United States Patent [19]

Spira et al.

[11] **3,731,142**

[45] **May 1, 1973**

[54] **HIGH-FREQUENCY FLUORESCENT TUBE LIGHTING CIRCUIT WITH ISOLATING TRANSFORMER**

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[73] Assignee: **Lutron Electronics Co., Inc.**, Coopersburg, Pa.

[22] Filed: **Aug. 20, 1971**

[21] Appl. No.: **173,530**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 843,927, July 23, 1969.

[52] **U.S. Cl.** **315/94**, 315/101, 315/244

[51] **Int. Cl.**.....**H05b 39/00**

[58] **Field of Search**.....315/105, 94, 221, 315/242, 290, DIG. 2, DIG. 5, 244; 328/223

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Primary Examiner—Nathan Kaufman
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[57] **ABSTRACT**

A pulse forming network, energized through a semiconductor switching circuit, contains an inductance and capacitance which develop a high-frequency pulse output. The inductance of the pulse forming network serves as the primary winding of a step-up voltage transformer which has a secondary winding connected in series with a gas discharge device where the voltage across the gas discharge device is higher than the voltages seen by the semiconductor device.

11 Claims, 18 Drawing Figures

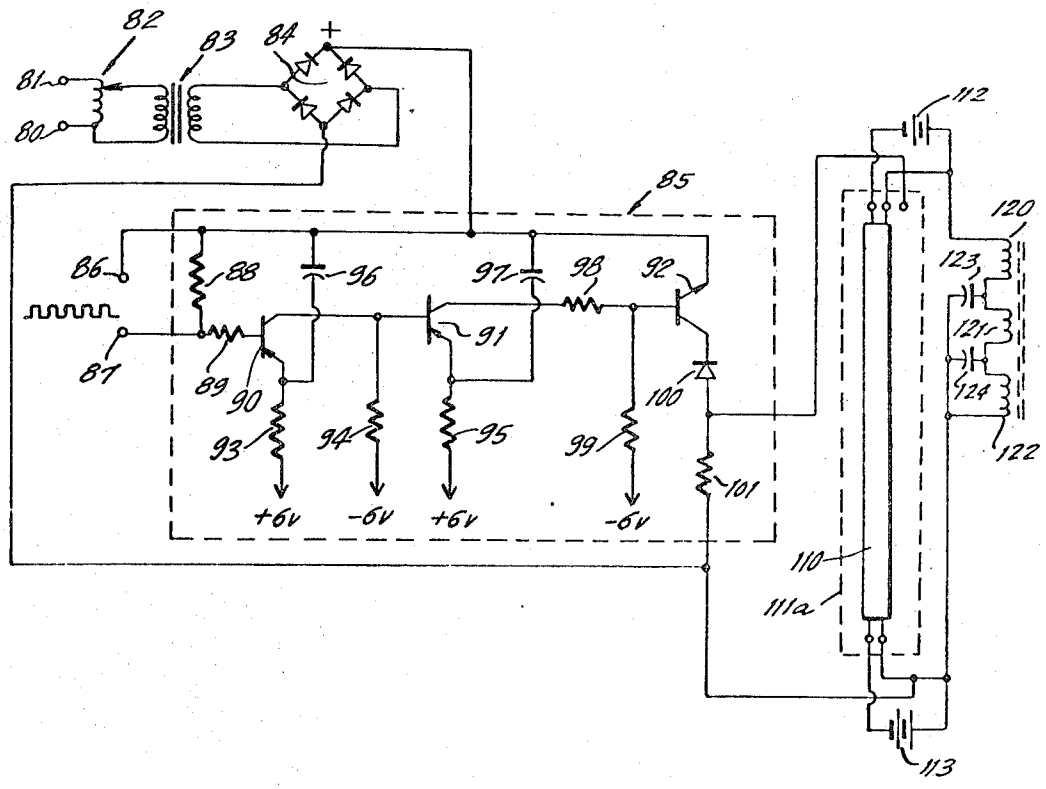


FIG. 1.

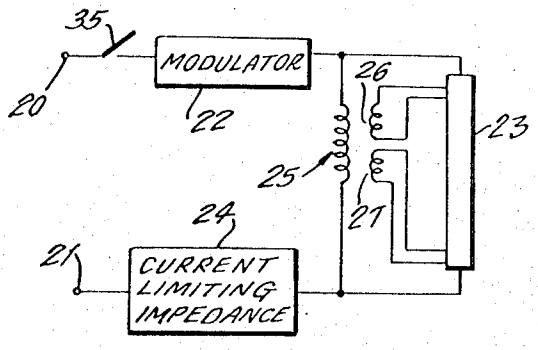
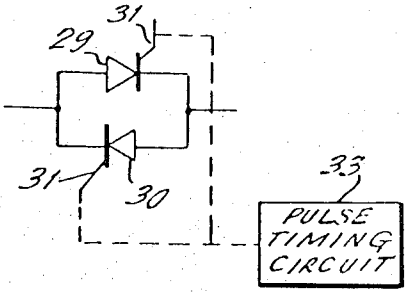


FIG. 2.



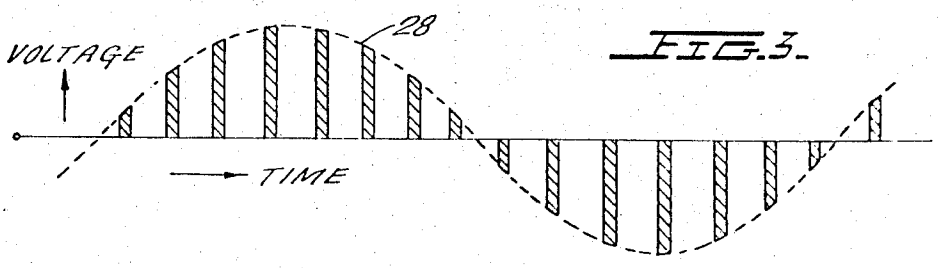


FIG. 3.

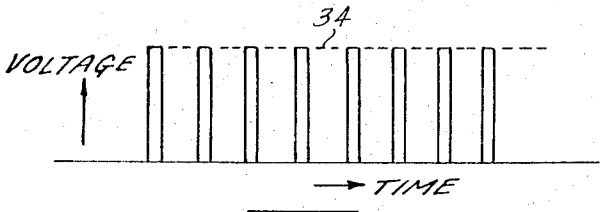


FIG. 4.

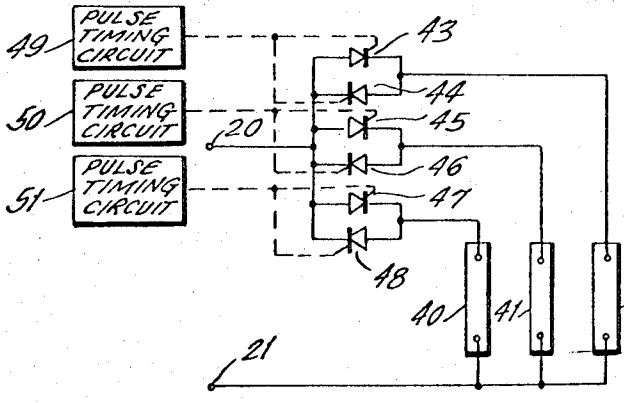


FIG. 5.

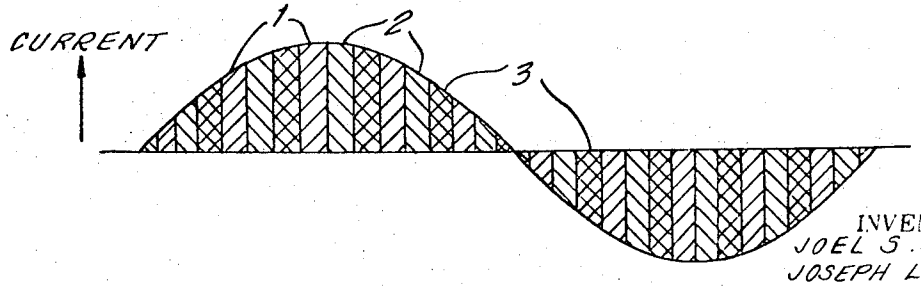


FIG. 6.

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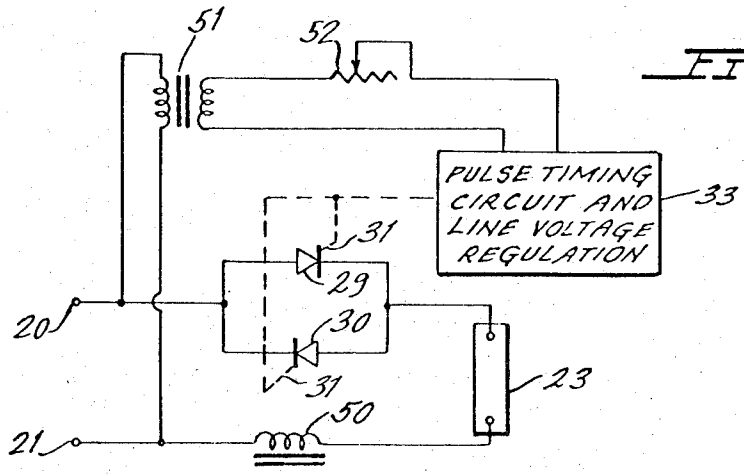


FIG. 7.

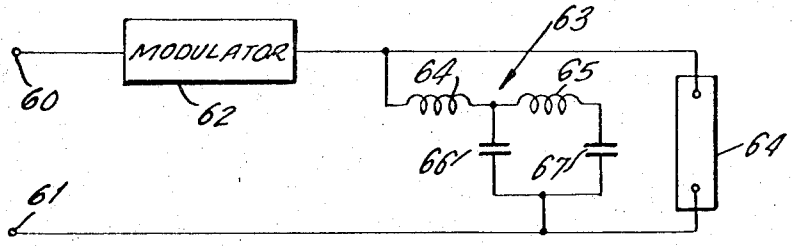


FIG. 8.

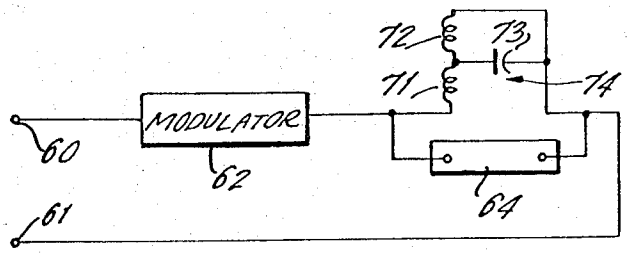


FIG. 9.

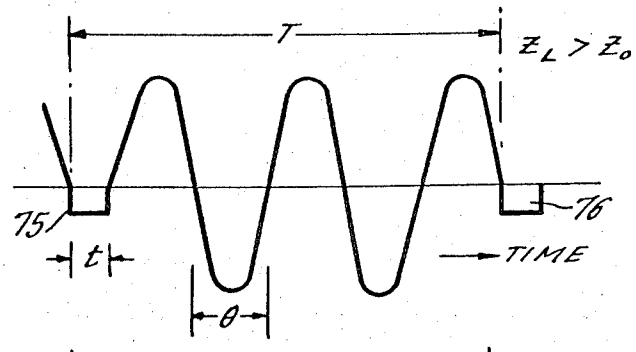


FIG. 10.

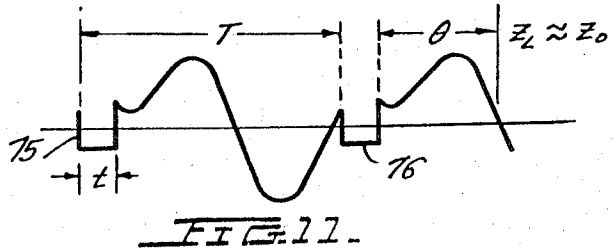


FIG. 11.

FIG. 12.

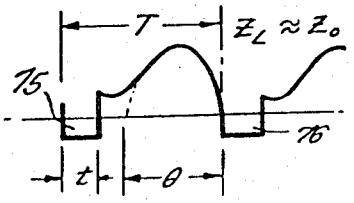


FIG. 13.

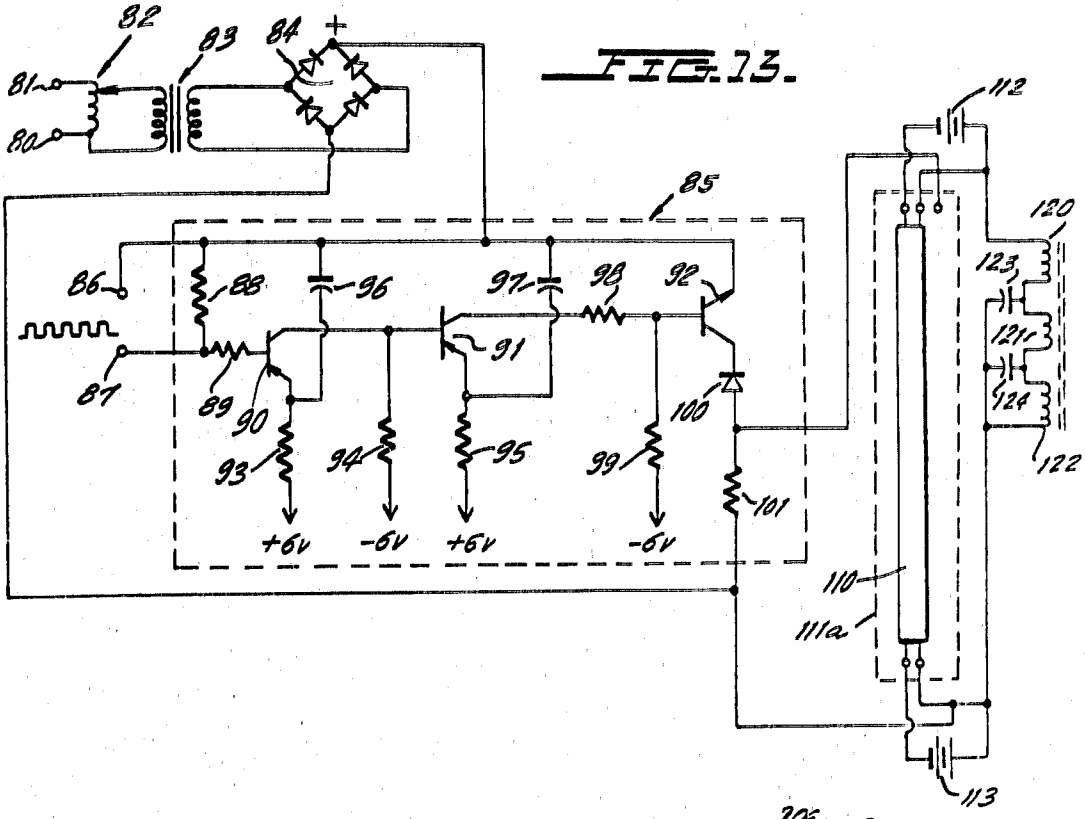


FIG. 14.

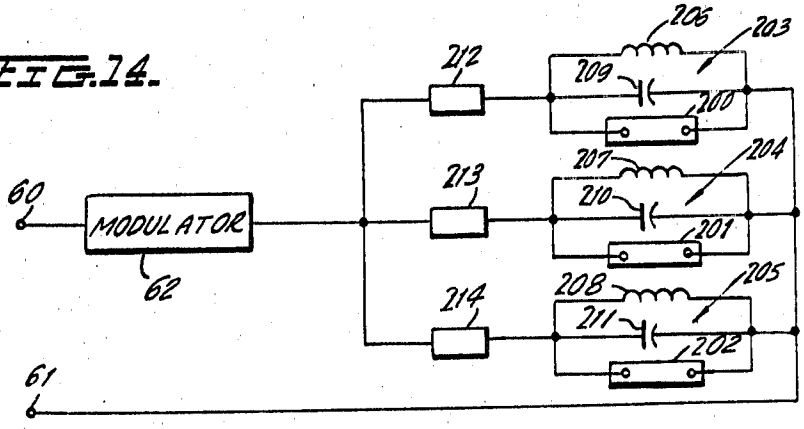


FIG. 15.

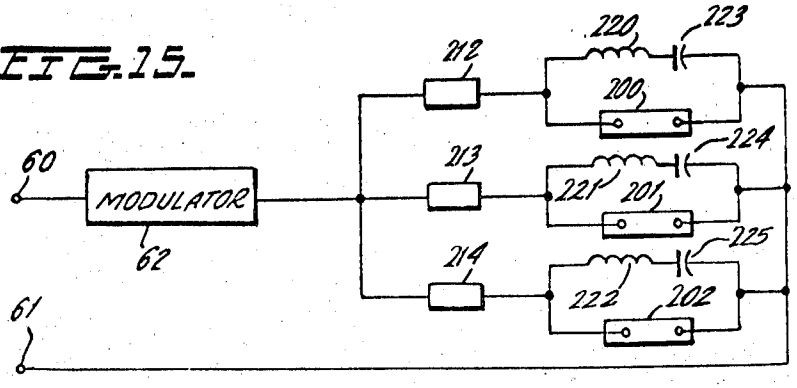


FIG. 16

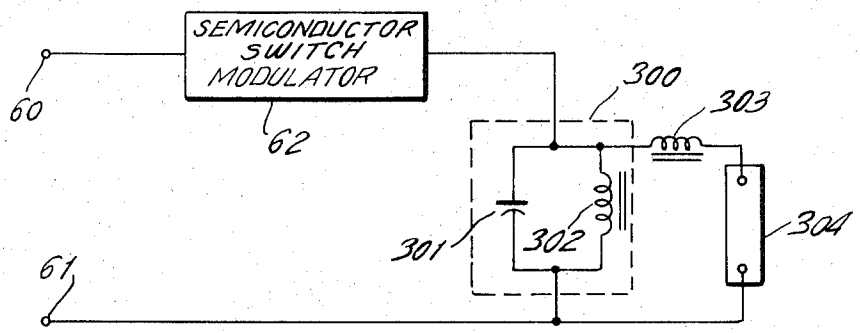


FIG. 17

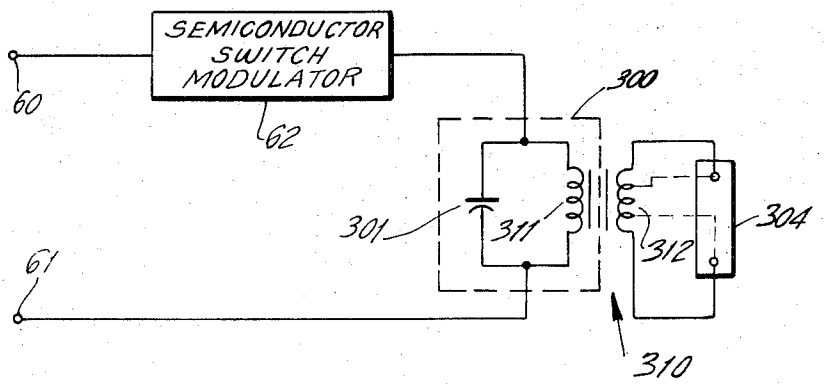
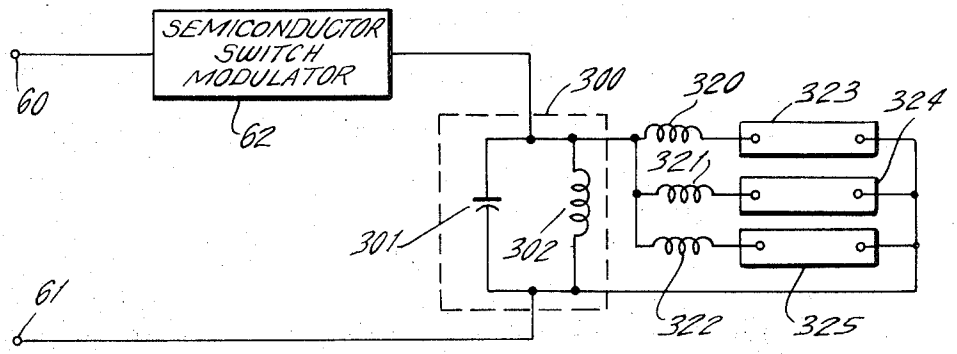


FIG. 18



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HIGH-FREQUENCY FLUORESCENT TUBE LIGHTING CIRCUIT WITH ISOLATING TRANSFORMER

RELATED APPLICATIONS

This application is a continuation-in-part of our copending application Ser. No. 843,927, filed July 23, 1969, entitled "High Frequency Fluorescent Tube Lighting Circuit and A-C Driving Circuit Therefor" (M-5844 and assigned to the assignee of the present invention.

BACKGROUND OF THE INVENTION

This invention relates to an a-c power supply for gas discharge tube lighting, and more particularly relates to a novel circuit for isolating semiconductor switching devices which drive pulse forming networks coupled to the gas tube from the relatively high voltages required in series with such tubes. More particularly, the invention consists of the use of an inductance in a pulse forming network as the low voltage winding of a voltage step-up transformer having its high voltage winding in series with the gas discharge tube.

In our above noted copending application Ser. No. 843,927, there is disclosed a circuit for operating a semiconductor switch into a pulse forming network (hereafter a PEN) which, in turn, developed the necessary operating voltages for driving the gas discharge tube. One difficulty with this design is that the relatively high voltage output of the PFN was connected across the semiconductor switch or modulator, so that special high voltage withstanding devices were needed. In accordance with the present invention, the PFN in series with the semiconductor switch is transformer-coupled to the tube rather than being directly connected thereto. Thus, it is now possible to operate the PFN and semiconductor switch at relatively low voltage, while transforming the voltage in series with the tube to the necessary high striking voltages required. Moreover, the novel circuit of the present invention permits the operation of a plurality of gas lamps from a common PFN and semiconductor switch since the inductor in the PFN can have a plurality of high voltage secondary windings, one for each of the gas lamps.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram of the combination of a modulator and gas discharge tube.

FIG. 2 schematically shows two gate controlled switches which could be used in the modulator circuit of FIG. 1.

FIG. 3 shows the output pulse current of the modulator of FIGS. 1 and 2 when the modulator is driven from a sinusoidal voltage source.

FIG. 4 shows the output pulse current of a circuit similar to that of FIG. 1 when the modulator is driven from a d-c source.

FIG. 5 illustrates the manner in which a plurality of tubes can share a continuous sine wave current input.

FIG. 6 illustrates the division of current pulses in the circuit of FIG. 5.

FIG. 7 shows a circuit diagram similar to FIG. 1 which includes line voltage regulation.

FIG. 8 illustrates the use of a delay line network in a circuit using a modulator and gas discharge tube load with the delay line connected in a voltage fed mode.

FIG. 9 is similar to FIG. 8 and shows the delay line connected in a current fed mode.

FIG. 10 shows the current-time characteristic of FIG. 9 when the load impedance is greater than the network characteristic impedance.

FIG. 11 shows the current-time characteristic of FIG. 9 when load impedance is about equal to the network characteristic impedance.

FIG. 12 shows the current-time characteristic of FIG. 9 when load impedance is about equal to the network characteristic impedance and the pulse charging time is close to the pulse time.

FIG. 13 shows a circuit diagram of a particular circuit similar to the circuit of FIG. 9.

FIG. 14 shows a circuit using the general concepts of the circuit of FIG. 9 where, however, a plurality of lamps and plurality of oscillation networks for each lamp are used with a common pulse modulator.

FIG. 15 is similar to FIG. 14 but uses individual oscillation networks which are modifications of the network shown in FIG. 8.

FIG. 16 shows a circuit diagram of the circuit of the present invention using autotransformer coupling between the PFN and gas lamp.

FIG. 17 is similar to FIG. 16 but illustrates the use of an isolated two-winding transformer.

FIG. 18 shows the manner in which multiple gas lamps can be driven from a common PFN and modulator.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIG. 1, there is shown the circuit disclosed in parent application Ser. No. 843,927, wherein a voltage source is connected to terminals 20 and 21 and in series with pulse modulator 22, a gas discharge tube 23 and a current limiting impedance 24. Tube 23 may be of any desired commercially available variety. It is possible to eliminate impedance 24 if the conduction time of tube 23 is made sufficiently short. When conduction time is made sufficiently short, ionization does not have time to build up to a high degree. For example, with a small neon tube, a pulse time of less than about 6 microseconds can be used. Therefore, the effective impedance of the lamp is relatively high and the current will not build up to extremely high value, and thus the tube will operate satisfactorily without excessive heating. Where the tube 23 has hot cathode filaments, a filament current supply can be provided by transformer 25 which has filament heater windings 26 and 27. Transformer 25 could be an autotransformer, and could be arranged in series with tube 23. A suitable starting circuit (not shown) may be provided if needed for the particular tube selected.

The voltage source connected to terminals 20 and 21 could be a standard low frequency a-c source, where low frequency is intended to refer to the usual frequencies used in home lighting and commercial lighting circuits such as 50 or 60 cycles. FIG. 3 shows the sinusoidal voltage wave form of this low frequency source as dotted line 28.

The modulator 22 is constructed as a pulse modulator such as a semiconductor switch, and, accordingly, applies the pulse voltage shown in FIG. 3 in shaded lines to the tube. The pulse repetition frequency is shown to be about 1,000 cycles per second in FIG. 3

and may vary from about 200 cycles per second to any desired upper frequency limit. The modulator, and thus the pulse current may typically have a conduction time of about 100 microseconds and nonconductive time of about 900 microseconds. These times can be varied as desired. It has been found that once the tube **23** has been ignited, it need not be reignited with each successive voltage pulse from modulator **22**. That is, the deionizing time of the tube is sufficiently long that the tube is not deionized between successive voltage pulses when the pulse repetition frequency is sufficiently high.

Since the tube **23** is now driven by a relatively high frequency source, the transformer **25** will be smaller than the equivalent transformer which is designed for low frequency operation. Moreover, transformer **25** will be appropriately tuned for operation at the relatively high frequency. Similarly, the current limiting impedance, which could be a reactive type component, will have a smaller size as the frequency of the current conducted thereby is increased. Moreover, since tube **23** is driven at a relatively high frequency, it will have an increased lumen efficiency and longer life. Moreover, by making the modulator in such a manner that pulse length can be controlled, the output of lamp **23** can be controlled or "dimmed."

Modulator **22** may be made in any desired manner; for example, as shown in FIG. **2**, the modulator **22** may include two back-to-back connected gate controlled switches **29** and **30** which are conductive so long as a gate signal is applied to their gates **31** and **32**, respectively. A suitable pulse timing circuit **33** is then connected to gates **31** and **32** and delivers timed firing pulses to gates **31** and **32**.

It has been found possible to apply a d-c source to terminals **20** and **21**, with modulator **22** generating pulses from the d-c source as shown in FIG. **4**. Thus, while the d-c voltage, shown by dotted lines **34**, is below the tube striking voltage, once the tube is fired, the pulse repetition time is less than the deionizing time of the tube so that the tube will operate with each successive pulse from modulator **22**. Note that filament transformer **25** and current limiting impedance will see the relatively high pulse repetition frequency of modulator **22**.

A single modulator could be used in connection with a plurality of tubes **23** in FIG. **1**, or any of the other configurations herein. Any suitable means could be used to insure proper striking and conduction of all of such parallel connected tubes. Thus, considerable economy is achieved in the savings of the ballasts for each lamp, and the cost of the modulator per each lamp of a large number becomes very small. Moreover, the modulator **22** can be combined in the same wall box with the ON-OFF switch **35** so that the designer of the fixture for lamp **23** (or a plurality of such lamps) need not consider the bulk of a ballast, or the housing for modulator **22**, in his fixture design.

A plurality of tubes can be arranged to sequentially share current pulses from a continuous sinusoidal current supply. FIG. **5** shows a circuit in which three tubes **40**, **41** and **42** (which could be respective groups of tubes) are connected in series with terminals **20** and **21** (as in FIG. **1**) which are connected to a suitable low frequency source. Each of tubes **40**, **41** and **42** are then connected in series with respective pulse modulators, shown as back-to-back pairs of gate controlled switches **43–44**, **45–46** and **47–48**, respectively. Each of the pairs of switches is provided with a respective pulse timing circuit, such as pulse timing circuits **49**, **50** and **51**, respectively, which causes the current from terminals **50** and **51** to sequentially switch or commutate from tube **40** to tube **41** to tube **42** and back to tube **40**, etc. Thus, a continuous and sinusoidal current is drawn from the source connected to terminals **20** and **21**, thereby substantially decreasing radio interference.

This continuous sinusoidal current wave form is shown in FIG. **6**. Referring to FIG. **6**, the current pulse to tubes **40**, **41** and **42** is shown respectively as the cross-hatched pulses (labeled "1"), in which the hatch lines rise from left to right, as the cross-hatched pulses (labeled "2") in which the hatch lines fall from left to right, and as the double hatched pulses (labeled "3"). Clearly, the envelope of the current pulses of FIG. **6** defines a continuous sinusoid.

Note that FIGS. **5** and **6** require that the pulse "OFF" time is twice as long as the pulse "ON" time since three tubes share the total sinusoid current. Clearly, any desired number of tubes could be used to share the total current with the ratio of "ON" to "OFF" pulse time being suitably adjusted.

The use of a pulse modulator permits many desirable control functions in the lighting circuit. As previously stated, it permits dimming by controlling the length of the conducting pulse in the circuit of FIG. **1**. FIG. **7** shows the manner in which the novel concept can be used to offset the effect of varying line voltage. Note that the circuit of FIG. **7** uses the modulator of FIG. **2** in the circuit of FIG. **1** and shows a choke **50** as the current limiting impedance. Thus in FIG. **7**, the terminals **20** and **21** are connected to an a-c source which has a varying voltage. This would normally vary the intensity of the output of tube **23**. The pulse timing circuit, however, is further provided with a suitable circuit for changing pulse conduction time in response to varying line voltage. Thus, a potential transformer **51** is connected across terminals **20** and **21** and applies an input voltage to the pulse timing circuit. The pulse timing circuit is suitably arranged so that pulse conduction time, or the pulse repetition frequency, is varied inversely with the output voltage of transformer **51**. A decrease in line voltage will, therefore, increase the pulse length so that light intensity can be held constant. Similarly, an increase in line voltage will decrease pulse time so that light intensity will be constant. An adjustable resistor **52** can be connected in series with the output of transformer **51** and serve for manual adjustment of output light intensity, or "dimming."

FIGS. **8** and **9** illustrate embodiments of the invention in which the pulse modulator is followed by an oscillator type circuit formed of a modified pulse forming network with the combination operating to provide a high frequency current output to one or more fluorescent lamps.

Referring to FIG. **9**, there is shown a circuit having input terminals **60** and **61**, a modulator **62**, an oscillating network **74** and a fluorescent lamp **64**. Either a low frequency a-c power source or a d-c source can be connected to terminals **60** and **61**, as previously described in connection with FIG. **1**. The modulator **62** may be the same as the modulator **22** of FIGS. **1** and **2**, it only

being necessary that modulator **62** acts to pulse the voltage connected to terminals **60** and **61**. Lamp **64** may be of any desired type.

Network **74** is connected in a current fed mode (a shorted delay line) and consists of two chokes **71** and **72**, and capacitor **73** connected as shown. Circuits of this type (with additional stages) are well known as delay line-pulse shaping circuits for radar modulators.

This type PFN circuit, which is an oscillation network, follows the pulse modulator and acts to provide an oscillating output current having a generally sinusoidal characteristic wave shape.

FIGS. **10**, **11** and **12** show the current applied to tube **64** from the oscillation network **74** for various designs of the network **74**. FIG. **10** shows the system when the impedance of tube **64** is substantially larger (for example, 5 times) than the characteristic impedance of network **74**. In FIG. **10**, pulses **75** and **76** are the pulses delivered from modulator **62**. These pulses have a period T and a conductive time t. These pulses can be considered to "charge" network **74** which subsequently oscillates with a period 2θ as shown in FIG. **10**. Thus, in period T, tube **64** will have 6 current pulses applied thereto (including pulse **75**) with a waveform approximating a sine wave. Note that the closer the pulse time t is to θ, the closer the wave shape is to a sinusoid. Therefore, if the pulse repetition frequency of modulator **62** is 1,000 p.p.s., the tube **64** will carry a driving current of about 6,000 cycles per second.

As shown in FIG. **10**, the circuit has a resonant ring since the load impedance is much greater than the characteristic impedance of network **74**. The network can be made non-resonant, as shown in FIGS. **11** and **12**, by making the load impedance about equal to the network characteristic impedance. Thus, in FIG. **11**, a sinusoid is obtained with the period T of pulses **75** and **76** approximately equal to $(2\theta + t)$. A better or smoother waveform is obtained in FIG. **12** by reducing the period T of pulses **75** and **76** with respect to the oscillation period 2θ, and by making $T=\theta+t$, and t approximately equal to θ.

An important advantage of the circuit of FIG. **9** is that it provides an essentially pure a-c input to the tube, even though a d-c operating voltage is applied to terminals **60** and **61**.

In one particular test that was performed on a circuit of the type shown in FIG. **9**, a d-c voltage was connected to terminals **60** and **61**, which was such that approximately 100 volts a-c was measured across the terminals of lamp **64**. The d-c content of this a-c voltage was measured to be less than 0.2 volts. This d-c component is believed to be present since the chokes **71** and **72** represent a short circuit to d-c current so that the 0.2 volts was an IR drop across the coils. Obviously, this IR drop could be even further reduced by merely using windings for the coils which have a lower resistance.

In the case of the current fed PFN of FIG. **9**, starting may be automatic. When the tube is "OFF," its impedance is extremely high (in the order of megohms), and thus the tube impedance is very much greater than the characteristics impedance of the network, regardless of the ratio of load impedance to tube impedance selected in accordance with FIGS. **10**, **11** and **12**. Thus, the network, during starting, will supply very high voltage pulses to the tube, thereby firing it. It is also possible to wind a few turns on choke **71** or **72** and drive the filaments with these turns to effect completely self-contained starting and operation for a rapid start lamp.

Another technique for starting may use inductance in the circuit which is adjusted for low Q when the tube is operating. However, when the tube is "OFF," the inductance has a higher Q and comes out of saturation, therefore generating a high voltage for starting.

FIG. **8** is similar to the circuit of FIG. **9**, but operates in a voltage fed mode rather than a current fed mode. Thus, in FIG. **8** the oscillation network **63** is connected in parallel with tube **64** and consists of chokes **64** and **65** and capacitors **66** and **67**. The circuit operates in a similar fashion as previously described in connection with FIGS. **10**, **11** and **12**.

In the foregoing, the combination of an a-c or d-c voltage source, a modulator and an oscillation network have been described in connection with a fluorescent lamp load. It should be understood, however, that any type load could have been used, particularly where the load impedance is much greater (for the current fed case) than the network characteristic impedance (as in FIG. **10**). Thus, the circuit can operate as a frequency converter per se when the input to terminals **60** and **61** of FIGS. **8** and **9** is a-c, or as a d-c to a-c converter if d-c is applied to terminals **60** and **61**. FIG. **13** shows a circuit which was constructed to carry out the current fed mode of operation described in FIG. **9**. Referring to FIG. **13**, the power source consisted of a 120 volt, 60 cycle source connected to terminals **80** and **81** of a variable transformer **82**. The output of variable transformer **82** is variable between 0 to 140 volts and is connected to an isolation transformer **83**. The isolation transformer secondary winding is then connected to a full wave rectifier bridge **84** which supplies a d-c input voltage to the pulse modulator portion of the circuit.

The pulse modulator was formed of the circuit shown within dotted block **85** and is equivalent to modulator **22** of FIG. **1** or modulator **62** of FIGS. **8** and **9**. The modulator **85** has input terminals **86** and **87** which are connected to a suitable pulse timing circuit. Any standard pulse timing circuit could be connected to terminals **86** and **87**, and, for experimental purposes, a commercially available pulse generator, manufactured by Tektronics Corporation was used as a source of timing pulses.

A resistor **88** (47 ohms) is provided across terminals **86** and **87** to terminate the pulse generator and a resistor **89** (2.2K) connected to the base of transistor **90** (2N4037 and serves as a current limiting and isolating resistor. The collector of transistor **90** is connected to the base of transistor **91** (2N4037). The collector of transistor **91** is in turn connected to the base of power transistor **92** (MJ423) through resistor **98** (10 ohms).

Suitable decoupling resistors **93** (33 ohms), **94** (330 ohms), **95** (33 ohms) and **99** (1K) are provided along with decoupling capacitors **96** (50 microfarads) and **97** (50 microfarads). Each of resistors **93**, **94**, **95** and **99** were connected to biasing voltage sources as indicated which were provided by batteries. Clearly, a standard rectifier power supply could be used for this purpose.

The emitter-collector circuit of power transistor **92** is then connected in series with the output of rectifier **84**,

diode 100 (1N647), and resistor 101 (10K). Diode 100 protects transistor 92 against voltage reversal and resistor 101 dissipates energy from the oscillating network when the lamp is turned off, as will be described. The lamp was fluorescent lamp 110 which was a 40 watt lamp manufactured by Sylvania type F40CW "Life Line." A metal foil starting aid to simulate the fixture 111a, shown in dotted lines, was placed along the tube and connected to one of its electrodes as shown. The cathode filaments of lamp 110 were heated by two 6-volt batteries 112 and 113, it being obvious that a suitable transformer circuit could be used for this purpose.

The oscillating network was then formed of chokes 120, 121 and 122 and capacitors 123 and 124. Note that the network is connected in the current-fed mode of FIG. 9. Each of chokes 120, 121 and 122 had an inductance of 1.7 millihenrys and each of capacitors 123 and 124 were 0.17 microfarad, 400 volt capacitors.

The circuit of FIG. 13 operates as follows:

When a positive pulse is applied to terminals 86 and 87, transistor 90, which is biased to normally conduct, is turned off. This turns the transistor 91 on, transistor 91 being biased to be normally off. The conduction of transistor 91 causes transistor 92 to turn on, transistor 91 being normally off. Thus, a positive going pulse applied to terminals 86 and 87 turns transistor 92 on for the duration of the input pulse.

When transistor 92 turns on, the output voltage of rectifier 84 appears across resistor 101 and thus across the oscillating network and tube 110. The oscillating network, consisting of chokes 120, 121, 122 and capacitors 123 and 124 is charged for the duration of the pulse across resistor 101, and after the pulse disappears, the circuit oscillates as shown in FIG. 10. Therefore, the tube 110 is driven by the oscillating current shown in FIG. 10, and the tube is driven in a high frequency mode in accordance with the invention.

It is to be noted that the circuit of FIG. 13 uses a particular modulator which responds only to positive pulses at terminals 86 and 87. Clearly, the circuit could be modified so that both positive and negative pulses could drive the modulator. Moreover, it will be apparent that all biasing voltages could be directly derived from the high frequency circuit by means of relatively small transformers.

It will also be understood that the lamp 110 could have been replaced by a general load which requires a generally sinusoidal wave shape. By way of example, a winding could be taken from one of chokes 120, 121 and 122 to serve as a high frequency input to a biasing voltage circuit.

Referring next to FIG. 14, there is illustrated a circuit using the general concepts of the circuit of FIG. 9 where, however, a plurality of gas discharge lamps are operated from the common modulator 62. Thus, in FIG. 14 there is shown three lamps 200, 201 and 202 which may be any desired type of gas discharge lamp, such as a fluorescent tube, and each of the tubes 200 to 202 is provided with a respective oscillator network 203, 204 and 205. The oscillator networks 203, 204 and 205 are each of the "current-fed" variety as in the case of FIG. 9, and it will be seen that they are each identical to the networks of FIG. 9 if the coil 71 of FIG. 9 is removed. More specifically, it has been found in connection with circuits of the type shown in FIG. 9 that coil 71 can be eliminated. Preferably, however, coil 71 may have an extremely low inductance, for example, 1 microhenry, as compared to a typical value of millihenrys for coil 72, where the small inductive impedance of coil 71 prevents high surge currents from being drawn from modulator 62 directly through capacitor 73 which could damage modulator 62. A small resistance could also perform this current-limiting effect.

In FIG. 14 the pulse-forming networks 203 to 205 consist of chokes 206, 207 and 208, respectively, and capacitors 209, 210 and 211, respectively. Each of the individual circuits are then connected in series with suitable isolating impedances 212, 213 and 214 which essentially decouple the parallel-connected circuits from one another and provides the current-limiting impedance necessary to limit the magnitude of the pulse current drawn from modulator 62 directly through capacitors 209, 210 or 211. Impedances 212, 213 and 214 may be capacitors.

When using a circuit of the type shown in FIG. 14, it will be apparent that substantial economies are obtained since only a single pulse modulator 62 is needed for a plurality of individual lamps. Note that any number of lamps can be used. Moreover, the size of the components used in oscillating networks 203, 204 and 205 is kept small since they each operate only in connection with a single lamp. This also makes it possible to locate the oscillating networks close to the lamps so that long transmission lines are not needed to convey the high frequency power from the oscillating network to its particular gas discharge lamp.

FIG. 15 is similar to FIG. 14, but shows a modified version of the oscillating network of FIG. 8 used in connection with the lamps 200, 201 and 202. Thus, in FIG. 15 the oscillating networks consist of the series-connected chokes 220, 221 and 222, respectively, and capacitors 223, 224 and 225, respectively, for the tubes 200, 201 and 202. Each of the oscillating networks of FIG. 15 is essentially identical to the network of FIG. 8 with the choke 65 and capacitor 67 removed. Tests have demonstrated that these components may be eliminated to develop the simpler series oscillating circuit shown in FIG. 15.

FIG. 16 shows a first embodiment of the present invention wherein an autotransformer couples the energy of the PFN to the gas discharge tube so that the high voltages required for the fluorescent tube are removed from the semiconductor switch or modulator. In FIG. 16, the device illustrated is connected between terminals 60 and 61 and incorporates the modulator 62 of the preceding figures which is specifically a semiconductor switch device. The PFN 300 is similar to that shown, for example, in FIG. 14 and consists of capacitor 301 and inductor 302 wherein the inductor 302 further serves as the primary winding of an autotransformer having a high voltage step-up winding 303. Winding 303 is then connected in series with lamp 304.

In the embodiment of FIG. 16, the high operating voltages needed for the lamp 304 are obtained from the step-up ratio between windings 302 and 303. Thus, the voltage across the PFN 300 will be relatively low so that the semiconductor switch or modulator 62 may contain components which do have to withstand ex-

tremely high reverse voltages. Therefore, the switch becomes less expensive and more reliable.

It should be noted that, in the embodiment of FIG. 16, and the embodiments described hereinafter, the PFN circuit could be eliminated and the invention of the use of an isolating transformer, such as that containing windings 302 and 303 in FIG. 16 could be used in combination with the pulse modulator alone.

FIG. 17 is similar to FIG. 16 and schematically illustrates a two-winding transformer 310 containing primary winding 311 and secondary winding 312 in place of the autotransformer containing windings 302 and 303 in FIG. 16. In all other respects, the circuits of FIGS. 16 and 17 are identical.

An important aspect of the use of an isolating transformer for connecting the PFN to the gas discharge lamp is that it simplifies lamp circuit configurations. Thus, FIG. 18 illustrates the circuit of FIG. 16, where, however, primary winding 302 of the autotransformer of the invention is provided with a plurality of secondary windings 320, 321 and 322 which are connected in series with gas discharge lamps 323, 324 and 325, respectively. Thus, in accordance with the invention, it now becomes possible to use a single modulator 62 and single PFN 300 for a plurality of lamps. Moreover, a relatively low voltage will be applied to the semiconductor switch or modulator 62 since the transformer connection permits winding 302 to operate at low voltage with windings 320, 321 and 322 operating at high voltage. Note that the circuit of FIG. 18 could also be modified such that the transformer has independent windings on a common core, so that secondary windings 320, 321 and 322 are electrically isolated from one another. Moreover, it will be understood that filament heater taps can be taken from the windings 302 and 303 in FIG. 16 or winding 312 alone in FIG. 17 for supplying filament energy, as in FIG. 1. FIG. 17 illustrates a dotted-line connection from portions of winding 312 to the schematically illustrated filaments of tube 304 to show the above connection.

It is to be understood that the novel use of the transformer shown in FIGS. 16, 17 and 18, connected as an autotransformer, or conventional transformer with insulated windings, can be directly applied to the circuits shown in any of the preceding figures.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appended claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. A gas discharge lamp energizing circuit comprising, in combination:

a voltage source, a pulse modulator means including semiconductor device switching means, a transformer having a first winding and a second winding magnetically coupled to one another, and a gas discharge lamp; said voltage source, pulse modulator means and second winding being permanently connected in series with one another during the normal operation of said lamp; said pulse modulator means being alternately conductive and nonconductive, thereby to apply voltage pulses across said second winding; said first winding being permanently connected in series with said gas discharge lamp and applying relatively high voltage thereto during normal operation of said lamp, responsive to conduction of said pulse modulator means.

2. The energizing circuit of claim 1 which further includes a pulse forming network in series with said pulse modulator means; said pulse forming network containing capacitor means and inductor means connected in circuit relation with one another to define an oscillating network; at least a portion of said inductor means comprising said second winding of said transformer.

3. The energizing circuit of claim 2 wherein said transformer is an autotransformer.

4. The energizing circuit of claim 1 wherein said transformer contains a plurality of first windings each coupled to said second winding; and a plurality of gas discharge lamps, each permanently connected in series with a respective one of said plurality of first windings.

5. The energizing circuit of claim 2 wherein said transformer contains a plurality of first windings each coupled to said second winding; and a plurality of gas discharge lamps, each permanently connected in series with a respective one of said plurality of first windings.

6. The energizing circuit of claim 4 wherein said transformer is an autotransformer.

7. The energizing circuit of claim 5 wherein said transformer is an autotransformer.

8. The energizing circuit of claim 2 which further includes filament winding means on said transformer and filament means in said gas discharge lamp; said filament winding means connected to said filament means.

9. The energizing circuit of claim 1 wherein said transformer is an autotransformer.

10. The energizing circuit of claim 1 which further includes filament winding means on said transformer and filament means in said gas discharge lamp; said filament winding means connected to said filament means.

11. the energizing circuit of claim 1 which further includes control means connected to said pulse modulator means for adjustably controlling the current flow in said gas discharge lamp.

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