

"Lamp ballast circuit"

BACKGROUND OF THE INVENTION

This invention relates to a ballast circuit for generating a substantially rectangular driving signal sufficient to ignite a lamp load, comprising:

inductor means;

capacitor means serially connected to said inductor means; and

5 generating means for applying a generated signal to said serially connected inductor means and capacitor means, said generated signal having at least a fundamental frequency f_1 ;

the inductor means and capacitor means having a resonant frequency f_0 .

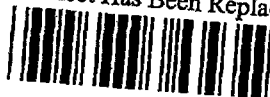
Inductor means are to understand to be means adapted to exhibit the
10 properties of an inductor. Capacitor means are to understand to be means adapted to exhibit the properties of a capacitor.

Conventionally the lamp load is connected across the capacitor. In a known circuitry the series L-C circuit operates during pre-ignition of the lamp load substantially at its resonant frequency. That is, the driving signal applied to the series
15 L-C circuit is at or near the resonant frequency of the series L-C circuit. In this way a sufficiently high pre-ignition voltage is applied across the lamp load for ignition of the latter.

The lamp load, typically of a fluorescent type, following ignition, achieves a substantially steady-state sinusoidal current flow therethrough by reducing the
20 driving signal frequency well below the resonant frequency of the series L-C circuit. In determining when to switch from the resonant frequency to a different steady-state operating frequency, feedback circuitry is required in the known ballast circuit for sensing lamp ignition.

A sufficiently high voltage during pre-ignition of the lamp and sinusoidal
25 lamp current following ignition (i.e. steady state operation), is commonly provided by a bridge inverter. Both full bridge and half-bridge inverters are known in the ballast circuit art. The (half)-bridge inverter includes switching to control the frequency of the

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driving signal applied to the series L-C circuit. Control circuitry, responsive to the feedback circuitry, is required for controlling the speed at which the switching takes place.

Known lamp ballast circuits, as described above, suffer from several drawbacks. For example, known lamp ballast circuits require generating two different frequencies, that is, the resonant frequency during pre-ignition of the lamp load and a different therefrom a steady-state operating frequency. Such ballast circuits also require sensing circuitry to determine when to switch from the resonant frequency to the steady state operating frequency.

It is particularly undesirable to operate at or near the resonant frequency of the series L-C circuit before lamp ignition inasmuch as unsafe, high voltages and current levels can occur (i.e. above the maximum ratings of one or more ballast circuit components). By operating below resonance during pre-ignition of the lamp load, capacitive switching of the inverter can easily occur producing high switching losses. Additional circuitry is therefore required to prevent the inverter from operating below the series L-C circuit resonant frequency during pre-ignition of the lamp load.

The inductance of inductor L is normally determined based on the desired lamp current during steady state conditions. The capacitance of capacitor C is thereafter chosen so as to provide a resonant condition (typically between 20-50 kHz for a fluorescent lamp). Generally, the capacitance of capacitor C is between about 5 to 10 nanofarads with the additional high voltage capability leading to a relatively costly capacitor requiring a relatively large space on a printed circuit board.

Accordingly, it is desirable to provide a lamp ballast circuit having a safe open circuit (i.e., pre-ignition) voltage and current level, with relatively low switching losses. The improved lamp ballast circuit should not need a driving signal at more than one frequency, this frequency being well below resonance of the series L-C circuit. It is also desirable that the improved lamp ballast circuit permit use of a relatively less expensive, smaller capacitor in order to lower the lamp ballast manufacturing cost and to reduce the reactive current flowing through the capacitor after lamp ignition thus lowering circuit power loss.

SUMMARY OF THE INVENTION

In accordance with the invention, a ballast circuit for generating a driving



signal sufficient to ignite a lamp-load as mentioned in the preamble is characterized in that for the fundamental frequency f_1 and the resonant frequency f_0 it holds:

$$nf_1 < f_0 < (n+1)f_1 \text{ with } n = \text{an even integer.}$$

By operating in these regions during pre-ignition, safe voltage and current levels will be maintained. A single drive frequency results in safe non-resonant operation before lamp ignition as well as correct lamp current after ignition. Feedback circuitry for sensing ignition of the lamp load for switching to a different steady-state lamp operating frequency need not be provided. By eliminating the need to operate at the resonant frequency of the series connected L-C circuit during pre-ignition of the lamp load, the value and resulting size of the capacitor can be chosen far smaller than normally used in a conventional series connected L-C circuit in a known ballast circuit.

In accordance with a feature of the invention, the generated signal which is a train of square waves, is generated preferably by a half-bridge or full bridge inverter. In yet another feature of the invention, the resonant frequency of the series connected L-C circuit is less than the third harmonic frequency of the generated square wave drive thereby avoiding unsafe third harmonic voltages and current levels during pre-ignition of the lamp load. Substantially the same generated signal frequency is used during pre-ignition and steady-state operation of the lamp load.

Accordingly, it is an object invention to provide an improved ballast circuit in which the unloaded, open circuit voltage and current levels are within the operating range of the ballast circuit components.

It is another object of the invention to provide an improved ballast circuit in which the same inverter driving signal can be used during pre-ignition and steady-state operation of the lamp load.

It is a further object of the invention to provide an improved ballast circuit in which less costly components can be used to lower the manufacturing cost of the ballast.

It is still another object of the invention to provide an improved ballast circuit which eliminates the need for feedback circuitry for sensing lamp ignition for changing the inverter frequency.

It is still a further object of the invention to provide an improved ballast circuit in which the inverter driving signal frequency is substantially less than the resonant frequency of a series connected L-C output circuit during pre-ignition of the



lamp load.

The invention accordingly comprises several steps in a relation of one or more of such steps with respect to each of the others, and the device embodying features of construction, a combination of elements and arrangement of parts which are adapted to effect such steps, all is exemplified in the following detailed disclosure and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF DRAWINGS

For a fuller understanding of the invention, reference is made to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a circuit diagram of a ballast output circuit in accordance with the present invention;

Figs. 2(a), 2(b) and 2(c) are timing diagrams of an inverter substantially rectangular output voltage, output current at its fundamental frequency and output current at its third harmonic, respectively in the circuit according to Fig. 1;

Fig. 3 is a schematic diagram of a ballast circuit in accordance with the invention;

Figs. 4(a), 4(b), 4(c) and 4(d) are timing diagrams of signals produced within the ballast circuit of Fig. 3 during pre-ignition and steady-state operation of the lamp load; and

Fig. 5 is a diagram of simulation of current in circuit of Fig. 1 as function of the ratio fundamental frequency and resonant frequency.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The figures shown herein illustrate a preferred embodiment of the invention. Those elements/components shown in more than one figure of the drawings have been identified by like reference numerals/letters and are of similar construction and operation.

Referring now to Figs. 1, 2(a), 2(b) and 2(c), a ballast circuit having a ballast output circuit 10 includes an inductor L and a capacitor C serially connected across the output of a square wave generator 13. Square wave generator 13 is preferably, but not limited to, a bridge inverter generating a substantially square wave of voltage $\pm E$ (i.e. the inverter output voltage). A lamp load 16 is connected across



capacitor C through a switch SW. A current I flowing through inductor L includes a fundamental frequency component I_n and a third harmonic component of the fundamental frequency I_{3n} . Other currents at higher odd harmonics are present but are significantly smaller. For the sake of simplicity in calculations with respect to the
5 preferred embodiment as described hereafter only terms concerning the fundamental frequency f_1 and the 3rd harmonic are taken into account.

In accordance with the Fourier transform square wave voltage 13 contains a sinusoidal wave at a fundamental frequency f_1 and odd harmonics of the fundamental frequency including a sinusoidal wave at a third harmonic $3f_1$. The amplitude of third
10 harmonic component f_1 of voltage E is one third the amplitude of fundamental frequency component f_1 of voltage E.

To achieve low switching losses within square wave generator 13 during pre-ignition of lamp load 16 (generally at trailing edges E_T of voltage E), current I is preferably inductive (i.e., current lagging drive voltage) rather than capacitive (i.e.,
15 current leading drive voltage) during the voltage transitions of voltage E. Accordingly, the sum of fundamental frequency current component I_n and third harmonic-current component I_{3n} is inductive wherein I_{1f} and I_{3n} are the capacitive and inductive components of I, respectively. To achieve an overall inductive current I, an impedance Z of circuit 10 as viewed from square wave generator 13 requires that the inductive
20 impedance at the third harmonic Z_{3n} be less than one third the capacitive impedance at the fundamental frequency Z_n . In other words, third harmonic component current I_{3n} is greater than fundamental frequency component I_n . This relationship is illustrated in Figs. 2(b) and 2(c) wherein an amplitude P represents the peak value of fundamental frequency current component I_n but is less than the peak value of third harmonic
25 current component I_{3n} . In this way the sum of I_n and I_{3n} remains inductive at the voltage transitions of voltage E.

Lamp load 16 prior to ignition (i.e. during pre-ignition) appears as an open circuit. This open circuit condition is represented by switch SW in an open state (turned OFF). Following ignition, lamp load 16 is in its steady-state mode of operation and is
30 represented by switch SW being turned ON such that lamp load 16 is connected in parallel with capacitor C.

Impedance Z_{3n} , which must be less than one third impedance Z_n during pre-ignition of lamp load 16, is therefore based on switch SW in its open state (i.e.,



turned OFF). This condition can be expressed as follows:

$$|Z_n| > |3 Z_{3n}| \quad (\text{eq. 1})$$

That is,

$$|2\pi f_1 xL - 1/(2\pi f_1 xC)| > 3 |6\pi f_1 xL - 1/(6\pi f_1 xC)| \quad (\text{eq. 2})$$

- 5 Since impedance Z is capacitive at fundamental frequency f_1 and inductive at the third harmonic $3f_1$,

$$1/(2\pi f_1 xC) - 2\pi f_1 xL > 18\pi f_1 xL - 1/(2\pi f_1 xC)$$

That is,

$$10 \quad 1/(2\pi f_1 xC) > 5(2\pi f_1 xL) \quad (\text{eq. 3})$$

Eq. 3 can be rewritten as follows:

$$1/\sqrt{LC} > \sqrt{5} 2\pi f_1 \quad (\text{eq. 4})$$

- 15 A resonant frequency f_0 of circuit 10 during pre-ignition (i.e., with switch SW open) can be defined as follows:

$$1/\sqrt{LC} = 2\pi f_0 \quad (\text{eq. 5})$$

Substituting the value of $1/\sqrt{LC}$ defined by eq. 4 for the value of $1/\sqrt{LC}$ in eq. 5 results in

$$2\pi f_0 > \sqrt{5} 2\pi f_1 \quad (\text{eq. 6})$$

- 20 Accordingly, resonant frequency f_0 can be expressed as follows:

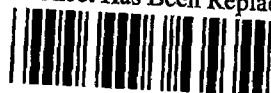
$$f_0 > \sqrt{5} f_1 \quad (\text{eq. 7})$$

In other words, third harmonic inductive current component I_{3n} is greater than fundamental frequency capacitive current component I_n when resonant frequency f_0 is greater than $\sqrt{5}$ times the fundamental frequency of voltage E.

- 25 To ensure that unsafe voltages and currents present at resonant frequency f_0 cannot occur, resonant frequency f_0 also should be less than third harmonic frequency $3f_1$ of voltage E. Therefore, the values of inductor L and capacitor C should be chosen such that:

$$\sqrt{5}f_1 < f_0 < 3f_1 \quad (\text{eq. 8})$$

- 30 By designing ballast circuit 10 such that resonant frequency f_0 is within the range of frequencies defined by eq. 8, the unsafe voltages and currents which occur at resonant frequency f_0 during pre-ignition of lamp load 16 are avoided and total current delivered by square wave generator 13 remains inductive. There is no need to vary the



frequency of voltage E between resonant frequency f_0 during pre-ignition of lamp load 16 and a different frequency immediately thereafter as in conventional ballast circuitry. Feedback circuitry designed to sense ignition of lamp load 16 for determining when to vary the frequency of voltage E from resonant frequency f_0 to a different operating

5 frequency can be eliminated. In accordance with the invention, a safer, simpler circuit is provided by maintaining resonant frequency f_0 within the boundaries defined by eq. 8. Due to the fact that the calculation as shown has only taken into account the fundamental frequency f_1 and its 3rd harmonic $3f_1$, the lower value of the range for choosing the resonant frequency f_0 is $\sqrt{5}$ times f_1 . However, when taken into account the

10 existence of higher harmonics this value reaches the limit 2.

The result of a simulation in which at least the first 25 harmonics are taken into account is shown in figure 5.

In Fig. 5 the depicted curve displays the total current I_{Σ} in the circuit of Fig. 1 at the moment the voltage switches from -E to +E of the generator 13 as

15 function of ratio of the fundamental frequency f_1 and the resonant frequency f_0 . The circuit operates in the inductive mode in all those regions that the current I_{Σ} is lagging to the voltage, thus is negative. From the Fig. 5 it is clear that these regions fulfil the relation

$$nf_1 < f_0 < (n+1)f_1 \text{ with } n = \text{an even integer.}$$

20 A ballast circuit 20 in accordance with the invention is shown in Fig. 3. An input voltage of 277 volts, 60 hertz is supplied to an electromagnetic interference (EMI) suppression filter 23. Filter 23 filters high frequency components inputted thereto lowering conducted and radiated EMI. The output of filter 20 provided at a pair of terminals 24 and 25 is supplied to a full wave rectifier 30 which includes diodes D_1 , D_2 ,

25 D_3 and D_4 . The anode of diode D_1 and cathode of diode D_2 are connected to terminal 24. The anode of diode D_3 and cathode of diode D_4 are connected to terminal 25. The output of rectifier 30 (i.e. rectified a.c. signal) at a pair of output terminals 31 and 32 is supplied to a boost converter 40. The cathodes of diodes D_1 and D_3 are connected to terminal 31. The cathodes of diodes D_2 and D_4 are connected to terminal 32.

30 Converter 40 boosts the magnitude of the rectified A.C. signal supplied by rectifier 30 and produces at a pair of output terminals 41 and 42 a regulated D.C. voltage supply. Boost converter 40 includes a choke L_3 , a diode D_5 the anode of which is connected to one end of choke L_3 . The other end of choke L_3 is connected to output



terminal 31 of rectifier 30. The output of boost converter 40 at output terminals 41, 42 is applied across an electrolytic capacitor C_E , one end of which is connected to the cathode of diode D_5 . A transistor (switch) Q_1 is connected to the junction between choke L_1 and the anode of diode D_5 . The other end of transistor Q_1 is connected to the
5 junction between the other end of capacitor C_E , output terminal 32 of rectifier 30 and output terminal 42.

A preconditioner control 50, which is powered by a D.C. supply voltage V , controls the switching duration and frequency of transistor Q_1 . Preconditioner control 50 is preferably, but not limited to, a Motorola MC33261 Power Factor Controller
10 Integrated Circuit. Transistor Q_1 is preferably a MOSFET, the gate of which is connected to preconditioner control 50. Rectifier 30 and boost converter 40, including preconditioner control 50, form a preconditioner 80 for ballast circuit 20. Output terminals 41 and 42 of boost converter 40 serve as the output for preconditioner 80 across which a regulated D.C. voltage is produced.

15 A lamp drive 90, which is supplied with the regulated D.C. voltage outputted by preconditioner 80, includes a half bridge inverter having a level shifter 60 and a half-bridge drive 70. The half bridge inverter includes a pair of transistors Q_6 and Q_7 , which serve as switches, a pair of capacitors C_5 and C_6 and a transformer T_1 . Half-bridge drive 70 produces a square wave driving signal to drive transistor Q_7 and has a
20 50-50 duty cycle. Level shifter 60 inverts the driving signal supplied to transistor Q_7 for driving transistor Q_6 . The driving signals produced by level shifter 60 and half-bridge drive 70 are approximately 180° out of phase with each other so as to prevent conduction of transistors Q_6 and Q_7 at the same time, respectively.

A source S of transistor Q_6 and one end of level shifter 60 are connected to
25 output terminal 41 of boost converter 40. A drain D of transistor Q_6 is connected to a terminal A. The other end of level shifter 60, one end of half-bridge drive 70 and a source S of transistor Q_7 are also are connected to terminal A. The other end of half-bridge drive 70 and a drain D of transistor Q_7 are connected to output terminal 42 of boost converter 40. Capacitor C_5 is connected at one end to output terminal 41. The
30 other end of capacitor C_5 and one end of capacitor C_6 are connected to a terminal B. The other end of capacitor C_6 is connected to output terminal 42.

A primary winding T_p of transformer T_1 is connected to terminals A and B. A secondary winding T_s is connected at one end to an inductor L_7 , the latter which



generally represents either the leakage inductance of transformer T_1 or a discrete choke. Connected to the other end of inductor L_7 is one end of a capacitor C_{10} and one end of a lamp load LL . Lamp load LL can include any combination of lamps and is shown, but not limited to, the series combination of two fluorescent lamps LL_1 and LL_2 . The other
5 ends of capacitor C_{10} and lamp load LL are connected to the other end of secondary winding T_s .

The turns ratio between primary winding T_p and secondary winding T_s of transformer T_1 is N_p/N_s . Transformer T_1 electrically isolates lamp load LL from the output voltage produced by preconditioner 80 and provides sufficient open circuit
10 voltage during pre-ignition to ignite lamp load LL .

The inductance of inductor L_7 is based on the desired current flow through lamp load LL once the latter has ignited and is in its steady-state mode of operation. The DC voltage across each capacitor C_3 and capacitor C_6 is approximately half the output voltage of preconditioner 80.

15 The waveforms shown in Figs. 4(a), 4(b), 4(c) and 4(d) produced by ballast circuit 20 are based on turns ratio N_s/N_p of about 1.5, inductor L_7 of approximately 4.3 millihenries, capacitor C_{10} of about 1.2 nanofarads and capacitors C_3 and C_4 of about 0.33 microfarads, nominally rated at 630 volts. Both lamp LL_1 and lamp LL_2 are 40 watt low pressure mercury vapor tubular fluorescent lamps. The
20 fundamental frequency of the square wave produced by the half-bridge inverter is approximately 28kHz. The resonant frequency of inductor L_7 and capacitor C_{10} is approximately 70kHz, that is, approximately 2.5 times fundamental frequency f_1 .

During pre-ignition of lamp load LL , the output of the half-bridge inverter, which is across terminals A-B, forms a substantially square wave voltage train.
25 Inductor L_7 and capacitor C_{10} form an L-C series connected circuit. During pre-ignition, lamp load LL appears as a substantially open circuit (i.e. no load condition) drawing substantially no power except for filament heating (assuming lamps LL_1 and LL_2 are fluorescent lamps of, for example, the rapid-start type).

Fig. 4(a) illustrates a voltage V_{AB} , that is, between terminals A and B.
30 Voltage V_{AB} is square wave voltage train which is applied across primary winding T_p , varying between approximately +240 volts and -240 volts during no load conditions. Fig. 4(b) illustrates current I_{PRI} flowing through primary winding T_p during no load conditions, that is, prior to ignition of lamp load LL and having a peak value of

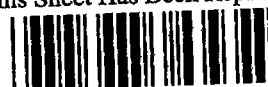


approximately ± 400 milliamperes. Once lamp load LL is ignited and is in its steady-state operation, current I_{PRI} flowing through primary winding T_p , as shown in Fig. 4(c), has a somewhat sinusoidal wave shape with a peak value of approximately ± 800 milliamperes. Capacitor C_{10} serves to smooth this somewhat sinusoidal current waveform resulting in a substantially sinusoidal lamp current I_{LAMP} as shown in FIG. 4(d) having a peak value of approximately ± 380 milliamperes.

Inductor L_7 serves as the lamp current ballasting element. Capacitor C_{10} , which is placed across lamp load LL, provides a more sinusoidal open circuit voltage and keeps total half bridge current inductive while also lowering higher harmonic content of current flowing through lamp load LL. Inductor L_7 and capacitor C_{10} together form a series connected L-C output circuit. The value for capacitor C_{10} is chosen such that safe open circuit operation is provided, that is, within the range of resonant frequencies defined by eq. 8. Accordingly, no additional circuits to protect lamp drive circuit 90 are required.

When ballast circuit 20 is first turned on, prior to the voltage being boosted by preconditioner 80, the input voltage of approximately 277 volts results in a square wave voltage of approximately 390 volts peak to peak being applied across primary winding T_p of transformer T_1 which is stepped up to approximately 570 volts peak to peak across secondary winding T_s . During this time the lamp cathodes are heated. After approximately 0.5 seconds, preconditioner 80 turns ON resulting in a regulated D.C. voltage of approximately 480 volts across output terminals 41, 42 of boost converter 40 and a voltage of approximately 700 volts peak to peak across secondary winding T_s , the latter of which is sufficient for igniting lamp load LL. Once lamp load LL is ignited (i.e. during steady-state lamp operation), the lamp voltage (i.e. voltage across lamp load LL) drops to approximately ± 300 volts peak with the remainder of the secondary winding T_s output voltage across inductor L_7 . The number of and connections between the lamps within lamp load LL can be varied as desired with the value of inductor L_7 being chosen so as to provide the desired lamp current I_{LAMP} during steady-state operation of lamp load LL.

Referring again to Fig. 3, the rectified AC (i.e. pulsating DC) signal supplied to preconditioner 80 from diode bridge rectifier 30 is boosted in magnitude by choke L_3 and diode D_5 to charge capacitors C_E , C_5 and C_6 . In Fig. 3, capacitor C_E is separate from capacitors C_5 and C_6 , capacitor C_E being a large electrolytic capacitor in



the range of 5 to 100 microfarads. Capacitors C_5 and C_6 are high frequency bridge capacitors. Since capacitor C_E is in parallel with the series combination of capacitors C_5 and C_6 , these three capacitors can be reconfigured as capacitors C_5' and C_6' .

Preconditioner 80 is an up-converter and boosts the rectified AC input voltage as follows. When transistor Q_6 (which serves as a switch) is closed, choke L_3 is short circuited to ground. Current flows through choke L_3 . Transistor Q_1 is then opened (turned OFF). Choke L_3 with transistor Q_1 open transfers stored energy through diode D_5 into capacitor C_E . The amount of energy transferred to capacitor C_E is based on the time during which transistor Q_1 is turned ON, that is, based on the frequency and duration of the driving signal supplied to the gate of transistor Q_1 by the preconditioner control 50. Asynchronous operation of transistor Q_1 with respect to voltage V_{LN} results.

Choke L_3 operates in a discontinuous mode, that is, the current through choke L_3 during each cycle is reduced to substantially zero before a new cycle is initiated. The frequency at which transistor Q_1 is turned ON and OFF is varied by preconditioner control 50 so that the peak current through choke L_3 is kept constant. Transistors Q_6 and Q_7 have internal diodes (not shown). These diodes, which can either be internal or external to the transistors, permit inductive currents to flow through transistors Q_6 and Q_7 at the initial turn ON and turn OFF of transistors Q_6 and Q_7 .

Preferably, capacitors C_5 and C_6 are electrolytic capacitors having a pair of discharge resistors in parallel, respectively. Transformer T_1 is a leakage transformer, that is, having a leakage inductor of inductance L_M which serves as the ballast for lamp load LL (i.e. to limit steady state current flow through the lamp load). Alternatively, when transformer T_1 has little or no leakage inductance an external inductor of inductance L_M is required for ballast purposes.

Transformer T_1 has a main secondary winding T_M . A resonant capacitor C_{10} is in series with inductor L_7 and reflects back to the primary winding of transformer T_1 as a series LC combination across the half-bridge inverter.

As now can be readily appreciated, by maintaining the fundamental sinusoidal frequency f_1 well below resonant frequency f_0 of the series L-C output circuit, the undesirable and unsafe high voltages and current levels produced in conventional ballast circuits during pre-ignition of lamp load LL are avoided. More particularly, by choosing the values of inductor L_7 and capacitor C_{10} such that their resonant frequency f_0 is defined as described hereinbefore, the voltage level across



inductor L_7 and capacitor C_{10} and current flow therethrough will be maintained at levels far below conventional ballast output circuits during pre-ignition of lamp load LL.

By not requiring the combination of inductor L_7 and capacitor C_{10} to be operated at its resonant frequency f_0 during pre-ignition of lamp load LL, the value of capacitor C_{10} can be significantly reduced. For example, conventional values for capacitor C_{10} range from about a nominal value of 6.8 nanofarads to about a nominal value of 9.2 nanofarads. In accordance with the invention, however, capacitor C_{10} can be reduced in value by approximately one-fourth to one-sixth (e.g. to approximately 1.2 nanofarads). Consequently, a far smaller, less expensive capacitor C_{10} is required reducing the manufacturing cost and space requirements of the ballast output circuit.

The reduced value of capacitor C_{10} results on top of this in substantially all current flowing through lamp load LL with relatively little current flowing through capacitor C_2 . Power requirements for the ballast circuit can be reduced and/or less costly wiring (higher resistance) can be used in the series connected L-C ballast output circuit while maintaining the same power requirements as in a conventional ballast output circuit. In other words, a less costly and/or more efficient ballast with smaller space requirements is provided by the present invention.

Preferably, resonant frequency f_0 should range from approximately 2.3 to 2.6 times fundamental frequency f_1 of the square wave generated by the square wave generator. Consequently, stray inductances and the like which may be difficult to account for will not increase the overall inductance. Resonant frequency f_0 will not approach third harmonic frequency $3f_1$. Unsafe operation (i.e., resonant operation of the series L-C output circuit) of ballast circuit 20 is prevented.

Generally, in calculating the inductance of inductor L_7 for determining resonant frequency f_0 , the leakage inductance of transformer T_1 or inductance of the discrete choke used for inductor L_7 is far greater than the stray inductance or other inductances within ballast circuit 20. Therefore, as a first order approximation, the inductance of inductor L_7 can be used without taking into account stray inductances and the like in determining the resonant frequency f_0 . For a tightly wound transformer T_1 in which very little or an insufficient amount of leakage inductance exists, a discrete inductor will be required to serve as the ballasting element for lamp load LL (i.e., to control the lamp current I_{LAMP}).

As now can be readily appreciated, the generated voltage (i.e. voltage E of

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Fig. 1 and voltage $V_{A,B}$ of Fig. 4(a)) is at a frequency which is far less than the resonant frequency of the series connected L-C circuit and therefore provides safe open circuit (pre-ignition) voltages and current levels. The frequency of this generated signal need not be changed following pre-ignition since it is never at or near resonant

- 5 frequency f_0 of the series connected L-C circuit. Feedback circuitry for sensing ignition of lamp load LL for switching to a different steady-state lamp operating frequency need not be provided. By eliminated the need to operate at resonant frequency f_0 of the series L-C circuit during pre-ignition of lamp load LL, the value and resulting size of the capacitor for the series connected L-C circuit can be far smaller than normally used in a
- 10 conventional series connected L-C circuit.

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CLAIMS:



1. A ballast circuit for generating a substantially rectangular driving signal sufficient to ignite a lamp load, comprising:
inductor means;
capacitor means serially connected to said inductor means; and
5 generating means for applying a generated signal to said serially connected inductor means and capacitor means, said generated signal having at least a fundamental frequency f_1 ;
the inductor means and capacitor means having a resonant frequency f_0 , characterized in that for the fundamental frequency and the resonant frequency it holds:
10 $nf_1 < f_0 < (n+1)f_1$ with $n = \text{an even integer}$.
2. A ballast circuit of claim 1, characterized in that the generating means includes a half-bridge inverter.
3. A ballast circuit of claim 1 or 2, wherein the resonant frequency f_0 is less than a third harmonic of said fundamental frequency f_1 .
- 15 4. A ballast circuit of claim 1, 2 or 3, wherein the lamp load after ignition enters into a steady-state mode of operation in which current therethrough is maintained at a substantially constant level, characterized in that in the steady-state mode the generating means apply said generated signal to said serially connected inductor means and capacitor means.
- 20 5. A ballast circuit of claim 1, 2, 3 or 4 wherein said lamp load is connected across the capacitor means.
6. A ballast circuit of claim 1, 2, 3, 4 or 5, wherein the lamp load includes at least one fluorescent lamp.

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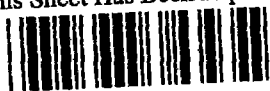
ABSTRACT:

"Lamp ballast circuit"

A ballast circuit having a series inductor (L_7) and capacitor (C_{10}) in which the lamp load (LL) is connected in parallel with the capacitor. During pre-ignition of the lamp load, the driving signal supplied by an inventor generating a substantially rectangular signal includes a fundamental frequency f_1 . The resonant frequency f_0 of the series connected L-C circuit is at least 2 times greater than the fundamental frequency f_1 but less than the third harmonic of the driving signal.

Fig. 3.

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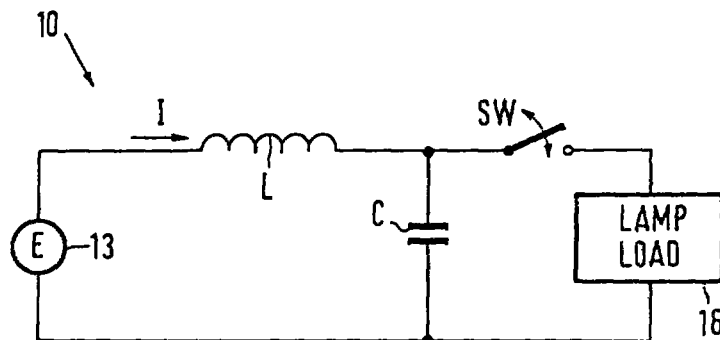


FIG. 1

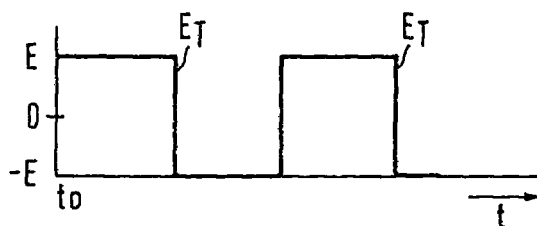


FIG. 2a

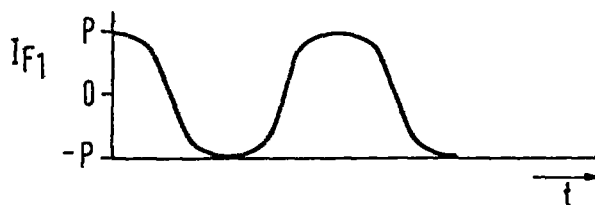


FIG. 2b

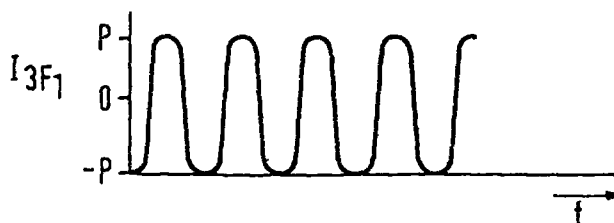


FIG. 2c

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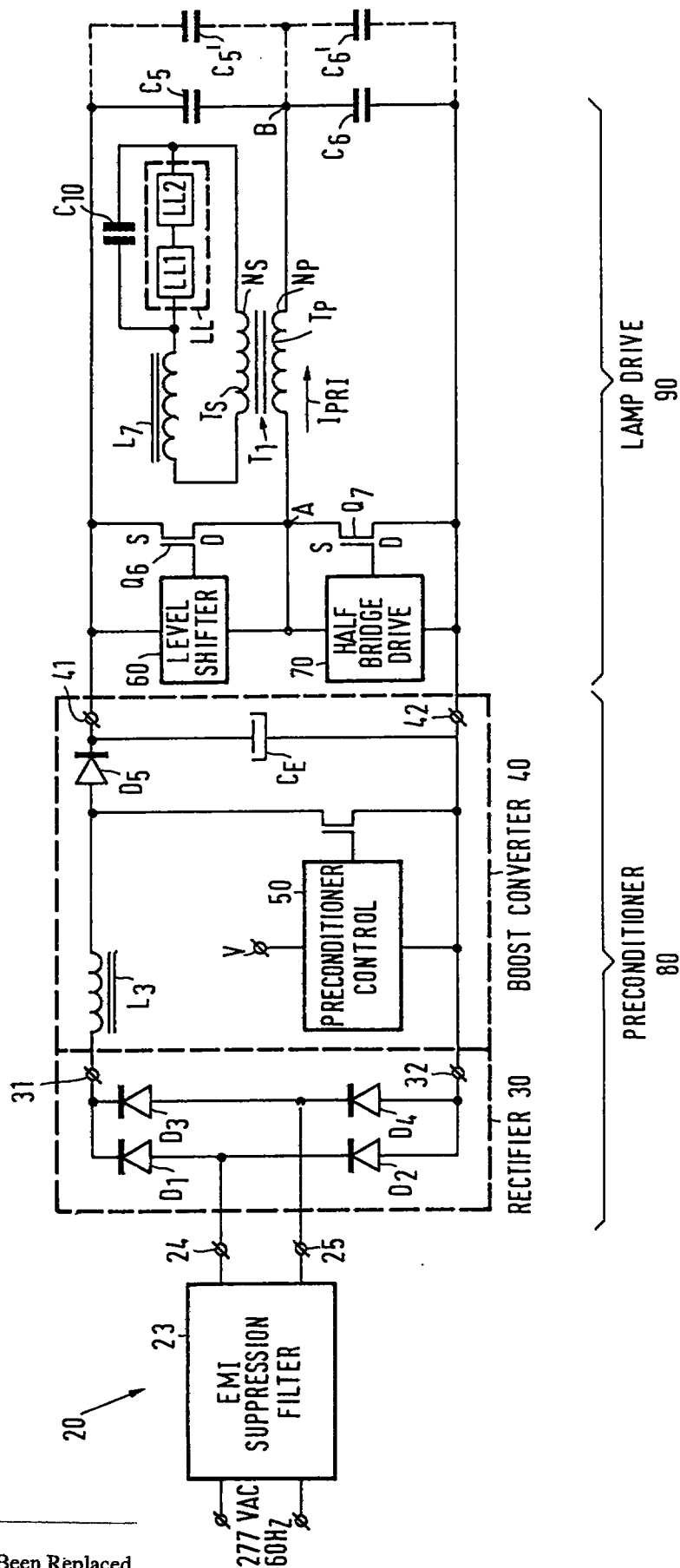


FIG.3

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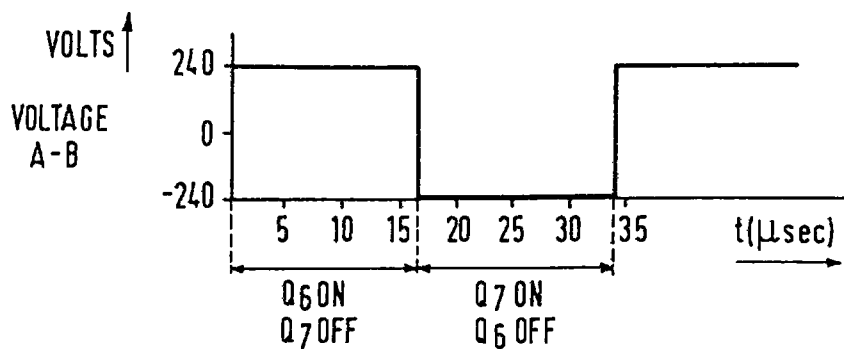


FIG. 4a

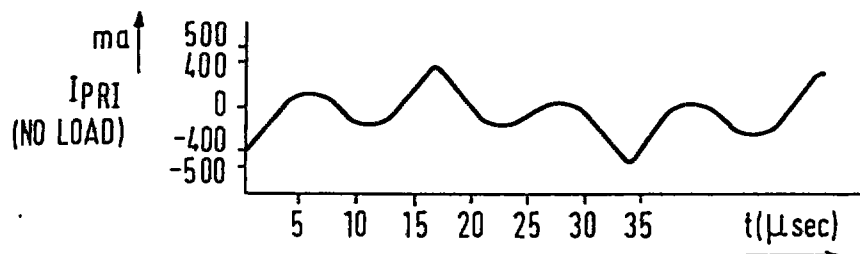


FIG. 4b

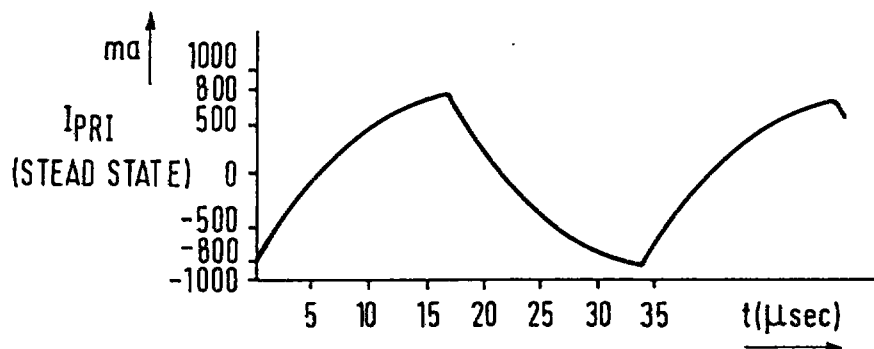


FIG. 4c

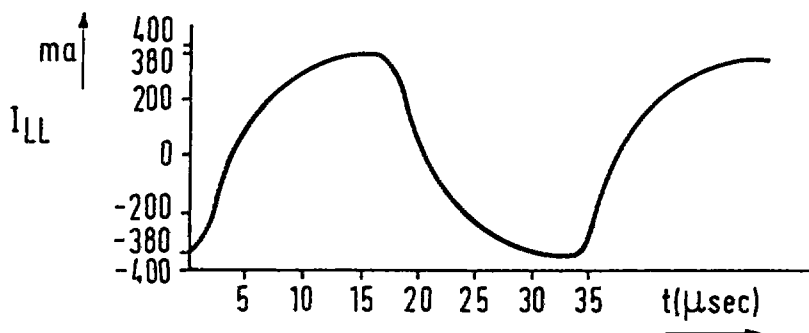


FIG. 4d

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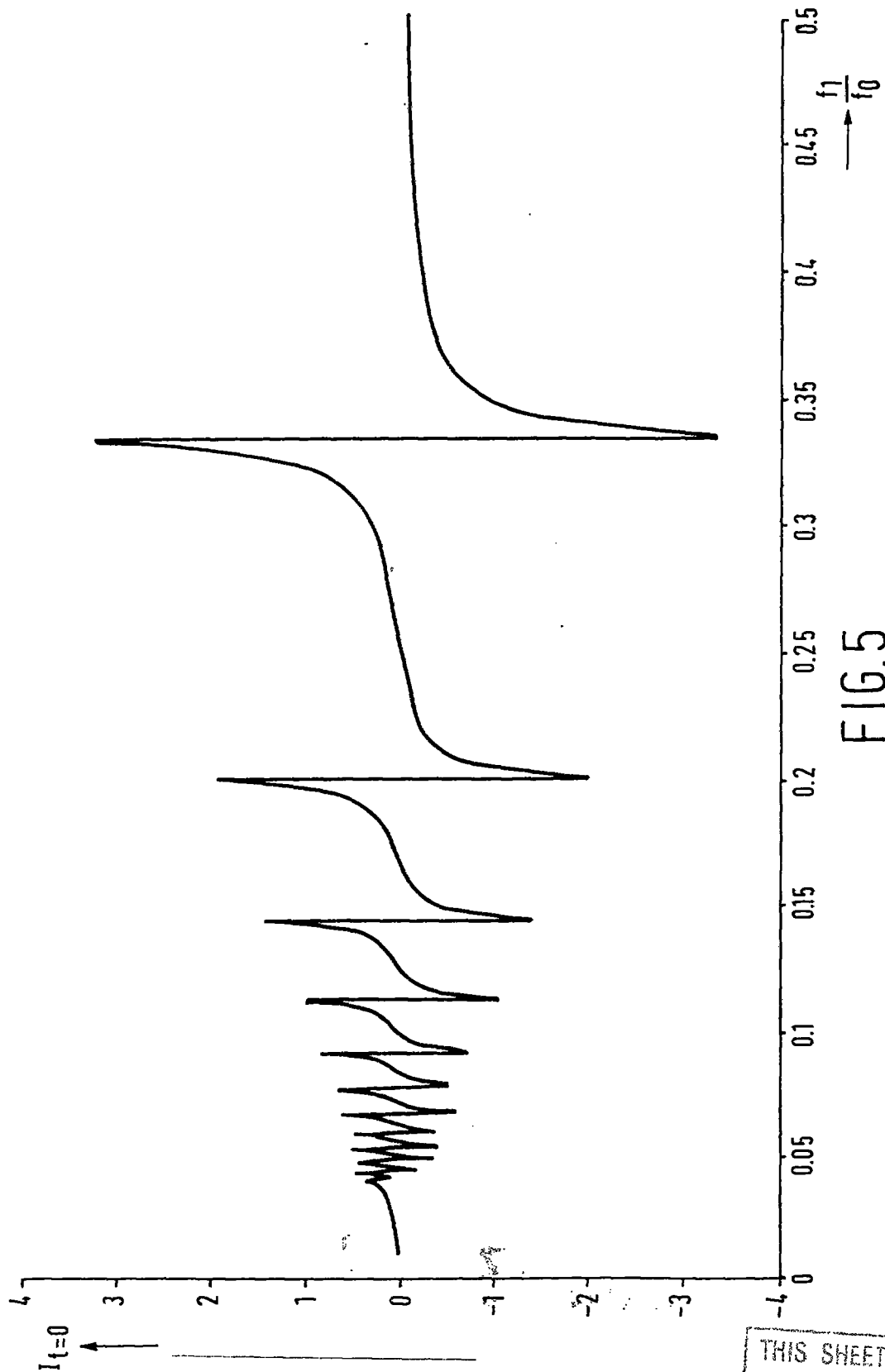
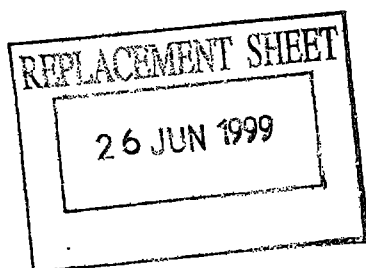


FIG. 5

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TITLE: LAMP BALLAST CIRCUIT

BACKGROUND OF THE INVENTION

This invention relates to a ballast circuit for generating a substantially rectangular driving signal sufficient to ignite a lamp load, comprising:

inductor means;

capacitor means serially connected to said inductor means; and

generating means for applying a generated signal to said serially connected inductor means and capacitor means, said generated signal having at least a fundamental frequency f_1 ;

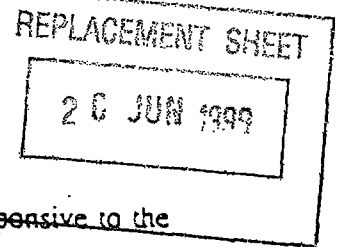
the inductor means and capacitor means having a resonant frequency f_0 .

Inductor means are to understand to be means adapted to exhibit the properties of an inductor. Capacitor means are to understand to be means adapted to exhibit the properties of a capacitor.

Conventionally the lamp load is connected across the capacitor. In a known circuitry the series L-C circuit operates during pre-ignition of the lamp load substantially at its resonant frequency. That is, the driving signal applied to the series L-C circuit is at or near the resonant frequency of the series L-C circuit. In this way a sufficiently high pre-ignition voltage is applied across the lamp load for ignition of the latter.

The lamp load, typically of a fluorescent type, following ignition, achieves a substantially steady-state sinusoidal current flow therethrough by reducing the driving signal frequency well below the resonant frequency of the series L-C circuit. In determining when to switch from the resonant frequency to a different steady-state operating frequency, feedback circuitry is required in the known ballast circuit for sensing lamp ignition.

A sufficiently high voltage during pre-ignition of the lamp and sinusoidal lamp current-following ignition (i.e. steady state operation), is commonly provided by a bridge inverter. Both full bridge and half-bridge inverters are known in the ballast circuit art. The (half)-bridge inverter includes switching to control the frequency of the



driving signal applied to the series L-C circuit. Control circuitry, responsive to the feedback circuitry, is required for controlling the speed at which the switching takes place.

Known lamp ballast circuits, as described above, suffer from several drawbacks. For example, known lamp ballast circuits require generating two different frequencies, that is, the resonant frequency during pre-ignition of the lamp load and a different therefrom a steady-state operating frequency. Such ballast circuits also require sensing circuitry to determine when to switch from the resonant frequency to the steady state operating frequency.

It is particularly undesirable to operate at or near the resonant frequency of the series L-C circuit before lamp ignition inasmuch as unsafe, high voltages and current levels can occur (i.e. above the maximum ratings of one or more ballast circuit components). By operating below resonance during pre-ignition of the lamp load, capacitive switching of the inverter can easily occur producing high switching losses. Additional circuitry is therefore required to prevent the inverter from operating below the series L-C circuit resonant frequency during pre-ignition of the lamp load.

The inductance of inductor L is normally determined based on the desired lamp current during steady state conditions. The capacitance of capacitor C is thereafter chosen so as to provide a resonant condition (typically between 20-50 kHz for a fluorescent lamp). Generally, the capacitance of capacitor C is between about 5 to 10 nanofarads with the additional high voltage capability leading to a relatively costly capacitor requiring a relatively large space on a printed circuit board.

Accordingly, it is desirable to provide a lamp ballast circuit having a safe open circuit (i.e., pre-ignition) voltage and current level, with relatively low switching losses. The improved lamp ballast circuit should not need a driving signal at more than one frequency; this frequency being well below resonance of the series L-C circuit. It is also desirable that the improved lamp ballast circuit permit use of a relatively less expensive, smaller capacitor in order to lower the lamp ballast manufacturing cost and to reduce the reactive current flowing through the capacitor after lamp ignition thus lowering circuit power loss.

SUMMARY OF THE INVENTION

In accordance with the invention, a ballast circuit for generating a driving

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signal sufficient to ignite a lamp-load as mentioned in the preamble is characterized in that for the fundamental frequency f_1 and the resonant frequency f_0 it holds:

$$nf_1 < f_0 < (n+1)f_1 \text{ with } n = \text{an even integer.}$$

By operating in these regions during pre-ignition, safe voltage and current levels will be maintained. A single drive frequency results in safe non-resonant operation before lamp ignition as well as correct lamp current after ignition. Feedback circuitry for sensing ignition of the lamp load for switching to a different steady-state lamp operating frequency need not be provided. By eliminating the need to operate at the resonant frequency of the series connected L-C circuit during pre-ignition of the lamp load, the value and resulting size of the capacitor can be chosen far smaller than normally used in a conventional series connected L-C circuit in a known ballast circuit.

In accordance with a feature of the invention, the generated signal which is a train of square waves, is generated preferably by a half-bridge or full bridge inverter. In yet another feature of the invention, the resonant frequency of the series connected L-C circuit is less than the third harmonic frequency of the generated square wave drive thereby avoiding unsafe third harmonic voltages and current levels during pre-ignition of the lamp load. Substantially the same generated signal frequency is used during pre-ignition and steady-state operation of the lamp load.

Accordingly, it is an object invention to provide an improved ballast circuit in which the unloaded, open circuit voltage and current levels are within the operating range of the ballast circuit components.

It is another object of the invention to provide an improved ballast circuit in which the same inverter driving signal can be used during pre-ignition and steady-state operation of the lamp load.

It is a further object of the invention to provide an improved ballast circuit in which less costly components can be used to lower the manufacturing cost of the ballast.

It is still another object of the invention to provide an improved ballast circuit which eliminates the need for feedback circuitry for sensing lamp ignition for changing the inverter frequency.

It is still a further object of the invention to provide an improved ballast circuit in which the inverter driving signal frequency is substantially less than the resonant frequency of a series connected L-C output circuit during pre-ignition of the

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lamp load.

The invention accordingly comprises several steps in a relation of one or more of such steps with respect to each of the others, and the device embodying features of construction, a combination of elements and arrangement of parts which are adapted to effect such steps, all is exemplified in the following detailed disclosure and the scope of the invention will be indicated in the claims.

BRIEF DESCRIPTION OF DRAWINGS

For a fuller understanding of the invention, reference is made to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a circuit diagram of a ballast output circuit in accordance with the present invention;

Figs. 2(a), 2(b) and 2(c) are timing diagrams of an inverter substantially rectangular output voltage, output current at its fundamental frequency and output current at its third harmonic, respectively in the circuit according to Fig. 1;

Fig. 3 is a schematic diagram of a ballast circuit in accordance with the invention;

Figs. 4(a), 4(b), 4(c) and 4(d) are timing diagrams of signals produced within the ballast circuit of Fig. 3 during pre-ignition and steady-state operation of the lamp load; and

Fig. 5 is a diagram of simulation of current in circuit of Fig. 1 as function of the ratio fundamental frequency and resonant frequency.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The figures shown herein illustrate a preferred embodiment of the invention. Those elements/components shown in more than one figure of the drawings have been identified by like reference numerals/letters and are of similar construction and operation.

Referring now to Figs. 1, 2(a), 2(b) and 2(c), a ballast circuit having a ballast output circuit 10 includes an inductor L and a capacitor C serially connected across the output of a square wave generator 13. Square wave generator 13 is preferably, but not limited to, a bridge inverter generating a substantially square wave of voltage $\pm E$ (i.e. the inverter output voltage). A lamp load 16 is connected across

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capacitor C through a switch SW. A current I flowing through inductor L includes a fundamental frequency component I_n and a third harmonic component of the fundamental frequency I_{3n} . Other currents at higher odd harmonics are present but are significantly smaller. For the sake of simplicity in calculations with respect to the preferred embodiment as described hereafter only terms concerning the fundamental frequency f_1 and the 3rd harmonic are taken into account.

In accordance with the Fourier transform square wave voltage 13 contains a sinusoidal wave at a fundamental frequency f_1 and odd harmonics of the fundamental frequency including a sinusoidal wave at a third harmonic $3f_1$. The amplitude of third harmonic component f_1 of voltage E is one third the amplitude of fundamental frequency component f_1 of voltage E.

To achieve low switching losses within square wave generator 13 during pre-ignition of lamp load 16 (generally at trailing edges E_r of voltage E), current I is preferably inductive (i.e., current lagging drive voltage) rather than capacitive (i.e., current leading drive voltage) during the voltage transitions of voltage E. Accordingly, the sum of fundamental frequency current component I_n and third harmonic-current component I_{3n} is inductive wherein I_{1r} and I_{3n} are the capacitive and inductive components of I, respectively. To achieve an overall inductive current I, an impedance Z of circuit 10 as viewed from square wave generator 13 requires that the inductive impedance at the third harmonic Z_{3n} be less than one third the capacitive impedance at the fundamental frequency Z_n . In other words, third harmonic component current I_{3n} is greater than fundamental frequency component I_n . This relationship is illustrated in Figs. 2(b) and 2(c) wherein an amplitude P represents the peak value of fundamental frequency current component I_n but is less than the peak value of third harmonic current component I_{3n} . In this way the sum of I_n and I_{3n} remains inductive at the voltage transitions of voltage E.

Lamp load 16 prior to ignition (i.e. during pre-ignition) appears as an open circuit. This open circuit condition is represented by switch SW in an open state (turned OFF). Following ignition, lamp load 16 is in its steady-state mode of operation and is represented by switch SW being turned ON such that lamp load 16 is connected in parallel with capacitor C.

Impedance Z_{3n} , which must be less than one third impedance Z_n during pre-ignition of lamp load 16, is therefore based on switch SW in its open state (i.e.,

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turned OFF). This condition can be expressed as follows:

$$|Z_n| > |3 Z_{3n}| \quad (\text{eq. 1})$$

That is,

$$|2\pi f_1 xL - 1/(2\pi f_1 xC)| > 3 |6\pi f_1 xL - 1/(6\pi f_1 xC)| \quad (\text{eq. 2})$$

Since impedance Z is capacitive at fundamental frequency f_1 and inductive at the third harmonic $3f_1$,

$$1/(2\pi f_1 xC) - 2\pi f_1 xL > 18\pi f_1 xL - 1/(2\pi f_1 xC)$$

That is,

$$1/(2\pi f_1 xC) > 5(2\pi f_1 xL) \quad (\text{eq. 3})$$

Eq. 3 can be rewritten as follows:

$$1/\sqrt{LC} > \sqrt{5} 2\pi f_1 \quad (\text{eq. 4})$$

A resonant frequency f_0 of circuit 10 during pre-ignition (i.e., with switch SW open) can be defined as follows:

$$1/\sqrt{LC} = 2\pi f_0 \quad (\text{eq. 5})$$

Substituting the value of $1/\sqrt{LC}$ defined by eq. 4 for the value of $1/\sqrt{LC}$ in eq. 5 results in

$$2\pi f_0 > \sqrt{5} 2\pi f_1 \quad (\text{eq. 6})$$

Accordingly, resonant frequency f_0 can be expressed as follows:

$$f_0 > \sqrt{5} f_1 \quad (\text{eq. 7})$$

In other words, third harmonic inductive current component I_{3n} is greater than fundamental frequency capacitive current component I_n when resonant frequency f_0 is greater than $\sqrt{5}$ times the fundamental frequency of voltage E.

To ensure that unsafe voltages and currents present at resonant frequency f_0 cannot occur, resonant frequency f_0 also should be less than third harmonic frequency $3f_1$ of voltage E. Therefore, the values of inductor L and capacitor C should be chosen such that:

$$\sqrt{5}f_1 < f_0 < 3f_1 \quad (\text{eq. 8})$$

By designing ballast circuit 10 such that resonant frequency f_0 is within the range of frequencies defined by eq. 8, the unsafe voltages and currents which occur at resonant frequency f_0 during pre-ignition of lamp load 16 are avoided and total current delivered by square wave generator 13 remains inductive. There is no need to vary the

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frequency of voltage E between resonant frequency f_0 during pre-ignition of lamp load 16 and a different frequency immediately thereafter as in conventional ballast circuitry. Feedback circuitry designed to sense ignition of lamp load 16 for determining when to vary the frequency of voltage E from resonant frequency f_0 to a different operating frequency can be eliminated. In accordance with the invention, a safer, simpler circuit is provided by maintaining resonant frequency f_0 within the boundaries defined by eq. 8. Due to the fact that the calculation as shown has only taken into account the fundamental frequency f_1 and its 3rd harmonic $3f_1$, the lower value of the range for choosing the resonant frequency f_0 is $\sqrt{5}$ times f_1 . However, when taken into account the existence of higher harmonics this value reaches the limit 2.

The result of a simulation in which at least the first 25 harmonics are taken into account is shown in figure 5.

In Fig. 5 the depicted curve displays the total current I_{Σ} in the circuit of Fig. 1 at the moment the voltage switches from $-E$ to $+E$ of the generator 13 as function of ratio of the fundamental frequency f_1 and the resonant frequency f_0 . The circuit operates in the inductive mode in all those regions that the current I_{Σ} is lagging to the voltage, thus is negative. From the Fig. 5 it is clear that these regions fulfil the relation

$$nf_1 < f_0 < (n+1)f_1 \text{ with } n = \text{an even integer.}$$

A ballast circuit 20 in accordance with the invention is shown in Fig. 3. An input voltage of 277 volts, 60 hertz is supplied to an electromagnetic interference (EMI) suppression filter 23. Filter 23 filters high frequency components inputted thereto lowering conducted and radiated EMI. The output of filter 20 provided at a pair of terminals 24 and 25 is supplied to a full wave rectifier 30 which includes diodes D_1 , D_2 , D_3 and D_4 . The anode of diode D_1 and cathode of diode D_2 are connected to terminal 24. The anode of diode D_3 and cathode of diode D_4 are connected to terminal 25. The output of rectifier 30 (i.e. rectified a.c. signal) at a pair of output terminals 31 and 32 is supplied to a boost converter 40. The cathodes of diodes D_1 and D_3 are connected to terminal 31. The cathodes of diodes D_2 and D_4 are connected to terminal 32.

Converter 40 boosts the magnitude of the rectified A.C. signal supplied by rectifier 30 and produces at a pair of output terminals 41 and 42 a regulated D.C. voltage supply. Boost converter 40 includes a choke L_1 , a diode D_5 the anode of which is connected to one end of choke L_1 . The other end of choke L_1 is connected to output

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terminal 31 of rectifier 30. The output of boost converter 40 at output terminals 41, 42 is applied across an electrolytic capacitor C_8 , one end of which is connected to the cathode of diode D_3 . A transistor (switch) Q_1 is connected to the junction between choke L_1 and the anode of diode D_3 . The other end of transistor Q_1 is connected to the junction between the other end of capacitor C_8 , output terminal 32 of rectifier 30 and output terminal 42.

A preconditioner control 50, which is powered by a D.C. supply voltage V , controls the switching duration and frequency of transistor Q_1 . Preconditioner control 50 is preferably, but not limited to, a Motorola MC33261 Power Factor Controller Integrated Circuit. Transistor Q_1 is preferably a MOSFET, the gate of which is connected to preconditioner control 50. Rectifier 30 and boost converter 40, including preconditioner control 50, form a preconditioner 80 for ballast circuit 20. Output terminals 41 and 42 of boost converter 40 serve as the output for preconditioner 80 across which a regulated D.C. voltage is produced.

A lamp drive 90, which is supplied with the regulated D.C. voltage outputted by preconditioner 80, includes a half bridge inverter having a level shifter 60 and a half-bridge drive 70. The half bridge inverter includes a pair of transistors Q_6 and Q_7 , which serve as switches, a pair of capacitors C_7 and C_8 and a transformer T_1 . Half-bridge drive 70 produces a square wave driving signal to drive transistor Q_7 and has a 50-50 duty cycle. Level shifter 60 inverts the driving signal supplied to transistor Q_7 for driving transistor Q_6 . The driving signals produced by level shifter 60 and half-bridge drive 70 are approximately 180° out of phase with each other so as to prevent conduction of transistors Q_6 and Q_7 at the same time, respectively.

A source S of transistor Q_6 and one end of level shifter 60 are connected to output terminal 41 of boost converter 40. A drain D of transistor Q_6 is connected to a terminal A. The other end of level shifter 60, one end of half-bridge drive 70 and a source S of transistor Q_7 are also connected to terminal A. The other end of half-bridge drive 70 and a drain D of transistor Q_7 are connected to output terminal 42 of boost converter 40. Capacitor C_7 is connected at one end to output terminal 41. The other end of capacitor C_7 and one end of capacitor C_8 are connected to a terminal B. The other end of capacitor C_8 is connected to output terminal 42.

A primary winding T_p of transformer T_1 is connected to terminals A and B. A secondary winding T_s is connected at one end to an inductor L_7 , the latter which

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generally represents either the leakage inductance of transformer T_1 or a discrete choke. Connected to the other end of inductor L_7 is one end of a capacitor C_{10} and one end of a lamp load LL . Lamp load LL can include any combination of lamps and is shown, but not limited to, the series combination of two fluorescent lamps LL_1 and LL_2 . The other ends of capacitor C_{10} and lamp load LL are connected to the other end of secondary winding T_1 .

The turns ratio between primary winding T_p and secondary winding T_s of transformer T_1 is N_p/N_s . Transformer T_1 electrically isolates lamp load LL from the output voltage produced by preconditioner 80 and provides sufficient open circuit voltage during pre-ignition to ignite lamp load LL .

The inductance of inductor L_7 is based on the desired current flow through lamp load LL once the latter has ignited and is in its steady-state mode of operation. The DC voltage across each capacitor C_3 and capacitor C_4 is approximately half the output voltage of preconditioner 80.

The waveforms shown in Figs. 4(a), 4(b), 4(c) and 4(d) produced by ballast circuit 20 are based on turns ratio N_p/N_s of about 1.5, inductor L_7 of approximately 4.3 millihenries, capacitor C_{10} of about 1.2 nanofarads and capacitors C_3 and C_4 of about 0.33 microfarads, nominally rated at 630 volts. Both lamp LL_1 and lamp LL_2 are 40 watt low pressure mercury vapor tubular fluorescent lamps. The fundamental frequency of the square wave produced by the half-bridge inverter is approximately 28kHz. The resonant frequency of inductor L_7 and capacitor C_{10} is approximately 70kHz, that is, approximately 2.5 times fundamental frequency f_1 .

During pre-ignition of lamp load LL , the output of the half-bridge inverter, which is across terminals A-B, forms a substantially square wave voltage train. Inductor L_7 and capacitor C_{10} form an L-C series connected circuit. During pre-ignition, lamp load LL appears as a substantially open circuit (i.e. no load condition) drawing substantially no power except for filament heating (assuming lamps LL_1 and LL_2 are fluorescent lamps of, for example, the rapid-start type).

Fig. 4(a) illustrates a voltage V_{AB} , that is, between terminals A and B. Voltage V_{AB} is square wave voltage train which is applied across primary winding T_p , varying between approximately +240 volts and -240 volts during no load conditions. Fig. 4(b) illustrates current I_{PR} flowing through primary winding T_p during no load conditions, that is, prior to ignition of lamp load LL and having a peak value of

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approximately ± 400 milliamperes. Once lamp load LL is ignited and is in its steady-state operation, current I_{PRI} flowing through primary winding T_p , as shown in Fig. 4(c), has a somewhat sinusoidal wave shape with a peak value of approximately ± 800 milliamperes. Capacitor C_{10} serves to smooth this somewhat sinusoidal current waveform resulting in a substantially sinusoidal lamp current I_{LAMP} as shown in FIG. 4(d) having a peak value of approximately ± 380 milliamperes.

Inductor L_7 serves as the lamp current ballasting element. Capacitor C_{10} , which is placed across lamp load LL, provides a more sinusoidal open circuit voltage and keeps total half bridge current inductive while also lowering higher harmonic content of current flowing through lamp load LL. Inductor L_7 and capacitor C_{10} together form a series connected L-C output circuit. The value for capacitor C_{10} is chosen such that safe open circuit operation is provided, that is, within the range of resonant frequencies defined by eq. 8. Accordingly, no additional circuits to protect lamp drive circuit 90 are required.

When ballast circuit 20 is first turned on, prior to the voltage being boosted by preconditioner 80, the input voltage of approximately 277 volts results in a square wave voltage of approximately 390 volts peak to peak being applied across primary winding T_p of transformer T_1 which is stepped up to approximately 570 volts peak to peak across secondary winding T_s . During this time the lamp cathodes are heated. After approximately 0.5 seconds, preconditioner 80 turns ON resulting in a regulated D.C. voltage of approximately 480 volts across output terminals 41, 42 of boost converter 40 and a voltage of approximately 700 volts peak to peak across secondary winding T_s , the latter of which is sufficient for igniting lamp load LL. Once lamp load LL is ignited (i.e. during steady-state lamp operation), the lamp voltage (i.e. voltage across lamp load LL) drops to approximately ± 300 volts peak with the remainder of the secondary winding T_s output voltage across inductor L_7 . The number of and connections between the lamps within lamp load LL can be varied as desired with the value of inductor L_7 being chosen so as to provide the desired lamp current I_{LAMP} during steady-state operation of lamp load LL.

Referring again to Fig. 3, the rectified AC (i.e. pulsating DC) signal supplied to preconditioner 80 from diode bridge rectifier 30 is boosted in magnitude by choke L_1 and diode D_1 to charge capacitors C_2 , C_3 and C_4 . In Fig. 3, capacitor C_2 is separate from capacitors C_3 and C_4 , capacitor C_2 being a large electrolytic capacitor in

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the range of 5 to 100 microfarads. Capacitors C_5 and C_6 are high frequency bridge capacitors. Since capacitor $\bar{C}_6$ is in parallel with the series combination of capacitors C_5 and C_6 , these three capacitors can be reconfigured as capacitors C_5' and C_6' .

Preconditioner 80 is an up-converter and boosts the rectified AC input voltage as follows. When transistor Q_6 (which serves as a switch) is closed, choke L_3 is short circuited to ground. Current flows through choke L_3 . Transistor Q_1 is then opened (turned OFF). Choke L_3 with transistor Q_1 open transfers stored energy through diode D_3 into capacitor C_2 . The amount of energy transferred to capacitor C_2 is based on the time during which transistor Q_1 is turned ON, that is, based on the frequency and duration of the driving signal supplied to the gate of transistor Q_1 by the preconditioner control 50. Asynchronous operation of transistor Q_1 with respect to voltage V_{LN} results.

Choke L_3 operates in a discontinuous mode, that is, the current through choke L_3 during each cycle is reduced to substantially zero before a new cycle is initiated. The frequency at which transistor Q_1 is turned ON and OFF is varied by preconditioner control 50 so that the peak current through choke L_3 is kept constant. Transistors Q_6 and Q_7 have internal diodes (not shown). These diodes, which can either be internal or external to the transistors, permit inductive currents to flow through transistors Q_6 and Q_7 at the initial turn ON and turn OFF of transistors Q_6 and Q_7 .

Preferably, capacitors C_5 and C_6 are electrolytic capacitors having a pair of discharge resistors in parallel, respectively. Transformer T_1 is a leakage transformer, that is, having a leakage inductor of inductance L_M which serves as the ballast for lamp load LL (i.e. to limit steady state current flow through the lamp load). Alternatively, when transformer T_1 has little or no leakage inductance an external inductor of inductance L_M is required for ballast purposes.

Transformer T_1 has a main secondary winding T_M . A resonant capacitor C_{10} is in series with inductor L_7 and reflects back to the primary winding of transformer T_1 as a series LC combination across the half-bridge inverter.

As now can be readily appreciated, by maintaining the fundamental sinusoidal frequency f_1 well below resonant frequency f_0 of the series L-C output circuit, the undesirable and unsafe high voltages and current levels produced in conventional ballast circuits during pre-ignition of lamp load LL are avoided. More particularly, by choosing the values of inductor L_7 and capacitor C_{10} such that their resonant frequency f_0 is defined as described hereinbefore, the voltage level across

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inductor L_7 and capacitor C_{10} and current flow therethrough will be maintained at levels far below conventional ballast output circuits during pre-ignition of lamp load LL.

By not requiring the combination of inductor L_7 and capacitor C_{10} to be operated at its resonant frequency f_0 during pre-ignition of lamp load LL, the value of capacitor C_{10} can be significantly reduced. For example, conventional values for capacitor C_{10} range from about a nominal value of 6.8 nanofarads to about a nominal value of 9.2 nanofarads. In accordance with the invention, however, capacitor C_{10} can be reduced in value by approximately one-fourth to one-sixth (e.g. to approximately 1.2 nanofarads). Consequently, a far smaller, less expensive capacitor C_{10} is required reducing the manufacturing cost and space requirements of the ballast output circuit.

The reduced value of capacitor C_{10} results on top of this in substantially all current flowing through lamp load LL with relatively little current flowing through capacitor C_2 . Power requirements for the ballast circuit can be reduced and/or less costly wiring (higher resistance) can be used in the series connected L-C ballast output circuit while maintaining the same power requirements as in a conventional ballast output circuit. In other words, a less costly and/or more efficient ballast with smaller space requirements is provided by the present invention.

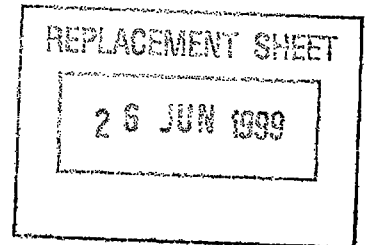
Preferably, resonant frequency f_0 should range from approximately 2.3 to 2.6 times fundamental frequency f_1 of the square wave generated by the square wave generator. Consequently, stray inductances and the like which may be difficult to account for will not increase the overall inductance. Resonant frequency f_0 will not approach third harmonic frequency $3f_1$. Unsafe operation (i.e., resonant operation of the series L-C output circuit) of ballast circuit 20 is prevented.

Generally, in calculating the inductance of inductor L_7 for determining resonant frequency f_0 , the leakage inductance of transformer T_1 or inductance of the discrete choke used for inductor L_7 is far greater than the stray inductance or other inductances within ballast circuit 20. Therefore, as a first order approximation, the inductance of inductor L_7 can be used without taking into account stray inductances and the like in determining the resonant frequency f_0 . For a tightly wound transformer T_1 in which very little or an insufficient amount of leakage inductance exists, a discrete inductor will be required to serve as the ballasting element for lamp load LL (i.e., to control the lamp current I_{LAMP}).

As now can be readily appreciated, the generated voltage (i.e. voltage E of

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Fig. 1 and voltage V_{A-B} of Fig. 4(a)) is at a frequency which is far less than the resonant frequency of the series connected L-C circuit and therefore provides safe open circuit (pre-ignition) voltages and current levels. The frequency of this generated signal need not be changed following pre-ignition since it is never at or near resonant frequency f_0 of the series connected L-C circuit. Feedback circuitry for sensing ignition of lamp load LL for switching to a different steady-state lamp operating frequency need not be provided. By eliminated the need to operate at resonant frequency f_0 of the series L-C circuit during pre-ignition of lamp load LL, the value and resulting size of the capacitor for the series connected L-C circuit can be far smaller than normally used in a conventional series connected L-C circuit.



CLAIMS:

1. A ballast circuit for generating a substantially rectangular driving signal sufficient to ignite a lamp load, comprising:
inductor means;
capacitor means serially connected to said inductor means; and
generating means for applying a generated signal to said serially connected inductor means and capacitor means, said generated signal having at least a fundamental frequency f_1 ;
the inductor means and capacitor means having a resonant frequency f_0 ,
characterized in that for the fundamental frequency and the resonant frequency it holds:
$$nf_1 < f_0 < (n+1)f_1 \text{ with } n = \text{an even integer.}$$
2. A ballast circuit of claim 1, characterized in that the generating means includes a half-bridge inverter.
3. A ballast circuit of claim 1 or 2, wherein the resonant frequency f_0 is less than a third harmonic of said fundamental frequency f_1 .
4. A ballast circuit of claim 1, 2 or 3, wherein the lamp load after ignition enters into a steady-state mode of operation in which current therethrough is maintained at a substantially constant level, characterized in that in the steady-state mode the generating means apply said generated signal to said serially connected inductor means and capacitor means.
5. A ballast circuit of claim 1, 2, 3 or 4 wherein said lamp load is connected across the capacitor means.
6. A ballast circuit of claim 1, 2, 3, 4 or 5, wherein the lamp load includes at least one fluorescent lamp.

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ABSTRACT
LAMP BALLAST CIRCUIT

A ballast circuit having a series inductor (L_1) and capacitor (C_{10}) in which the lamp load (LL) is connected in parallel with the capacitor. During pre-ignition of the lamp load, the driving signal supplied by an inverter generating a substantially rectangular signal includes a fundamental frequency f_1 . The resonant frequency f_0 of the series connected L-C circuit is at least 2 times greater than the fundamental frequency f_1 but less than the third harmonic of the driving signal.

Fig. 3.

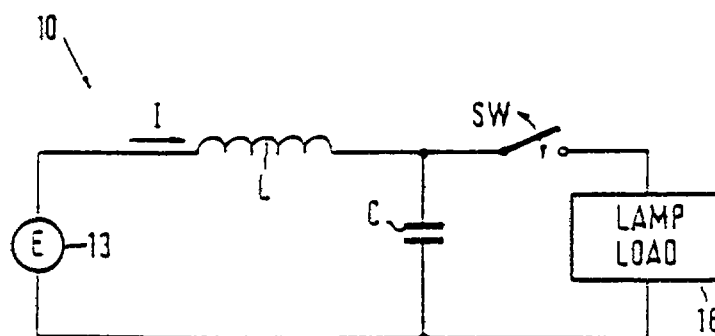


FIG. 1

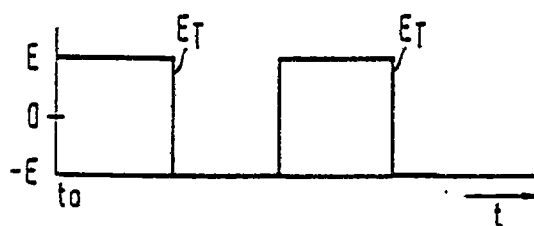


FIG. 2a



FIG. 2b

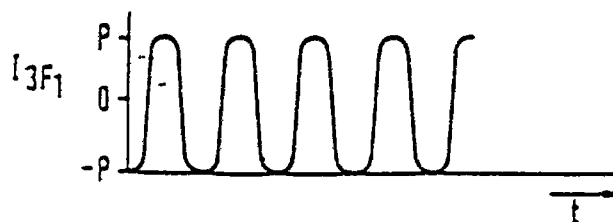


FIG. 2c

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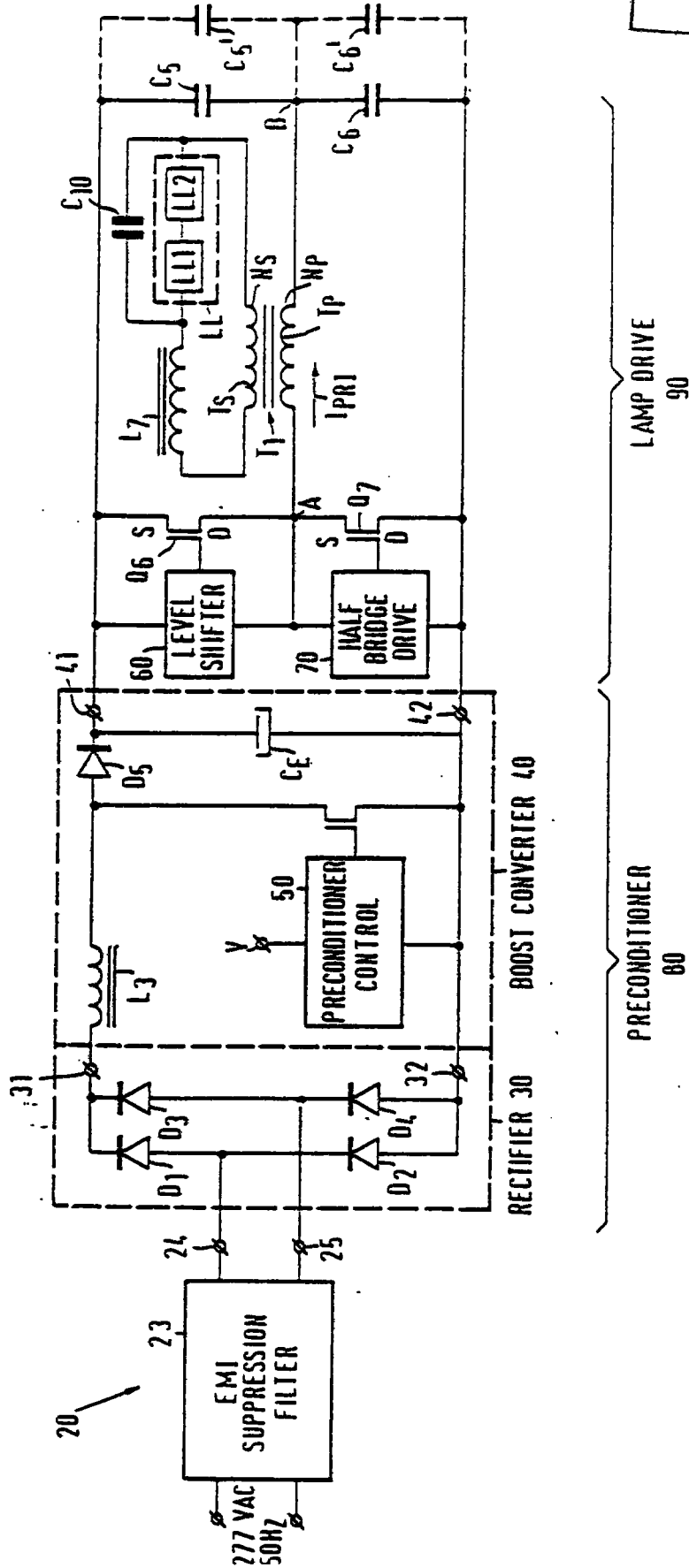


FIG.3

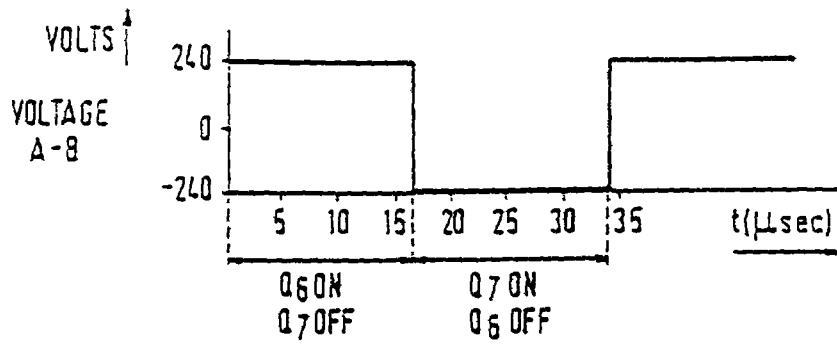
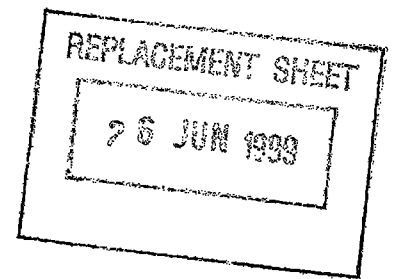


FIG.4a

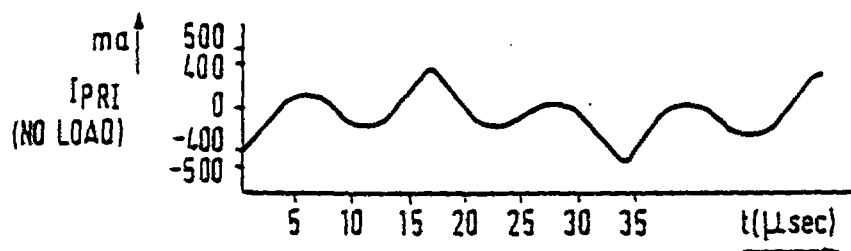


FIG.4b

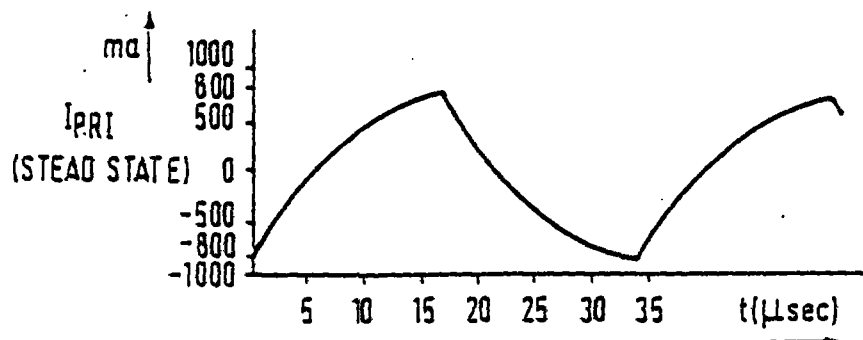


FIG.4c

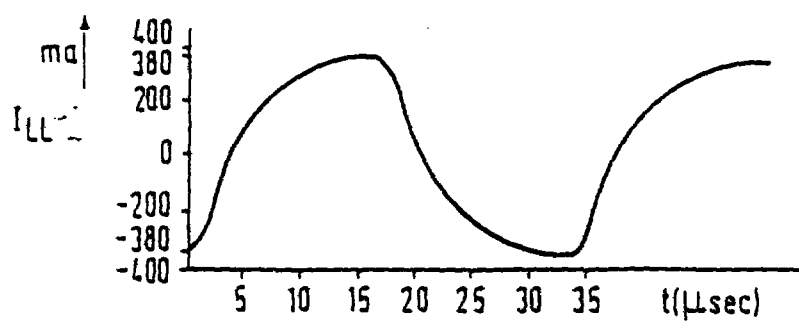


FIG.4d

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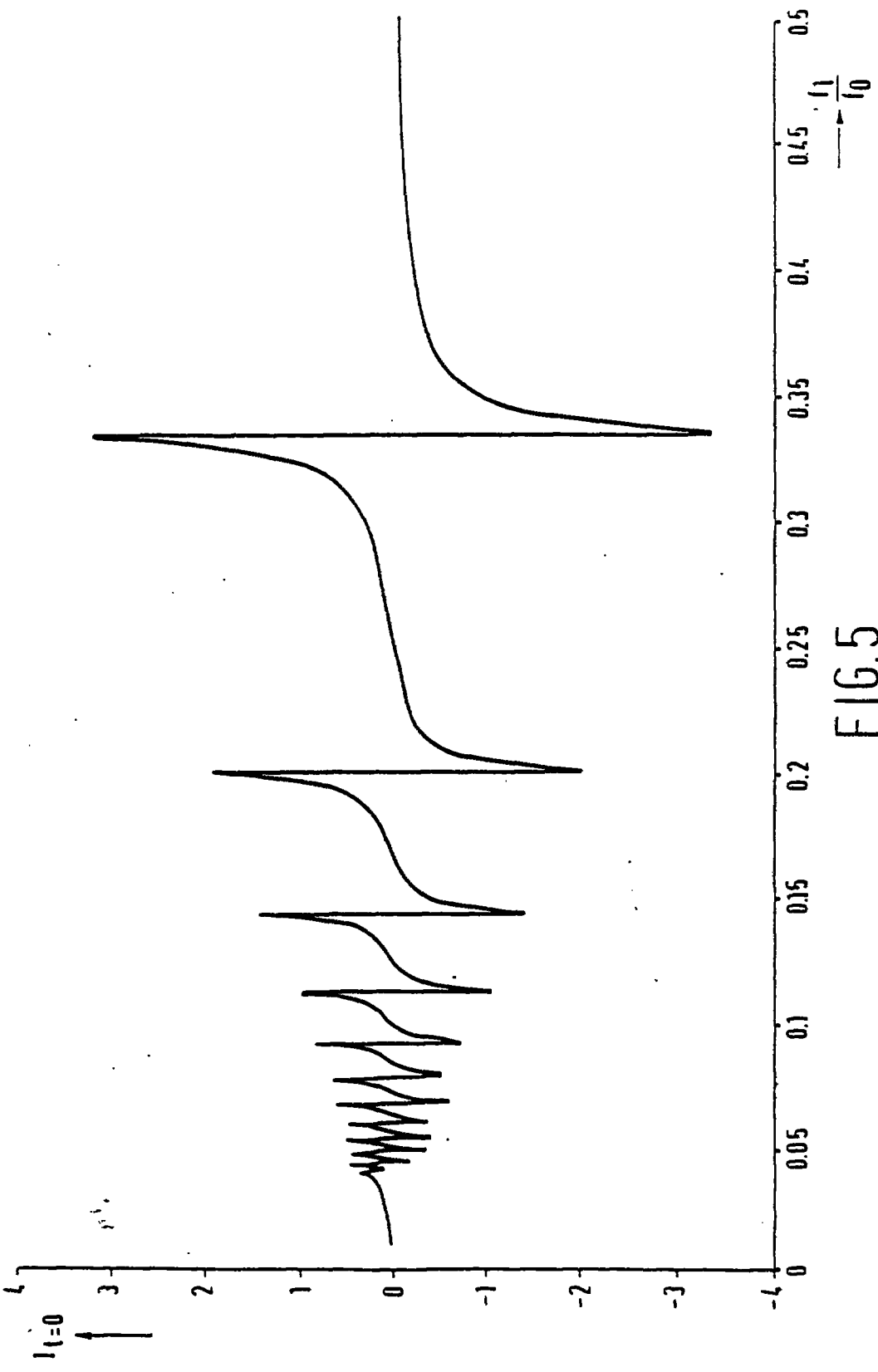


FIG.5