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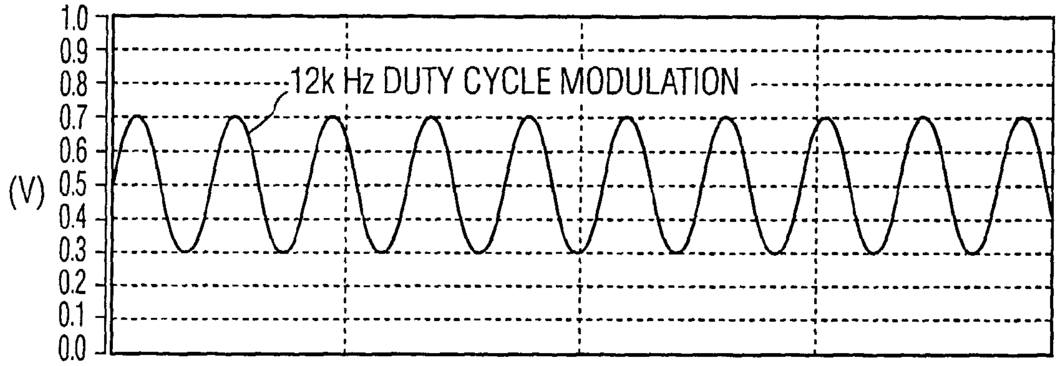
(54) Title: METHOD FOR COLOR MIXING OF HID LAMPS OPERATED AT VHF FREQUENCIES USING DUTY CYCLE MODULATION



(57) Abstract: A method of color mixing a very high frequency operated HID lamp which effectuates power modulation to the HID lamp at a frequency of the second longitudinal acoustic mode by modulating the duty cycle of a half bridge configured resonant inverter. The duty cycle is modulated with a modulation frequency which is substantially one-half the frequency of the second longitudinal acoustic mode of the HID lamp. In operation, exciting the second longitudinal acoustic mode of the HID lamp with the half bridge configured resonant inverter operated with a modulated duty cycle achieves color mixing along a vertical axis of the HID lamp.

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METHOD FOR COLOR MIXING OF HID LAMPS OPERATED AT VHF FREQUENCIES USING DUTY CYCLE MODULATION.

This invention relates to methods for reducing vertical segregation in high intensity discharge (HID) lamps, and more particularly, to a method for color mixing of HID lamps operated at very high frequencies which employs duty cycle modulation for operation of a half bridge circuit topology of the resonant inverter.

High intensity discharge lamps are not typically operated on high frequency sinusoidal waveforms due to instabilities caused by acoustic resonances. In an attempt to overcome such instabilities, the HID lamps can be stabilized by operating the HID lamp at frequencies above its highest acoustic resonance. Operating the HID lamp above its highest acoustic resonance is known as very high frequency (VHF) operation. Nevertheless, the frequencies of the acoustic resonances depend on a variety of factors, one of which includes the dimensions of the lamp and thus varies from one HID lamp to another HID lamp.

Moreover, when HID lamps are operated in a vertical orientation, certain HID lamps display a phenomenon called vertical segregation whereby the color of the light emitted from the HID lamp is not uniform along its vertical axis. As a result, attempts have been made to overcome the disadvantage of vertical segregation. In one such attempt, the second longitudinal acoustic mode is excited to mix the chemistry in the lamp yielding a uniform color along the vertical axis of the HID lamp.

As can be readily seen, it is desirable to operate the HID lamp at VHF and also excite the second longitudinal acoustic mode to create color mixing or, in other words, to minimize, if not essentially eliminate, vertical segregation.

The present invention contemplates a method of color mixing which includes operating an HID lamp at VHF, and power modulating at a frequency of a second longitudinal acoustic mode of the HID lamp by modulating the duty cycle of a half bridge configured resonant inverter to excite the second longitudinal acoustic mode of the HID lamp to achieve color mixing along a vertical axis of the HID lamp. The method also contemplates the ability to maintain a constant switching frequency of the half bridge configured resonant inverter. The invention also concerns a half bridge configured resonant driver capable of performing the method of the invention.

Fig. 1 illustrates a schematic diagram of a conventional resonant inverter.

Fig. 2 illustrates the duty cycle modulation waveform of the present invention.

Fig. 3 illustrates the HID lamp voltage waveform over time of the present invention.

Fig. 4 illustrates the power spectrum waveform over a frequency spectrum of the present invention.

Referring now to Fig. 1, the schematic diagram of the conventional half bridge configured resonant inverter 20 is shown. The present invention employs a conventional half bridge configured resonant inverter 20 coupled to a high intensity discharge (HID) lamp 50 to carry out the method of the present invention to achieve color mixing by excitation of the second longitudinal acoustic mode. The resonant inverter 20 includes a half bridge circuit with two transistors or switches S1 and S2, which are complementarily switched or driven at VHF with a nominal duty cycle (the amount of time a switch is on) of 50% or 0.5.

Referring still to the schematic diagram, the resonant inverter 20 includes a high DC voltage source 22, which is coupled in parallel with energy storage capacitor C1 and delivers input voltage Vin. The energy storage capacitor C1 is connected in parallel with the half bridge circuit defined by the two transistors or switches S1 and S2. In the exemplary embodiment, transistors or switches S1 and S2 are MOSFETs but may be other suitable power switching devices. Thus, the first terminal and the second terminal of the energy storage capacitor C1 are coupled to the drain of transistor or switch S1 and the source of transistor or switch S2, respectively. The source of transistor or switch S1 is coupled to the drain of transistor or switch S2 via half bridge output node A. The gates of transistors or switches S1 and S2 are coupled to an inverter control circuit (NOT SHOWN) to control the conducting and non-conducting states thereof.

The resonant inverter 20 further includes a DC blocking capacitor C2 having a first terminal coupled to the half bridge output node A and a second terminal coupled to a first terminal of inductor L1 of the main resonant filter. The main resonant filter is defined by inductor L1 and capacitor C3. The HID lamp 50 is coupled in parallel with capacitor C3. The negative terminal of the high DC voltage source 22, the second terminal of the energy storage capacitor C1, the source of transistor or switch S2, and the second terminal of capacitor C3 are tied together.

Referring now to FIGS. 2-4, the method of the present invention employing the resonant inverter 20 to achieve color mixing by excitation of the second longitudinal acoustic mode will now be described in detail. In order to achieve color mixing by excitation of the second longitudinal acoustic mode, the power to the HID lamp 50 must be modulated at the frequency of the second longitudinal acoustic mode. In the exemplary embodiment, the second longitudinal acoustic mode is approximately 24kHz.

The method of the present invention derives the necessary power modulation by modulating the duty cycle of transistors or switches S1 and S2 while keeping the switching frequency constant. In general, the power to the load presented by the HID lamp 50 is at a maximum when the duty cycle is 50% or 0.5. As the duty cycle is decreased or, alternately, increased from 50%, the load power will decrease. Thus, the load power can be modulated simply by modulating the duty cycle appropriately so that it is increased and decreased about the nominal value.

To create a 24kHz modulation of the load power, the duty cycle (DC) can be switched between 50% and 40% at a frequency of 12kHz. Since the second longitudinal acoustic mode of the HID lamp 50 is 24kHz, the load power will be modulated by a first amount. On the other hand, by varying the duty cycle (DC) between 50% and 30%, the load power will be modulated by a second amount wherein the second amount is larger than the first amount. As can be appreciated, the degree of excitation of the second longitudinal acoustic mode can be varied and controlled. Thus, modulating the duty cycle DC in a manner which varies the duty cycle DC accordingly, modulates the load power in a manner to excite the second longitudinal acoustic mode in the HID lamp 50 operated at VHF to achieve color mixing or, in other words, to minimize, if not eliminate, vertical segregation.

The duty cycle DC can be modulated with a sinusoidal function or other symmetrical waveform functions. Only one example of a modulated duty cycle will be described in detail since there are numerous modulation functions and to describe such functions is prohibitive. An exemplary sinusoidally modulated duty cycle (DC_m) can be expressed as

$$DC_m = DC_n + a_m \sin(2*pi*f_m*t) \qquad \text{(Eq.1)}$$

wherein DC_n is the nominal value of the duty cycle; a_m is a modulation index; and f_m is the modulation frequency. In the exemplary embodiment, the DC_n is substantially 0.5 or 50%; the modulation index a_m varies between 0 and 0.5; and the modulation frequency f_m is set to substantially one-half (½) of the frequency of the second longitudinal acoustic mode. The modulation index a_m controls the amount of power or degree of excitation in the HID lamp 50 at a frequency of twice the modulation frequency f_m. The modulation index is varied according to the desired degree of excitation of the second longitudinal acoustic mode. By increasing the modulation index, more power is delivered to the lamp at the second longitudinal acoustic mode. In practice, there is a balance between exciting the second longitudinal acoustic mode to get color mixing, while not over-exciting which could lead to lamp instabilities. The modulated power is independent of the carrier frequency as long as the carrier frequency is reasonably higher than the modulating frequency. If the carrier frequency is varied, the modulated power is still fixed. Thus, for other applications it would be possible to apply frequency modulation, e.g., sweep the carrier frequency from 450kHz to 550kHz, without substantially altering the modulated power component at 24kHz.

In view of the foregoing, the above modulation function is only one suitable function which can be used to modulate the duty cycle to control the amount of power or degree of excitation of the HID lamp 50.

In an exemplary example, the HID lamp 50 is operated at a VHF of approximately 500 kHz, as best seen in Fig. 3. Fig. 3 illustrates an exemplary sinusoidal lamp voltage waveform of substantially 500kHz. The lamp voltage waveform is represented in volts (-600V to +600V) verses time in seconds (0.001s to 0.0018s). The modulation frequency f_m is approximately 12kHz at a depth of 0.2. In other words, the duty cycle varies from 0.3 (30%) to 0.7 (70%) around the nominal duty cycle DC_n of 0.5 (50%), as best seen in Fig. 2. Fig. 2 illustrates an exemplary waveform of a sinusoidally modulated duty cycle (DC_m) with a modulation frequency f_m of approximately 12kHz. The waveform is represented as volts (0.0V to 1.0V) verses time in seconds. In operation, the 12kHz duty cycle modulation of Fig. 2 creates a substantially 24kHz frequency component in the load power spectrum, as best seen in Fig. 4. Fig. 4 illustrates the power spectrum of this exemplary example. The power spectrum waveform is represented as dB(-jHz) (-80 to +60) verses frequency in Hertz (0.0 to 1.25 meg).

In view of the foregoing, for an exemplary HID lamp 50 with a second longitudinal acoustic mode at approximately 24kHz, a fixed and controlled frequency excitation at 24kHz may be used to excite acoustic resonances to create color mixing or, in other words, to minimize, if not eliminate, vertical segregation.

In summary, the above is a general method of injecting controlled frequency components into a load that is operated at very high frequencies (VHF). Thus, utilizing more complex duty cycle modulation schemes will allow more complex frequency excitation to be coupled into the load.

Numerous modifications to and alternative embodiments of the present invention will be apparent to those skilled in the art in view of the foregoing description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the best mode of carrying out the invention. Details of the structure may be varied substantially without departing from the spirit of the invention and the exclusive use of all modifications which come within the scope of the appended claims is reserved.

CLAIMS:

1. A method of color mixing an HID lamp, comprising the steps of:

(a) operating a high intensity discharge (HID) lamp (50) at a very high frequency (VHF);

(b) modulating a duty cycle of a half bridge configured resonant inverter (20); and,

(c) exciting a second longitudinal acoustic mode of the HID lamp (50) with the half bridge configured resonant inverter (20) to achieve color mixing along a vertical axis of the HID lamp (50).

2. The method according to claim 1, further comprising:

(d) providing a constant switching frequency to the half bridge configured inverter (20).

3. The method according to claim 1, wherein the step (b) includes modulating the duty cycle at a modulation frequency which is equal to substantially one-half of a frequency of the second longitudinal acoustic mode.

4. The method according to claim 1, wherein the step (b) effectuates power modulation to the HID lamp (50) at a frequency of the second longitudinal acoustic mode.

5. The method according to claim 1, wherein the VHF is approximately 500kHz.

6. The method according to claim 1, wherein the step (b) includes modulating the duty cycle with a sinusoidal function.

7. The method according to claim 1, wherein the duty cycle has a nominal value of 50% and varies symmetrically about the nominal value plus or minus 20%.

8. A half bridge configured resonant inverter for powering a high intensity lamp (HID), comprising:

a half bridge circuit (S1, S2) operating the HID lamp (50) at a very high frequency (VHF), having a constant switching frequency and having a modulated duty cycle to effectuate power modulation to the HID lamp (50), which excites a second longitudinal acoustic mode of the HID lamp (50) to achieve color mixing or reduction in vertical segregation along a vertical axis of the HID lamp (50);

a resonant filter (L1,C3) coupled between the half bridge circuit (S1, S2) and the HID lamp (50).

9. The inverter according to claim 8, wherein the modulated duty cycle has a modulation frequency which is equal to substantially one-half of a frequency of the second longitudinal acoustic mode.

10. The inverter according to claim 8, wherein the VHF is approximately 500kHz.

11. The inverter according to claim 8, wherein the modulated duty cycle is modulated with a sinusoidal function.

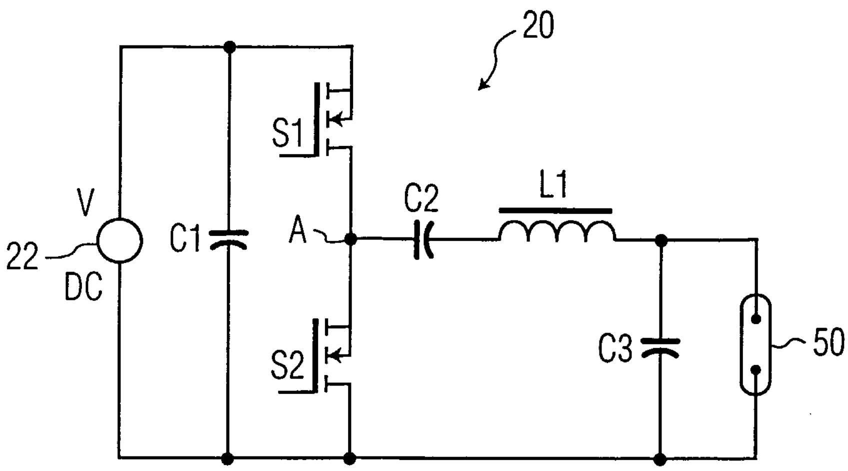
20
S1
V
22
DC
C1
A
C2
L1
S2
C3
50

FIG. 1

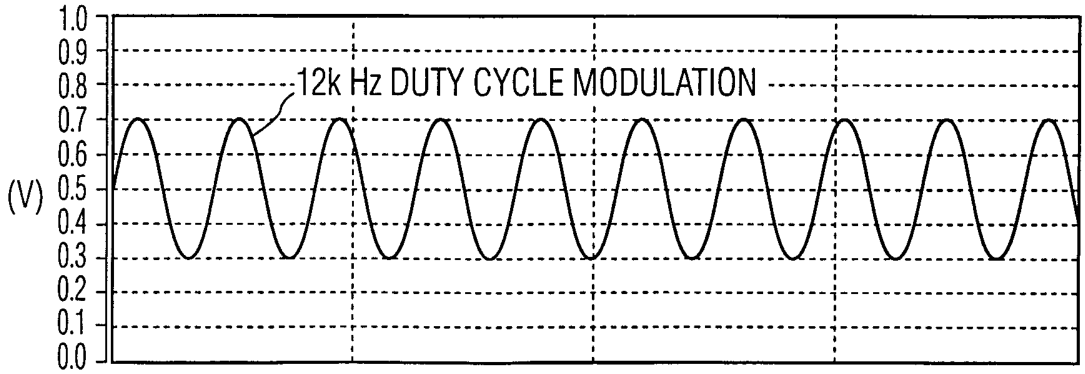
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
(V)
12k Hz DUTY CYCLE MODULATION

FIG. 2

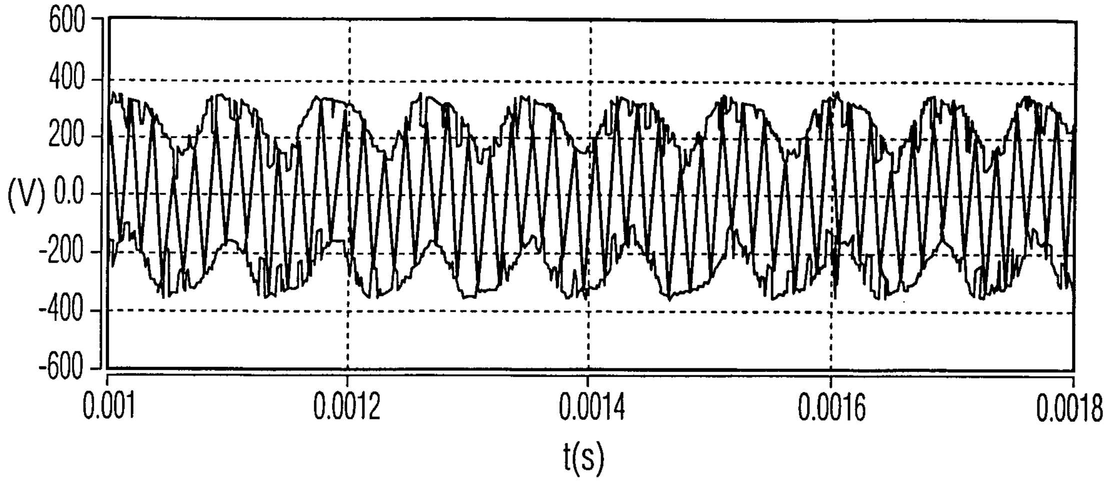
600
400
200
(V) 0.0
-200
-400
-600
0.001
0.0012
0.0014
0.0016
0.0018
t(s)

FIG. 3

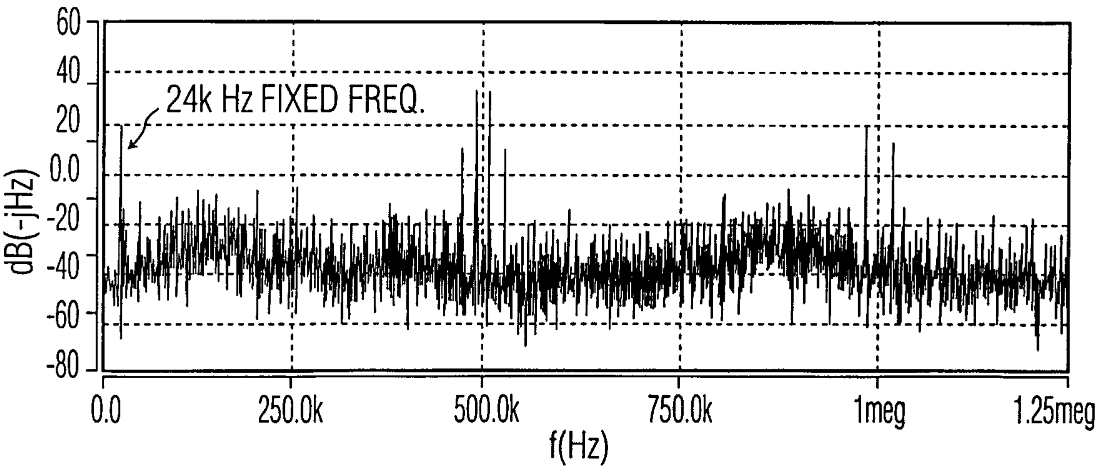
60
40
20
0.0
-20
-40
-60
-80
dB(-jHz)
24k Hz FIXED FREQ.
0.0
250.0k
500.0k
750.0k
1meg
1.25meg
f(Hz)

FIG. 4

INTERNATIONAL SEARCH REPORT

Intei ıal Application No
PCT/IB 02/03262

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H05B41/292 H05B41/392

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 6 184 633 B1 (KRAMER JERRY M) 6 February 2001 (2001-02-06) column 2, line 8 -column 2, line 21 column 3, line 45 -column 3, line 55 column 4, line 48 -column 5, line 36; figures 1A,1B,2B ---	1,8
A,P	WO 02 30162 A (KONINKL PHILIPS ELECTRONICS NV) 11 April 2002 (2002-04-11) page 2, line 25 -page 3, line 10 page 7, line 16 -page 9, line 7; figures 1,3,5,7 ---	1,8
A	EP 0 744 883 A (PRAEZISA IND ELEKTRONIK) 27 November 1996 (1996-11-27) ---	
A	US 5 684 367 A (OLSEN JOSEPH A ET AL) 4 November 1997 (1997-11-04) ---	

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 October 2002	17/10/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Speiser, P

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 02/03262

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 483 126 A (BOENIGK MICHAEL ET AL) 9 January 1996 (1996-01-09)	

INTERNATIONAL SEARCH REPORT

formation on patent family members

Inte ial Application No
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