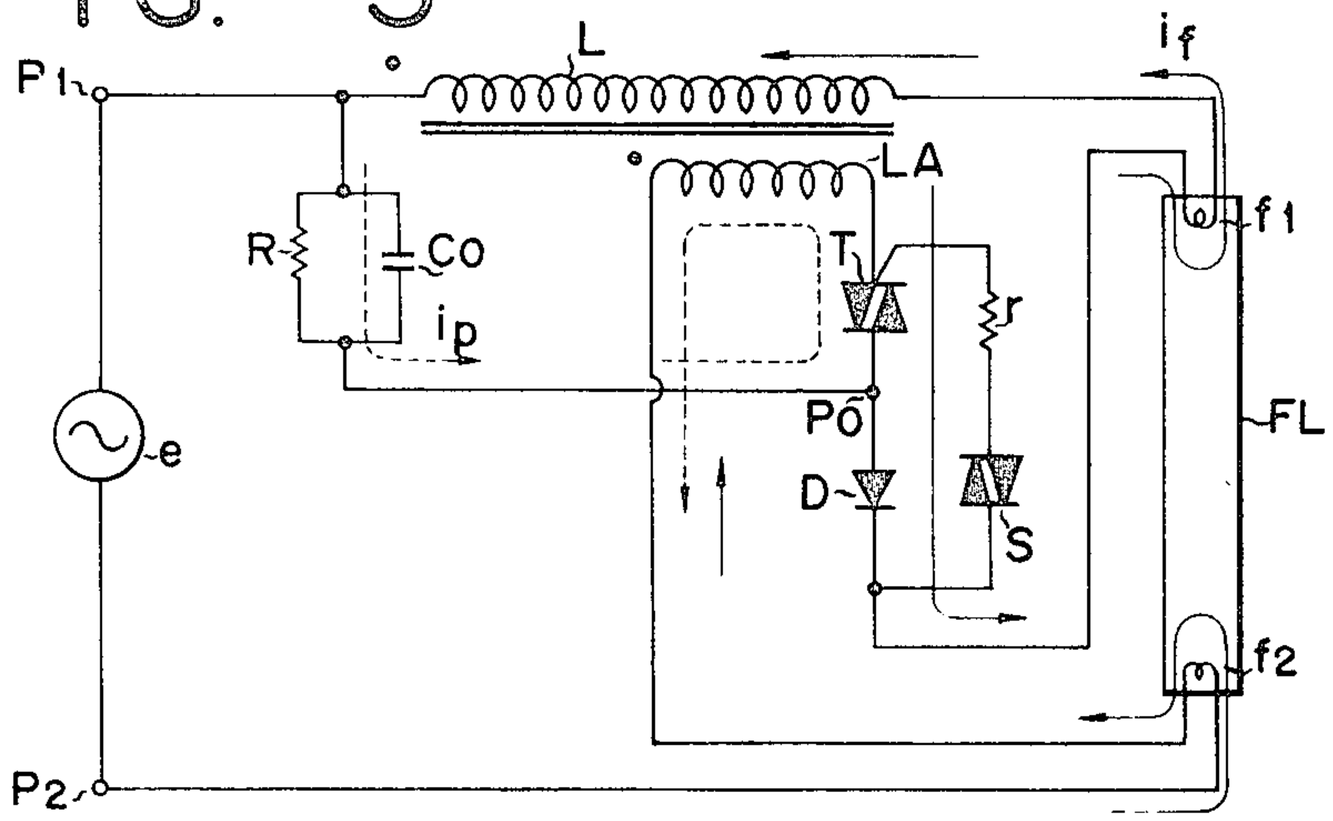


FIG. 4

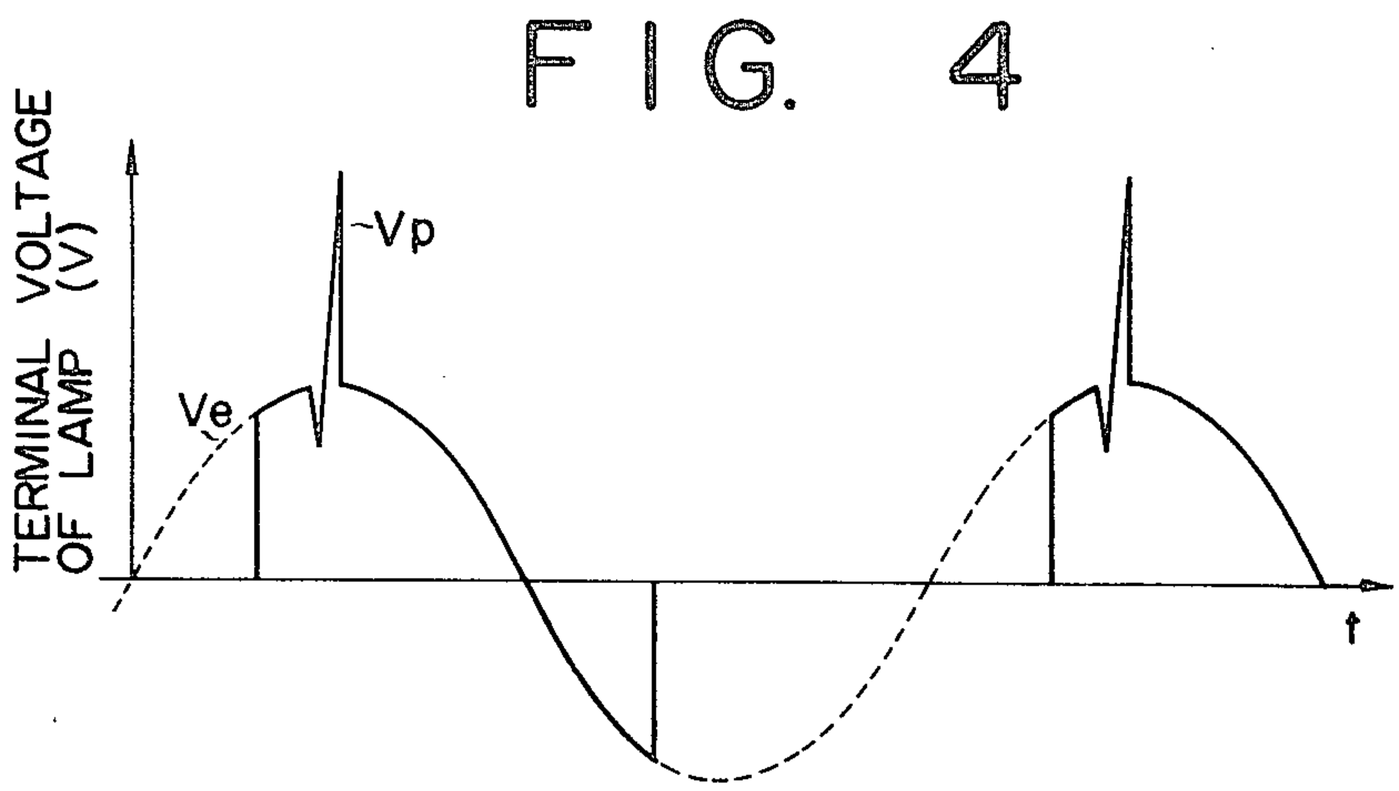


FIG. 5

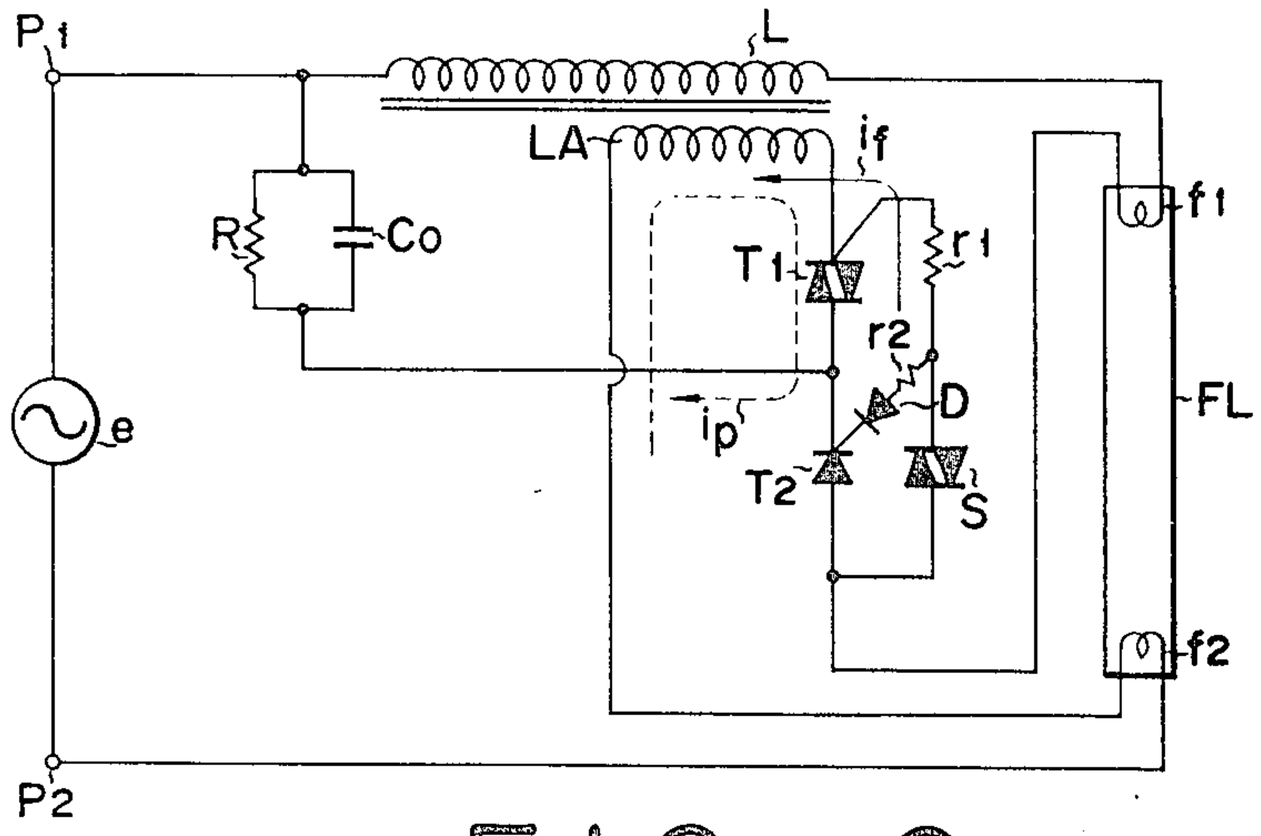


FIG. 6

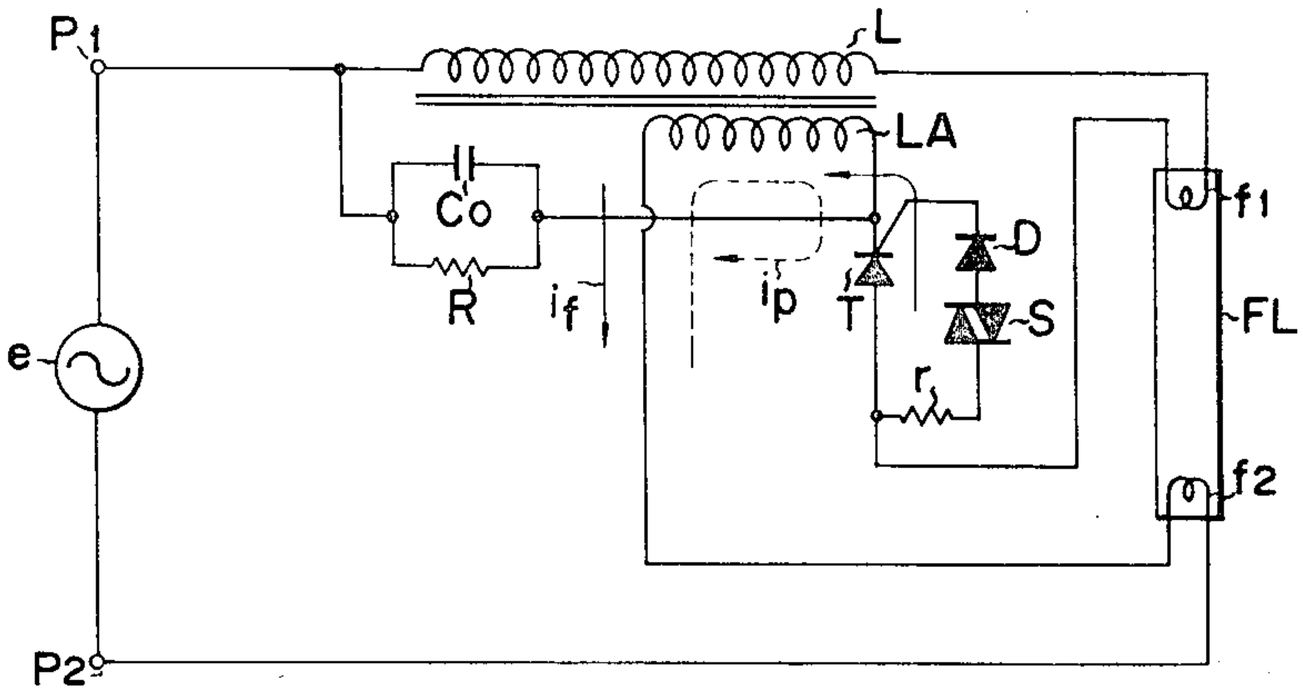


FIG. 7

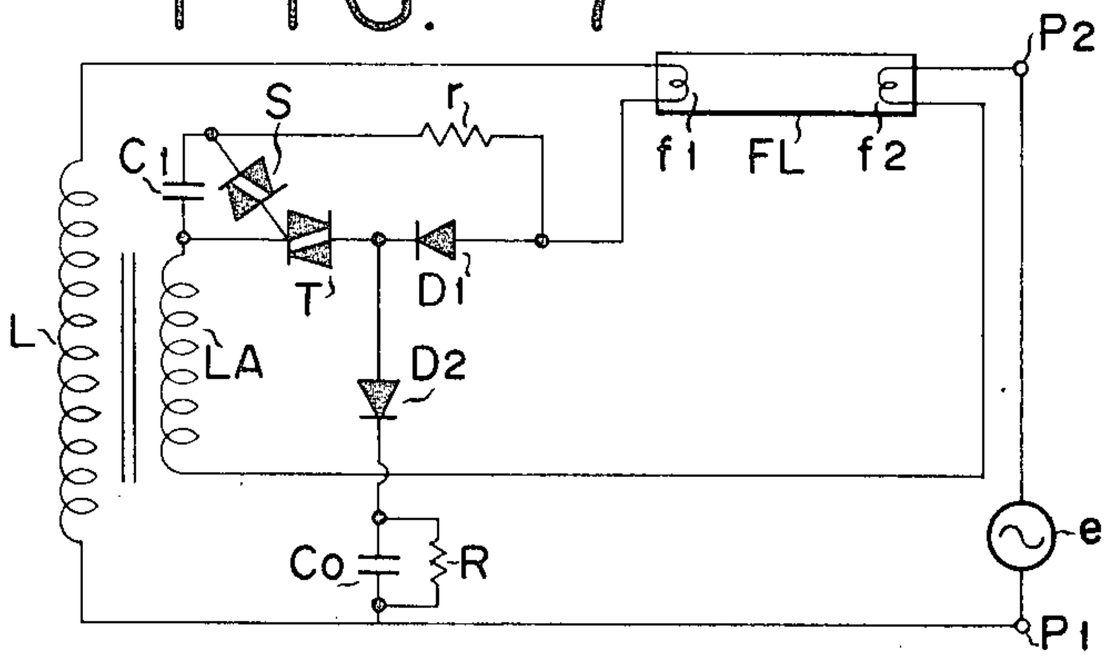


FIG. 8

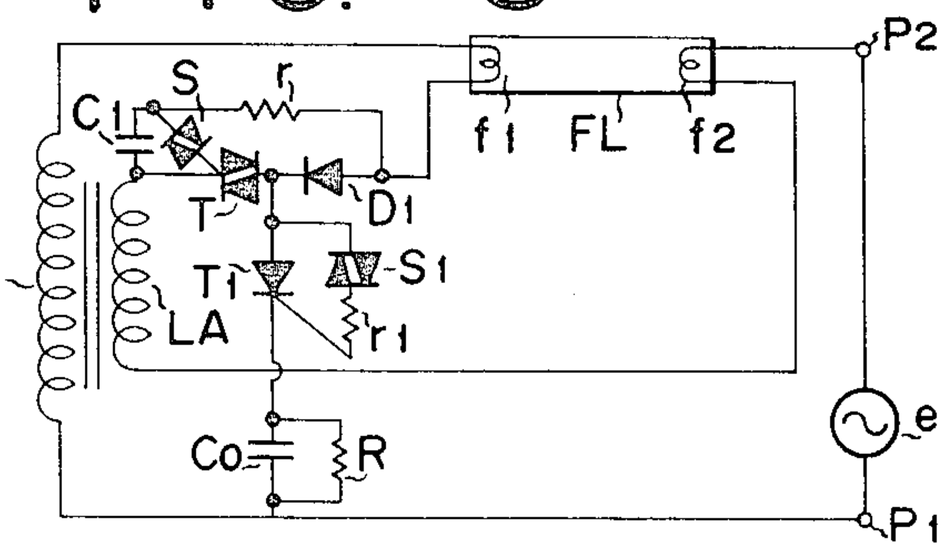


FIG. 9

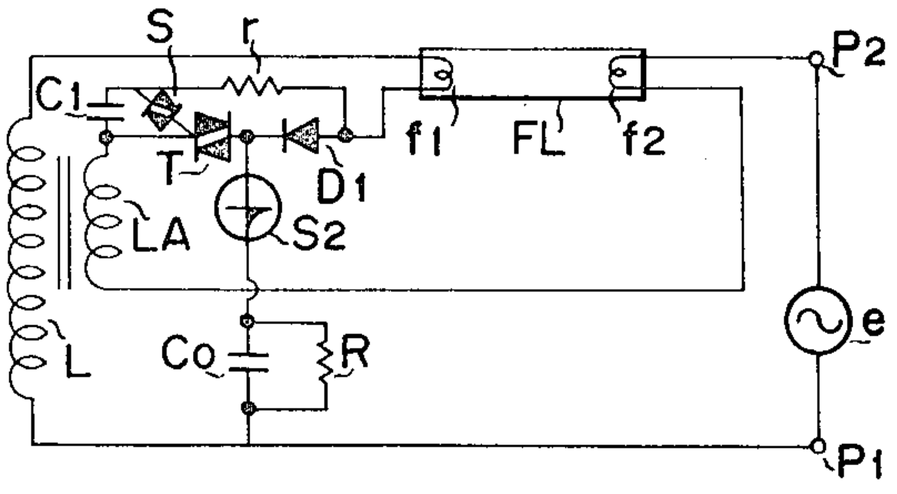


FIG. 10

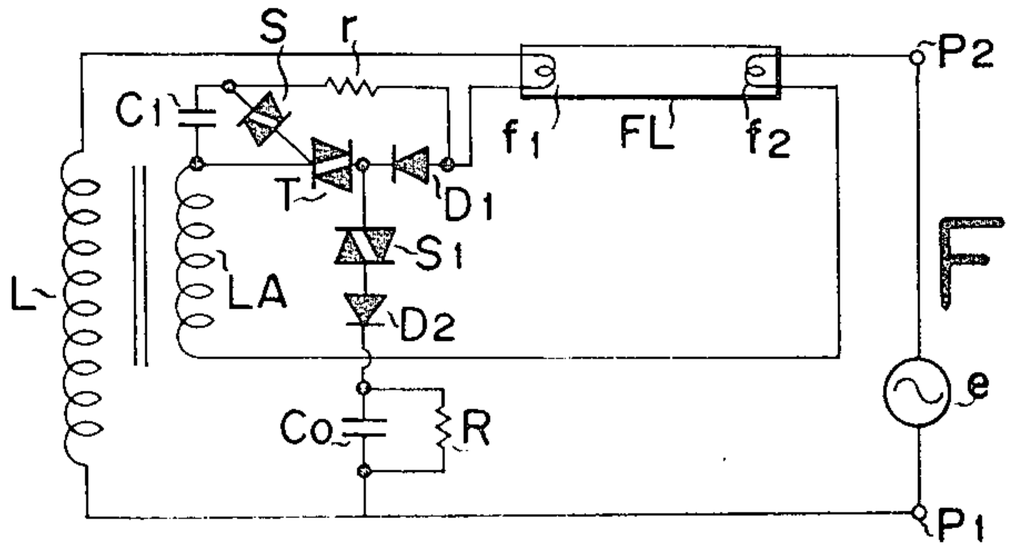
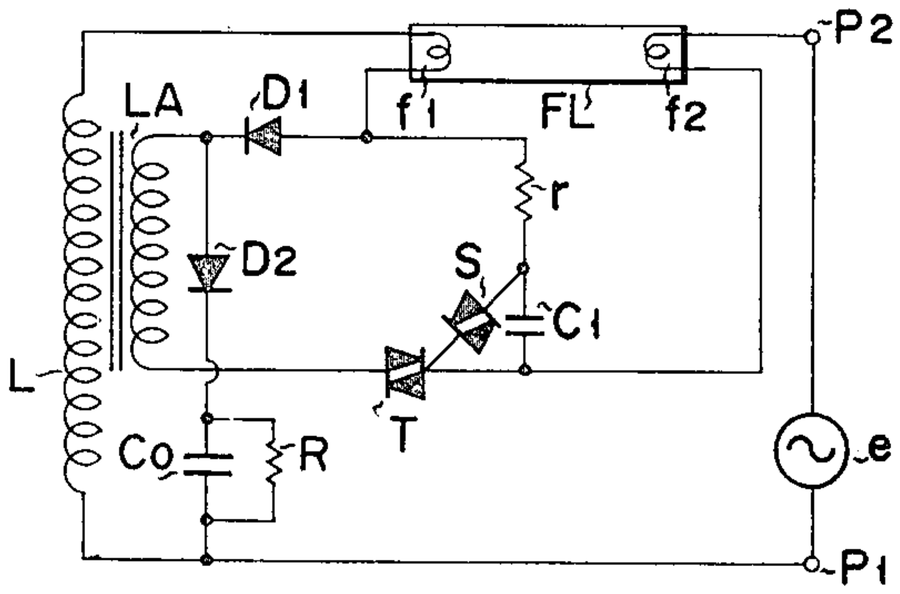


FIG. 11



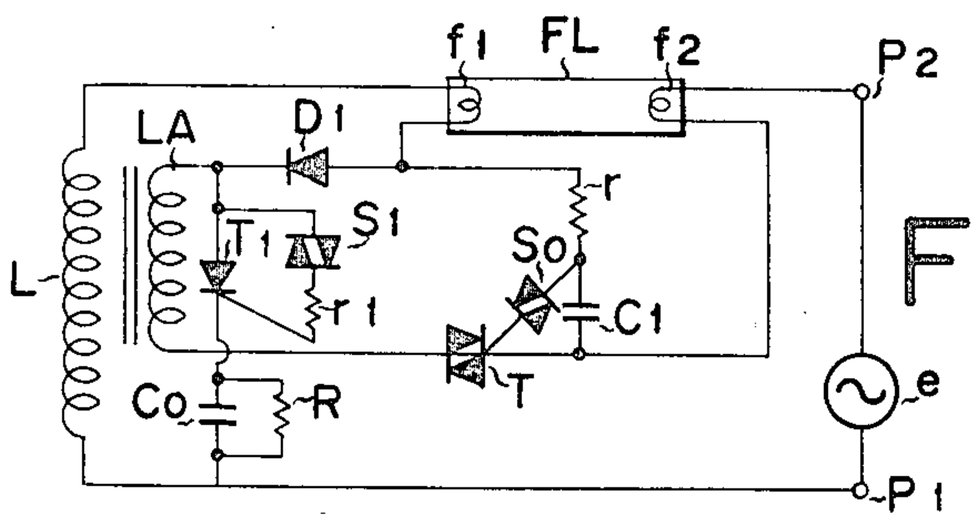


FIG. 12

FIG. 13

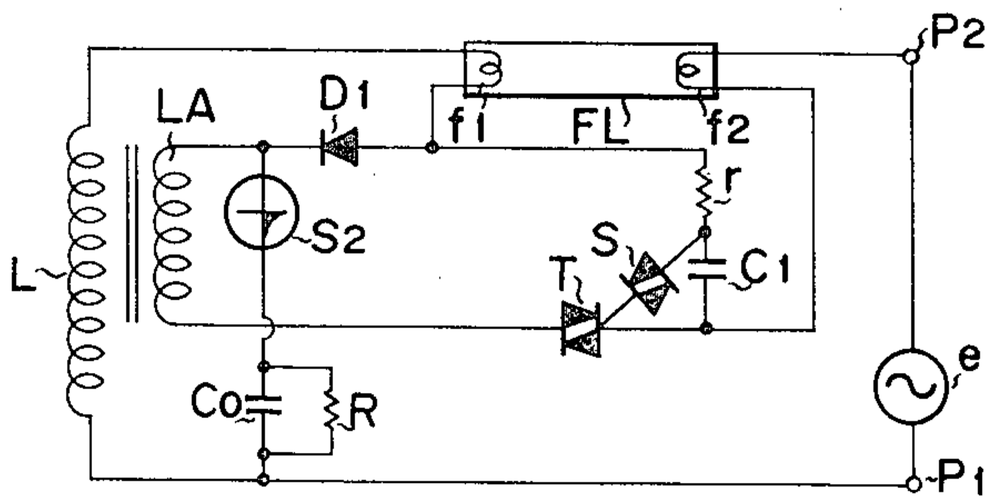


FIG. 14

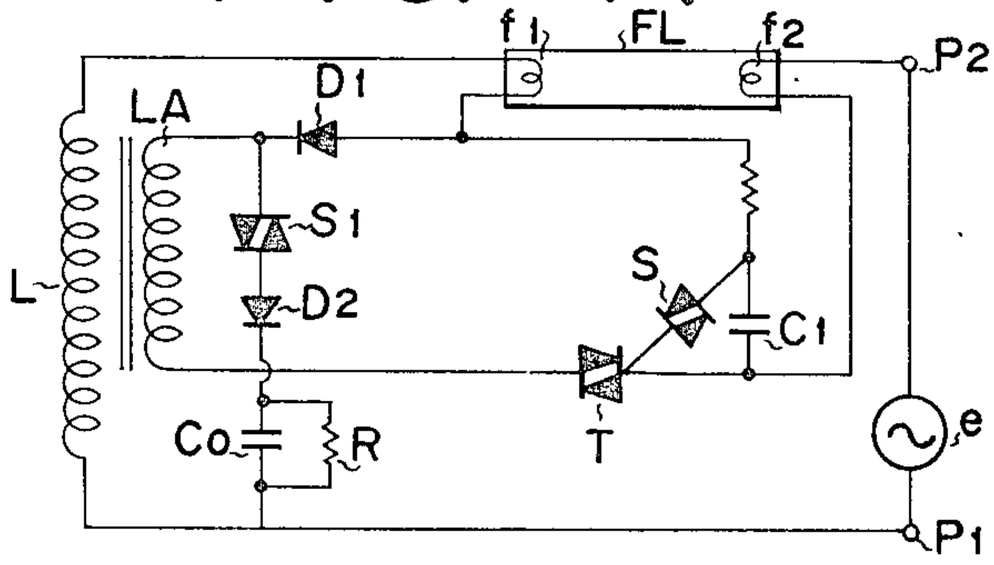


FIG. 15A

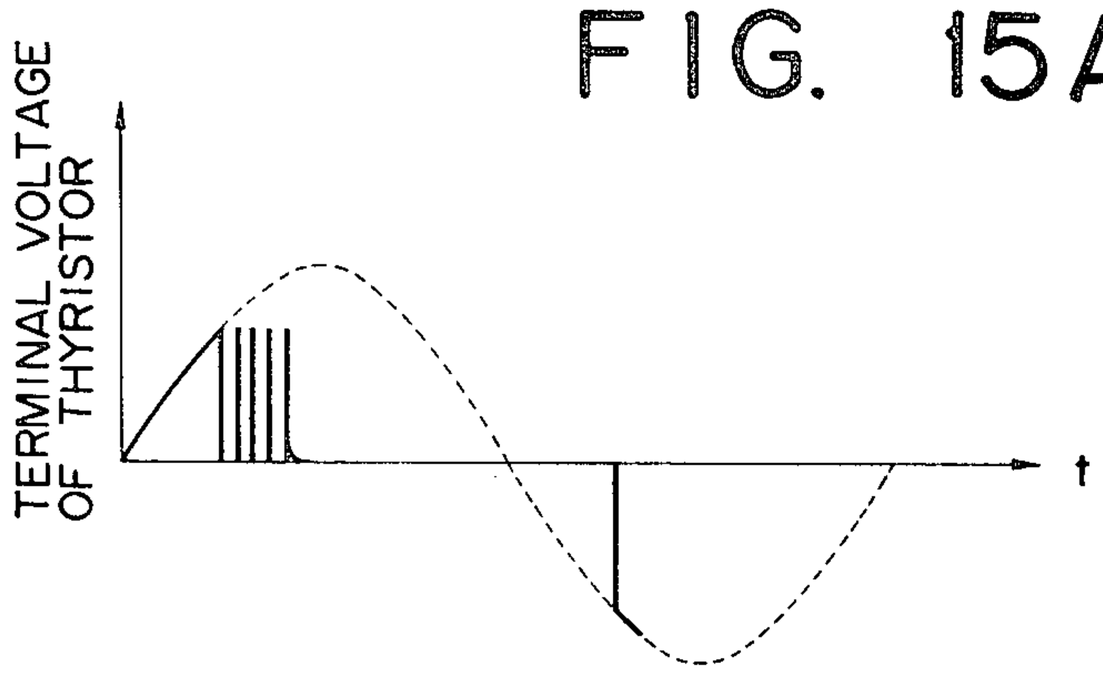


FIG. 15B

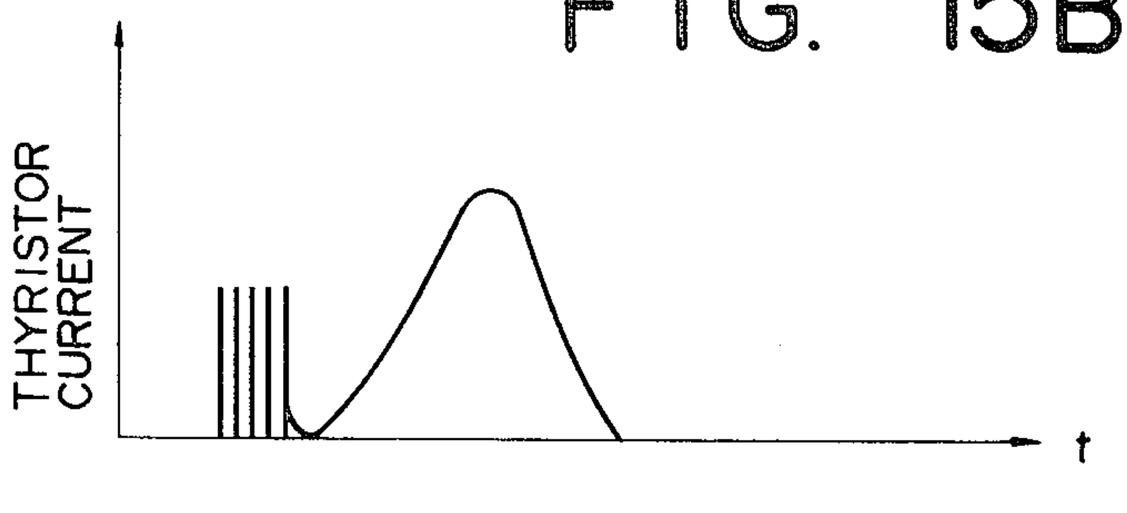


FIG. 16A

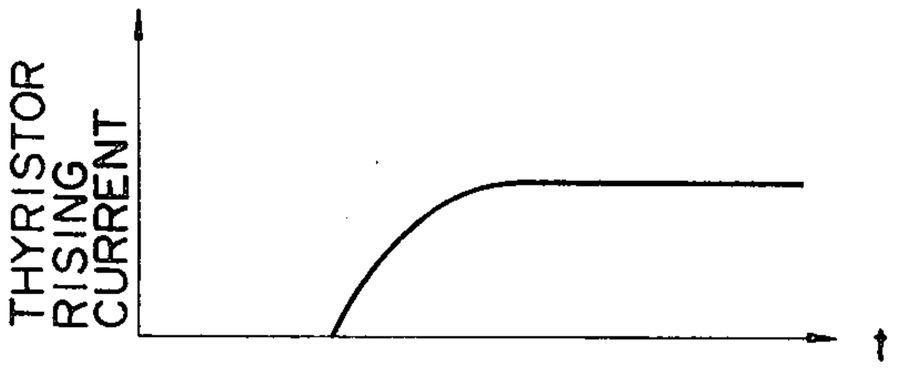


FIG. 16B

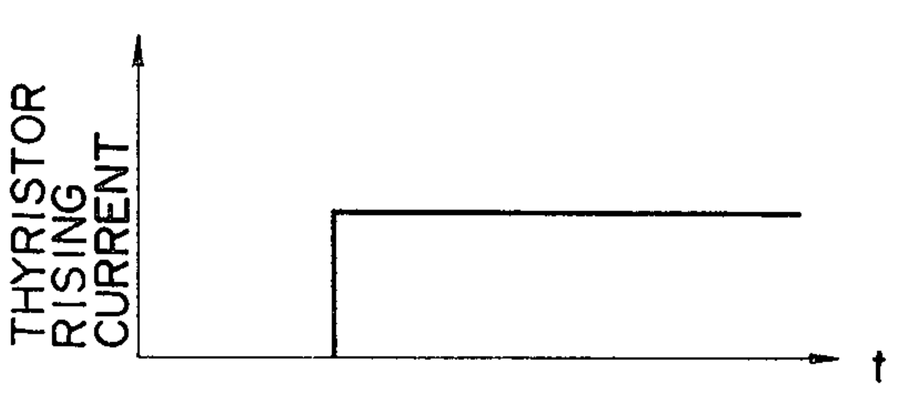


FIG. 17

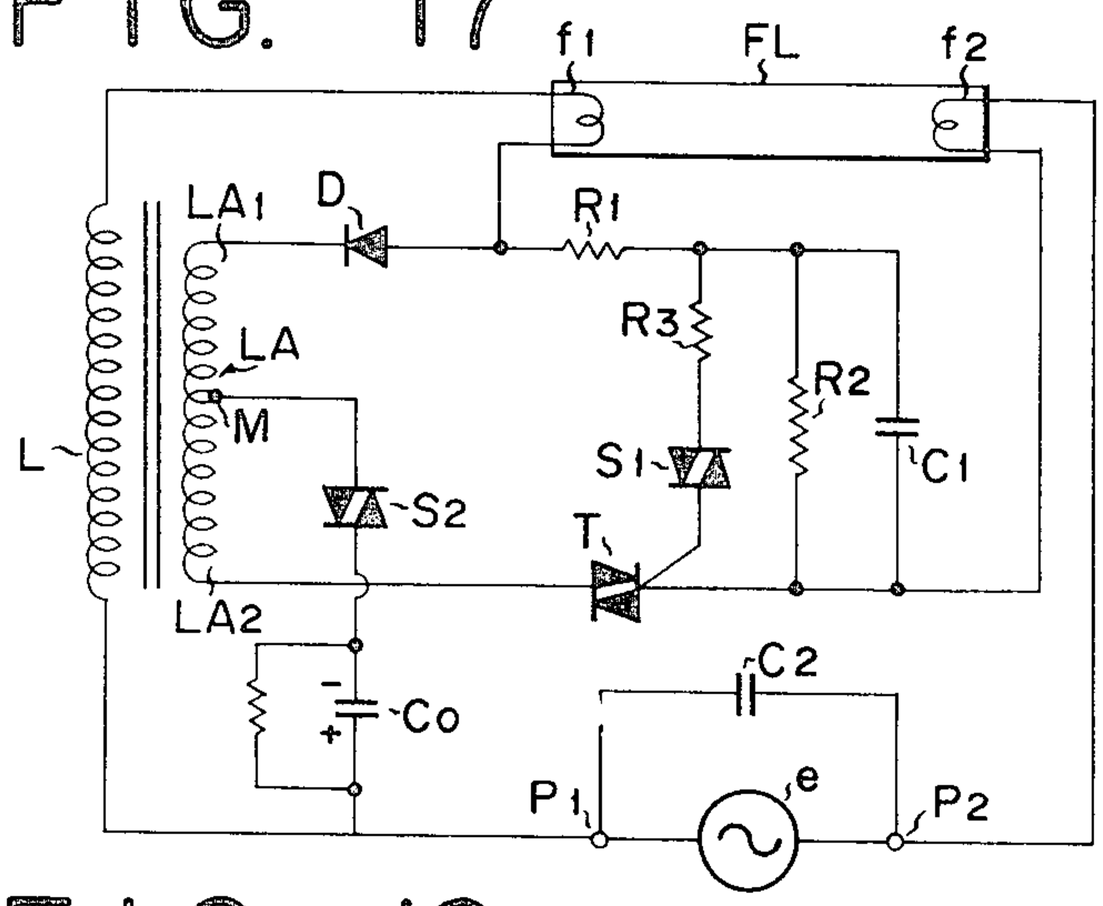
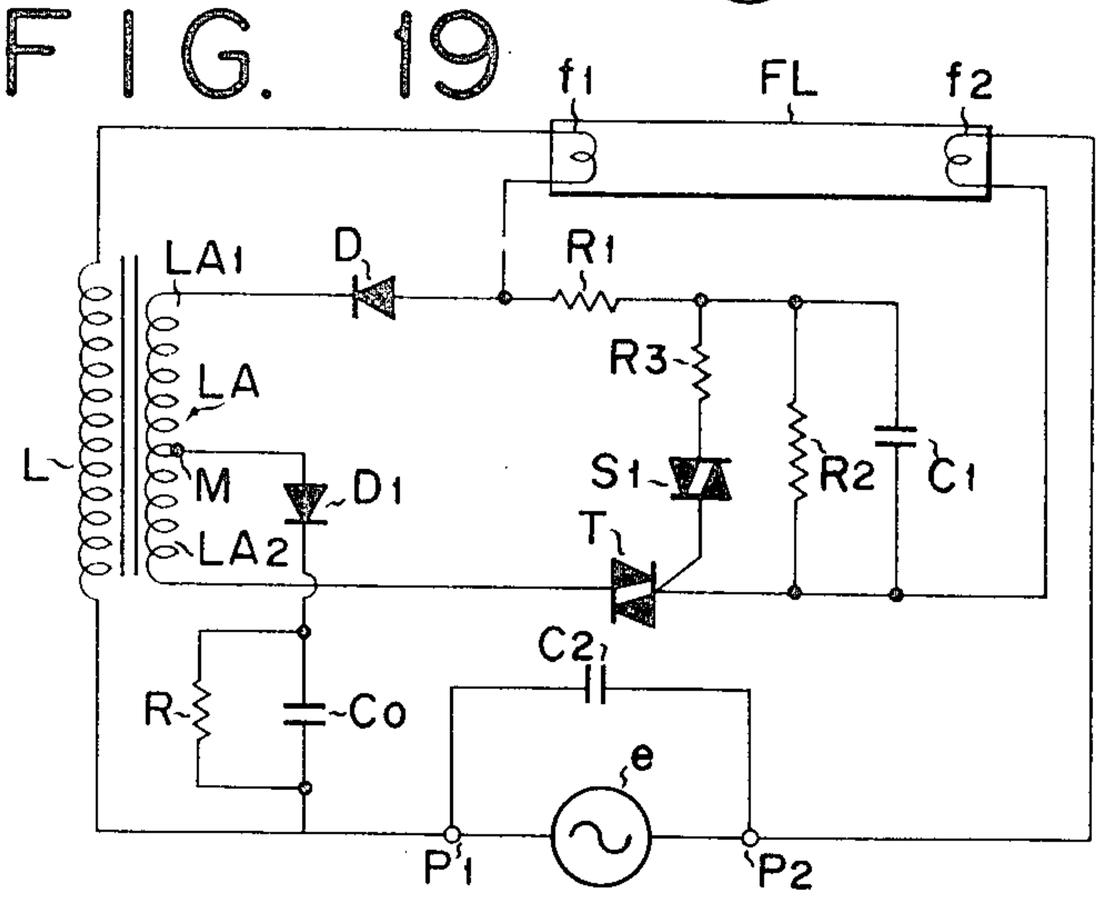


FIG. 19



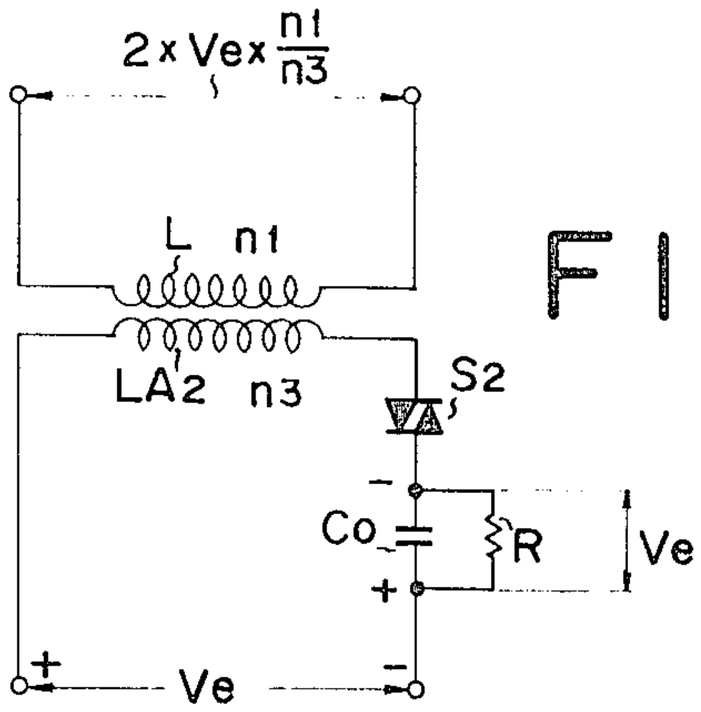


FIG. 18

FIG. 20

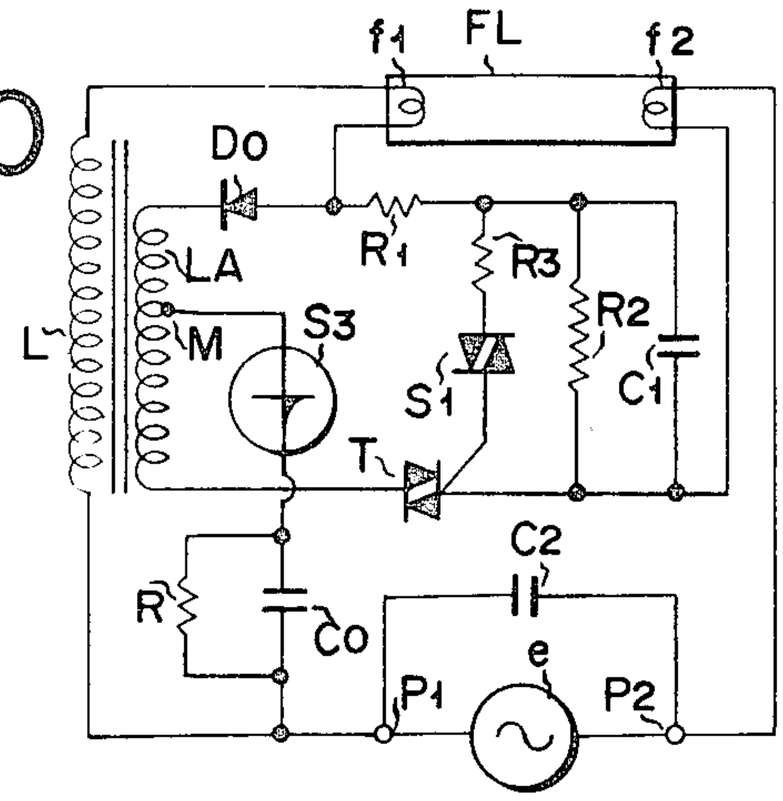


FIG. 21

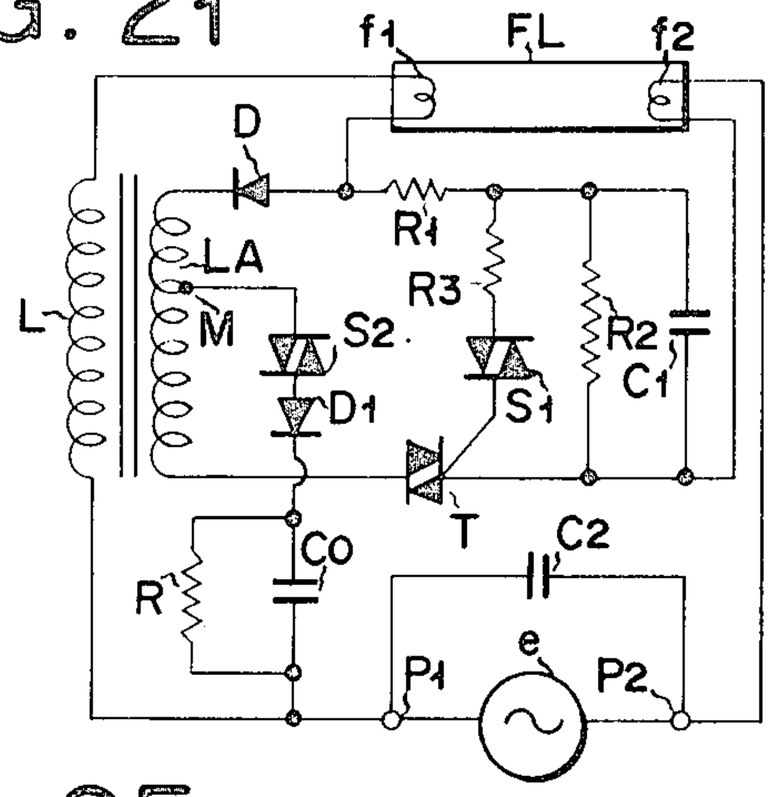
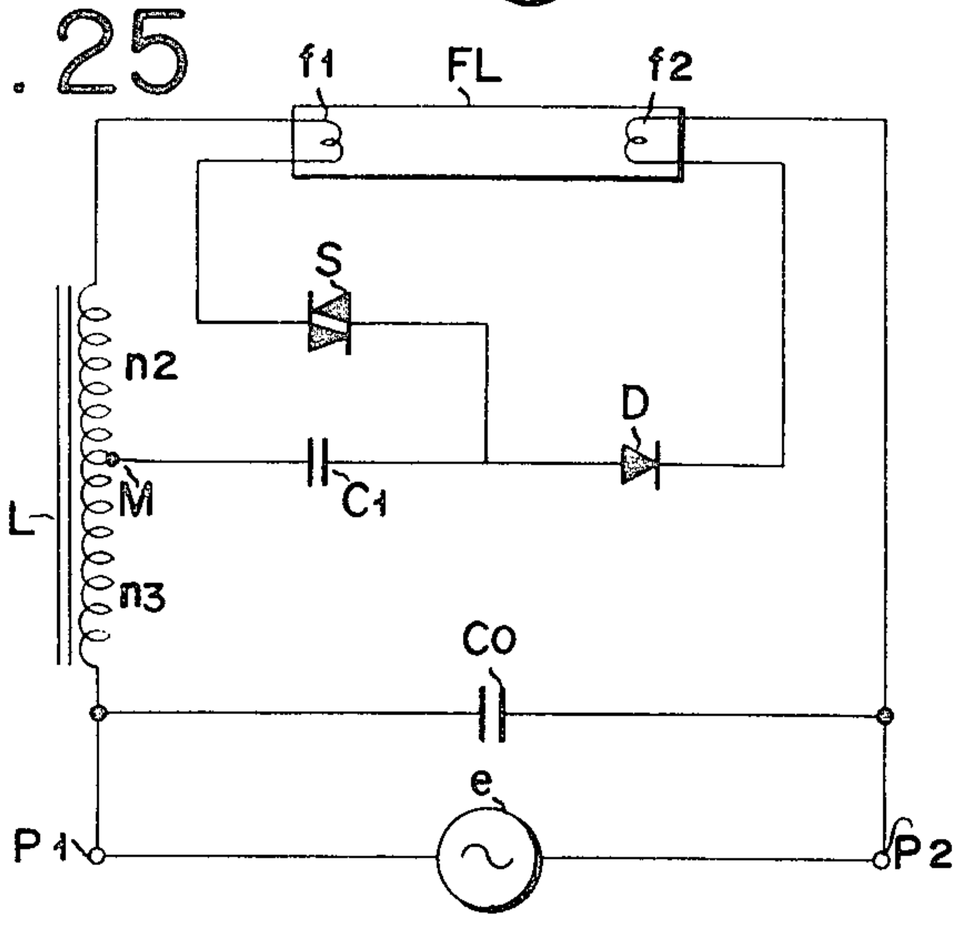


FIG. 25



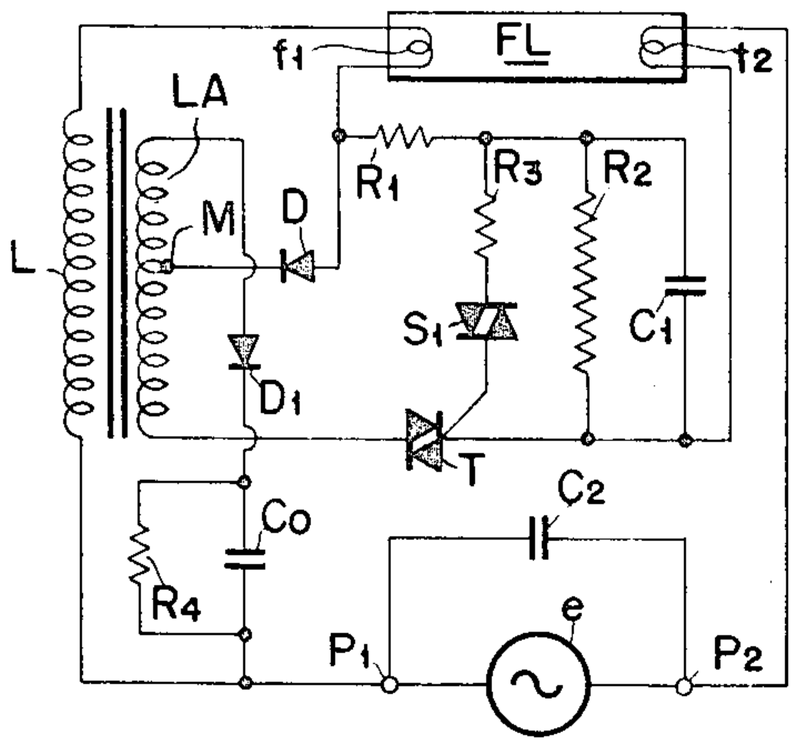


FIG. 22

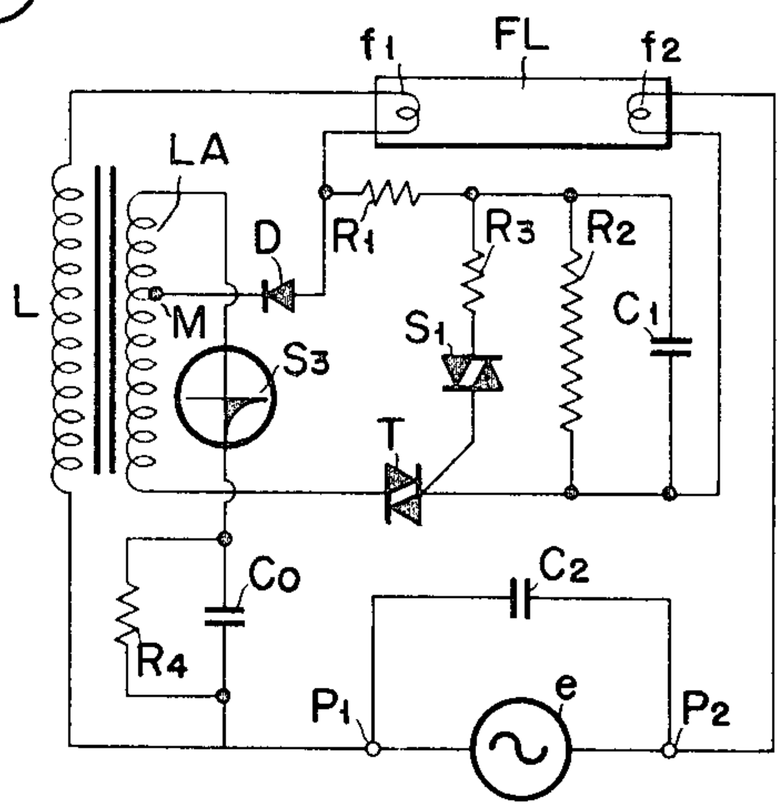


FIG. 23

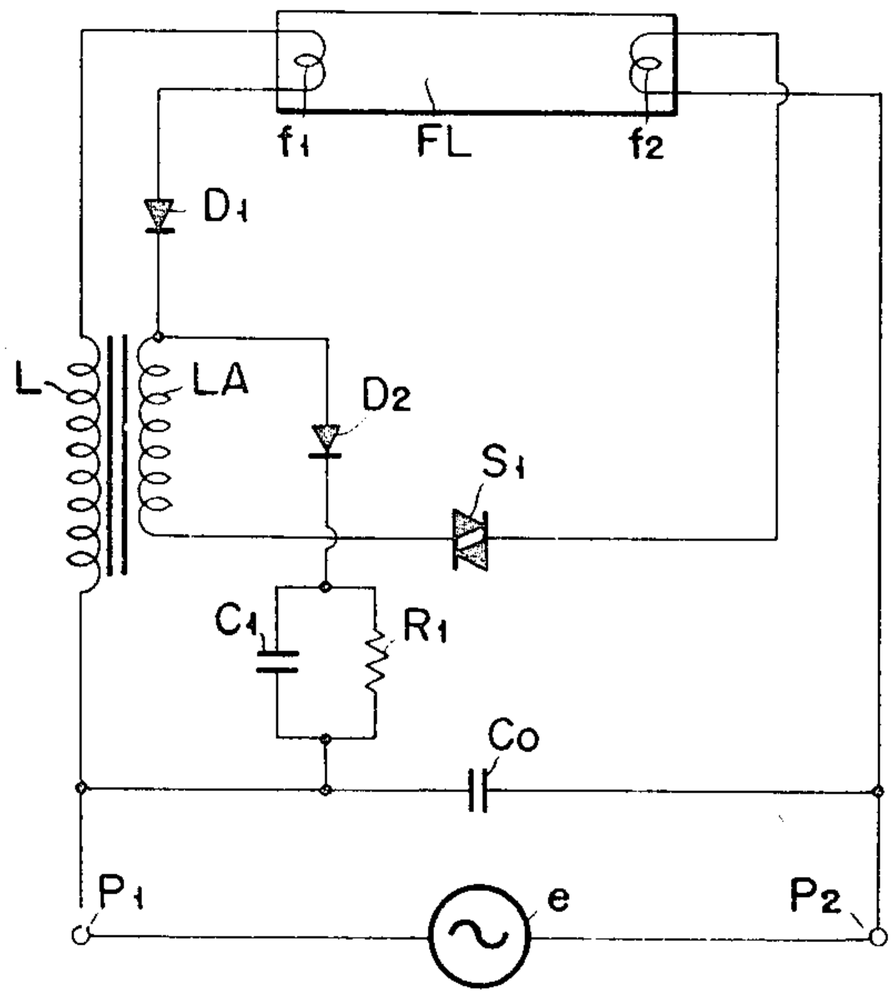


FIG. 30

FIG. 24

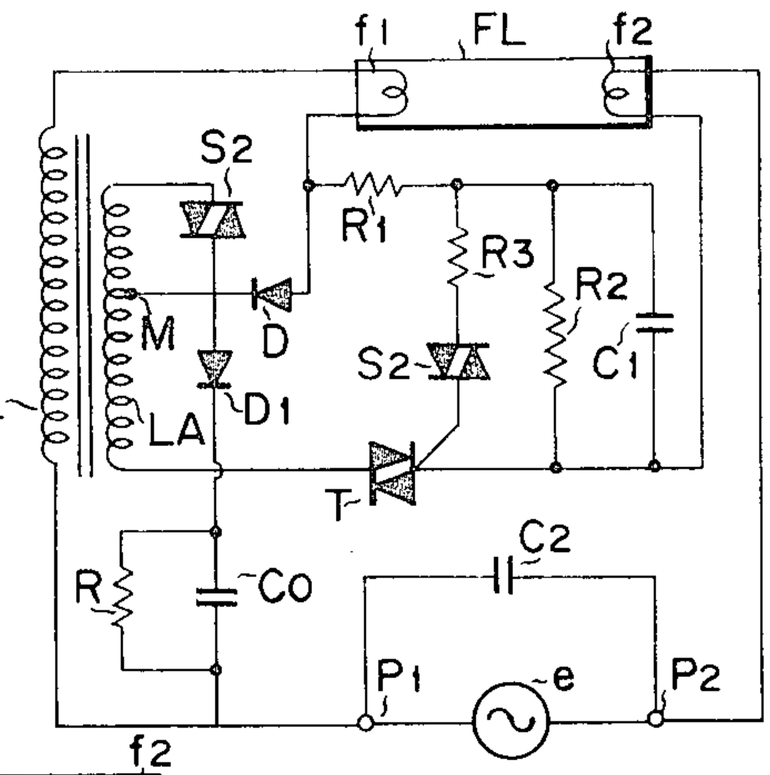


FIG. 27

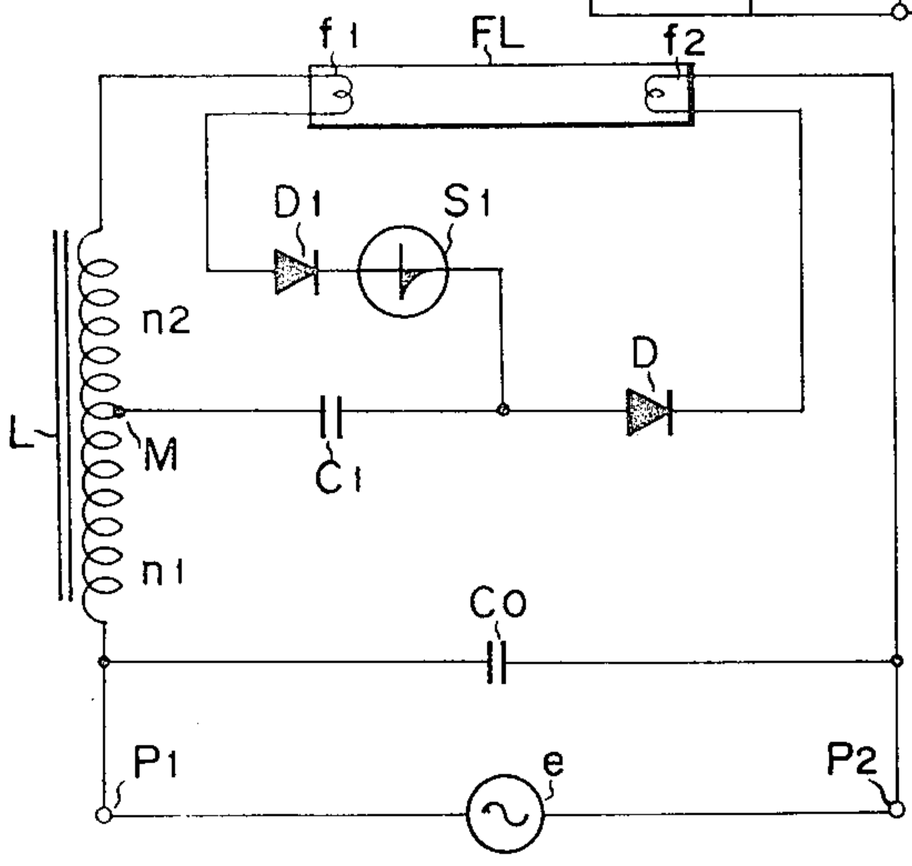


FIG. 31

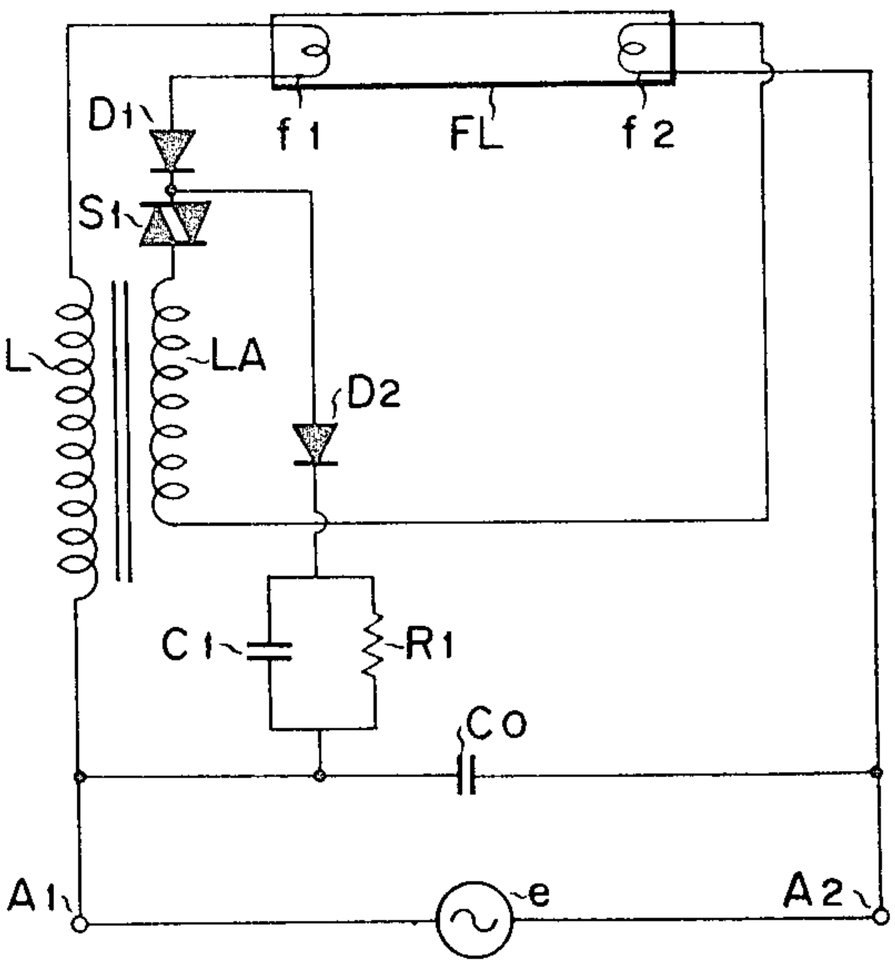


FIG. 26A

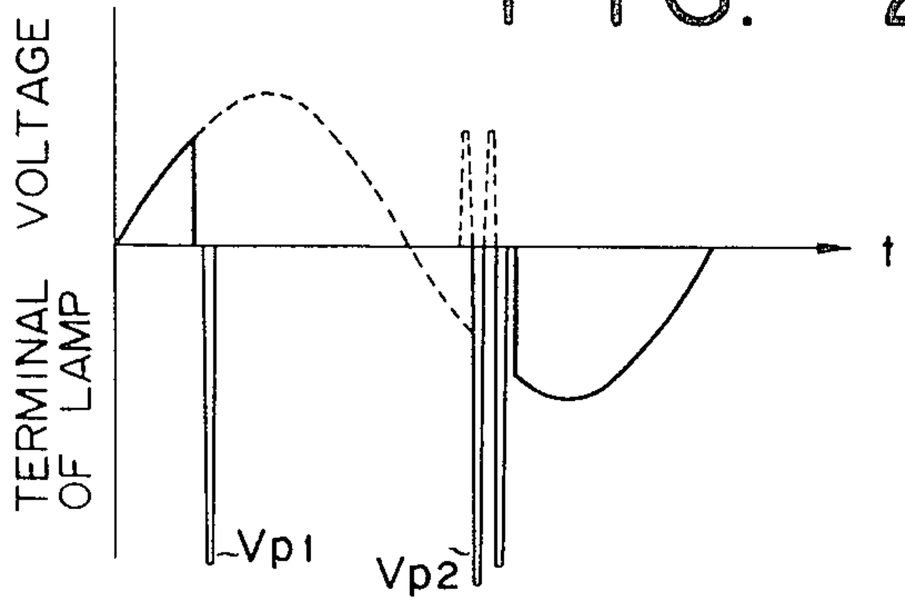


FIG. 26B

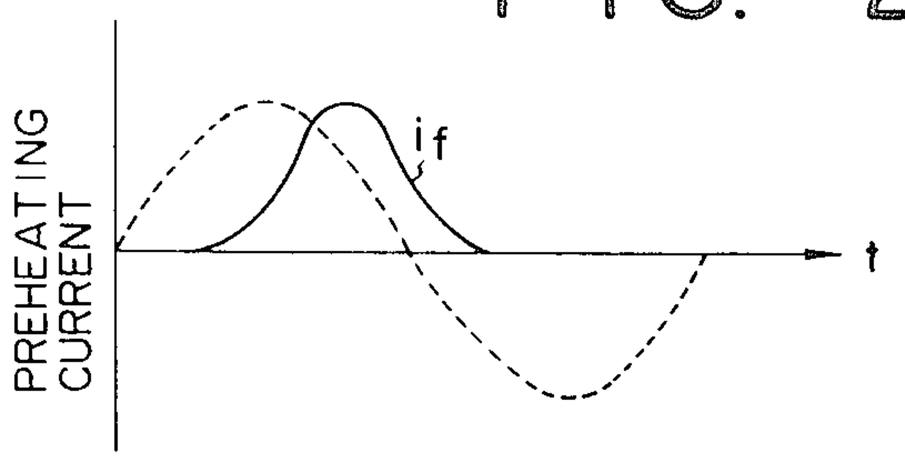


FIG. 28

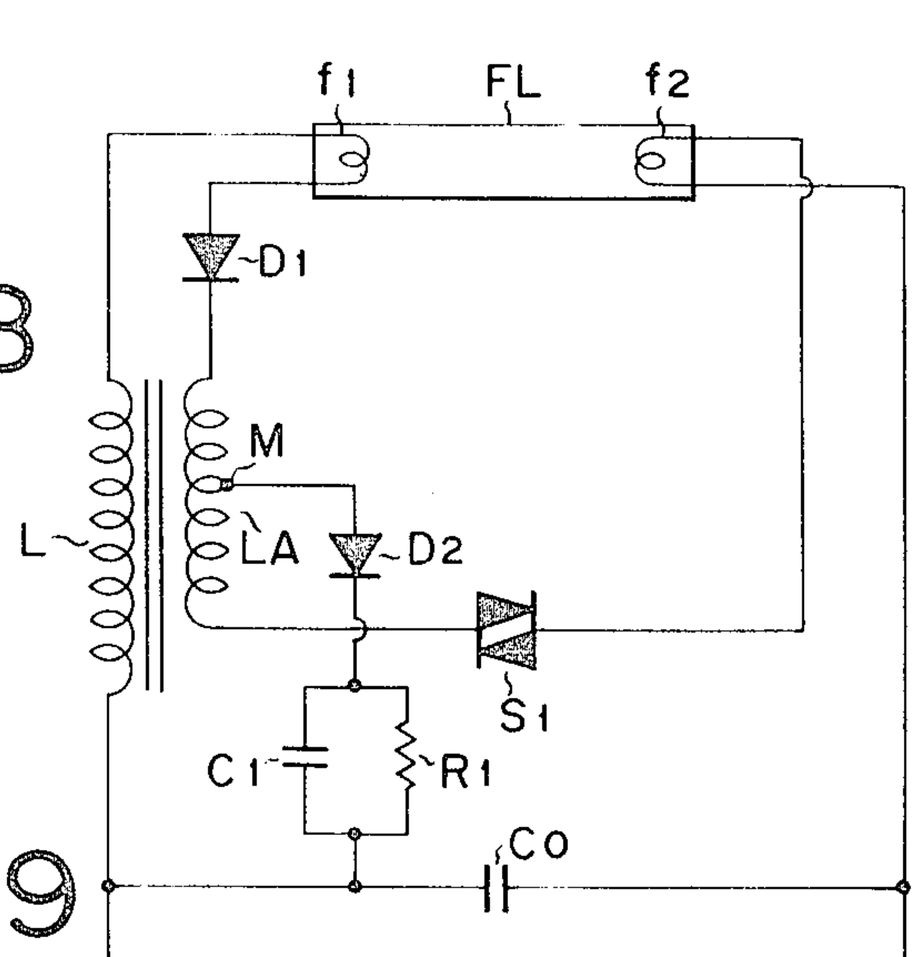
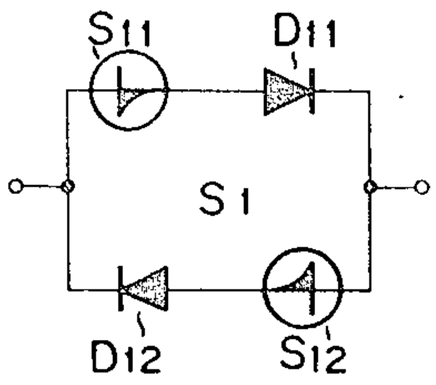


FIG. 29



APPARATUS FOR LIGHTING DISCHARGE LAMPS

This invention relates to apparatus for starting and operating electric gaseous discharge lamps, such as for example, fluorescent lamps and high pressure mercury vapor lamps and more particularly to apparatus including a semiconductor switching element.

Conventional apparatus used can be classified into the preheat start type utilizing a starter switch by glow discharge and the rapid start type utilizing leakage transformers.

The former is not advantageous in that it takes a long starting and operating time and that the operating life of the starter switch units lamp is relatively short whereas the latter is defective in that while its starting time is short and its construction is complicated. Especially, it requires a large transformer so that it is not suitable for commercial use.

To eliminate these defects starting and operating apparatus have been recently developed wherein semiconductor switching elements are substituted for starter switches. However, in order to generate a kick voltage to light the discharge lamp in the same manner as in the starter switches it is necessary to use a relatively complicated circuit.

It is therefore an object of this invention to provide a novel apparatus for lighting discharge lamps which can superpose a pulse voltage upon the source voltage with a relatively simple circuit construction thus enabling rapid and positive lighting of the discharge lamp.

According to this invention this object can be attained by employing a switching element in common for a preheating circuit and for a pulse generating circuit and by operating the switching element from a trigger pulse generating circuit.

This invention can be more fully understood from the following detailed description when taken with reference to the accompanying drawings, in which:

FIG. **1** is an electrical circuit diagram illustrating one embodiment of the apparatus for lighting a discharge lamp constructed according to this invention;

FIG. **2** shows an illustration of an oscillogram of the waveform provided by the apparatus shown in FIG. **1**;

FIG. **3** is a circuit diagram of a modified embodiment of this invention;

FIG. **4** shows an oscillogram of the waveform provided by the apparatus shown in FIG. **3**;

FIGS. **5** and **6** show circuit diagrams of other embodiments of this invention which operate in substantially the same manner as that shown in FIG. **3**;

FIG. **7** shows a connection diagram of still another modification of this invention;

FIGS. **8** to **14** show respectively circuit diagrams of further modifications of this invention which operate in substantially the same manner as that shown in FIG. **7**;

FIGS. **15A**, **15B**, **16A** and **16B** show respectively operating characteristics provided by the apparatus shown in FIGS. **7** to **14** in which, FIG. **15A** shows an oscillogram of the waveform of the thyristor voltage, FIG. **15B** is a plot showing waveform of the thyristor current, FIG. **16A** shows the rising of the thyristor current in the absence of a diode and FIG. **16B** shows the same rising characteristic in the presence of a diode;

FIG. **17** is a circuit diagram of the other embodiment according to the invention;

FIG. **18** is a circuit diagram to explain the operation of circuit as shown in FIG. **17**;

FIGS. **19** to **24** are respectively circuit diagrams of the other embodiments which are basically the same with one another;

FIG. **25** is a circuit diagram of the other embodiment according to the invention;

FIGS. **26A** and **26B** show oscillograms provided by the circuit as shown in FIG. **25** wherein FIG. **26A** shows a waveform of a terminal voltage of lamp and FIG. **26B** a waveform of a preheating current;

FIG. **27** shows a circuit diagram modifying the circuit as shown in FIG. **25**;

FIG. **28** shows a circuit diagram of the other embodiment according to the invention;

FIG. **29** shows a switching circuit diagram capable of being used in the circuit as shown in FIG. **28**; and

FIGS. **30** and **31** are respectively circuit diagrams modifying the circuit of FIG. **28**.

In a preferred embodiment shown in FIG. **1**, one terminal of a first filament electrode f_1 of a preheat start type discharge lamp FL is connected to one terminal P_1 of an AC source e through a choke coil L while one terminal of a second filament electrode f_2 of the lamp FL is directly connected to the other terminal P_2 of the source. Other terminals of the first and second filament electrodes f_1 and f_2 are respectively connected to first and second terminals A and B of a composite three-terminal switching circuit S_o and an impedance compensating coil LD differentially coupled with choke coil L is connected between the terminal A and the filament electrode f_1. Between terminal P_1 and a third terminal C of the switching circuit S_0 is connected a series circuit comprising a pulse generating coil LA cumulatively coupled with choke coil L and a capacitor C_o which is connected in parallel with a discharge resistor R.

The three-terminal switching circuit S_o comprises a series circuit connected across terminals A and B and including a diode D and a three-terminal bidirectional semiconductor switching element having a sufficiently higher breakover voltage than the source voltage and the operating voltage of the discharge lamp FL, for example a Triac (trade name) T. The juncture of the series circuit, that is the juncture between a second anode of the Triac T and the cathode electrode of the diode D is connected to terminal C. Across the gate electrode of the Triac T and the anode electrode of diode D is connected a series circuit including a current limiting resistor r and a two-terminal bidirectional semiconductor switching element having a breakover voltage which is lower than the source voltage but sufficiently higher than the lamp voltage, for example a Diac (trade name) S. If desired, the three-terminal switching circuit S_o may be formed as a composite or an integrated circuit.

In the circuit shown in FIG. **1**, the series circuit including compensating coil LD, diode D and Triac T constitutes a preheating circuit for the discharge lamp FL, and the circuit including pulse generating coil LA, capacitor C_o added in shunt to resistor R, and Triac T constitutes a pulse generating circuit. Further, the series circuit including resistor r and Diac S constitutes a trigger pulse generating circuit for the Triac T.

An AC voltage Ve from source e is applied across Triac T and Diac S via choke coil L, filament electrode f_1, compensating coil LD, diode D and filament electrode f_2 and via coil LA, capacitor C_o and filament electrode f_2. When the impressed voltage reaches a predetermined level the Diac S turns on to supply a gate current to the gate electrode of Triac T. This results in the decrease of the breakover voltage of Triac T which in turn renders on the Triac T to supply a heating current to filament electrodes f_1 and f_2 to sufficiently preheat these filaments. During preheating, current of only the positive half cycles flows since negative half cycles are blocked by diode D.

When Triac T turns on, charging current rapidly flows through capacitor C_o via coil LA thus inducing a pulse voltage V_p across choke coil L which is superposed upon the source voltage. This pulse voltage is generated each time the Triac turns on in each half cycle of the AC voltage. However, since the preheating current Ih flows in each positive half cycle in the circuit, the pulse voltage Vp is not induced across the choke coil L during positive half cycles but is induced only during negative half cycles.

FIG. **2** shows waveforms of the voltage Ve impressed across the discharge lamp FL and of the preheating current Ih.

Consequently, the filament electrodes f_1 and f_2 of the discharge lamp FL are sufficiently preheated and since the pulse voltage superposed upon the source voltage Vp is impressed across the lamp it is started or lighted very quickly and positively.

The purpose of the compensating coil LD is to assure a sufficiently high preheating current so that the coil may be eliminated where a sufficient preheating current can be provided.

In the following modified embodiments, the diode, three-terminal switching element, two-terminal switching element and capacitor are designated by the same reference characters D, T. S and C, respectively as in the previous embodiment and where more than two identical elements are employed they are identified by the same symbols followed by numerals **1** and **2**.

In the modified embodiment shown in FIG. **3**, between the other terminals of the first and second filament electrodes f_1 and f_2 of the discharge lamp FL is connected a preheating series circuit including a diode D, a bidirectional three-terminal thyristor T and a coil or winding LA magnetically coupled to a stabilizing coil L. The juncture between anode of thyristor T and the anode electrode of diode D is connected to input terminal P_1 via a capacitor C_0. Capacitor C_0, discharge resistor R connected in parallel therewith, thyristor T and coil LA constitute a pulse generating circuit. Across the gate electrode of the thyristor T and the cathode electrode of diode D is connected a series circuit comprising a resistor r and a bidirectional two-terminal thyristor S, which acts as a trigger circuit for thyristor T. Coils L and LA are wound in the same direction on the same magnetic core.

During positive half cycles of the source voltage current flows through the trigger circuit extending through terminal P_2, filament electrode f_2, coil LA, resistor r, trigger electrode of thyristor T, thyristor S, filament electrode f_1, coil L and terminal P_1, thus turning on the thyristor T. As a result, current i_f flows through terminal P_2, filament electrode f_2, coil LA, thyristor T, diode D, filament electrode f_1, coil L and terminal P_1, as indicated by a solid line arrow to preheat filaments.

Since current flows in opposite directions through coils L and LA, thus differentially coupling these coils to decrease the circuit impedance to the preheating current.

During negative half cycles, a gate current flows through the trigger circuit in the same manner as above described to turn on thyristor T, but the flow of the preheating current is blocked by diode D. However, as shown by a dotted line arrow, charging current i_p flows through terminal P_1, capacitor C_0, thyristor T, coil LA, filament electrode f_2 and terminal P_2 to charge capacitor C_0. Consequently, a high voltage pulse Vp determined by the turn ratio between coils LA and L is induced in coil L and this pulse is applied across the discharge lamp FL. In this case, since the current flowing through the coil L has the same direction as that flowing through the coil LA and since coils LA and L are cumulatively coupled, the induced high voltage pulse Vp is superposed upon the source voltage Ve in the same sense as shown in FIG. **4** and the sum of these voltages is impressed across discharge lamp FL.

In this manner, since filaments f_1 and f_2 of discharge lamp FL are preheated during positive half cycles and are impressed with high voltage pulses during negative half cycles, the lamp can start rapidly and positively. Upon lighting of the lamp, the voltage across it or the voltage impressed across the trigger circuit decreases to about two-thirds of the source voltage, so that thereafter the gate current does not flow and hence thyristor T is not made conductive and the lamp operates stably.

FIGS. **5** and **6** show other modifications of this invention which are basically identical to the embodiment shown in FIG. **3** except source differences in the elements comprising the trigger circuit and the preheating circuit. In In FIG. **5** the trigger circuit and the preheating circuit are constructed as follows. More particularly, the cathode of a three-terminal thyristor, for example, a Triac T_1 is connected to coil LA In the anode thereof is connected to the cathode electrode of another three-terminal unidirectional thyristor, for example, a silicon controlled rectifier T_2. A series circuit comprising a resistor r_1 and a bidirectional two-terminal thyristor S is connected between the gate of the Triac T_1 and the anode of the silicon controlled rectifier T_2. The juncture between resistor r_1 and the thyristor S is connected to the gate of the silicon controlled rectifier T_2 through a resistor r_2 and diode D connected in series. The anode of silicon controlled rectifier T_2 is connected to filament electrode f_1.

This embodiment operates in the same manner as the previous embodiment. In addition, after starting the discharge lamp FL the parallel circuit of capacitor C_0 and resistor R is completely isolated from the source to make more stable the operation of lamp FL.

The trigger circuit and the preheating circuit of the embodiment shown in FIG. **6** are constructed as follows. Thus, there are provided a three-terminal semiconductor switching element T with its cathode connected to coil LA, and a series combination of a resistor r, a bidirectional two-terminal semiconductor switching element S and a diode D which are connected across the gate and the anode of the switching element T. The anode electrode of this switching element is connected to the filament electrode f_1.

With this simplified arrangement the preheating current i_f and the pulse current i_p flow in the same manner as in the previous embodiments.

FIGS. **7** to **17** illustrate further embodiments of this invention.

In the embodiment shown in FIG. **7**, across first and second filament electrodes f_1 and f_2 of a discharge lamp FL is connected a series circuit including a starting thyristor circuit and an auxiliary coil LA magnetically coupled to a stabilizing coil L, thus forming the filament preheating circuit. The starting thyristor circuit comprises a diode D_1 and bidirectional three-terminal thyristor T which are connected in series such that the cathode of the diode is connected to the anode of the thyristor. The starting thyristor circuit and auxiliary coil LA are connected such that one terminal of the coil is connected to the cathode of the thyristor. Across the gate of thyristor T and the anode of the diode D_1 is connected an ignition or trigger circuit including a bidirectional two-terminal thyristor S and resistor r connected in series. A capacitor C_1 is connected across both terminals of the ignition thyristor S via the gate and cathode electrodes of the thyristor T. Thyristor S is selected to have a breakover voltage which is lower than the source voltage but higher than the lamp voltage. Between terminal P_1 and the cathode of diode D_1 is connected a second diode D_2 and capacitor C_0 which are connected in series and capacitor C_0 is shunted by a discharge resistor R. These elements D_2, C_0, R, thyristor T and a coil LA, having the other end connected to the filament electrode f_2, constitute the pulse generating circuit. As shown, diodes D_1 and D_2 are connected to have the same polarity.

In operation, during the positive and negative half cycles of the source voltage ignition capacitor C_1 is charged through resistor r. As capacitor C_1 is charged to increase its terminal voltage, the terminal voltage is impressed across the ignition thyristor S via the gate of thyristor T to ignite thyristor S. Then capacitor C_1 is discharged through the gate of thyristor T thus rapidly turning on the same. Consequently, the current flowing through the thyristor T rapidly builds up as shown in FIG. **16B**. FIG. **16A** shows the same characteristic in the absence of capacitor C_1. In this case, current builds up gradually since the gate current is supplied to thyristor T through resistor r.

During a positive half cycle in which the diode D_1 is forwardly biased, due to the rapid conduction of thyristor T the filament preheating current i_f flows from AC source e through terminal P_1, stabilizing coil L, filament F_1, diode D_1, thyristor T, auxiliary coil LA, filament f_2 and terminal P_2.

Where the pulse generating circuit does not include diode D_2 and where the capacitance of capacitor C_0 is increased to produce a large pulse, in addition to the aforementioned preheating current a large rush current will flow through terminal P_1, capacitor C_0, thyristor T, auxiliary coil LA, filament f_2 and terminal P_2. Due to the magnetic coupling between auxiliary coil LA and stabilizing coil L this rush current induces a pulse voltage across terminals of stabilizing coil L. Although capacitor C_0 has a characteristic to draw leading current, the current caused by this pulse voltage to flow through the auxiliary coil and filament f_2 is a lagging current so that current flows to capacitor C_0 via diode D_1. This phenomenon is repeated in each preheating half cycle, causing insufficient preheating of filament f_2 thus causing difficulty to start the lamp. FIGS. **15A**

and 15B show the voltage applied across the thyristor T and its current, respectively, under these circumstances. However, in this embodiment, since there is provided a second diode D_2, the preheating current i_f flows equally through both filaments f_1 and f_2 thus preheating them sufficiently.

During negative half cycles due to the rapid conduction of thyristor T as above described a rush current i_r flows from AC source e, through terminal P_2, filament f_2, auxiliary coil LA, thyristor T, diode D_2, capacitor C_O and terminal P_1 to induce a high voltage pulse in stabilizing coil L. This pulse is superposed upon the source voltage and the sum of these voltages is applied across discharge lamp FL to start the same. Rapid conduction of thyristor T results in the rapid flow of the rush current so that a sufficiently large current is induced in the stabilizing coil to assure positive starting of lamp FL.

After lighting of the lamp, since the lamp voltage is impressed across the thyristor ignition circuit, ignition thyristor S will not be ignited. As a result the discharge lamp continues its stable operation. This embodiment was tested under the following test conditions and the following results were obtained.

TEST CONDITIONS

Lamp used: FL–15/NL

Stabilizer used: FL–15 with an auxiliary coil (L:LA = 1150T:350T)

Thyristor T: SM2D41 (Toshiba)

Diodes $D_1$and D_2: 1N3195 (Toshiba)

Resistor r: 5.5 KΩ

Thyristor S: 1S1719 (Toshiba)

Capacitor C_1: 0.2 μf.

Capacitor C_2: 0.4 μf.

Resistor R: 1KΩ

RESULTS OF TEST

1. The generated pulse had a value of 370 volts and a width of 1 millisecond.

2. Starting time was as shown in the following table.

TABLE I

	Starting time (second)		
Source voltage	90V	100V	110V
Lamp number:			
1	0.7	0.5	0.4
2	0.6	0.4	0.4
3	0.6	0.4	0.3
4	0.7	0.5	0.4
5	1.0	0.6	0.5
6	0.5	0.5	0.3
7	0.6	0.4	0.4
8	0.7	0.7	0.6
9	0.8	0.5	0.5
10	0.8	0.6	0.9

In another embodiment shown in FIG. **8** the diode D_2 in FIG. **7** is replaced by a closed circuit including a three-terminal thyristor T_1, a bidirectional two-terminal thyristor S_1 and a resistor r_1 and this embodiment operates generally in the same manner as that shown in FIG. **7**. More particularly, the anode of silicon controlled rectifier T_1 is connected to the cathode of diode D_1 while the cathode of the silicon controlled rectifier is connected to capacitor C_O. Across the anode and the gate of the silicon controlled rectifier T_1 are serially connected two-terminal thyristor S_1 and resistor r_1.

In the embodiment shown in FIG. **9**, the diode D_2 shown in FIG. **7** is replaced by a unidirectional two-terminal thyristor S_2 having a switching characteristic to act as a diode.

In the embodiment shown in FIG. **10** a bidirectional two-terminal thyristor S_1 is added in series with the diode D_2 in the circuit as shown in FIG. **7** to improve its breakdown characteristic.

Embodiments shown in FIGS. **11** to **14** substantially correspond to those of FIGS. **7**, **8**, **9** and **10** respectively. In each case an auxiliary coil LA is included between diode D_1 and thyristor T comprising the starting thyristor circuit in order to prevent the voltage induced in auxiliary coil LA at the time of starting the discharge lamp FL from being applied across ignition thyristor S so as to increase the recycling voltage of the circuit.

Thus this invention provides a novel apparatus for lighting a discharge lamp wherein during one half cycle of one polarity of an AC source voltage, the filament of the lamp is preheated while in the other half cycle of the opposite polarity a superposed sum of a high voltage pulse and the source voltage is applied across the lamp. Moreover a diode is connected in series with a capacitor of a pulse generating circuit so that it is possible to prevent current from flowing through the capacitor during the preheating cycle whereby respective filaments of the lamp are uniformly heated to start rapidly and positively the discharge lamp.

In an embodiment shown in FIG. **17**, one terminal P_1 of an AC source e is connected to one terminal of a first filament electrode f_1 of a discharge lamp FL through a coil member L of N_1 turns and the other terminal P_2 to one terminal of a second filament electrode f_2. Between respective other terminals of first and second electrodes f_1, f_2 there is provided a preheating circuit comprising a diode D, an auxiliary winding LA which is separated by an intermediate tap M into two portions LA_1 and LA_2 whose turns bear a number of n_2 and n_3 respectively, and a bidirectional three-terminal thyristor T. The anode of diode D is directly connected to the other terminal of electrode f_1 and the cathode thereof to one end of coil LA, the other end of which is connected to the anode of thyristor T.

Across the other terminals of both electrodes f_1, f_2 is provided a series dividing voltage circuit including first and second resistors R_1, R_2 which have a fully larger impedance than that of a lamp FL, a capacitor C_1 connected in parallel to second resistor R_2, and a branch circuit having a third resistor R_3 and a bidirectional two-terminal thyristor S_1.

The branch circuit is connected across the gate of said switching semiconductor element T and the juncture between two resistors R_1 and R_2. Thyristor S_1 is of a sufficiently higher breakdown voltage than the operating voltage of discharge lamp FL but a fully lower than the source voltage. Thus, a gate trigger circuit is constituted by the aforementioned elements R_1, R_2, R_3, S_1 and C_1.

A pulse generating circuit includes, in addition to thyristor T, a series circuit connected between intermediate tap M and first terminal P_1, which comprises a bidirectional two-terminal thyristor S_2, capacitor C_O, and a resistor R connected in parallel to capacitor C_O.

In the above device, during each half cycle of the source voltage, thyristor S_1 becomes a conductive state when the terminal voltage of resistor R_2 is increased to over the breakover voltage of thyristor S_2 to turn it on, thereby discharging capacitor C_1 via the gate and cathode of thyristor S_1. In the case of the half cycle generated by respectively applying positive and negative voltages to the first and second terminals P_1, P_2 when thyristor S_1 turns on, a filament preheating current i_f flows to terminal P_2 from terminal P_1 through winding L, filament f_1, diode D, coil LA, switching element T and filament f_2, so that filament electrodes f_1, f_2 are preheated. In the same time as flowing of current i_f, there flows the charging current i_c of capacitor C_O through a circuit arranged as terminal P_1 → condenser C_O → thyristor S_2 → part LA_2 of coil → thyristor T→ filament f_2 → terminal P_2, so that capacitor C_2 is charged till the magnitude of a voltage thereacross rises to that of the source voltage Ve in the polarity as shown in FIG. **17**. Next time, when the polarity of source voltage is reversed i.e., terminal P_1 is negative and terminal P_2 positive, source voltage Ve and said voltage across condenser C_O are superposed to each other to be impressed to the pulse generating circuit. Accordingly, since there flows through the part LA_2 of n_3 turns in said circuit a fully large current or rush current which is twice as large as that which occurs in the case where condenser C_0 does not charge, in coil L magnetically coupled with winding part LA_2 generates a pulse voltage of $2 \times Ve \times n_1/n_3$ large.

The pulse is superposed upon the source voltage Ve and resultant high voltage is impressed to discharge lamp FL, so that lamp FL is lighted surely and rapidly. In the above circuit, if discharge lamp FL is not ignited, said operation is repeated over several cycles, thereby thereafter allowing surely said

lighting. When discharge lamp FL is lighted as above described, the lamp keeps its safety lighting state since the lamp voltage is decreased to about half as high as the source voltage, so that thyristor for ignition maintains its turnoff state. Further, as capacitor C_0 is connected in series to bidirectional two-terminal thyristor S_2, there is no possibility that current flows into capacitor C_0 via lamp FL, diode D and winding LA during lighting the lamp.

In the above embodiment, although the pulse generating circuit is arranged to include a part of auxiliary winding LA, it may be designed to use the whole of auxiliary winding LA. Further as the thyristor for generating pulses, there may be used a bidirectional three-terminal thyristor.

There will now be respectively described modifications of the circuit as shown in FIG. **17**, with reference to FIGS. **19** to **24**.

Referring to FIG. **19** bidirectional two-terminal thyristor S_2 shown in FIG. **17** in the pulse generating circuit is replaced by a diode D_1 of which anode is connected to tap M and cathode to first terminal P_1 of source e through capacitor C_0. Since the other circuits i.e., preheating circuit and trigger generating circuit in the device shown in FIG. **19** are the same construction as the corresponding circuit shown in FIG. **17**, description thereof is omitted.

This modification was tested under the following test conditions and the following results were obtained.

TEST CONDITIONS

Lamp used FL:	FL-15NL (Toshiba)
Stabilizer used:	
	winding L is of n_1=850 turns
	winding LA: LA_1 is of n_2=130 turns; LA_2 is of n_3=120 turns
Resistor R:	5KΩ
Resistor R_1:	18KΩ
Resistor R_2:	12KΩ
Resistor R_3:	100Ω
Condenser C_0:	0.1 μf.
Condenser C_1:	0.22 μf.
Condenser C_2:	0.2 μf.
Thyristor T:	SM2D41 (Toshiba)
Diode D:	1S1892 (Toshiba)
Diode D_1:	1S1942 (Toshiba)
Thyristor S_1:	1S1719 (Toshiba)

RESULTS OF TEST

1. Generated pulse voltage across discharge lamp FL

TABLE 2

Source voltage	90V	100V	110V
Pulse voltage	900V	1000V	1100V

2. Starting time (atmosphere temperature of 0° C.)

TABLE 3

	Starting time (second)		
Source voltage	90V	100V	110V
Lamp number:			
1	0.9	0.5	0.4
2	1.0	0.6	0.5
3	0.8	0.4	0.4
4	1.2	0.6	0.3
5	1.0	0.5	0.4
6	0.8	0.3	0.3
7	0.7	0.3	0.2
8	1.0	0.5	0.3
9	0.9	0.6	0.4
10	1.4	0.7	0.5

FIG. **20** shows the other modification of the circuit shown in FIG. **17**, in which there is provided a unidirectional two-terminal thyristor S_3, instead of diode D_1 described in the above embodiment.

Further modified circuit is shown in FIG. **21** in which a bidirectional two-terminal thyristor S_2 is added between tap M and the cathode of diode D_1 described in FIG. **17** so as to cause diode D_1 to increase its breakdown voltage.

The modification shown in FIG. **22** has substantially the same arrangement as the preceding one shown in FIG. **19**, except that the cathode of the first diode D is connected to tap M of coil LA and the anode of the second diode D_1 to one end of coil LA.

A circuit modifying one of FIG. **22** is shown in FIG. **23** where a unidirectional two-terminal thyristor S_3 is used in a pulse generating circuit instead of second diode D_1 described in the above circuit.

In a circuit as shown in FIG. **24**, a bidirectional two-terminal thyristor S_2 is additionally utilized in the pulse generating circuit shown in FIG. **22** with the both ends thereof respectively connected to auxiliary coil LA and the anode of the diode D_1.

There will now be described further embodiment according to the invention with reference to FIGS. **25** and **26**.

The first terminal P_1 of a source e is connected to the one end of a first filament f_1 of a discharge lamp FL through a stabilizer-winding L with an intermediate tap M and the second terminal P_2 of source e to the one end of a second filament of lamp FL. Across the other terminals of filaments f_1 and f_2 is connected a series circuit constituting a preheating circuit which includes a bidirectional two-terminal thyristor S and diode D. The cathode of diode D is directly connected to said the other terminal of filament f_2 and the anode to said the other terminal of filament f_1 through thyristor S. Thyristor S also constitutes a pulse generating circuit in combination with coil L. A trigger circuit for impressing a trigger signal to thyristor S is constructed by a capacitor C_1 connected across the juncture between thyristor S and diode D and tap M dividing coil L into two parts whose turn numbers are respectively n_2 and n_3. Across the terminals of source e there is also connected a capacitor C_0 of pulse bypass.

In the circuit constructed as above described, during one half cycle which occurs when first terminal f_1 is positive and second terminal f_2 negative there flows charging current of condenser C_1 through the circuit arranged as terminal f_1 → the part of n_3 in winding L → intermediate tap M → capacitor C_1 → diode D → filament f_2 → terminal P_2. Thereafter, when the voltage on capacitor C_1 becomes larger than the breakover voltage of thyristor S, the capacitor voltage applies to thyristor S, so that thyristor S turns on. Thus, capacitor C_1 is discharged thereby flowing the current through the circuit arranged as capacitor C_1 → intermediate tap M → the part of n_2 in winding L → filament f_1 → thyristor S → capacitor C_1, thereby flowing pulsatively a discharge current through the part of n_2 in coil L. As a result, there is induced in the part of n_3 in winding L a high voltage pulse Vp_1 having a reverse polarity to that of the source voltage so as to be impressed across discharge lamp FL. At the same time as the turn on of thyristor S, a preheating current i_f flows from terminal P_1 via the whole of winding L, filament f_1, thyristor S, diode D, filament f_2, and to terminal P_2 . Further, when the preheating current is decreased to be less than the self-maintaining current of thyristor S in magnitude, thyristor S comes to be in the turn on state so as to allow a high voltage to generate in the part of n_1 in winding L as a result of the self-maintaining thereof. The resultant high voltage does not actually appear across lamp FL, which is shown in FIG. **26** by a dotted line, since it is absorbed by capacitor C_1, but it charges capacitor C_1 , in such a manner that the voltage across capacitor C_1 becomes higher than the breakover voltage V_{BO} of thyristor S. In this result, thyristor S is again turned on so as to generate a high voltage in the part of n_1 in coil L to impress it across lamp FL as in the previous case. The operation of charging capacitor C, turning on thyristor S, and generating pulses in coil L is repeated in several cycles. Thus lamp FL may be surely lighted during the above operation cycles.

After the lighting of lamp FL, the lamp current flows through the circuit arranged as terminal P_1 ⇆ the whole of winding L ⇆ filament f_1 ⇆ lamp FL ⇆ filament f_2 ⇆ terminal P_2 and there is charged capacitor C_1 only by the lamp voltage. Accordingly, thyristor is not conducted, so that lamp FL keeps its safety lighting condition.

This embodiment was tested under the following test conditions and the following results were obtained.

TEST CONDITIONS

AC source *e*:	50Hz., 100v.
Stabilizer:	n_2=30 turns
	n_3=845 turns
Thyristor S:	K2F (Shindengen)
Diode D:	1S1892 (Toshiba)
Capacitor C_0:	0.22 μf.
Capacitor C_1:	0.22 μf.
Discharge lamp FL:	FL-15N/L (Toshiba)

RESULTS OF TEST

Generated pulse: 900 – 1000 v.

Starting time: about 0.5 second on average

(source voltage: 90 – 110 v.)

In the embodiment above detailed although bidirectional two-terminal thyristor is used as the common switching element in the preheating and pulse generating circuits, there may be also used a reverse-preventing type two-terminal thyristor or three-terminal thyristor. In the latter case, it is requested to further add a gate circuit responding to the voltage across the discharge lamp. In the case of using the unidirectional two-terminal thyristor S_1 , as shown in FIG. **27**, there may be utilized a diode D_1 which is connected between filament f_1 and thyristor S_1 to become the same polarity as another diode D so as to cause diode D_1 to increase its breakdown voltage.

The circuits as shown in FIGS. **25** and **27**, not only cause the discharge lamp to light surely and rapidly, but allow their constructions to simplify.

There will now be described the other embodiments according to the invention with reference to FIGS. **28** to **31**.

Referring to FIG. **28**, the circuit includes an AC source *e* to both ends of which there are respectively provided first and second terminals P_1, P_2. Both terminals are respectively connected to first terminals of respective first and second filament electrodes of a discharge lamp FL so as to allow a primary coil L of a stabilizer to be connected across first terminal P_1 and the first terminal of filament f_1. Across the second terminals of filaments f_1 and f_2 there is provided a preheating series circuit arranged such that the cathode of a diode D_1 of which anode is directly connected to the second terminal of filament f_2 is connected to one end of a bidirectional two-terminal thyristor S_1 via a secondary coil LA of said stabilizer, the other end of thyristor S_1 being connected to the second terminal of filament f_2. A pulse generating circuit is constituted by a series circuit comprising a resistor R_1 and diode D_2 of which cathode is connected to terminal P_1 via resistor R_1 and anode is connected to an intermediate tap M of second coil LA, a part in coil LA defined by tap M and its one end connected to thyristor S_1, a capacitor C_1 connected parallel to resistor R_1, and thyristor S_1.

Across source *e* is further connected a capacitor C_0. As the thyristor S_1, for example, there may be utilized a silicon symmetric switching element (SSS) or Diac (trade name) and thyristor S_1 is selected in such a manner that its breakdown voltage is lower than the source voltage but fully higher than the lamp voltage. The values of capacitor C_1 and resistor R_1 are selected to prevent thyristor S_1 from its reoperation in the time of lighting lamp FL.

In the above circuit, during one half circle when the voltage is impressed across first and second terminals P_1 , P_2 in a manner to allow terminals P_1 and P_2 to be positive and negative respectively, there flows a filament preheating current through a closed circuit arranged as terminal P_1 → primary coil L → filament f_1 → diode D_1 → the whole of secondary coil LA → thyristor S_1 → filament f_2 → terminal P_2. On the other hand, during the other half cycle impressed with the voltage having the reverse polarity with the former case, there flows pulsely a charging current of capacitor C_1 through a circuit arranged as terminal P_2 → filament f_2 → thyristor S_1 → the part of secondary coil LA → tap M → diode D_2 → the parallel circuit constituted by resistor R_1 and capacitor C_1 → terminal P_1. Accordingly, a high voltage pulse is generated in primary coil L magnetically connected to secondary coil LA and impressed to discharge lamp FL to ignite and light it. In the case of being lighted, during former half one cycle the voltage across thyristor S_1 is decided by lamp voltage alone, so that lamp may keep its safety lighting conditions without occurring the reoperation of thyristor S_1. On the other hand, during the latter half cycle at the initiative of the cycle of the charging current flows to terminal P_2 → filament f_1 → filament f_2 → diode D_1 → the part of secondary coil LA → diode D_2 → the parallel circuit defined by capacitor C_1 and resistor R_1 → terminal P_1. Accordingly, in this initial state the parallel circuit of capacitor C_1 and resistor R_1 may be thought as the short-circuit, so that thyristor is impressed with the source voltage thereby rising a problem that thyristor S_1 is reoperated. However, the problem occurred may be resolved by selecting the values of capacitor C_1 and resistor R_1 in such a manner that the parallel circuit consisting of these two elements C_1, R_1 recovers its initial impedance before the voltage impressed to thyristor S_1 reaches its breakover voltage V_B, and thus thyristor is not reoperated to maintain the stable lighting condition of lamp. Further, if the values of capacitor C_1 and resistor R_1 are selected in such a manner that capacitor C_1 is fully charged due to the turn on of thyristor S_1 and thus during the turn on thereof pulse current does not substantially flow in the thyristor, the lighting condition of lamp FL also may be kept stable.

This embodiment was tested under the following test conditions and the following results were obtained.

In this test, as bidirectional two-terminal thyristor S_1 described above, a closed circuit as shown in FIG. **29** was used, which is constituted by connecting in reverse-parallel two series circuits respectively consisting of a diode D_{11} and a unidirectional two-terminal thyristor S_{11} which are connected in the same polarity, and a diode D_{12} and a thyristor S_{12} which are connected in the same direction. In this case, if thyristors S_{11}, S_{12} have a fully large breakdown voltage, diodes D_{11}, D_{12} need not be utilized.

TEST CONDITIONS

Stabilizer:	primary coil = 856 turns
	secondary coil = 125 + 125 turns
Diode D_1:	1S1892 (Toshiba)
Diode D_2:	1S1942 (Toshiba)
Thyristors	breakover voltage = 110–120v.
S_{11} and S_{12}:	holding current = less than 200ma.
	rated current = 0.8ma.
Capacitor C_1:	0.1 μf.
Resistor R_1:	5KΩ(2 w.)
Capacitor C_0:	0.22 μf.
Discharge lamp:	FL-15S/NL (Toshiba)

RESULTS OF TEST

1. The generated pulse had a value of 800 – 1,100 v.
2. Starting time was as shown in the following table.

TABLE 4

	Starting time (second)		
Source voltage	90V	100V	110V
Lamp number:			
1	0.8	0.5	0.3
2	0.8	0.6	0.3
3	1.0	0.4	0.4
4	1.0	0.5	0.5
5	0.7	0.6	0.4

There were also conducted tests with the values of capacitor C_1 and resistor R_1 varied. Then it was disclosed that in case of $C_1>5$ μF and $R_1<400\Omega$, when the lamp was lighted, S_1 was prevented from being reoperated.

A circuit shown in FIG. **30** is basically of the same arrangement as the circuit shown in FIG. **28** except for the connecting relation between secondary coil LA and diode D_2. That is, in this circuit, one intermediate tap is not used and diode D_2 is connected to the one end of coil LA where the other diode D_1 is connected so as to use the whole of coil LA in the pulse generating circuit.

Further, a circuit shown in FIG. **31** is of substantially the same construction as that shown in FIG. **30** except that thyristor S_1 is not connected between filament f_2 and coil LA, and arranged in such a manner that to the juncture across thyristor S_1 and diode D_1 is connected the terminal of the anode of diode D_2.

What we claim is:

1. Apparatus for lighting a discharge lamp having first and second filaments comprising:

first coil means connected between one terminal of said first filament and one terminal of an AC source;

means for interconnecting one terminal of said second filament and the other terminal of said AC source;

a preheating circuit including at least one switching semiconductor element connected across the other terminals of said first and second filaments which passes a heating current from said AC source through said first and second filaments when said at least one switching element is conducting; and

a pulse generating circuit generating a pulse voltage which is superposed upon the voltage of said AC source when said at least one switching element turns on said pulse generating circuit including:

said at least one switching element in common with said preheating circuit;

a capacitor coupled between said one terminal of said AC source and one terminal of said at least one switching element; and

a second coil inductively cooperating with said first coil means and connected in series with said capacitor, said series combination being coupled to said at least one switching element and being further coupled to said other terminal of said second filament.

2. Apparatus according to claim **1** further including a trigger generating circuit for supplying a trigger signal to said at least one switching semiconductor element to turn it on, said trigger generating circuit being coupled between the other terminals of said first and second filaments.

3. Apparatus according to claim **2**, wherein:

said at least one switching element includes a three-terminal bidirectional switching element;

said pulse generating circuit comprises a capacitor and a first resistor connected in parallel with said capacitor, one terminal of said second coil being connected to said one terminal of said AC source and the other terminal of said second coil being connected to the second anode electrode of said three-terminal switching element through said capacitor;

said preheating circuit comprises a diode and said three-terminal switching element connected in series with said diode, the anode of said diode being connected to the other terminal of said first filament, the cathode of said diode being connected to the first anode electrode of said three-terminal switching element, and the second anode electrode of said three-terminal switching element being connected to the other terminal of said second filament; and

said trigger circuit comprises a series circuit including a second resistor and a two-terminal bidirectional switching element, one terminal of said trigger circuit being connected to the gate electrode of said three-terminal switching element and the other terminal of said two-terminal switching element being connected to the anode electrode of said diode through said second resistor.

4. Apparatus according to claim **2** wherein said preheating circuit further comprises a third coil connected between said other terminal of said first filament and the anode of said diode, said third coil being differentially inductively coupled to said first coil means.

5. Apparatus according to claim **1**, wherein said at least one switching element includes a three-terminal bidirectional switching element coupled in series with said capacitor and second coil, and said pulse generating circuit further comprises a first resistor connected in parallel with said capacitor, the second anode electrode of said three-terminal switching element being connected to one terminal of said second coil, the other terminal of said second coil being connected to said other terminal of said second filament, and the first anode of said three-terminal switching element being connected to said one terminal of said source through said capacitor.

6. Apparatus according to claim **5** wherein said preheating circuit comprises a series circuit including said second coil, said three-terminal bidirectional switching element and a diode, the anode of said diode being connected to the first anode of said three-terminal switching element, the second anode of said three-terminal switching element being connected to said other terminal of said second filament through said second coil, the cathode of said diode being connected to said other terminal of said first filament and wherein the trigger circuit comprises a series circuit including a second resistor and a two-terminal bidirectional switching element, one terminal of said two-terminal switching element being connected to the gate of said three-terminal switching element through said second resistor and the other terminal of said two-terminal switching element being connected to the cathode electrode of said diode.

7. Apparatus according to claim **5** wherein said preheating circuit comprises a series circuit including said second coil, said three-terminal bidirectional switching element and a three-terminal unidirectional switching element, the second anode of said three-terminal bidirectional switching element being connected to said other terminal of said second filament through said second coil, the first anode of said three-terminal bidirectional switching element being connected to the cathode of said three-terminal unidirectional switching element, and the anode of said three-terminal unidirectional switching element being connected to said other terminal of said first filament and wherein said trigger circuit comprises a second resistor and a two-terminal bidirectional switching element coupled in series, a diode and a third resistor coupled in series, one terminal of said two-terminal bidirectional switching element being connected to the gate of said three-terminal switching element through said second resistor, the other terminal of said two-terminal switching element being connected to the anode of said three-terminal unidirectional switching element, the anode of said diode being connected on one terminal of said two-terminal switching element through said third resistor, and the cathode of said diode being connected to the gate electrode of said three-terminal unidirectional switching element.

8. Apparatus according to claim **2** wherein:

said at least one switching element includes a three-terminal unidirectional switching element with its cathode connected to one terminal of said second coil and its anode connected to the other terminal of said first filament, said one terminal of said second coil being further connected to said one terminal of said AC source through said capacitor, the other terminal of said second coil being connected to the other terminal of said second filament;

said pulse generating circuit comprises a first resistor connected in parallel with said capacitor;

said preheating circuit comprises a series circuit including said second coil and said three-terminal unidirectional switching element, the anode of said three-terminal unidirectional switching element being connected to the

other terminal of said first filament, the cathode of said three-terminal unidirectional switching element being coupled to said other terminal of said second filament; and

said trigger circuit comprises a series circuit including a diode, a two-terminal bidirectional switching element and a second resistor, one terminal of said two-terminal bidirectional switching element being connected to the anode of said three-terminal unidirectional switching element through said second resistor, the other terminal of said two-terminal bidirectional switching element being connected to the anode of said diode, the cathode of said diode being connected to the gate of said three-terminal unidirectional switching element.

9. Apparatus according to claim 2 wherein:

said preheating circuit comprises a series circuit including said second coil coupled to said first coil means, a three-terminal bidirectional thyristor and a diode, the second anode of said thyristor being connected to said other terminal of said second filament through said second coil, the first anode of said thyristor being connected to the cathode of said diode, the anode of said diode being connected to said other terminal of said first filament;

said trigger circuit comprises a series circuit including a trigger resistor and a two-terminal bidirectional switching element, and a trigger capacitor, one terminal of said two-terminal switching element being connected to the gate of said three-terminal switching element, the other terminal of said two-terminal switching element being connected to the anode of said diode through said trigger resistor and to said second coil through said trigger capacitor; and

said pulse generating circuit comprises a series circuit including said second coil, said three-terminal bidirectional switching element, a unidirectional semiconductor means having a given polarity and a pulse generating coil, and a pulse generating resistor connected in parallel with said pulse generating diode, said unidirectional semiconductor means being connected between one terminal of said AC source via said capacitor of said pulse generating circuit and the first anode of said three-terminal bidirectional switching element with its polarity being same as that of said diode.

10. Apparatus according to claim 2 wherein:

said preheating circuit comprises a series circuit including a preheating diode, said second coil coupled to said first coil means and a three-terminal bidirectional switching element, the anode of said preheating diode being connected to said other terminal of said first filament, the cathode of said preheating diode being connected via said second coil to the first anode of said three-terminal bidirectional switching element, the second anode thereof being connected to the other terminal of said second filament;

said trigger circuit comprises a series circuit including a two-terminal bidirectional switching element and a trigger capacitor, and a trigger resistor, one terminal of said two-terminal switching element being connected to the second anode of said three-terminal bidirectional switching element through said trigger capacitor and to the other terminal of said first filament through said trigger resistor, the other terminal of said two-terminal switching element being connected to the gate of said three-terminal bidirectional switching element; and

said pulse generating circuit comprises a series circuit including said three-terminal bidirectional switching element, said second coil, a unidirectional semiconductor means having a given polarity, said capacitor of said pulse generating circuit, and a pulse generating resistor, said unidirectional semiconductor means being connected between the cathode electrode of said diode and one terminal of said AC source through said capacitor of said pulse generating circuit with its polarity being same as that of said diode.

11. Apparatus according to claim 2 comprising a tapped coil means having a tap point intermediate the ends thereof and comprising said second coil, and wherein:

said preheating circuit comprises a series circuit including a diode, said tapped coil, and a bidirectional two-terminal thyristor, the anode of said diode being connected to said other terminal of said filament, and the cathode of said diode being connected through said tapped coil to the first anode of said thyristor, the second anode of said thyristor being connected to said other terminal of said filament;

said trigger generating circuit comprises a series circuit including a first and second resistor, of which one end is connected to the anode of said diode and the other end is connected to said other terminal of said second filament, a trigger capacitor connected in parallel to the second resistor, and a series circuit consisting of a third resistor and bidirectional two-terminal thyristor of which one end is connected to the juncture between the first and second resistors, and the other end is connected to the gate of said three-terminal thyristor; and

said pulse generating circuit comprises a series circuit comprised of a second bidirectional two-terminal thyristor, said second coil which is comprised of the part of said tapped coil means which is defined between the intermediate tap and one end thereof, and said capacitor, and a fourth resistor connected in parallel to said tapped coil means, one end of said second two-terminal thyristor through said part of said tapped coil means and the other end to the first terminal of said AC source through said capacitor.

12. Apparatus according to claim 11 which further includes another capacitor coupled across said AC source.

13. Apparatus according to claim 2 comprising a tapped coil means having a tap point intermediate the ends thereof and comprising said second coil, and wherein:

said preheating circuit comprises a series circuit including a diode, said tapped coil and a bidirectional three-terminal thyristor, the anode of said diode being connected to said other terminal of said first filament and the cathode of said diode being connected through the part of said tapped coil which is defined between one end thereof and the intermediate tap to the first anode of said three-terminal thyristor,

14. Apparatus according to claim 1 wherein:

said preheating circuit comprises a series circuit including a first diode, a coil with an intermediate tap magnetically connected to said first coil means and a bidirectional two-terminal thyristor, the anode of said diode being connected to said other terminal of said filament and the cathode of said diode being connected through said tapped coil to one end of said two-terminal thyristor, the other end of said two-terminal thyristor being connected to said other terminal of said second filament; and

said pulse generating circuit comprises a series circuit including a resistor, a second diode, said second coil which includes the part of said tapped coil which is defined between one end thereof and the intermediate tap, said bidirectional two-terminal thyristor, and said capacitor connected in parallel to said resistor, the anode of said second diode being connected to the intermediate tap of said tapped coil and the cathode through said capacitor to the first terminal of said AC source.

15. Apparatus according to claim 14 which further includes a second capacitor coupled across the AC source.

16. Apparatus according to claim 1 wherein:

said preheating circuit comprises a series circuit including a first diode, a coil with an intermediate tap magnetically connected to said first coil means, and a bidirectional two-terminal thyristor, the anode of said diode being connected to said other terminal of said first filament and the cathode of said diode being connected through said tapped coil to one end of said two-terminal thyristor, the other end of said two-terminal thyristor

said pulse generating circuit comprises a series circuit including said two-terminal thyristor, said second coil which includes at least a portion of said tapped coil, a second diode and said capacitor, and a resistor connected in parallel to said capacitor, the anode of said second diode being connected to the cathode of said first diode and the cathode of said second diode being connected through said capacitor to said one terminal of AC source.

17. Apparatus according to claim **16** which further includes another bidirectional two-terminal thyristor connected between the cathode of said first diode and said tapped coil.

18. Apparatus according to claim **1** wherein:

said first coil means has an intermediate tap;

said preheating circuit comprises a series circuit including said second coil which is comprised of the part of said first coil means which is defined between one end thereof and the intermediate tap, a second capacitor and a diode, the cathode of said diode being connected to said other terminal of said second filament and the anode of said diode being connected to the intermediate tap of said first coil means through said second capacitor; and

said pulse generating circuit includes a series closed circuit comprised of said part of said first coil means between one end thereof and the intermediate tap, and a bidirectional two-terminal semiconductor means with a given polarity.

19. Apparatus according to claim **1** wherein:

said first coil means has an intermediate tap;

said preheating circuit comprises a series circuit including a bidirectional two-terminal switching means and a diode, the cathode of the diode being connected to said other terminal of said first filament through said bidirectional two-terminal switching means;

said pulse generating circuit comprises a series circuit including said second coil which is comprised of the part of said first coil means which is defined between one end thereof and the intermediate tap, a further coil and said diode, one end of said capacitor being connected to the intermediate tap of said first coil means and the other end of said capacitor being to the anode of said diode.

20. Apparatus according to claim **19** which further includes a second capacitor coupled across said AC source.

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