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(71) Applicant: **Toshiba Lighting & Technology Corporation**
Shinagawa-ku,
Tokyo 140-8640 (JP)

(72) Inventors:
- **Kamata, Masahiko,**
  c/o Toshiba Lighting &
  Shinagawa-ku
  Tokyo 140-8640 (JP)
- **Takahara, Yuuichiro,**
  c/o Toshiba Lighting &
  Shinagawa-ku
  Tokyo 140-8640 (JP)
- **Mita, Kazutoshi,**
  c/o Toshiba Lighting &
  Shinagawa-ku
  Tokyo 140-8640 (JP)

(74) Representative: **Jennings, Nigel Robin et al**
KILBURN & STRODE
20 Red Lion Street
London WC1R 4PJ (GB)

(54) High intensity discharge lamp lighting device and illumination apparatus

(57) A lighting device which lights a high intensity discharge lamp (7) adds together a high-frequency component from high-frequency generating means (3) and a low-frequency component from low-frequency generating means (4) in adding means (6) and supplies a superimposed wave current containing the high-frequency component and low-frequency component to the high intensity discharge lamp (7) to light the same.

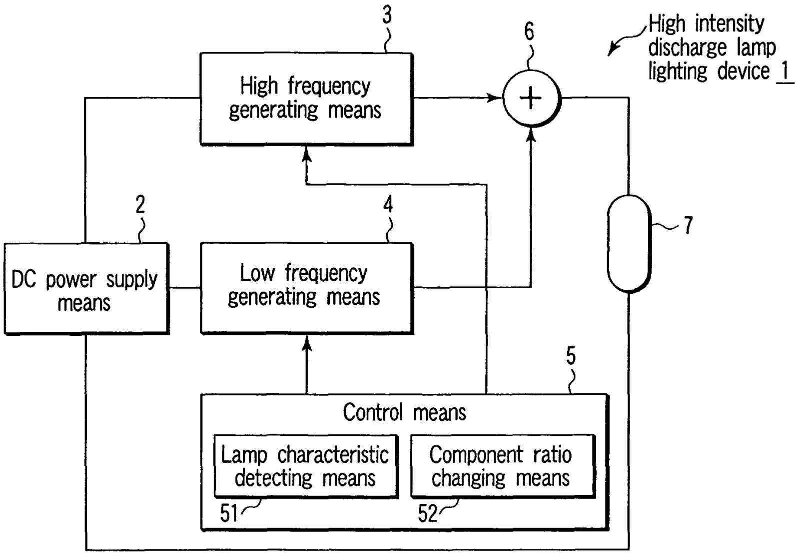


FIG. 1

EP 1 768 468 A2

Description

[0001] This invention relates to a high intensity discharge lamp lighting device and illumination apparatus which light a high intensity lamp at a high frequency.

[0002] In general, in a discharge lamp lighting device, in order to make parts thereof small and light in weight and perform a stable lighting operation without flickering, a high-frequency lighting operation is performed by use of a switching power supply circuit.

[0003] It is known that if a discharge lamp is lighted at a high frequency, an acoustic resonance phenomenon tends to occur and the lighting state becomes unstable.

[0004] Various types of switching power supply circuits used for high-frequency lighting are provided. In this example, a chopper type switching power supply circuit and a high intensity discharge lamp lighting device which converts the output voltage of the switching power supply circuit to high-frequency AC voltage by use of an inverter circuit and supplies the AC voltage to a high intensity discharge lamp used as a load are explained.

[0005] Generally, in a high intensity discharge lamp lighting device using an inverter circuit which lights a high intensity discharge (HID) limp, the switching frequency (which is hereinafter referred to as an operation frequency) of a switching element of the inverter circuit is set in a range of a non-resonance frequency band in order to prevent the high intensity discharge lamp from causing an acoustic resonance phenomenon. The lamp output is controlled with the operation frequency thereof set substantially constant.

[0006] For example, a high intensity discharge lamp lighting device is known in which a voltage step-up chopper circuit is provided in the switching power supply circuit, an inverter circuit is connected to the voltage step-up chopper circuit and the high intensity discharge lamp is lighted by the inverter circuit. In the high intensity discharge lamp lighting device, the lamp power is controlled by controlling DC voltage from the voltage step-up chopper circuit without greatly changing the operation frequency of the inverter circuit.

[0007] In Jpn. Pat. Appln. KOKOKU Publication No. S57-18317, the technique for lighting a high intensity discharge lamp at a high frequency is disclosed and it is disclosed that an acoustic resonance phenomenon caused in the high intensity discharge lamp is detected, the output frequency is changed accordingly and the discharge lamp is lighted by use of the frequency which does not cause the acoustic resonance phenomenon.

[0008] Further, in Jpn. Pat. Apln. KOKAI Publication No. S63-55894 and Jpn. Pat. Appln. KOKAI Publication No. H6-283286, the technique for using a fluorescent lamp as a load and increasing the duty ratio (the percentage of the ON period of the switching cycle) at the lamp dimming time (when the lamp current is reduced) is disclosed. In this case, an increase in the loss caused by an increase in the switching frequency and occurrence of striation at the dimming lamp lighting time can be prevented.

[0009] The term "striation" means that a stripe pattern appears on the tube wall when a discharge lamp containing inert gas such as argon having a large atomic weight is lighted by use of AC voltage. It tends to occur when the lamp ambient temperature is low or the lamp is lighted in the dimming mode and it gives flickering which causes unpleasant feelings.

[0010] The high intensity discharge lamp is used with a small lamp current or large lamp current in comparison with a rated lamp current of the lamp in some cases. For example, in the dimming mode, the lamp is lighted with the small lamp current in comparison with the rated lamp current. Further, since the lamp voltage is low at the rise time after the lamp is lighted, a slightly larger lamp current tends to flow. In addition, a rising operation of light output is accelerated in some cases by intentionally causing a large current to flow after the lamp is lighted.

[0011] However, generally, in the high intensity discharge lamp, the electrode temperature tends to be lowered if the duty ratio of the ON period of the switching element is made asymmetrical.

[0012] Generally, it is not preferable to light the high intensity discharge lamp with a lamp current which is significantly different from the rated lamp current. If the lamp is lighted with a lamp current lower than the rated lamp current, the electrode temperature is lowered, the lamp tends to be extinguished and flickering tends to occur. Further, the process of sputtering an electrode material can be more actively performed and the service life of the lamp may be shortened. On the other hand, if the lamp current is large, the electrode temperature becomes high, an evaporation amount of an electrode material becomes excessively large and the service life of the lamp is shortened.

[0013] The high intensity discharge lamp has an adequate range of electrode temperatures and if the electrode temperature thereof is set outside the range, the service life of the lamp becomes short. If the dimensions of the electrodes and the like are determined, the adequate range of the lamp current is limited since the electrode temperature is determined by the lamp current. Therefore, there occurs a problem that the service life becomes short when the lamp is lighted in the dimming mode or the stronger dimming operation cannot be performed. Further, an excessively large lamp current flows at the rise time after the lamp is lighted to shorten the service life.

[0014] According to a first aspect of this invention, there are provided a high intensity discharge lamp lighting device and illumination apparatus which can maintain adequate electrode temperature in a wide lamp current range.

[0015] This invention includes superimposed power outputting means which outputs power containing high-frequency and low-frequency components to a high intensity discharge lamp. The high intensity discharge lamp contains a mercury lamp, metal halide lamp, high intensity sodium lamp and the like. Further, it also contains a ceramic discharge lamp using an alumina tube as a light emission tube.

[0016] It is preferable to set the frequency of the high-frequency component in a range of 15 kHz to 500 kHz. If the frequency is low and extends into an audio frequency range, for example, if it is equal to or lower than 15 kHz, generation of a sound from the high intensity discharge lamp lighting device cannot be prevented. If the frequency is set equal to or higher than 500 kHz, a large amount of radiation noises are generated.

[0017] It is preferable to set the frequency of the low-frequency component in a range of 10 Hz to 500 Hz. If the frequency is set equal to or lower than 10 Hz, a variation in the light emission intensity of the lamp can be visually recognized and causes flickering. If the frequency is set equal to or higher than 500 Hz, generation of a sound from the high intensity discharge lamp lighting device cannot be prevented. Further, the waveforms of the high-frequency and low-frequency components are set to a sinusoidal wave, rectangular wave, triangular wave or the like and are not particularly limited.

[0018] When a superimposed wave current containing high-frequency and low-frequency components is caused to flow in the high intensity discharge lamp as a lamp current, the electrode temperature is lowered in comparison with a case wherein a normal lamp current of a constant current value which is not superimposed (that is, a lamp current caused by only one of the frequency components) is used. This is found by the study of the inventors of this application. By utilizing the electrode temperature characteristic, the electrode temperature can be controlled and set in an adequate range to make the service life of the lamp longer.

[0019] In this invention, the superimposed current value output from the superimposed power outputting means has a current value I_1 of the high-frequency component and a current value I_2 of the low-frequency component which are set in the relation of $I_1 > I_2$.

[0020] The superimposed wave current can be divided into a current of the high-frequency component and a current of the low-frequency component. The effective value I of the superimposed wave current is obtained as $I = I_1 + I_2$ if the effective value of the current of the high-frequency component and the effective value of the current of the low-frequency component are respectively set to I_1 and I_2. In this case, if the current value I_1 of the high-frequency component is set larger than the current value I_2 of the low-frequency component, it means that the high-frequency component is mainly used. Thus, parts of the high intensity discharge lamp light device can be made small and light in weight.

[0021] In this invention, the superimposed power outputting means includes component ratio changing means which changes the component ratio of the high-frequency component to the low-frequency component.

[0022] The inventors of this application found that the electrode temperature varies according to the component ratio of I_1:I_2 of the current value I_1 of the high-frequency component and the current value I_2 of the low-frequency component even when the current value I of the superimposed wave is kept unchanged. By changing the component ratio, the electrode temperature can be controlled and temperature adjustment can be made. Therefore, the service life of the lamp can be elongated and occurrence of a problem such as flickering or extinguishing of the lamp can be suppressed.

[0023] In this invention, the component ratio changing means changes the high-frequency component and low-frequency component contained in the output of the superimposed power outputting means at the rise time of the high intensity discharge lamp.

[0024] At the rise time after lighting, a current larger than the current flowing at the stable lighting time is caused to flow in the lamp in order to rapidly raise the light output. At this time, by passing the superimposed current having the high-frequency component and low-frequency component, the electrode temperature can be lowered and the electrode temperature can be maintained in an adequate range. As a result, the service life of the lamp can be made longer since an evaporation amount of the electrode material can be reduced.

[0025] Since the rise time period after the high intensity discharge lamp is lighted is a preset time period (approximately 60 seconds) after it is lighted as shown in FIG. 7, it is preferable to perform the above control operation during the above period of time and suppress a rise in the electrode temperature.

[0026] In this invention, the component ratio changing means changes the component ratio of the high-frequency component to the low-frequency component according to the level of a dimming signal input from the exterior.

[0027] The high intensity discharge lamp lighting device having the dimming function controls the lamp current supplied to the high intensity discharge lamp and performs the dimming operation according to the level of a dimming signal input from the exterior.

[0028] The component ratio changing means adjusts the electrode temperature by changing the component ratio I_1:I_2 of the current value I_1 of the high-frequency component and the current value I_2 of the low-frequency component according to the level of a dimming signal. That is, as shown in FIG. 3, when the lamp current becomes small by the dimming operation, the component ratio I_1:I_2 is controlled to be separated from 1:1. Further, when the lamp current becomes large by the dimming operation, the component ratio I_1:I_2 is controlled to become closer to 1:1. Thus, the electrode temperature can be maintained substantially constant before and after the dimming operation. Therefore, the service life of the lamp can be made longer and occurrence of a problem such as flickering or extinguishing can be suppressed.

[0029] In this invention, the component ratio changing means changes the component ratio of the high-frequency component to the low-frequency component according to the detection result of lamp characteristic detecting means which detects the characteristic of the high intensity discharge lamp. In this case, the lamp characteristic indicates the characteristic of the lamp voltage, lamp current, lamp power or light output indicating the lighting state of the high intensity discharge lamp.

[0030] By changing the component ratio of the high-frequency component to the low-frequency component according to the detection result of the lamp characteristic detecting means, the electrode temperature of the lamp is controlled according to a variation in the characteristic obtained at this time. Thus, the electrode temperature of the lamp can be maintained substantially constant irrespective of the variation in the lamp characteristic.

[0031] In this invention, the lamp characteristic detecting means includes lamp current detecting means for detecting the lamp current. Then, the component ratio changing means changes the component ratio of the current value of the high-frequency component to the current value of the low-frequency component according to the detection result of the lamp current of the lamp current detecting means.

[0032] The lamp current is a factor which gives a large influence on the electrode temperature of the lamp. Therefore, the electrode temperature can be kept substantially constant irrespective of a variation in the lamp current by detecting the lamp current and changing the component ratio I_1:I_2 according to an increase or decrease in the lamp current.

[0033] In this invention, when the lamp current detecting means detects an increase in the lamp current and a state in which the electrode temperature rises is set up, the component ratio changing means controls the ratio of the current value of the high-frequency component to the current value of the low-frequency component to set the same closer to the ratio 1:1 of the high-frequency component to the low-frequency component which causes the electrode temperature to be set to the lowest temperature. That is, the component ratio changing means detects the lamp current and when the lamp current increases, it performs the control operation to lower the electrode temperature by setting the component ratio I_1:I_2 closer to 1:1 as shown in FIG. 3.

[0034] In this invention, the superimposed power outputting means includes inverter means and control means. The inverter means supplies DC voltage from DC power supply means to two terminals of each of two switching elements which are alternately turned ON/OFF to convert the same to high-frequency voltage, applies the thus converted voltage to the high intensity discharge lamp and lights the same. The control means alternately ON/OFF-controls the two switching elements of the inverter means. It performs the control operation so that the duty ratios of the two switching elements will be alternately changed on a cycle longer than a switching cycle of the two switching elements. As a result, a low-frequency component is superimposed on a high-frequency component.

[0035] For example, the DC power supply means includes a full-wave rectifier circuit which rectifies AC power supply voltage and a voltage step-up chopper circuit which is supplied with the rectified voltage and raises the same to generate DC voltage. For example, the inverter means includes a half-bridge type high-frequency inverter having two switching elements which are serially connected and are alternately turned ON/OFF and an LC resonance circuit and the operation frequency thereof is controlled by the control means. The inverter circuit applies the high-frequency output across the high intensity discharge lamp to light the high intensity discharge lamp at a high frequency.

[0036] In this invention, lamp voltage detecting means which detects lamp voltage of the high intensity discharge lamp is further provided. The control means performs the control operation to set the switching frequency of the two switching elements to a frequency which is different from the switching frequency at the starting time and prevents occurrence of an acoustic resonance phenomenon when the lamp voltage detected by the lamp voltage detecting means exceeds a preset value used to determine occurrence of the acoustic resonance phenomenon.

[0037] For example, the lamp voltage detecting means includes a detecting circuit which detects high-frequency voltage across the high intensity discharge lamp and a voltage doubler rectifier circuit which rectifies and smoothes the high-frequency voltage by use of two sets of a diode and capacitor. The lamp voltage detecting means is used to detect lamp voltage in the transition state and stable lighting state after the lamp is lighted. Since the lamp voltage is changed and raised when the acoustic resonance phenomenon occurs, the lamp voltage detecting means sets a threshold value used to determine occurrence of an acoustic resonance phenomenon and is used to detect occurrence of an acoustic resonance phenomenon.

[0038] In the illumination apparatus of this invention, the service life of the lamp can be elongated by using a lighting device which can stably control and set the electrode temperature of a high intensity discharge lamp substantially constant irrespective of a variation in the lamp characteristic and occurrence of flickering and extinguishing of the lamp can be suppressed.

[0039] With the configuration of this invention, the electrode temperature can be kept in an adequate range over a wide lamp current range. For example, this invention is effectively applied to lamps having electrode dimensions smaller than a normal design value. In the case of the above lamp, if the lamp is lighted by use of a normal lamp current wave in a full lighting mode in which it is lighted by a rated lamp current or at the rise time when it is lighted by a current larger than the rated lamp current, the electrode temperature tends to become higher than the adequate temperature.

[0040] According to this invention, the electrode temperature can be lowered to the adequate temperature by adjusting the component ratio of the high-frequency component I_1 to the low-frequency component I_2. Even when the lamp current is adjusted to a small value at the dimming time, for example, the electrode temperature can be set to an adequate electrode temperature. Thus, the long service life can be attained in a wide lamp current range and occurrence of a problem such as flickering and extinguishing can be prevented.

[0041] According to this invention, the electrode temperature can be made lower by supplying superimposed wave power containing the high-frequency component and low-frequency component to the high intensity discharge lamp in comparison with a case wherein both of the above components are not superimposed. By using this characteristic, the service life of the lamp can be elongated and occurrence of a problem such as flickering and extinguishing can be prevented. Further, parts of the high intensity discharge lamp lighting device can be made smaller and light in weight by increasing the high-frequency component contained in the superimposed wave current.

[0042] According to this invention, the electrode temperature can be adjusted. That is, at the rise time after lighting of the high intensity discharge lamp, a rise in the electrode temperature can be suppressed and the electrode temperature can be kept constant by changing the component ratio of the high-frequency component to the low-frequency component. Further, at the dimming time, a lowering in the electrode temperature is prevented and the electrode temperature can be kept constant by changing the component ratio of the high-frequency component to the low-frequency component according to the degree of dimming.

[0043] According to this invention, the electrode temperature can be controlled and set to the lowest state by changing the component ratio of the high-frequency component to the low-frequency component according to the detected value of the lamp current, for example, by setting the ratio of the current value of the high-frequency component to the current value of the low-frequency component closer to 1:1.

[0044] According to this invention, a lamp driving signal wave can be obtained by superimposing the high-frequency component and low-frequency component and supplied to the high intensity discharge lamp. The switching frequency of the switching element at the lamp lighting time can be controlled and set to a frequency different from an acoustic resonance frequency.

[0045] The invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram schematically showing a high intensity discharge lamp lighting device according to a first embodiment of this invention.

FIG. 2 is a diagram for illustrating the principle of the high intensity discharge lamp lighting device of FIG. 1.

FIG. 3 is a diagram showing the relation between the waveform of the superimposed wave current and a variation in the electrode temperature when the superimposition rate of the low-frequency component in the superimposed wave current of a high-frequency component and low-frequency component supplied to a high intensity discharge lamp is changed with 50% set as a reference.

FIG. 4 is a diagram showing the variation characteristic of the electrode temperature with respect to a variation in the superimposition rate of the low-frequency component current in the lamp current.

FIG. 5 is a waveform diagram showing the superimposed wave current when each of the high-frequency component and low-frequency component is set to a sinusoidal wave.

FIG. 6 is a waveform diagram showing the superimposed wave current when the high-frequency component is set to a sinusoidal wave and the low-frequency component is set to a triangular wave.

FIG. 7 is a characteristic diagram of the lamp voltage V_L in the high intensity discharge lamp lighting device.

FIG. 8 is a circuit diagram showing the high intensity discharge lamp lighting device according to the first embodiment of this invention.

FIG. 9 is a diagram showing the relation between the duty ratios of the switching elements and an increase in the lamp current in the first embodiment of this invention.

FIG. 10 is a diagram showing the relation between the electrode temperature and a variation in the duty ratios of the switching elements while the lamp is being lighted with the magnitude of the lamp current used as parameters in the first embodiment of this invention.

FIG. 11 is a diagram showing the relation between the electrode temperature and a variation in the lamp current when the duty ratio control operation of FIG. 9 is performed.

FIG. 12 is a diagram showing the lamp current wave and the duty ratio control operation of the switching elements when the lamp starts to be driven and after the lamp is lighted.

FIG. 13 is a diagram showing one example of the lamp voltage characteristic after the lamp is lighted in the first embodiment of this invention.

FIG. 14 is a waveform diagram showing an output signal of the lamp voltage detecting circuit in the first embodiment of this invention.

FIG. 15 is a diagram showing one example of the current waveform of the switching element at the lamp starting time in the first embodiment of this invention.

FIG. 16 is a diagram showing one example of the current waveform of the switching element while the lamp is being lighted in the first embodiment of this invention.

FIG. 17 is a diagram showing one example of the current waveform of the switching element while the lamp is being lighted with the duty ratios inverted with respect to that of the current waveform of FIG. 16 in the first embodiment of this invention.

FIG. 18 is a diagram showing one example of the lamp current waveform in the first embodiment of this invention.

FIG. 19 is a diagram for illustrating the relation between the ON/OFF operation of the switching element and the lamp current waveform of the high intensity discharge lamp in the first embodiment of this invention.

FIG. 20 is a cross sectional view showing the structure of an illumination apparatus according to this invention.

FIG. 21 is a cross sectional view showing the structure of the high intensity discharge lamp.

FIG. 22 is a circuit diagram showing a high intensity discharge lamp lighting device according to a second embodiment of this invention.

FIG. 23 is a diagram showing the superimposition rate of the low-frequency component in the lamp current when the lamp current is changed.

FIG. 24 is a circuit diagram showing a high intensity discharge lamp lighting device according to a third embodiment of this invention.

FIG. 25 is a waveform diagram for illustrating the operation of the circuit shown in FIG. 24.

There will now be described embodiments of this invention with reference to the accompanying drawings.

(First Embodiment)

[0046] FIG. 1 is a block diagram showing the schematic configuration of a high intensity discharge lamp lighting device according to a first embodiment of this invention.

[0047] In FIG. 1, a high intensity discharge lamp lighting device 1 is configured by superimposed power outputting means including DC power supply means 2 for generating power of a DC power supply, high frequency generating means 3 for generating power of a high-frequency component, low frequency generating means 4 for generating power of a low-frequency component, adding means 6 for adding together power of the high-frequency component and power of the low-frequency component and supplying the added power to a high intensity discharge lamp 7, and control means 5 for controlling the magnitudes of outputs of the high-frequency component of the high frequency generating means 3 and the low-frequency component of the low frequency generating means 4.

[0048] The high intensity discharge lamp 7 is supplied with superimposed power containing power of the high-frequency component and power of the low-frequency component. As a result, it is lighted by a superimposed wave current containing the high-frequency component and low-frequency component.

[0049] For example, the control means 5 includes lamp characteristic detecting means 51 for detecting the characteristic of the high intensity discharge lamp 7 and component ratio changing means 52 for changing the component ratio of the high-frequency component to the low-frequency component according to the detection result of the lamp characteristic detecting means 51.

[0050] FIG. 2 is a diagram for illustrating the principle of the high intensity discharge lamp lighting device of FIG. 1. In FIG. 2, voltage of the high-frequency component from an output terminal 3-1 of the high frequency generating means 3 and voltage of the low-frequency component from an output terminal 4-1 of the low frequency generating means 4 are superimposed or added together in the adding means 6 and the superimposed voltage is applied between electrodes 7-1 and 7-2 at both ends of the high intensity discharge lamp 7. When the high intensity discharge lamp 7 is set into a lighting state, a superimposed wave current obtained by superimposing the high-frequency component current and low-frequency component current with the reference potential (0 V) set as a reference is supplied to the high intensity discharge lamp 7.

[0051] The control means 5 has operating means (not shown) and the superimposition ratio of the high-frequency component current to the low-frequency component current supplied to the high intensity discharge lamp 7 can be changed by use of the component ratio changing means 52 by operating the operating means. For example, the control means 5 can change both of the current value of the high-frequency component and the current value of the low-frequency component while the brightness of the high intensity discharge lamp 7 or lamp power is kept constant. Further, for example, the control means 5 can change the superimposition ratio of the current value of the low-frequency component to the current value of the high-frequency component by changing the current value of the low-frequency component with the current value of the high-frequency component kept constant. On the other hand, the control means 5 can change the superimposition ratio of the current value of the high-frequency component to the current value of the low-frequency component by changing the current value of the high-frequency component with the current value of the low-frequency component kept constant.

[0052] Further, the control means 5 can perform the control operation to always set the current value I_1 of the high-frequency component and the current value I_2 of the low-frequency component in the relation of $I_1 > I_2$ in the superimposed current value supplied to the high intensity discharge lamp 7, that is, set the superimposition rate of the high-frequency component always higher than that of the low-frequency component.

[0053] FIG. 3 shows current waveforms obtained when the superimposition ratios of the superimposed wave currents of the high-frequency components to the low-frequency components supplied to the high intensity discharge lamp 7 are sequentially changed. In the case of the present embodiment, current waveforms are shown in an order from the above in which the superimposition ratios of the current values of the low-frequency components to the current values of the high-frequency components are sequentially increased while the brightness of the high intensity discharge lamp 7 or lamp power is kept constant.

[0054] The superimposition rate is expressed by the following equation (1) when the effective value of the current (which is hereinafter simply referred to as the current value) of the high-frequency component is set to I_1 and the effective value of the current (which is hereinafter simply referred to as the current value) of the low-frequency component is set to I_2.

$$\text{Superimposition Rate} = \{I_2/(I_1+I_2)\}\times 100\ [\%] \quad (1)$$

[0055] In FIG. 3, the top current waveform indicates a case wherein the current value of the low-frequency component is set at "0" and the superimposition rate is 0%, that is, only the current of the high-frequency component is provided. The third current waveform from the top indicates a case wherein the superimposition rate is 50% and, at this time, the electrode temperature of the high intensity discharge lamp is set at the lowest temperature. The second current waveform from the top indicates a state in which the superimposition rate is set at an intermediate value between 0% and 50% and the fourth and fifth current waveforms from the top indicate states in which the superimposition rate is set between 50% and 100%. The electrode temperatures at both ends of the high intensity discharge lamp 7 become higher as the superimposition rate of the current value of the low-frequency component is increased or decreased with the current waveform of the superimposition rate 50% set at the center. That is, the electrode temperature is set at the highest temperature in a case wherein the superimposition rate is 0% and only the high-frequency component is provided and a case wherein the superimposition rate is 100% and only the low-frequency component is provided. Therefore, the electrode temperature can be controlled by controlling the superimposition rate of the current value of the low-frequency component.

[0056] In FIG. 3, the ratio of I_1:I_2 expresses the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component. I_1:I_2 is set to 1:1 when the superimposition rate of the current value I_1 of the high-frequency component and the current value I_2 of the low-frequency component is set at 50%, I_1:I_2 is set to 2:0 when the superimposition rate of the low-frequency component is set at 0%, and I_1:I_2 is set to 0:2 when the superimposition rate of the low-frequency component is set at 100%.

[0057] As the high intensity discharge lamp, a metal halide lamp with the rated lamp power 80W and rated lamp current 0.85A is used. The material of the electrode of the above lamp is tungsten and the diameter of the head portion thereof is 0.35 mm.

[0058] FIG. 4 shows the measurement result of the electrode temperature. The abscissa indicates the superimposition rate and the ordinate indicates the electrode temperature.

[0059] The electrode temperatures are measured when the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component is changed while the lamp current I which is a superimposed wave current is set to 0.6A to 1A. The lamp current I is a current obtained by superimposing a sinusoidal current of a frequency 20 kHz which is a high-frequency component and a rectangular wave current of a frequency 100 Hz which is a low-frequency component. In this case, the electrode temperature is measured based on an image photographed by a CCD camera, that is, luminance data.

[0060] In FIG. 4, an adequate temperature range of the electrode temperature is inserted. That is, if the electrode temperature is set in the adequate temperature range, the service life of the lamp can be made longer and occurrence of a problem such as flickering or extinguishing of the lamp can be prevented.

[0061] The high intensity discharge lamp lighting device 1 controls and sets the power consumption of the high intensity discharge lamp 7 to 50 to 70W according to the level of a dimming signal input from the exterior to the control means 5. At this time, the lamp current I is changed between 0.60A and 0.85A. Further, at the rise time after the lamp is lighted, the lamp current I up to the maximum current 1.1A flows.

[0062] It is understood from the measurement result of FIG. 4 that the electrode temperature is set to the lowest temperature when the superimposition rate of the current value I_2 of the low-frequency component shown in the equation (1) is set at 50% even if the lamp current I is changed between 0.6A and 1.0A and the electrode temperature is set to the highest temperature when the superimposition rate is set at 0% or 100%.

[0063] The waveforms of the high-frequency component and low-frequency component can be set to sinusoidal waveforms, rectangular waveforms, triangular waveforms and are not particularly limited to specified waveforms.

[0064] FIG. 5 shows a case wherein both of the high-frequency component and low-frequency component are set to sinusoidal waves and FIG. 6 shows a case wherein the high-frequency component is set to a sinusoidal wave and the low-frequency component is set to a triangular wave.

[0065] FIG. 7 is a characteristic diagram of the lamp voltage V_L in the high intensity discharge lamp lighting device 1. In FIG. 7, the abscissa indicates time (sec) and the ordinate indicates lamp voltage V_L. In FIG. 7, the starting time period (which is hereinafter referred to as the starting time) from turn-ON of the power supply to lighting of the lamp, the rise time period (which is hereinafter referred to as the rise time) from the lighting time to the stable lighting state and the stable lighting time period (which is hereinafter referred to as the stable lighting time) after the rise time are defined. The starting time from turn-ON of the power supply to the lighting time corresponds to a glow discharge period and the lighting state is set when the glow discharge operation is transited to an arc discharge operation. A time period from the time when the lighting state is set to the time when the stable lighting state is set is the rise time. For example, a case is shown in which a time period from turn-ON of the power supply to setting of the lighting state is set to one second and a time period from turn-ON of the power supply to setting of the stable lighting state is set to 60 seconds. At the turn-ON time of the power supply, impulse-like starting high voltage (not shown) which rapidly rises is applied across the high intensity discharge lamp 7.

[0066] FIG. 8 is a circuit diagram showing a high intensity discharge lamp lighting device according to the first embodiment of this invention.

[0067] In FIG. 8, a high intensity discharge lamp lighting device 10 includes an AC power supply AC, a noise filter circuit 11 configured by capacitors C1, C2 and transformer T1, a full-wave rectifier circuit 13 configured by diodes D1 to D4, a high-frequency component elimination filter C3, and a voltage step-up chopper circuit 14 which includes a coil L1, switching element Q1, diode D5 and capacitor C4, is supplied with rectified voltage from the full-wave rectifier 13 and outputs DC voltage VDC.

[0068] Further, the high intensity discharge lamp lighting device 10 includes a voltage detecting line 15 as DC voltage detecting means, an inverter circuit 16 which is inverter means including an LC resonance circuit 17 which supplies DC voltage VDC from the voltage step-up chopper circuit 14 to both ends of a series circuit of two switching elements Q2, Q3 which are alternately turned ON/OFF, converts the DC voltage to high-frequency AC voltage (which is hereinafter referred to as high-frequency voltage) and supplies the thus converted voltage to a high intensity discharge lamp HIDL to light the same, a current detecting circuit 18 which detects a switching element current of the inverter circuit 16, the high intensity discharge lamp HIDL, and a lamp voltage detecting circuit 19 used as lamp voltage detecting means for detecting lamp voltage of the high intensity discharge lamp HIDL. The current detecting circuit 18 also has a function of lamp current detecting means for attaining a signal corresponding to the lamp current.

[0069] Further, the high intensity discharge lamp lighting device 10 includes a control circuit 20 used as control means for controlling DC voltage VDC output from the voltage step-up chopper circuit 14 by controlling one or both of the duty ratio and the switching frequency of the switching element Q1 of the voltage step-up chopper circuit 14. Also, it controls the lighting frequency of the high intensity discharge lamp HIDL by controlling the switching frequency of the two switching elements Q2, Q3 of the inverter circuit 16, that is, the operation frequency. The duty ratio of the switching element Q1 indicates the ratio of the ON period to a period of the switching cycle.

[0070] The diode D8 and capacitor C10 configure a circuit which rectifies and smoothes voltage from the secondary coil of the transformer T2 provided on the input side of the voltage step-up chopper circuit 14 and supplies the thus obtained voltage to the control circuit 20 as the power supply voltage. Further, a resistor R6 provided between the source of the switching element Q1 of the voltage step-up chopper circuit 14 and a reference potential node is a resistor used to detect a current flowing through the switching element Q1 and transmit the detection result to the control circuit 20.

[0071] In the present embodiment, the control circuit 20 performs the control operation to alternately turn ON/OFF the two switching elements Q2, Q3 of the inverter circuit 16. That is, the control circuit 20 has a function of alternately ON/OFF-controlling the switching elements Q2, Q3 by use of a first duty ratio at the lamp starting time and alternately ON/OFF-controlling the switching elements by use of a second duty ratio different from the first duty ratio at the lamp lighting time. Further, it alternately inverts the second duty ratios of the switching elements Q2 and Q3 on a cycle longer than the switching cycle of the switching elements Q2, Q3 at the lamp lighting time.

[0072] The DC power supply circuit 12 includes the full-wave rectifier circuit 13 and voltage step-up chopper circuit 14. The voltage step-up chopper circuit 14 has the primary coil L1 of the transformer T2, switching element Q1, diode D5 and output capacitor C4 and it is supplied with full-wave rectified voltage from the full-wave rectifier circuit 13, raises the received voltage and generates preset DC voltage VDC.

[0073] The voltage step-up chopper circuit 14 stores energy in the primary coil L1 of the transformer T2 when the switching element Q1 is set in the ON state and makes the diode D5 conductive to discharge energy stored in the primary coil L1 to the output capacitor C4 when the switching element Q1 is set in the OFF state. At this time, since voltage generated across the primary coil L1 of the transformer T2 is serially added to the input voltage from the full-wave rectifier circuit 13, the output voltage becomes higher than the input voltage.

[0074] The DC voltage VDC output from the voltage step-up chopper circuit 14 can be varied by controlling one or both of the duty ratio and the switching frequency of the switching element Q1.

[0075] The inverter circuit 16 is configured by a half-bridge type high-frequency inverter having two switching elements Q2, Q3 serially connected, a DC-cut capacitor C5 and an LC resonance circuit 17 which includes a coil L2 and capacitor C6.

[0076] The inverter circuit 16 is supplied with DC voltage VDC from the voltage step-up chopper circuit 14 and alternately turns ON/OFF the switching elements Q2, Q3 by use of two switching pulses of the same switching frequency set in the inverted phase relation with the duty ratio set at 50% which is the first duty ratio at the starting time. Then, at the lighting time, it alternately turns ON/OFF the switching elements by use of two switching pulses of the same switching frequency set in the inverted phase relation with the duty ratio set at, for example, 70% which is the second duty ratio different from the first duty ratio.

[0077] As a result, the inverter circuit 16 converts the DC voltage VDC from the DC power supply circuit 12 into high-frequency voltage and supplies the thus converted voltage to the high intensity discharge lamp HIDL.

[0078] The lighting frequency of the high intensity discharge lamp HIDL is controlled by controlling the switching frequency of the two switching elements Q2, Q3, that is, the operation frequency of the inverter circuit 16 by use of the control circuit 20.

[0079] The high-frequency output from the inverter circuit 16 is applied across the high intensity discharge lamp HIDL to light the high intensity discharge lamp HIDL at a high frequency.

[0080] The inverter circuit 16 has the switching elements Q2, Q3 configured by, for example, N-channel FETs serially connected between the positive side output terminal of the output capacitor C4 of the voltage step-up chopper circuit 14 and a negative side output terminal used as a reference potential node. A parasitic diode (not shown) with the polarity which permits a current to flow in a direction opposite to that of a current flowing in the switching element Q2 is connected in parallel with the switching element Q2. Likewise, a parasitic diode (not shown) with the polarity which permits a current to flow in a direction opposite to that of a current flowing in the switching element Q3 is connected in parallel with the switching element Q3.

[0081] The resonance circuit 17 including the coil L2 and capacitor C6 is connected between the connection node of the switching elements Q2 and Q3 and the reference potential node via the capacitor C5 and the high intensity discharge lamp HIDL is connected in parallel with the capacitor C6 of the resonance circuit 17. The gates of the switching elements Q2, Q3 are supplied with switching pulses which alternately turn ON/OFF the switching elements Q2, Q3 at a desired operation frequency from the control circuit 20.

[0082] Next, the operation of the inverter circuit 16 is schematically explained.

[0083] When AC power AC is input, DC voltage VDC output from the DC power supply circuit 12 is supplied across the series circuit of the switching elements Q2, Q3. The switching elements Q2, Q3 are alternately turned ON/OFF by switching pulses of a preset frequency from the control circuit 20. When the switching element Q2 is set in the ON state and the switching element Q3 is set in the OFF state, a current flows through a path of positive side output terminal of output capacitor C4 → switching element Q2 → capacitor C5 → coil L2 → capacitor C6 → negative side output terminal of output capacitor C4.

[0084] When the switching element Q2 is turned OFF and the switching element Q3 is turned ON, a current flows through a path of coil L2 → capacitor C6 → parasitic diode (not shown) of switching element Q3 → capacitor C5 based on energy stored in the coil L2.

[0085] Thus, the capacitor C6 is charged and a current flows through a path of capacitor C6 → coil L2 → capacitor C5 → switching element Q3 → capacitor C6 based on charged voltage of the capacitor C6 in the ON period of the switching element Q3.

[0086] Next, if the switching element Q2 is turned ON and the switching element Q3 is turned OFF, a current first flows through a path of capacitor C6 → coil L2 → capacitor C5 → parasitic diode (not shown) of switching element Q2 based on energy stored in the coil L2. After this, a current flows again through a path of positive side output terminal of output capacitor C4 → switching element Q2 → capacitor C5 → coil L2 → capacitor C6 → negative side output terminal of output capacitor C4. That is, a resonance current is caused to flow by the coil L2 and capacitor C6 of the LC resonance circuit 17.

[0087] Then, the high intensity discharge lamp HIDL starts to discharge and is lighted by the resonance voltage caused at this time. After the high intensity discharge lamp HIDL is lighted, a discharge current flows through a current path mainly including the capacitor C5, coil L2 and high intensity discharge lamp HIDL. In the inverter circuit 16, the operation of charging and discharging the capacitor C5 and the operation of storing and discharging energy on and from the coil L2 are performed according to the ON/OFF operation of the switching elements Q2, Q3 and a high-frequency current flows in the high intensity discharge lamp HIDL so as to permit the high intensity discharge lamp HIDL to maintain the high-frequency lighting operation.

[0088] The lamp power detecting means includes the voltage detecting means configured by the detecting line 15 and the current detecting means 18 for detecting a current Idet flowing in the switching element Q3 of the inverter circuit 16. The voltage detecting means detects DC voltage VDCdet output from the DC power supply circuit 12. The current detecting means 18 includes resistors R1, R2 and capacitor C7.

[0089] The control circuit 20 derives a signal corresponding to the lamp power by deriving an average value of a current of one cycle (for example, 1/100 second) of the low frequency based on the detected current Idet and subjecting the average value of the current and the detected DC voltage VDCdet to an arithmetic operation. The control circuit 20 converts the detected current Idet into a lamp current. Power supply monitoring means in the control circuit 20 detects output voltage of the full-wave rectifier circuit 13 used as rectifying means.

[0090] The lamp voltage detecting circuit 19 includes a detecting circuit which divides the high-frequency voltage across the high intensity discharge lamp HIDL by use of a series circuit of resistors R3 and R4 and detects the divided voltage and a voltage doubler rectifier circuit using two circuits including first and second circuits.

[0091] The first circuit includes a diode D6 and capacitor C8 and rectifies and smoothes half-wave voltage of an AC half cycle of the high-frequency voltage. The second circuit includes a diode D7 and capacitor C9 and rectifies and smoothes voltage obtained by adding the half-wave voltage of the high-frequency voltage to the rectified and smoothed voltage of the first circuit.

[0092] The control circuit 20 checks a variation in the lamp voltage by use of detected lamp voltage VLdet detected by the lamp voltage detecting circuit 19. Further, since the lamp voltage rises when an acoustic resonance phenomenon occurs in comparison with a case wherein no acoustic resonance phenomenon occurs, the control circuit 20 detects the rise of the lamp voltage by using the detected lamp voltage VLdet and determines occurrence of the acoustic resonance phenomenon based on the detection result.

[0093] FIG. 9 shows the relation between the lamp current I and the duty ratios of the switching elements Q2, Q3 in the high intensity discharge lamp lighting device 10 of FIG. 8. Control curves A, B in FIG. 9 indicate two modes Am, Bm in which the duty ratio control operation for the switching elements Q2, Q3 is performed according to a variation in the lamp current I when the lamp current I is changed from 100% of the rated value to 200% of the rated value.

[0094] The mode Am indicates a case wherein the duty ratio of the switching element Q2 is linearly increased with an increase in the lamp current I. The mode Bm indicates a case wherein the duty ratio of the switching element Q2 is increased in a curved form with an increase in the lamp current I.

[0095] FIG. 10 shows the relation between the electrode temperature and the duty ratios of the switching elements Q2, Q3 while the lamp is being lighted in the high intensity discharge lamp lighting device 10 of FIG. 8. Curves a1, b1 and c1 respectively indicate the electrode temperatures according to the magnitude of the lamp current with the magnitudes of the lamp current used as parameters.

[0096] The electrode temperature is set to the highest temperature when the duty ratios of the ON/OFF-control operation of the switching elements Q2, Q3 are set at 50%. The electrode temperature is lowered by changing the duty ratios of the ON/OFF-control operation of the switching elements Q2, Q3 into the inverse ratio relation for each half cycle of the low-frequency component and controlling the duty ratios to become higher than 50%.

[0097] FIG. 11 is a diagram showing the relation between the electrode temperature and the lamp current. A variation in the electrode temperature with a variation in the lamp current can be suppressed by using the characteristic of FIG. 10 and controlling the duty ratio to increase with a rise in the lamp current as shown in FIG. 9. As a result, the electrode temperature can be kept substantially constant.

[0098] That is, when the electrode temperature rises with an increase in the lamp current I, the control circuit 20 controls and keeps the electrode temperature constant by increasing the duty ratios of the switching elements Q2, Q3.

[0099] In FIG. 11, a graph of dotted lines indicates a case wherein the electrode temperature control operation is not performed and a graph of a solid line indicates a case wherein the electrode temperature control operation is performed by the duty ratio control operation of the present embodiment.

[0100] FIG. 12 shows one example of the lamp current waveform and a variation in the duty ratio of the switching elements Q2, Q3 when the lamp starts to be driven and when the lamp starts to be lighted. A variation in the duty ratio indicates a variation in the duty ratio with the passage of time after the power supply is turned ON. The lamp current waveform indicates a variation in the lamp current of the high frequency which varies for each half cycle of the low frequency according to a variation in the duty ratio. The lamp current waveform is obtained by superimposing the low-frequency current on the high-frequency current.

[0101] In this example, the duty ratios of the switching elements Q2, Q3 are controlled and set to 50% in the starting time period from the time of turn-ON of the power supply to the lamp lighting start time at which an arc discharge is detected. Then, after the lamp lighting start time, the duty ratios of the switching elements Q2, Q3 are set to an inverse ratio relation for each half cycle of the low frequency of, for example, 100 Hz according to the lamp current of the lamp voltage rise characteristic.

[0102] Occurrence of a half-wave discharge in the high intensity discharge lamp HIDL is suppressed when a glow discharge is transited to an arc discharge by controlling the duty ratio to 50% during the glow discharge.

[0103] FIG. 13 shows one example of the lamp voltage characteristic after the lamp is lighted. FIG. 13 is a diagram obtained by enlarging a rise portion of the lamp voltage characteristic of FIG. 7. The lamp power characteristic after lighting of the lamp is set to the same transient characteristic as that of the lamp voltage. However, the lamp power is controlled and normally set to the rated power at least at the stable lighting time.

[0104] The lamp voltage characteristic shown in FIG. 13 indicates a characteristic inherent to the individual lamp and indicates a characteristic in which the lamp voltage gradually rises after lighting of the lamp. The temperature of the light emission tube of the high intensity discharge lamp HIDL rises in a voltage rising period at the rise time of the lamp voltage. The lamp voltage is set into the stable state and set to substantially the constant voltage after the rise time has elapsed.

[0105] FIG. 14 shows an output signal waveform of the capacitor C9 at a point g of the voltage doubler rectifier circuit in the lamp voltage detecting circuit 19.

[0106] In this case, the operation of the voltage doubler rectifier circuit in the lamp voltage detecting circuit 19 is explained with reference to the high intensity discharge lamp lighting device 10 of FIG. 8.

[0107] When voltage at one end "a" of the high intensity discharge lamp HIDL becomes negative potential and voltage at the other end "b" becomes positive potential while high-frequency voltage is applied between the two ends "a" and "b" and the lamp is set in the high-frequency lighting state, then the potential of a point "e" is also set to negative potential with respect to the other end "b". In this state, the positive potential of the other end "b" is applied to the anode of the diode D6. Thus, the diode D6 is made conductive to charge the capacitor C8. As a result, potential at the point "f" is set to positive potential and potential at point "e" is set to negative potential.

[0108] In this state, if the polarities of the terminal voltages of the high intensity discharge lamp HIDL are inverted, the potential at the end "b" is set to the negative potential and the potential at the end "a" is set to positive potential, then the potential at the point "e" is set to positive potential. In this state, the potential of the point "f" is set to potential obtained by adding the positive voltage of the point "e" to the voltage charged on the capacitor C8. As a result, voltage which is almost twice the voltage of the point "e" appears on the point "f" and the capacitor C9 is charged via the diode D7 by the voltage.

[0109] Thus, voltage smoothed in the capacitor C9, that is, voltage corresponding to substantially an envelope curve waveform k of a high-frequency voltage waveform j shown in FIG. 14 is output the output terminal "g" of the capacitor C9 and supplied to the control circuit 20 as the detected lamp voltage VLdet.

[0110] The detected lamp voltage VLdet more rises in a case wherein the acoustic resonance phenomenon occurs than in a case wherein no acoustic resonance phenomenon occurs. Therefore, the control circuit 20 compares the detected lamp voltage VLdet with reference voltage V1 and determines occurrence of an acoustic resonance phenomenon when the detected lamp voltage VLdet exceeds the reference voltage V1. Thus, the acoustic resonance phenomenon detecting means can detect occurrence of an acoustic resonance phenomenon based on the detection result of the detected lamp voltage VLdet by the lamp voltage detecting means.

[0111] Since the high intensity discharge lamp lighting device 10 of FIG. 8 configured as described above can generate high voltage by use of LC resonance at the lamp starting time, an igniter circuit is not specifically required. Further, in order to prevent occurrence of an acoustic resonance phenomenon during the lamp lighting time, it can determine whether or not an acoustic resonance phenomenon occurs by detecting the lamp voltage.

[0112] FIGS. 15 to 17 show examples of the operation waveforms in the first embodiment of this invention.

[0113] FIG. 15 shows the current waveforms of the switching elements Q2, Q3 at the lamp starting time when the duty ratio is set at 50%.

[0114] FIG. 16 shows the current waveforms of the switching elements Q2, Q3 during the lamp lighting time when the duty ratio of the switching element Q2 is set at approximately 70% and the duty ratio of the switching element Q2 is set at approximately 30%.

[0115] FIG. 17 shows a state in which the duty ratios are set in an inverse ratio relation with respect to those of the current waveforms of FIG. 16 and shows a case where the duty ratio of the switching element Q2 is set at approximately 30% and the duty ratio of the switching element Q2 is set at approximately 70%.

[0116] In this case, the switching frequency at the lamp starting time in FIG. 15 is set twice the switching frequency set during the lighting time in FIGS. 16 and 17.

[0117] Thus, the switching frequency of the switching elements Q2, Q3, that is, the operation frequency of the inverter circuit 16 is changed at the lamp starting time and during the lamp lighting time. Specifically, the operation frequency of the inverter circuit 16 is set at a relatively high frequency at the starting time until lighting of the high intensity discharge lamp HIDL is started and set at a relatively low frequency which does not cause occurrence of an acoustic resonance phenomenon and is different from the operation frequency at the starting time after the lamp starts to be lighted. The lamp power of the high intensity discharge lamp HIDL is controlled to be reduced if the operation frequency of the inverter circuit 16 is set high and controlled to be increased if the operation frequency is set low. Therefore, the lamp power of the high intensity discharge lamp HIDL can be adjusted to a desired value by variably changing the operation frequency of the inverter circuit 16.

[0118] FIG. 18 shows one example of the lamp current waveform during the lamp lighting time. The lamp current waveform is a lamp current waveform when the switching control operation of FIG. 16 and the switching control operation of FIG. 17 are alternately performed for the inverter circuit 16 for each half cycle of the low-frequency cycle by use of the control circuit 20. The lamp current waveform is set to a waveform obtained by superimposing a rectangular wave of the low-frequency cycle on the operation frequency of the inverter circuit 16.

[0119] In the switching control operation of FIG. 16, a low-frequency component is superimposed for each half cycle of the lamp output waveform as shown in FIG. 18. Thus, since the low-frequency power component can be applied to the lamp, a rise in the electrode temperature of the high intensity discharge lamp HIDL can be suppressed and the lamp service life can be made longer.

[0120] A period in which "Q2 long" is described in FIG. 18 indicates that the duty ratio in which the ON-period of the switching element Q2 is longer than the ON-period of the switching element Q3 is set. Further, a period in which "Q3 long" is described indicates that the duty ratio in which the ON-period of the switching element Q3 is longer than the ON-period of the switching element Q2 is set.

[0121] FIG. 19 is a diagram for illustrating the relation between the ON/OFF operation of the switching elements Q2, Q3 and the lamp current waveform of the high intensity discharge lamp HIDL.

[0122] Specifically, FIG. 19 shows the operation waveforms and current waveforms obtained when the inverter circuit 16 performs the ON/OFF-operation for the switching elements Q2, Q3 at a high frequency of, for example, 40 kHz during the lamp lighting time and a case wherein the switching element Q2 is operated with the duty ratio of 70% and the switching element Q3 is operated with the duty ratio of 30% and a case wherein the switching element Q2 is operated with the duty ratio of 30% and the switching element Q3 is operated with the duty ratio of 70% are alternately switched for each half cycle of the low frequency of 100 Hz. By performing the above operation, a lamp current waveform as shown in FIG. 18 flows in the high intensity discharge lamp HIDL.

[0123] In FIGS. 16 to 19, a case wherein the operation of setting the ON-state duty ratios of the switching elements Q2, Q3 to 70% and 30% and the operation of setting the ON-state duty ratios to the inverse ratio relation of 30% and 70% are alternately switched for each half cycle of the low frequency is explained. However, a case wherein the operation of setting the ON-state duty ratios of the switching elements Q2, Q3 to 100% and 0% and the operation of setting the ON-state duty ratios to the inverse ratio relation of 0% and 100% are alternately switched is also contained in this invention.

[0124] In the high intensity discharge lamp lighting device 10 with the above configuration, the two switching elements Q2, Q3 can be efficiently driven only at the high frequency by use of the LC resonance by setting the duty ratio to 50%, for example, at the lamp starting time. Then, after the lamp lighting start time, a low-frequency component can be superimposed on the high-frequency component by additionally performing the control operation of, for example, switching the duty ratios 70% and 30% of the switching elements Q2, Q3 which are different from those at the starting time for each half cycle of the low frequency. As a result, the electrode temperature of the high intensity discharge lamp lighting device 10 can be suppressed from becoming excessively high.

[0125] Since the electrode temperature tends to become high with an increase in the lamp current at the rise time after the lamp is lighted, the high intensity discharge lamp lighting device 10 can perform the efficient lighting operation at the adequate electrode temperature by increasing the duty ratio of the switching element Q2 between 50% and 100% and returning the duty ratio to approximately 50% when it is set into the stable lighting state.

[0126] Further, the high intensity discharge lamp lighting device 10 switches and drives the switching elements Q2, Q3 of the inverter circuit 16 at a relatively high frequency at the starting time until the high intensity discharge lamp HIDL is lighted. When the high intensity discharge lamp HIDL starts to be lighted, the switching elements are switched and driven at a relatively low frequency which does not cause occurrence of an acoustic resonance phenomenon and is different from the switching frequency at the starting time. Thus, the high intensity discharge lamp lighting device 10 can control and set the lamp power to a desired value.

[0127] FIG. 20 is a cross sectional view showing the structure of an illumination apparatus according to this invention.

[0128] An illumination apparatus 21 includes the high intensity discharge lamp lighting device 10 shown in FIG. 8 and an equipment main body 23 on which the high intensity discharge lamp HIDL is mounted. The high intensity discharge lamp HIDL is mounted on a socket 24 of the equipment main body 23 and is lighted by the high intensity discharge lamp lighting device 10.

[0129] When the high intensity discharge lamp HIDL is lighted, light from the high intensity discharge lamp HIDL is reflected from a reflection plate 25 on the front surface side and emitted as emission light to the exterior via a front-side glass plate 26. Thus, the illumination apparatus 21 has the same effect as that of the high intensity discharge lamp lighting device 10.

[0130] FIG. 21 is a cross sectional view showing the structure of the high intensity discharge lamp HIDL. The high intensity discharge lamp HIDL has a pair of rod-like electrodes 62 and 63 whose head portions are disposed to face each other in a glass container 61. The electrodes 62, 63 have conductive wires wound on the head portions for the purpose of keeping warmth.

[0131] In the high intensity discharge lamp HIDL, it is preferable to set the current density Ia/D^2 in the range of 4 to 20 when the rated lamp current is Ia [A] and the diameter of the electrode is D [mm].

[0132] For the design of the dimming lamp, the lamp dimension is previously set to a small value in some cases. The electrode dimension is represented by the diameter of the electrode head portions 62, 63. However, if such a lamp is used, the electrode temperature is set slightly higher than the adequate value and the lamp service life becomes shorter when a lamp current is large at the full-lighting time or at the rise time.

[0133] With the configuration of this invention, the electrode temperature can be maintained in the adequate range over a wide range of the lamp current.

[0134] According to this invention, as described before, the electrode temperature can be lowered by adjusting the rate of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component. That is, the electrode temperature can be set to the adequate value. At the dimming time, the adequate electrode temperature can be attained by lighting the lamp with the adjusted lamp current waveform. Thus, occurrence of a problem such as the short service life, flickering and extinguishing of the lamp can be prevented over a wide range of the lamp current.

[0135] The following embodiments can be provided as described in the following items (1) to (3) as application examples of the first embodiment.

(1) In the high intensity discharge lamp lighting device 10, the component ratio changing means provided in the control circuit 20 may be configured to perform the control operation to change the high-frequency component and low-frequency component contained in the output of the superimposed power outputting means at the rise time of the high intensity discharge lamp HIDL.
An excessively large lamp current flows at the rise time after lighting. At this time, the electrode temperature can be lowered and maintained in the adequate range by passing the superimposed current containing the high-frequency component and low-frequency component. As a result, since an evaporation amount of the electrode material is suppressed, the service life of the lamp can be made longer.
The rise time after lighting of the high intensity discharge lamp HIDL is a preset time, for example, 60 seconds after lighting as shown in FIG. 7 and a rise in the electrode temperature is suppressed by passing the superimposed current containing the high-frequency component and low-frequency component during the above time period.

(2) In the high intensity discharge lamp lighting device 10, the lamp characteristic detecting means is lamp current detecting means for detecting a lamp current and it is preferable to change the ratio of the current value of the high-frequency component to the current value of the low-frequency component according to the detection result of the lamp current.
The lamp current is a factor which gives a large influence on the lamp electrode temperature. Therefore, the control circuit 20 can keep the electrode temperature substantially constant irrespective of a variation in the lamp current by detecting a lamp current based on the detected value of the current detecting circuit 18 and changing the component ratio of the high-frequency component to the low-frequency component according to an increase or decrease in the lamp current.

(3) In the high intensity discharge lamp lighting device 10, the lamp characteristic detecting means is lamp current detecting means for detecting a lamp current and the component ratio changing means provided in the control circuit 20 may be configured to control and set the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component closer to 1:1 when the lamp current increases.

[0136] The control circuit 20 detects a lamp current based on the detected value of the current detecting circuit 18. It performs the control operation to lower the electrode temperature by setting the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component closer to 1:1 as shown in FIG. 3 when the lamp current increases.

[0137] The high intensity discharge lamp lighting device 10 in the first embodiment described above and the illumination apparatus using the above lighting device can control the electrode temperature of the high intensity discharge lamp by changing the component ratio of the high-frequency component to the low-frequency component of the superimposed wave current or changing the duty ratios of the ON/OFF control periods of the two series-connected switching elements Q2, Q3. As a result, the service life of the high intensity discharge lamp can be made longer and occurrence of a problem such as flickering and extinguishing of the high intensity discharge lamp can be prevented.

(Second Embodiment)

[0138] FIG. 22 is a circuit diagram showing a high intensity discharge lamp lighting device according to a second embodiment of this invention. Portions which are the same as those of FIG. 8 are denoted by the same reference symbols and the explanation thereof is omitted.

[0139] In FIG. 22, a high intensity discharge lamp lighting device 10A includes an AC power supply AC, a noise filter circuit 11 configured by capacitors C1, C2 and transformer T1, a full-wave rectifier circuit 13 configured by diodes D1 to D4, a high-frequency component elimination capacitor C3, a voltage step-up chopper circuit 14 which is supplied with rectified voltage from the full-wave rectifier 13 and outputs DC voltage VDC, a voltage detecting line 15 as DC voltage detecting means, and an inverter circuit 16 which is inverter means including an LC resonance circuit 17 which converts DC voltage VDC from the voltage step-up chopper circuit 14 into high-frequency voltage, applies the thus converted voltage to a high intensity discharge lamp HIDL and lights the lamp.

[0140] The voltage step-up chopper circuit 14 includes coil LI, switching element QI, diode D5 and output capacitor C4. The inverter circuit 16 is supplied with the DC voltage from the voltage step-up chopper circuit 14 at both ends of a series circuit of two switching elements Q2, Q3 to convert the same into high-frequency voltage.

[0141] The high intensity discharge lamp lighting device 10A further includes a current detecting circuit 18 which is detecting means for detecting the switching element current of the inverter circuit 16, a high intensity discharge lamp HIDL, and a voltage detecting circuit 19 which is lamp voltage detecting means for detecting lamp voltage of the high intensity discharge lamp HIDL.

[0142] Further, the high intensity discharge lamp lighting device 10A includes a control circuit 20 which controls DC voltage VDC output from the voltage step-up chopper circuit 14 by controlling one or both of the duty ratio and the switching frequency of the switching element Q1 of the voltage step-up chopper circuit 14 and controls the lighting frequency of the high intensity discharge lamp HIDL by controlling the switching frequencies of the two switching elements Q2, Q3 of the inverter circuit 16, that is, the operation frequencies. The duty ratio of the switching element Q1 indicates the ratio of the ON period to a period of the switching cycle.

[0143] Also, the high intensity discharge lamp lighting device 10A includes a dimming signal generating circuit 28 which supplies a dimming signal, for example, a PWM (pulse width modulation) signal used to dim the high intensity discharge lamp HIDL to the control circuit 20. That is, the high intensity discharge lamp lighting device 10A has a dimming function.

[0144] In the present embodiment, the control circuit 20 alternately ON/OFF-controls the two switching elements Q2, Q3 of the inverter circuit 16. That is, the control circuit 20 has a function of controlling the switching elements Q2, Q3 with the duty ratios set at approximately 50% at the lamp starting time and with the duty ratios different from 50% at the lamp lighting time. At the lamp lighting time, the different duty ratios of the switching elements Q2 and Q3 are alternately switched into an inverse ratio relation on a cycle longer than the switching cycle of the switching elements Q2, Q3.

[0145] The inverter circuit 16 includes a half-bridge type high-frequency inverter having two switching elements Q2, Q3 which are serially connected, a DC-cut capacitor C5 and an LC resonance circuit 17 configured by a coil L2 and capacitor C6.

[0146] The inverter circuit 16 is supplied with DC voltage VDC from the voltage step-up chopper circuit 14 and alternately turns ON/OFF the switching elements Q2, Q3 by use of two switching pulses set in an inverted phase relation with the same switching frequency and the same duty ratio 50% at the lamp starting time. Then, at the lamp lighting time, it alternately turns ON/OFF the switching elements Q2, Q3 by use of two switching pulses set in an inverted phase relation with the same switching frequency and different duty ratios. For example, if the switching element Q2 is turned ON/OFF with the duty ratio 70%, the switching element Q3 is turned OFF/ON with the duty ratio 30%.

[0147] The high intensity discharge lamp lighting device 10A is supplied with DC voltage from the DC power supply circuit, converts the same into high-frequency voltage and supplies the thus converted voltage to the high intensity discharge lamp HIDL.

[0148] The lighting frequency of the high intensity discharge lamp HIDL is controlled by controlling the switching frequencies of the two switching elements Q2, Q3 of the inverter circuit 16. The high-frequency output from the inverter circuit 16 is applied across the high intensity discharge lamp HIDL to light the high intensity discharge lamp HIDL at the high frequency.

[0149] The lamp power detecting means includes voltage detecting means configured by a detecting line 15 and current detecting means 18 for detecting a current Idet flowing in the switching element Q3 of the inverter circuit 16. The voltage detecting means detects DC voltage VDCdet output from the DC power supply circuit 12. The current detecting means 18 is configured by resistors R1, R2 and capacitor C7.

[0150] The control circuit 20 derives a signal corresponding to the lamp power by deriving an average value of a current of one cycle (for example, 1/100 second) of the low frequency based on the detected current Idet and subjecting the average value of the current and the detected DC voltage VDCdet to an arithmetic operation.

[0151] Next, one example of the operation associated with the electrode temperature control operation at the dimming time in the high intensity discharge lamp lighting device 10A is explained with reference to FIG. 23.

[0152] FIG. 23 shows a variation in the superimposition rate of the low-frequency component current in the lamp current when the lamp current is changed. In FIG. 23, the abscissa indicates the lamp current and the ordinate indicates the superimposition rate of the low-frequency component current.

[0153] The control circuit 20 detects a lamp current based on the detected value of the current detecting circuit 18 and controls the superimposition rate of the current value I_2 of the low-frequency component to the sum of the current value I_1 of the high-frequency component and the current value I_2 of the low-frequency component as shown in FIG. 23.

[0154] That is, the control circuit 20 performs the control operation to set the superimposition rate of the low-frequency component closer to 0% or provide only the high-frequency component when the lamp current is small. On the other hand, it performs the control operation to set the superimposition rate of the low-frequency component closer to 50% or set the high-frequency component and low-frequency component to half and half when the lamp current is large.

[0155] Thus, the high intensity discharge lamp lighting device 10A can prevent the electrode temperature from being set excessively low when the lamp current is small and suppress the electrode temperature from being set excessively high when the lamp current is large. As a result, it can control the electrode temperature to be kept substantially constant irrespective of the degree of dimming. Therefore, the high intensity discharge lamp lighting device 10A can elongate the service life of the high intensity discharge lamp and prevent occurrence of a problem such as flickering and extinguishing.

[0156] In the second embodiment, the configurations as will be described below can be made as applications. That is, in the high intensity discharge lamp lighting device 10A, the control circuit 20 includes component ratio changing means for changing the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component. The component ratio changing means changes the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component in the superimposed wave current according to the level of a dimming signal input from the exterior.

[0157] In the high intensity discharge lamp lighting device 10A with the above configuration, a lamp current supplied to the high intensity discharge lamp HIDL is controlled to perform the dimming operation according to the level of a dimming signal input from the exterior. The component ratio changing means in the control circuit 20 changes the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component in the superimposed wave current according to the level of the dimming signal.

[0158] Thus, the high intensity discharge lamp lighting device 10A can adjust the electrode temperature of the high intensity discharge lamp HIDL. That is, the component ratio changing means performs the control operation to separate the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component apart from the component ratio 1:1 when the lamp current is made small due to the dimming operation. Further, it performs the control operation to set the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component closer to the component ratio 1:1 when the lamp current is made large due to the dimming operation. Thus, the high intensity discharge lamp lighting device 10A can keep the electrode temperature of the high intensity discharge lamp HIDL substantially constant even when the lamp current is changed before and after the dimming operation. As a result, the lamp service life of the high intensity discharge lamp HIDL can be made longer and occurrence of a problem such as flickering and extinguishing can be suppressed.

[0159] If the illumination apparatus is configured in the same manner as in FIG. 20 by use of the high intensity discharge lamp lighting device 10A of FIG. 22 and the high intensity discharge lamp HIDL, the illumination apparatus which permits the high intensity discharge lamp to have long service life can be realized.

[0160] The high intensity discharge lamp lighting device 10A described in the second embodiment and the illumination apparatus using the lighting device can control the electrode temperature of the high intensity discharge lamp and keep the electrode temperature substantially constant before and after the dimming operation by changing the component ratio of the high-frequency component to the low-frequency component or the duty ratios of the ON/OFF control operations of the two series-connected switching elements Q2, Q3 according to the level of the dimming signal when the high intensity discharge lamp is controlled for dimming. Thus, the service life of the high intensity discharge lamp can be made longer and occurrence of a problem such as flickering and extinguishing of the high intensity discharge lamp can be prevented.

[Third Embodiment]

[0161] FIG. 24 is a circuit diagram showing a high intensity discharge lamp lighting device according to a third embodiment of this invention.

[0162] In FIG. 24, a reference symbol 30 indicates a high intensity discharge lamp lighting device and the high intensity discharge lamp lighting device 30 includes an AC power supply 31, full-wave rectifier circuit 32, voltage step-up circuit 33, voltage step-down circuit 34, inverter circuit 35 and starting means 36.

[0163] The voltage step-down circuit 34 generates a waveform signal of a waveform having a non-resonance frequency component used to stably excite a discharge arc with the central line of the waveform kept at a constant level. The inverter circuit 35 configures means for alternately switching the polarity of the central line of the waveform signal at a frequency (low frequency) lower than the acoustic resonance frequency (high frequency). The starting means 36 supplies sufficiently high voltage to a high intensity discharge lamp 37 so as to cause the high intensity discharge lamp 37 to start the discharging operation.

[0164] The high intensity discharge lamp 37 is a high intensity discharge lamp having a metal halide and mercury sealed therein as a filling material in the glass tube which defines a discharge space. The high intensity discharge lamp lighting device 30 supplies a wave shown in FIG. 25 to the high intensity discharge lamp 37 to control the lighting operation thereof.

[0165] The circuit operation of the high intensity discharge lamp lighting device 30 with the above configuration is explained below.

[0166] In FIG. 25, w1 indicates an output waveform of the voltage step-down circuit 34 and w2 indicates an output waveform of the inverter circuit 35.

[0167] The voltage step-down circuit 34 configures a voltage step-down chopper circuit by use of a transistor 38, diode 39, choke coil 40 and capacitor 41 having variable electrostatic capacitance. It detects voltage corresponding to the lamp voltage by use of a series circuit of resistors 42 and 43, supplies a detection signal to a control circuit 45, detects voltage corresponding to the lamp current by use of a resistor 44, and supplies a detection signal to the control circuit 45.

[0168] The control circuit 45 derives lamp power based on the detection signal corresponding to the lamp voltage and the detection signal corresponding to the lamp current and variably changes the ON/OFF ratio of the transistor 38 to set the lamp power to the rated value.

[0169] The voltage step-down circuit 34 sets the ON/OFF switching frequency of the transistor 38 by the control circuit 45 to the non-resonance frequency used to stably excite the discharge arc. Further, it sets a filter circuit configured by the choke coil 40 and capacitor 41 to have a characteristic in which the non-resonance frequency component is not cut off. As a result, the output waveform w1 is set to be a waveform obtained by superimposing preset DC bias on a central line of a signal whose instantaneous value periodically varies at the non-resonance frequency used to stably excite the discharge arc, as shown in FIG. 25.

[0170] The inverter circuit 35 is configured by transistors 46, 47, 48, 49 and drive circuit 50. It converts an output waveform of the voltage step-down circuit 34 to an output waveform w2 whose polarity is alternately switched at a frequency lower than the high non-resonance frequency by alternately providing a period in which the transistors 46, 49 are set in the ON state and a period in which the transistors 47, 48 are set in the ON state according to an output signal from the drive circuit 50 and supplies the thus converted waveform to the high intensity discharge lamp 37.

[0171] The high intensity discharge lamp 37 which starts the discharging operation in response to high voltage from the starting means 36 is lighted by the output waveform w2 from the inverter circuit 35. The depth of modulation becomes smaller as the electrostatic capacitance of the capacitor 41 becomes larger and the depth of modulation becomes larger as the electrostatic capacitance of the capacitor 41 becomes smaller. In this case, the "depth of modulation" indicates the ratio of the amplitude of a high-frequency component P to that of a low-frequency component.

[0172] In the high intensity discharge lamp lighting device 30 with the above configuration, the component ratio of the current value of the high-frequency component to the current value of the low-frequency component can be changed, that is, the superimposition rate of the current value of the low-frequency component can be changed by setting the electrostatic capacitance of the capacitor 41 variable.

[0173] Therefore, the high intensity discharge lamp lighting device 30 can control the electrode temperature of the high intensity discharge lamp 37 by changing the electrostatic capacitance of the capacitor 41 and adjust a variation in the electrode temperature of the high intensity discharge lamp 37 to keep the same substantially constant. As a result, the service life of the high intensity discharge lamp can be made longer and occurrence of a problem such as flickering and extinguishing of the high intensity discharge lamp can be prevented.

[0174] If the illumination apparatus is configured like the case of FIG. 20 by use of the high intensity discharge lamp lighting device 30 of FIG. 24 and the high intensity discharge lamp 37, the illumination apparatus in which the service life of the high intensity discharge lamp 37 can be elongated can be realized.

[0175] The high intensity discharge lamp lighting device 30 of the third embodiment and the illumination apparatus using the above lighting device can control the electrode temperature of the high intensity discharge lamp 37 by changing the electrostatic capacitance of the capacitor 41. Even if the electrode temperature of the high intensity discharge lamp 37 is varied, the above lighting device and illumination apparatus can adjust a variation in the electrode temperature to keep the electrode temperature substantially constant. As a result, the service life of the high intensity discharge lamp can be made longer and occurrence of a problem such as flickering and extinguishing of the high intensity discharge lamp can be prevented.

Claims

1. A high intensity discharge lamp lighting device which has DC power supply means (2) and controls a lighting operation of a high intensity discharge lamp (7), **characterized by** comprising:

   superimposed power outputting means (3, 4, 5, 6) for outputting power containing a high-frequency component and low-frequency component to the high intensity discharge lamp.

2. The high intensity discharge lamp lighting device according to claim 1, **characterized in that** the superimposed power outputting means (3, 4, 5, 6) sets a current value I_1 of the high-frequency component and a current value I_2 of the low-frequency component of a superimposed current value in the output power into a relation of $I_1 > I_2$.

3. The high intensity discharge lamp lighting device according to one of claims 1 and 2, **characterized in that** the superimposed power outputting means (3, 4, 5, 6) includes component ratio changing means (52) for changing a component ratio of the high-frequency component to the low-frequency component.

4. The high intensity discharge lamp lighting device according to claim 3, **characterized in that** the component ratio changing means (52) changes the component ratio of the high-frequency component to the low-frequency component at rise time of the high intensity discharge lamp.

5. The high intensity discharge lamp lighting device according to claim 3, **characterized in that** the component ratio changing means (52) changes the component ratio of the high-frequency component to the low-frequency component according to a dimming signal input from an exterior.

6. The high intensity discharge lamp lighting device according to any one of claims 3 to 5, **characterized in that** the component ratio changing means (52) changes the component ratio of the high-frequency component to the low-frequency component according to a detection result of lamp characteristic detecting means (51) for detecting the characteristic of the high intensity discharge lamp (7).

7. The high intensity discharge lamp lighting device according to claim 6, **characterized in that** the lamp characteristic detecting means (51) is lamp current detecting means (18) for detecting a lamp current and the component ratio changing means (52) changes the component ratio of the current value I_1 of the high-frequency component to the current value I_2 of the low-frequency component according to a detection result of the lamp current by the lamp current detecting means (18).

8. The high intensity discharge lamp lighting device according to claim 7, **characterized in that** the component ratio changing means (52) performs a control operation to set the ratio of the current value of the high-frequency component to the current value of the low-frequency component closer to a ratio 1:1 of the high-frequency component to the low-frequency component in which the electrode temperature of the high intensity discharge lamp (7, HIDL) is set to the lowest temperature when the lamp current detecting means (18) detects an increase in the lamp current.

9. The high intensity discharge lamp lighting device according to any one of claims 1 to 8, **characterized in that** the superimposed power outputting means (3, 4, 5, 6) includes inverter means (16) having a series circuit of two switching elements (Q2, Q3) which are connected in series and alternately turned ON/OFF, and control means (20) for performing a control operation to alternately turn ON/OFF the two switching elements (Q2, Q3) of the inverter means (16), the inverter means (16) converts DC voltage from the DC power supply means (2, 12) to high-frequency voltage by applying the DC voltage across the series circuit of the two switching elements (Q2, Q3) and outputs the thus converted high-frequency voltage to the high intensity discharge lamp (7, HIDL), and the control means (20) changes duty ratios of the switching elements (Q2, Q3) on a cycle of a low frequency longer than a switching cycle of each switching element (Q2, Q3) and alternately changes the duty ratios of the switching elements (Q2, Q3) in an inverse ratio relation.

10. The high intensity discharge lamp lighting device according to claim 9, which further comprises lamp voltage detecting means (19) for detecting lamp voltage of the high intensity discharge lamp (7, HIDL) and in which the control means (20) controls and sets the switching frequency of the two switching elements (Q2, Q3) at lamp lighting time to a frequency which is different from the switching frequency at lamp starting time and does not cause an acoustic resonance phenomenon when the lamp voltage detected by the lamp voltage detecting means (19) exceeds a reference voltage used to determine occurrence of an acoustic resonance phenomenon.

11. An illumination apparatus having a high intensity discharge lamp (7, HIDL), **characterized by** comprising:

    a high intensity discharge lamp lighting device (1, 10, 10A) described in one of claims 1 to 10.

12. The illumination apparatus according to claim 11, **characterized in that** the high intensity discharge lamp (HIDL) has Ia/D^2 which is set in a range of 4 to 20 when a rated lamp current is set to Ia [A] and a diameter of an electrode is set to D [mm].

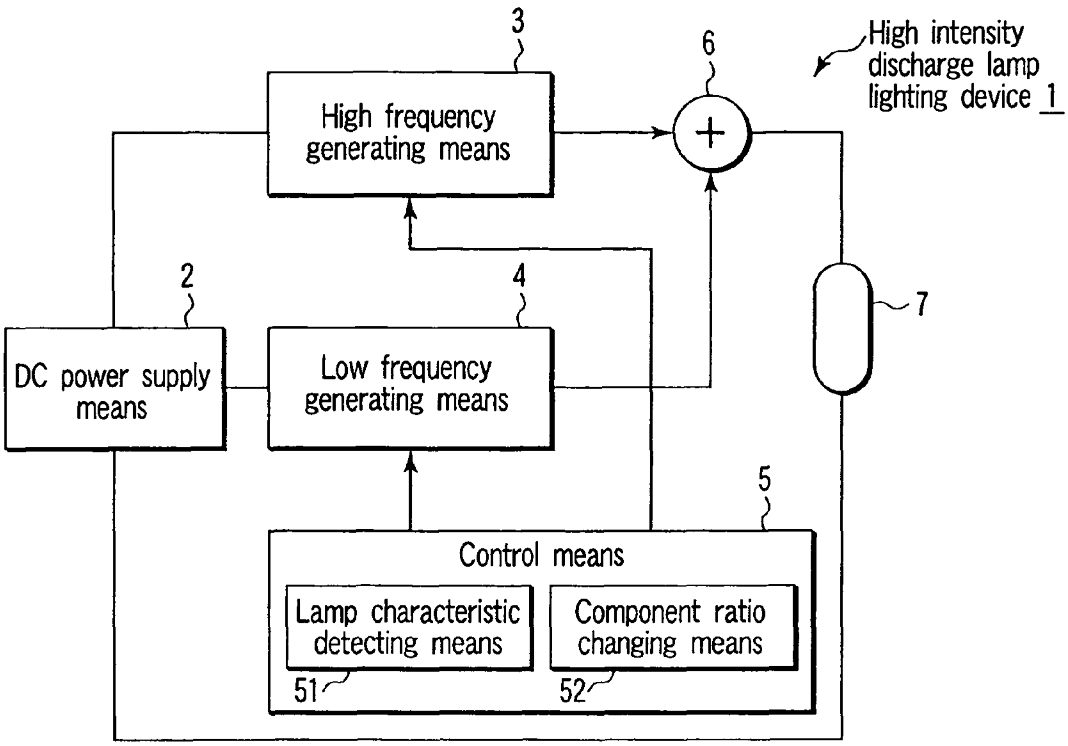

3
6
High intensity
discharge lamp
lighting device 1
High frequency
generating means
2
4
7
DC power supply
means
Low frequency
generating means
5
Control means
Lamp characteristic
detecting means
Component ratio
changing means
51
52

FIG.1

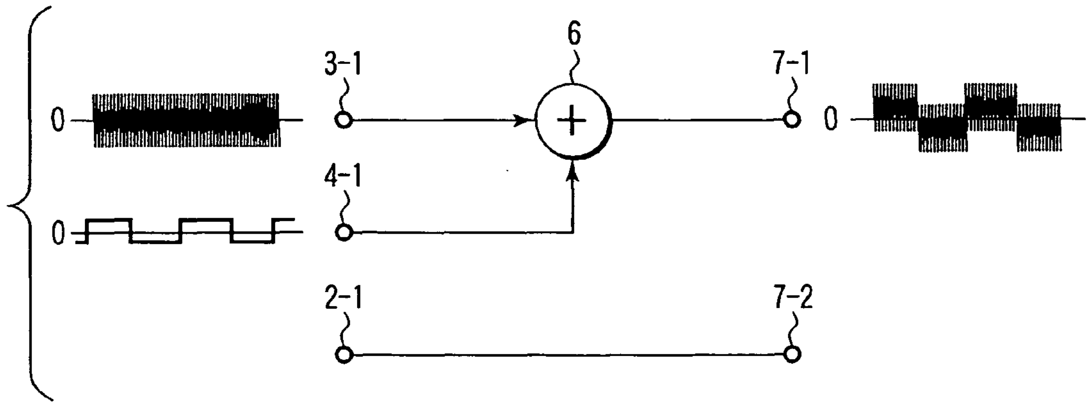
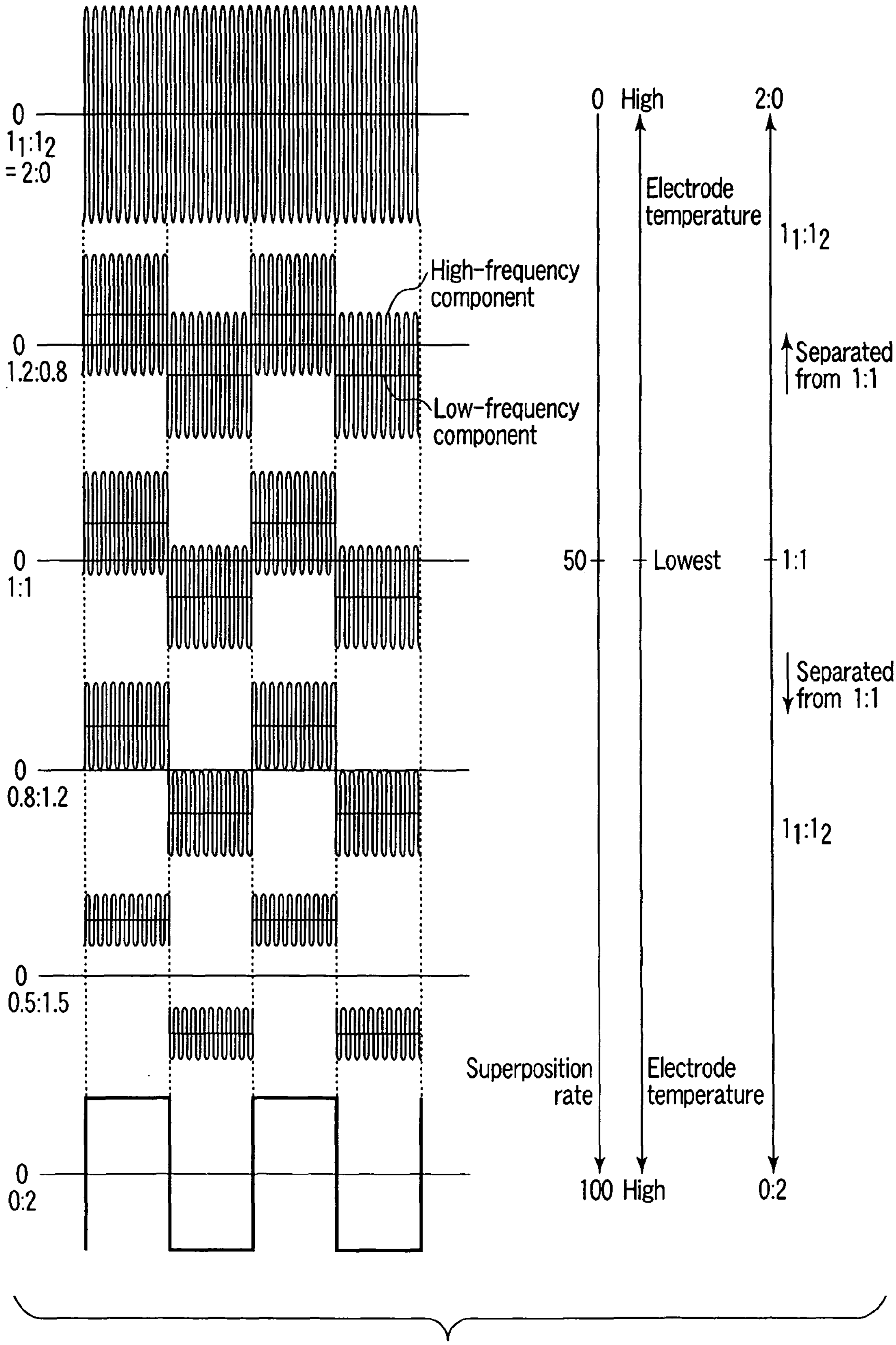

6
3-1
7-1
0
0
4-1
0
2-1
7-2

FIG.2



0
I1:I2
= 2:0
0
1.2:0.8
0
1:1
0
0.8:1.2
0
0.5:1.5
0
0:2
High-frequency component
Low-frequency component
0
50
100
Superposition rate
High
Electrode temperature
Lowest
Electrode temperature
High
2:0
I1:I2
Separated from 1:1
1:1
Separated from 1:1
I1:I2
0:2

FIG. 3

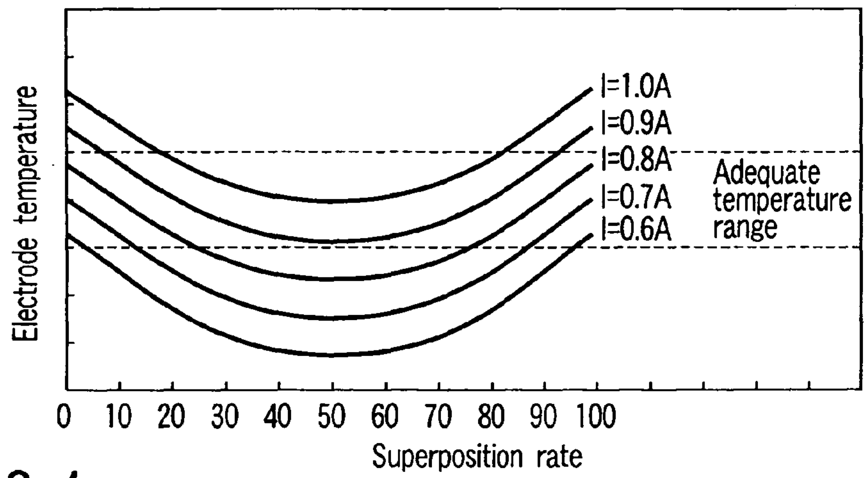


FIG. 4

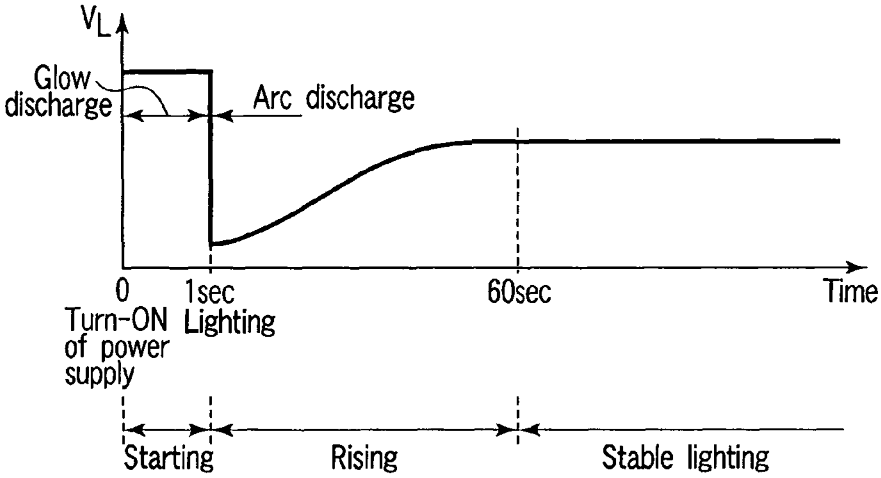


FIG. 7

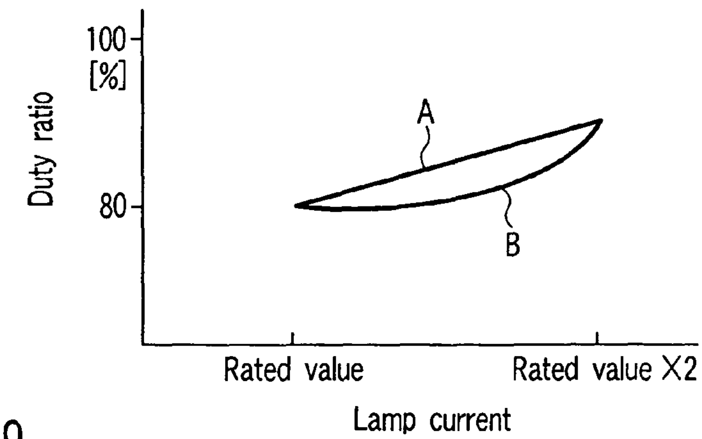


FIG. 9

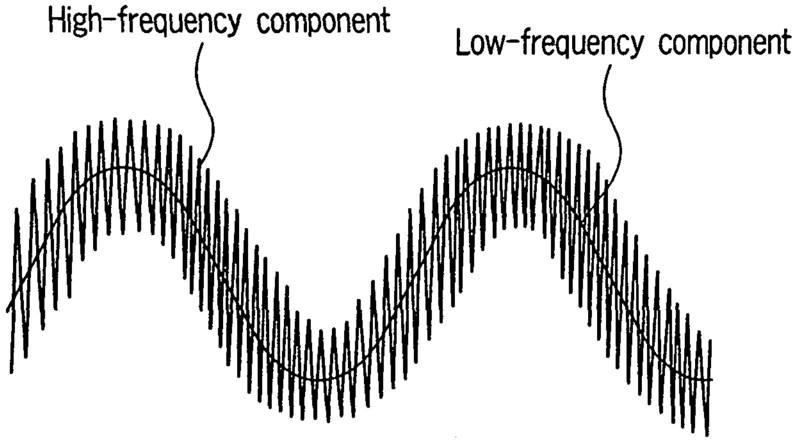

High-frequency component
Low-frequency component

FIG.5

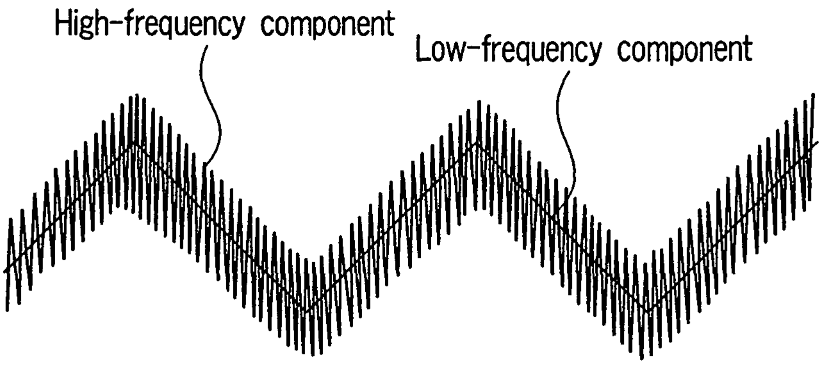
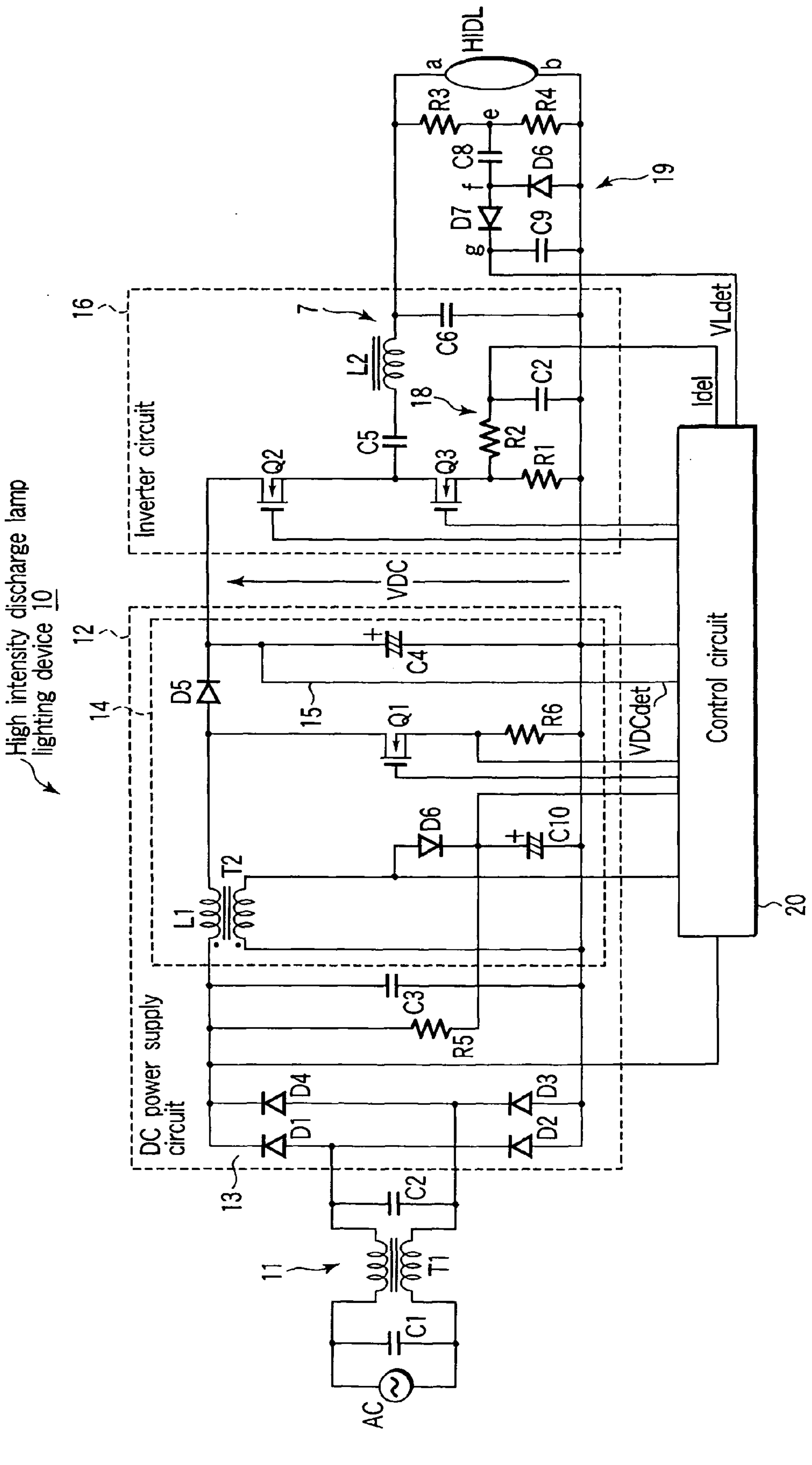

High-frequency component
Low-frequency component

FIG.6


High intensity discharge lamp lighting device 10
DC power supply circuit
Inverter circuit
Control circuit
AC
HIDL
VDC
VDCdet
Idel
VLdet
C1
T1
C2
D1
D2
D3
D4
R5
C3
L1
T2
D6
C10
Q1
R6
D5
C4
Q2
Q3
C5
R1
R2
L2
C6
D7
C9
C8
D6
R3
R4
a
b
e
f
g
7
11
12
13
14
15
16
18
19
20

F I G. 8

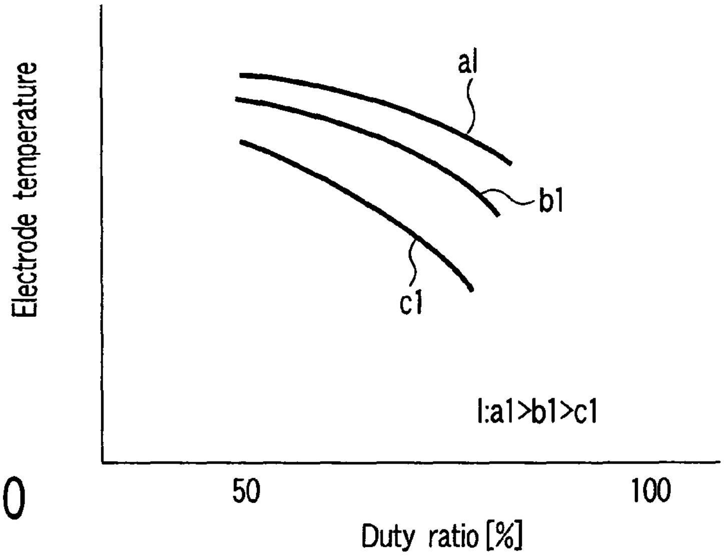


FIG. 10

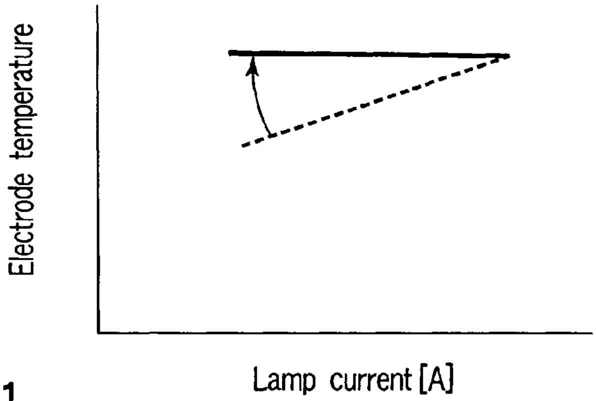


FIG. 11

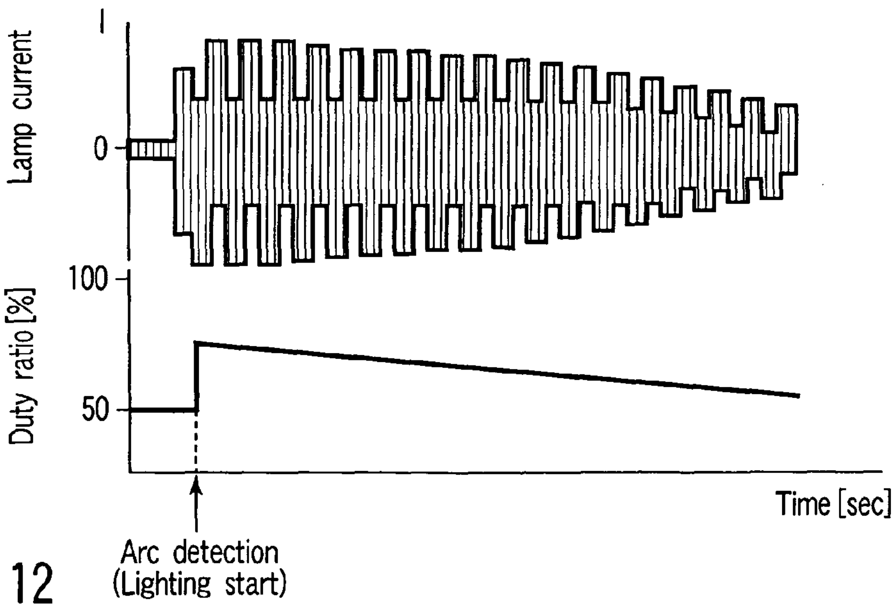
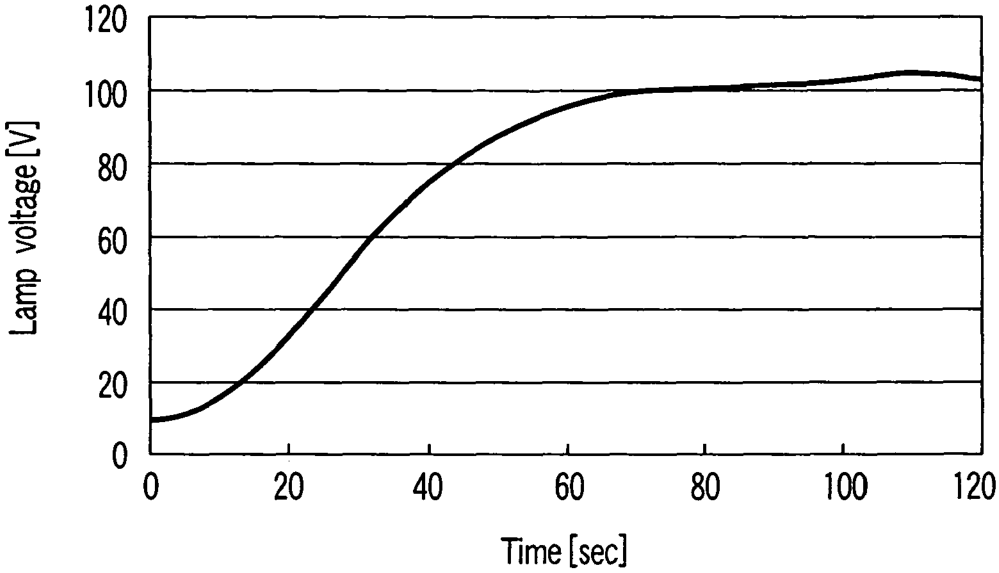
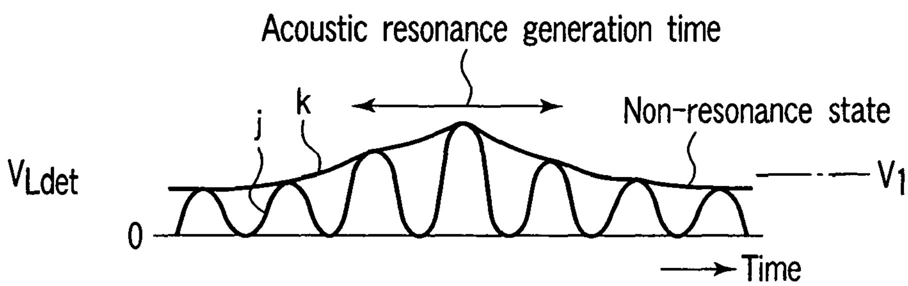


FIG. 12


120
100
80
60
40
20
0
Lamp voltage [V]
0
20
40
60
80
100
120
Time [sec]

F I G. 13


Acoustic resonance generation time
k
j
Non-resonance state
VLdet
V1
0
Time

F I G. 14

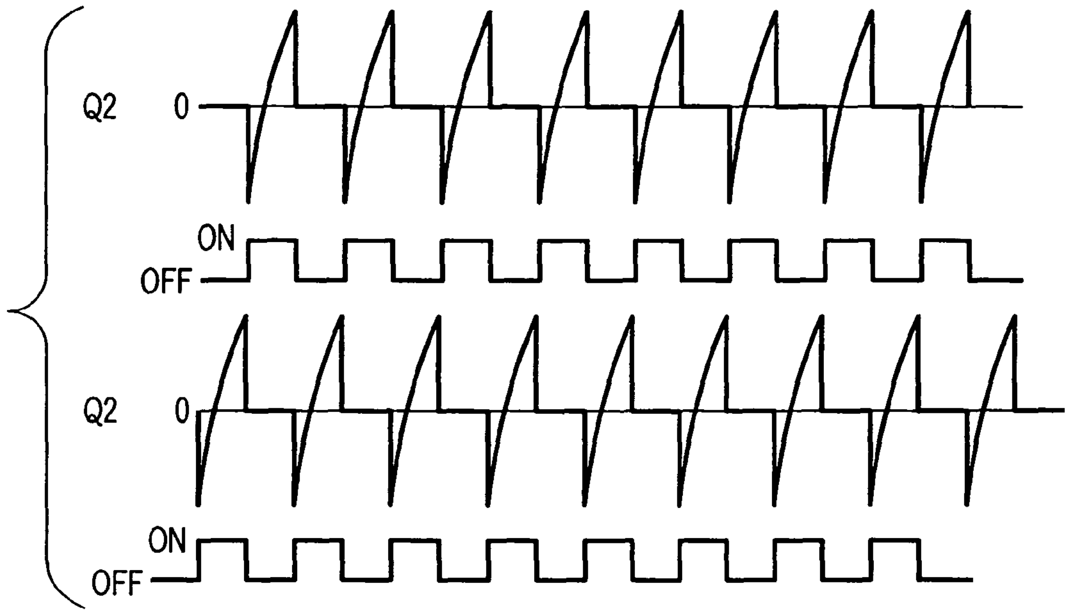


FIG. 15

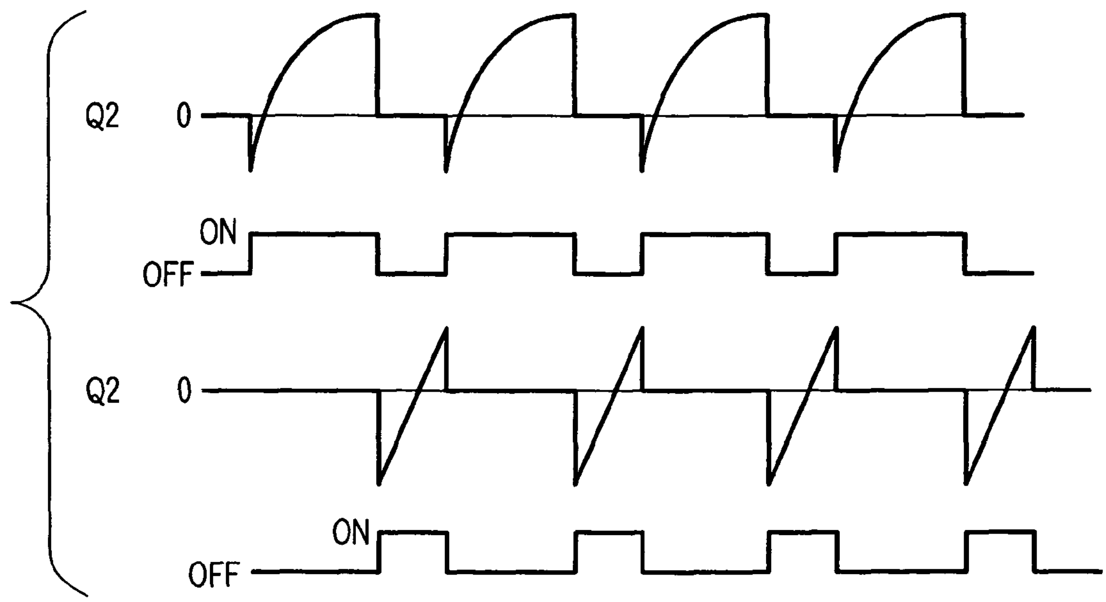
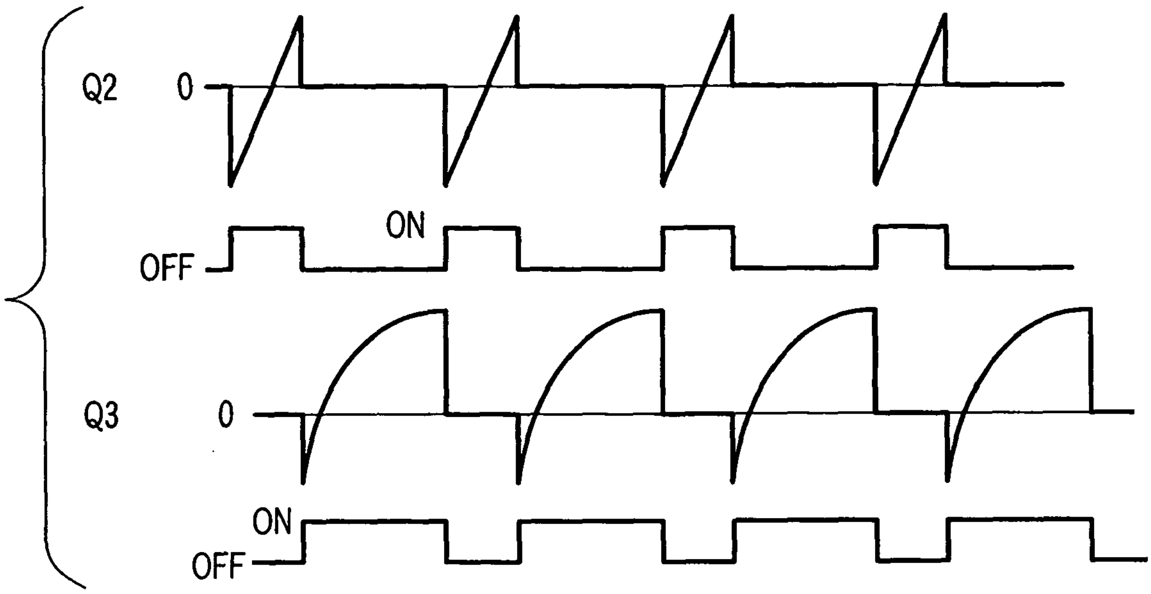
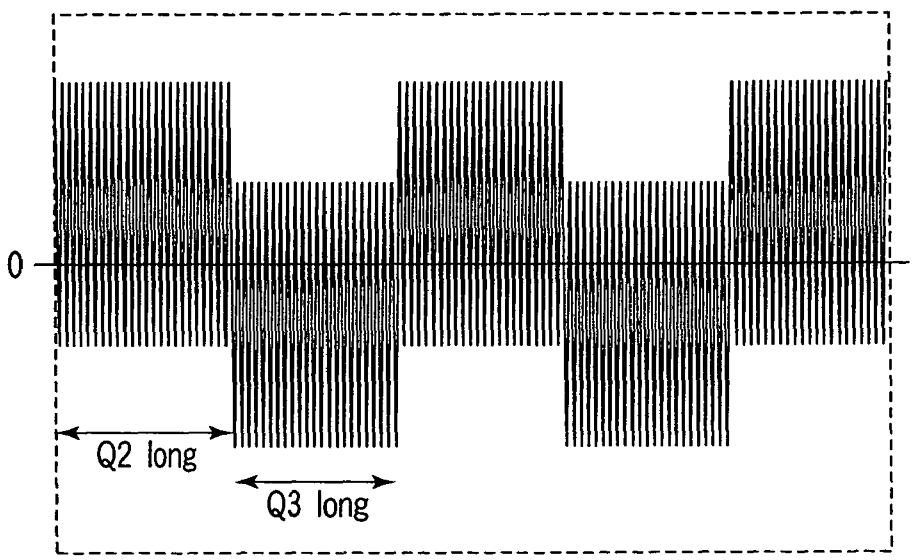


FIG. 16



F I G. 17



F I G. 18

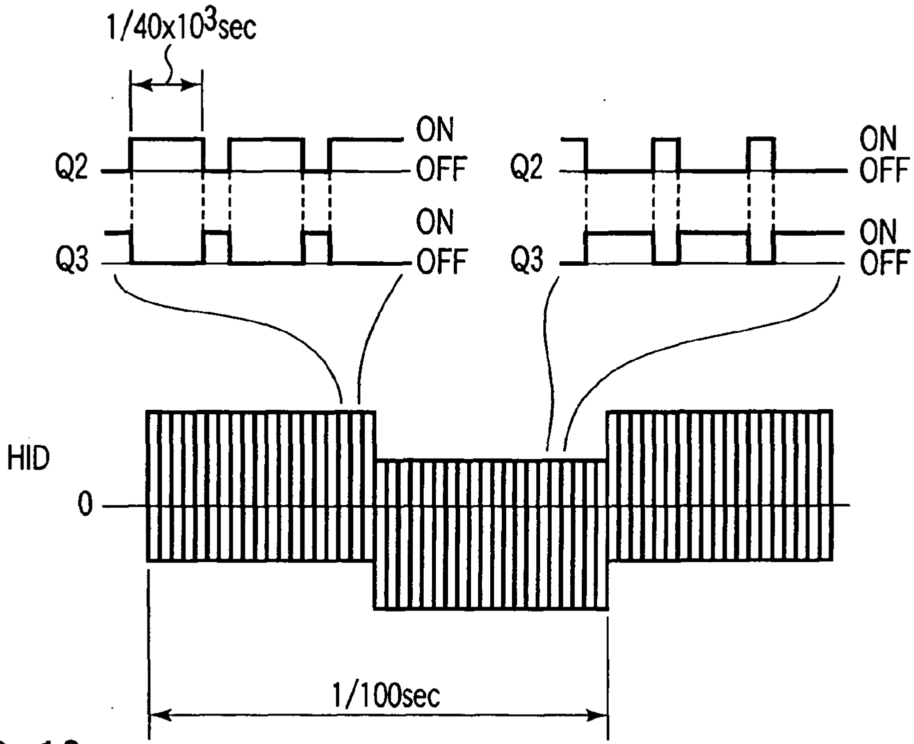

1/40x10³sec
Q2
Q3
ON
OFF
ON
OFF
Q2
Q3
ON
OFF
ON
OFF
HID
0
1/100sec

FIG. 19

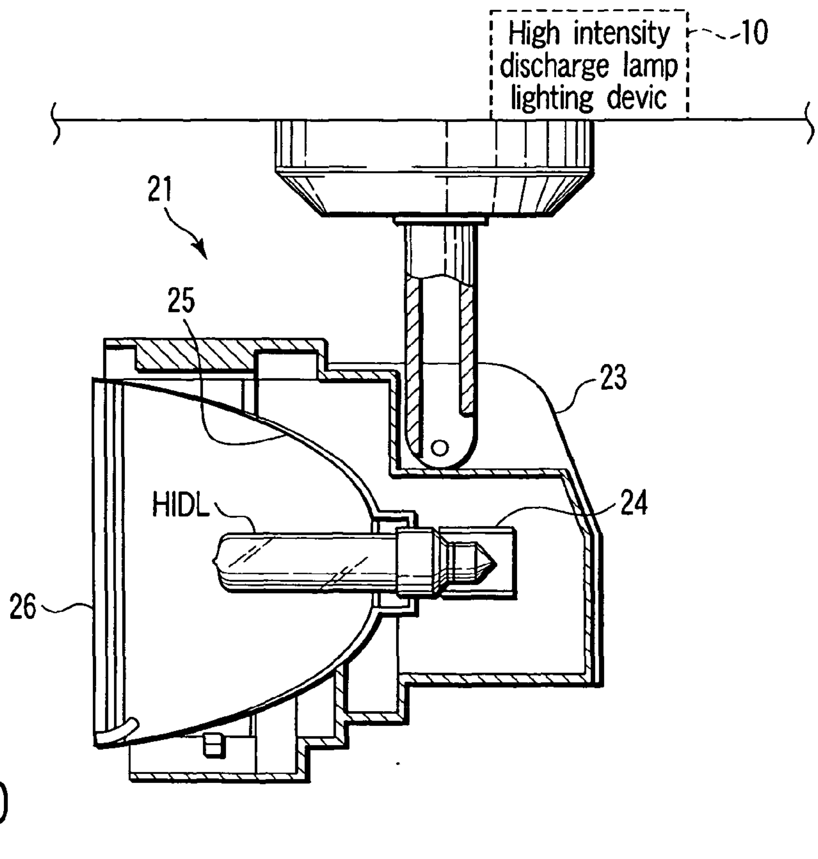

High intensity discharge lamp lighting devic
10
21
25
23
HIDL
24
26

FIG. 20

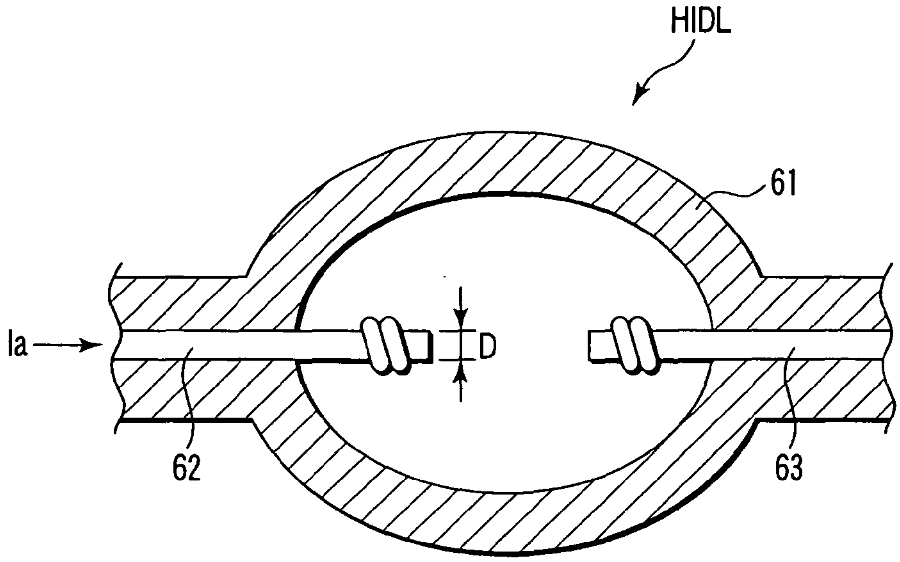

HIDL
61
Ia
D
62
63

FIG. 21

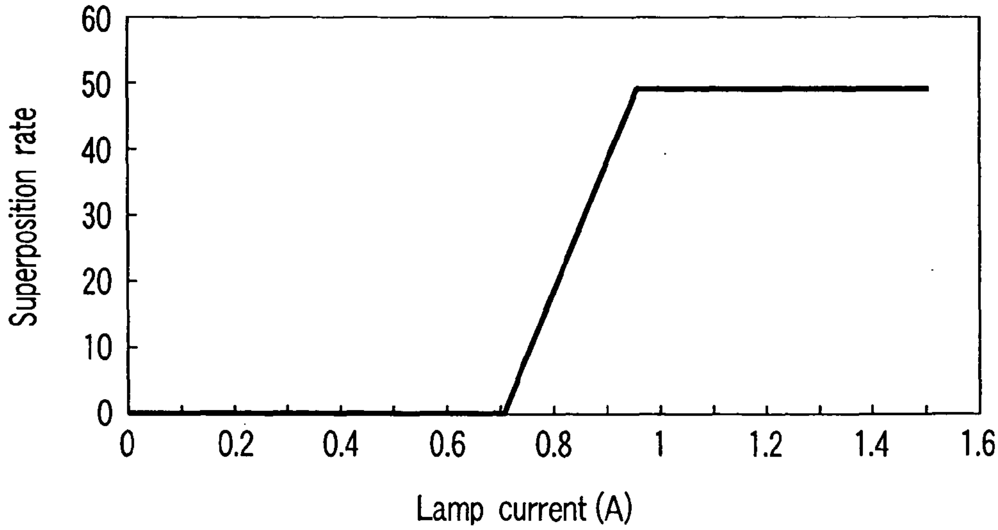

60
50
40
30
20
10
0
Superposition rate
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Lamp current (A)

FIG. 23

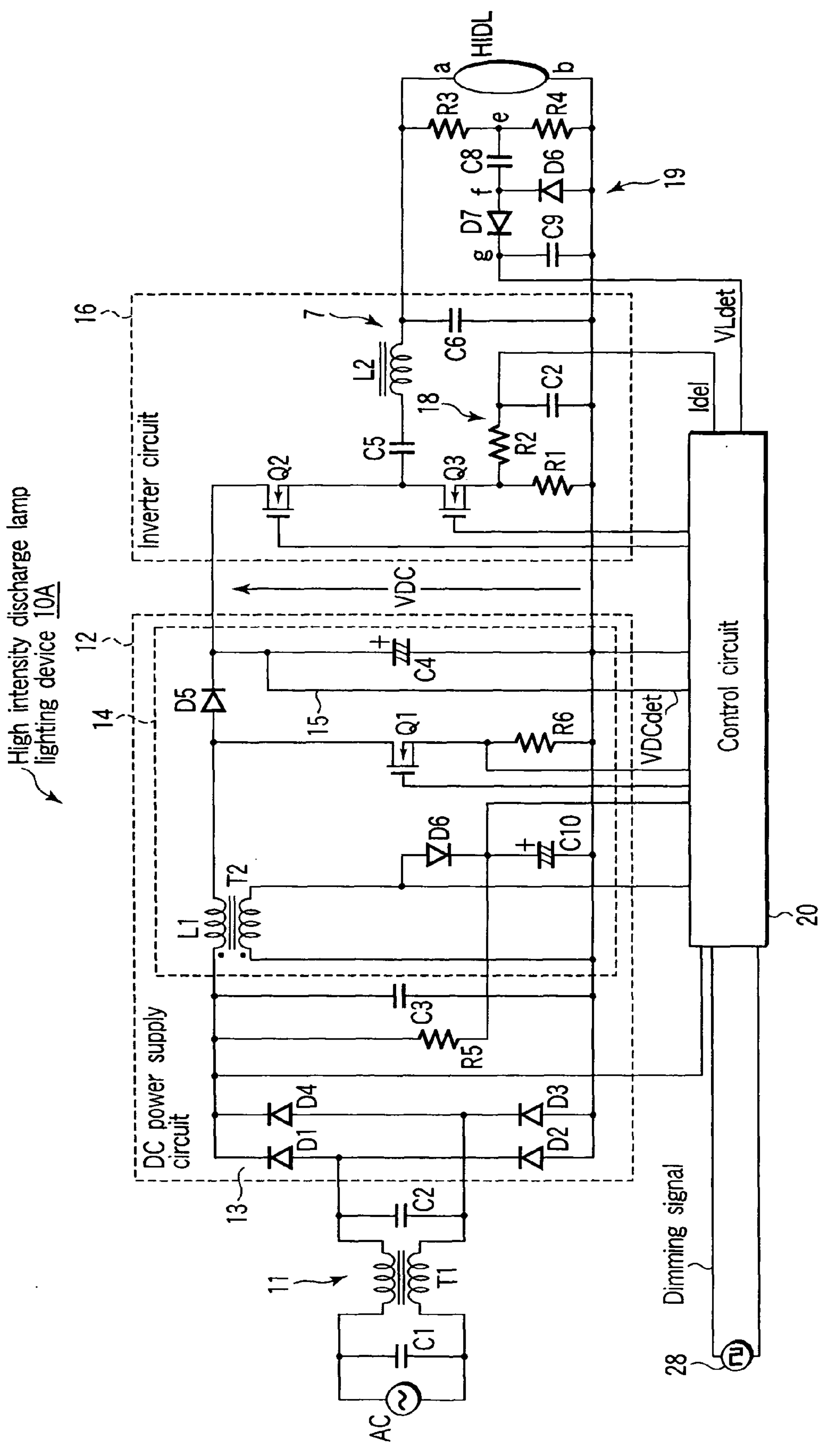
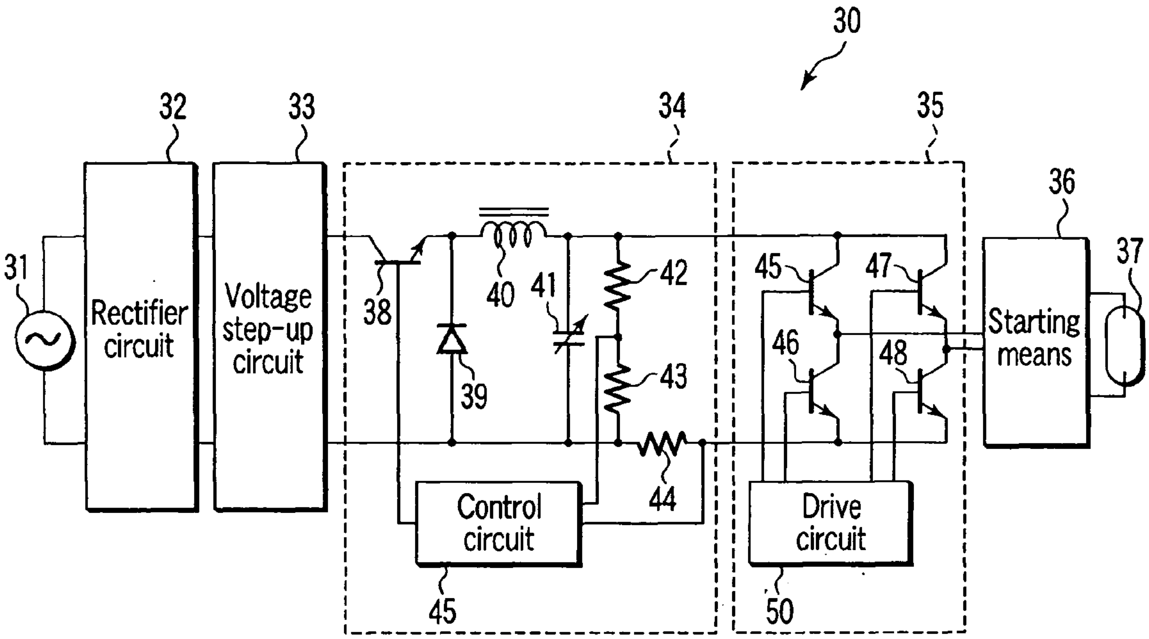
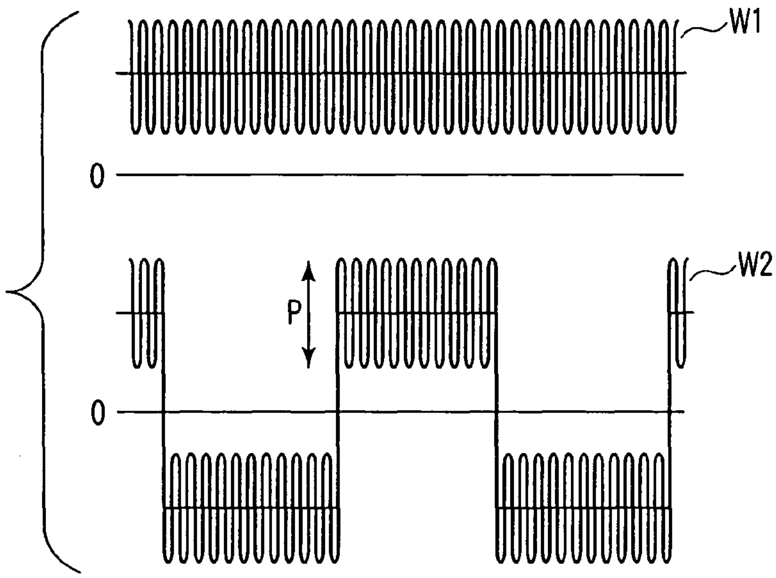

High intensity discharge lamp lighting device 10A
DC power supply circuit
Inverter circuit
Control circuit
Dimming signal
VDC
VDCdet
Idel
VLdet
HIDL
AC
C1
T1
C2
D1
D2
D3
D4
R5
C3
L1
T2
D6
C10
Q1
R6
D5
C4
Q2
Q3
C5
L2
R1
R2
C6
D7
C8
C9
R3
R4
a
b
e
f
g
7
11
12
13
14
15
16
18
19
20
28

FIG. 22


30
32
33
34
35
36
37
31
Rectifier circuit
Voltage step-up circuit
38
39
40
41
42
43
44
Control circuit
45
45
46
47
48
Drive circuit
50
Starting means

F I G. 24


W1
0
W2
P
0

F I G. 25

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP S5718317 B **[0007]**
- JP S6355894 B **[0008]**
- JP H6283286 B **[0008]**