# United States Patent [19]

**Spira et al.**

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[45] **July 16, 1974**


[54] **HIGH FREQUENCY FLUORESCENT TUBE LIGHTING CIRCUIT AND A-C DRIVING CIRCUIT THEREFOR**


[75] Inventors: **Joel S. Spira,** Allentown; **Joseph Licata,** Schnecksville, both of Pa.

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



[22] Filed: **Sept. 7, 1971**

[21] Appl. No.: **178,056**

**Related U.S. Application Data**

[62] Division of Ser. No. 843,927, July 23, 1969, Pat. No. 3,619,716.

[52] **U.S. Cl.** ..... **315/105,** 315/244

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

[58] **Field of Search** ..... 315/244, DIG. 5, DIG. 7, 315/105, 283, 285



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*Primary Examiner*—Nathan Kaufman

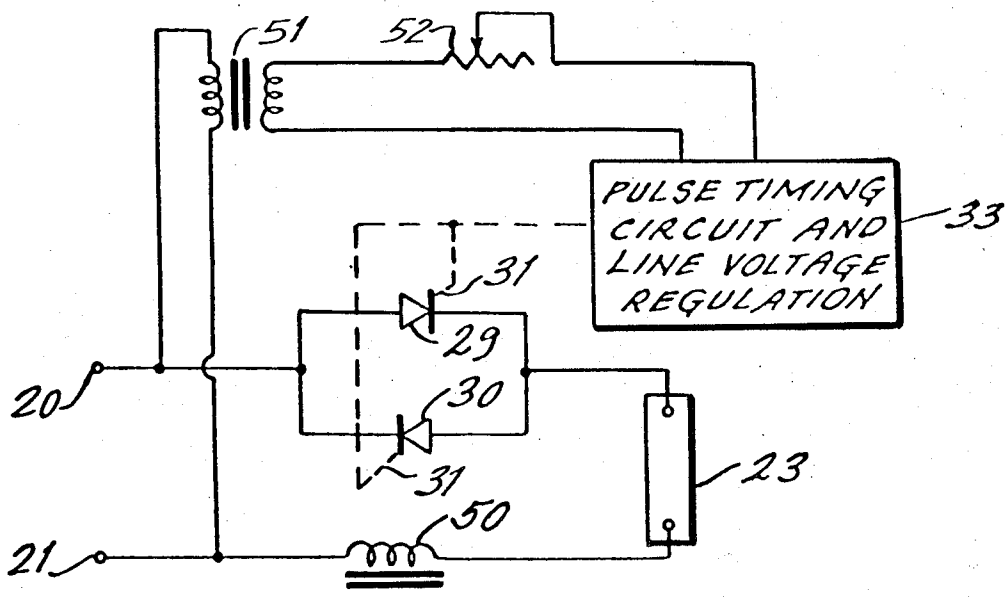
*Attorney, Agent, or Firm*—Ostrolenk, Faber, Gerb & Soffen



[57] **ABSTRACT**

A sinusoidal voltage source in series with a fluorescent, mercury vapor, sodium vapor device, etc. is pulsed at a given pulse repetition rate with the pulse having a given conduction time. Two or more tubes can sequentially conduct pulses with the current input being a continuous sinusoid. A particular pulsing circuit contains a modified pulse-forming network consisting of one or more stages of a closed series connection of a choke and two capacitors. The chokes of each stage are connected in series. The modified pulse-forming network is used as a frequency converter per se, as a d-c to a-c converter, or specifically is in parallel with a fluorescent tube load.


**10 Claims, 15 Drawing Figures**



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SHEET 1 OF 3

FIG. 1.

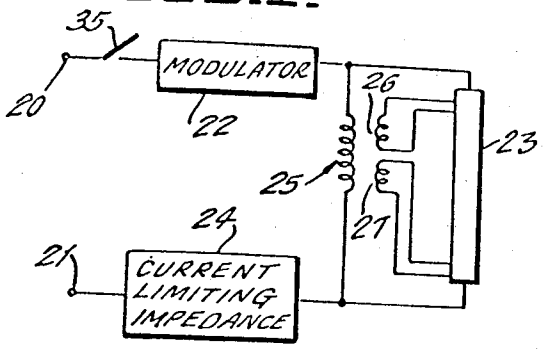
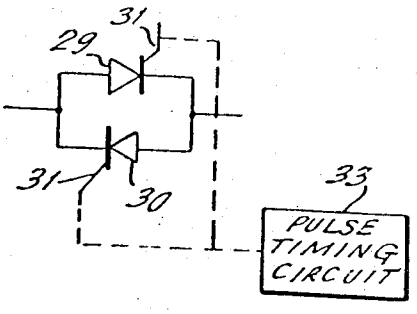



FIG. 2.



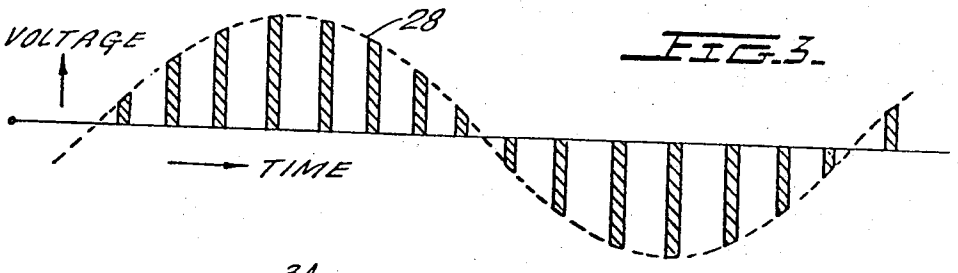




FIG. 3.

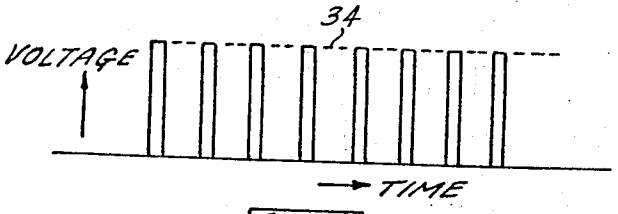



FIG. 4.

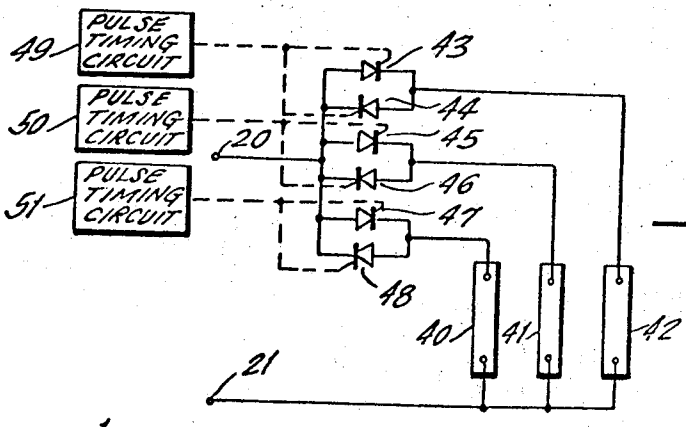



FIG. 5.

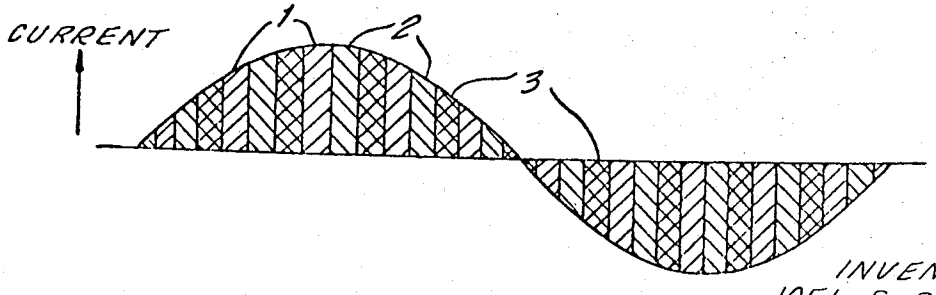



FIG. 6.

INVENTORS
JOEL S. SPIRA
JOSEPH LICATA
by
Ostrolenk, Faber, Gerb & Soffen
ATTORNEYS

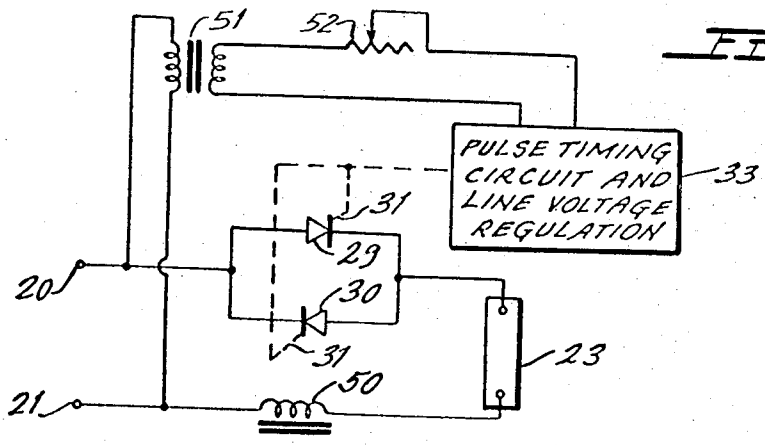



FIG. 7.

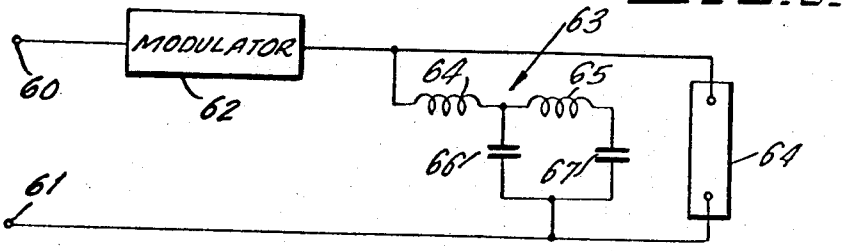



FIG. 8.

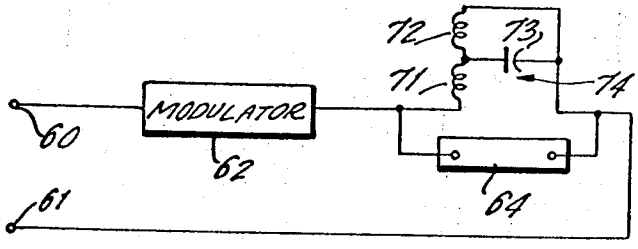



FIG. 9.

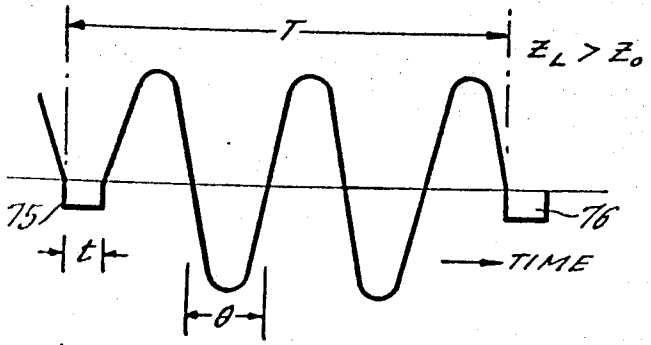



FIG. 10.

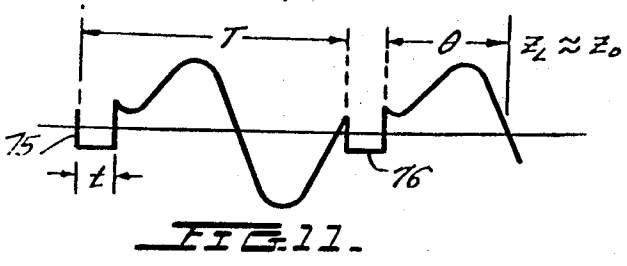



FIG. 11.

FIG. 12.

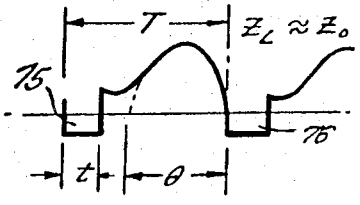


FIG. 13.

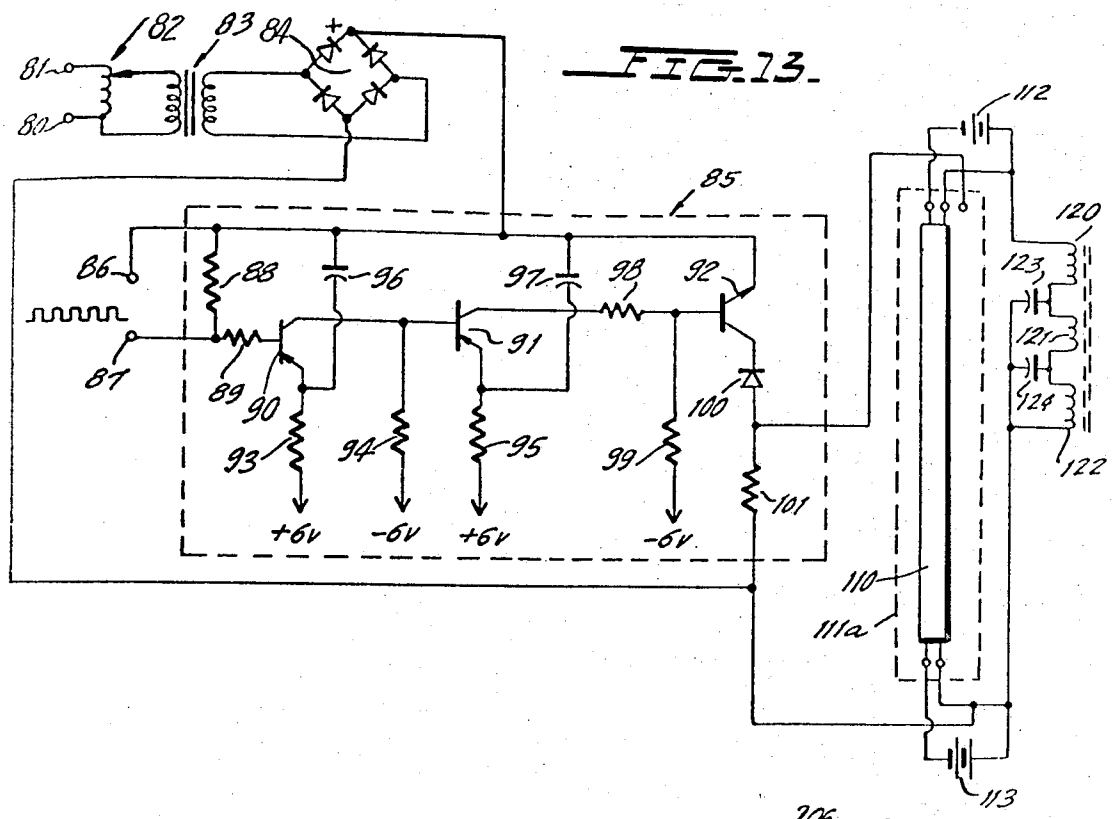



FIG. 14.

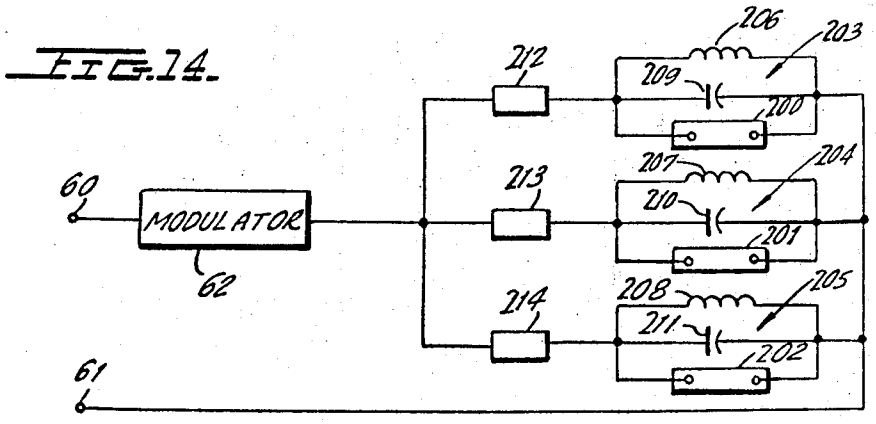
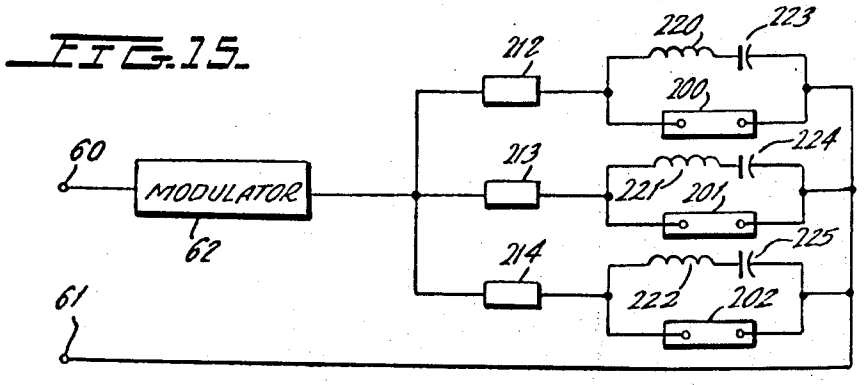



FIG. 15.



# HIGH FREQUENCY FLUORESCENT TUBE LIGHTING CIRCUIT AND A-C DRIVING CIRCUIT THEREFOR

## RELATED APPLICATIONS

This application is a divisional application of copending U.S. application Ser. No. 843,927, filed July 23, 1969, in the name of Joel S. Spira and Joseph Licata, entitled HIGH FREQUENCY FLUORESCENT TUBE LIGHTING CIRCUIT AND A-C DRIVING CIRCUIT THEREFOR, now U.S. Pat. No. 3,619,716 and is assigned to the assignee of the present invention.

## BACKGROUND OF THE INVENTION

This invention relates to a-c power supplies, and more particularly relates to a-c power supplies for gas discharge tube lighting which eliminates the need for a ballast or other inductances which are normally connected to gas discharge lamps.

A common gas discharge lamp which is operated from a sixty cycle source is commonly provided with a so-called ballast which consists of an inductance (or resistor) connected in series with the lamp. This ballast serves several functions. One function is to limit lamp current which would otherwise increase uncontrollably due to the negative resistance characteristic of the electric discharge in the lamp. Another purpose is to obtain lamp starting and voltage regulation. Thus, a lamp may require a relatively high starting (striking) voltage, but, after the arc is initiated, will have a considerably lower operating voltage. The series ballast will then absorb the differences between line voltage and lamp operating voltage. Note that full line voltage, or greater, is needed to strike the lamp arc to initiate conduction. A third major function of the ballast in certain types of tubes is to provide a transformer or autotransformer which can supply cathode filament voltage, and a voltage surge for initiating arc discharge.

Ballasts using a series resistor are relatively inefficient and are not commonly used. Normally, the ballast takes the form of a series inductance or transformer. Where these ballasts are used in the usual 60 cycle circuit, they are large, heavy, noisy and expensive. Moreover, the need for the ballast must be considered in the design of the lamp fixture. In order to limit the size and expense of ballasts, fluorescent circuits have been operated from high frequency power sources having frequencies up to a few thousand cycles per second. The use of higher frequencies is also advantageous in the operation of a fluorescent lamp since, at higher frequencies (than 60 cycles) the lamp has greater lumen efficiency, (increased lumens per watt) longer life and easier starting.

When using higher frequencies to drive fluorescent tubes, and having a 60 cycle source available, it is necessary to provide frequency changing apparatus such as mechanical rotating converters or electronic frequency converters. The size and expense of such conversion equipment often offsets the advantages of decreased ballast size and increased lamp efficiency. Moreover, the use of converters frequently requires special wiring mains and branch circuits of limited capacity, and decreases the reliability of the lighting system. Consequently, the use of higher frequency sources for fluorescent lighting has not gained wide commercial acceptance.



In accordance with one aspect of the present invention, a switching means is connected with the sixty cycle source and the fluorescent tube, and operates to turn on and off at a given frequency within the 60 cycle wave form. For example, the switching means may be conductive or ON for 100 microseconds, and nonconductive or OFF for 900 microseconds, whereby a 1,000 cycle fundamental is introduced into the 60 cycle wave shape. Obviously, the OFF times and ON times can be varied in any desired ratio to one another and have various repetition frequencies. As will be later described, the pulsing circuit may drive a delay line pulse-forming network which is in parallel with the tube and which is per se novel for use as a d-c to a-c converter or frequency changer. The switching means, as used in the novel combination of the invention (with a gas discharge tube) may use conventional switching circuits incorporating controlled rectifiers, transistors, and the like.

The modulation of a low frequency (frequencies such as 50 or 60 cycles per second, used in lighting circuits) sine wave form at various ON times and pulse repetition frequencies introduces many desirable effects in a fluorescent lighting circuit. A major advantage is that the conventional ballast can be eliminated. That is, the conduction time is short so that a current limiting impedance is not needed or can be provided by various simple and small resistors, inductances or capacitors, or combinations thereof. Output regulation may now be provided by varying either pulse repetition frequency or the ON time. Cathode filament voltage may now be extracted from the modulated since wave by transformers which are small and inexpensive and tuned to the high modulating frequency. Since the tube is driven at the high modulating frequency, it is subject to all the advantages of increased lumen efficiency, longer life and easier starting. Since the ballast can be eliminated, noise, size, weight and cost of the system is substantially decreased. At higher frequencies, noise is eliminated or greatly reduced by virtue of smaller and simpler inductive and capacitive components and also eliminated by operating at a frequency above the audio range. Moreover, the heat generated by the novel system is less than in a conventional ballast system so that the lamps can be operated more efficiently at higher current and light levels.

The novel system of the invention also lends itself to the complementary conduction of two or more lamps, thereby reducing complexity and radio frequency interference. Thus, the low frequency a-c source may conduct a continuous sine wave current. This current is thus sequentially switched between two or more lamps, each sequentially conducting for a given ON time. This arrangement permits a saving in hardware and reduces radio frequency interference since the power input will be a continuous low frequency sine wave instead of a chopped sine wave.

It is also possible to use a common switching means or modulator for each of a large number of tubes. Thus, a single modulator could serve 10 lamps or more so that the cost of the modulator per lamp becomes very small.

The novel combination of the invention also lends itself to light output regulation and to automatic regulation of light with line voltage change. Thus, light output can be changed by changing the conduction time of the lamp. A potentiometer type adjustment could therefore

provide controlled "dimming" of a fluorescent lamp. It is also possible to maintain constant illumination when input voltage changes by providing a suitable control circuit which varies conduction time inversely with changes in line voltage.

In accordance with an important feature of the invention, the lamp may be connected in parallel with a delay line type network previously adjusted to be used as a pulse-forming network. Such a circuit may be used as frequency converter per se or as a d-c to a-c converter per se in accordance with an important feature of the invention. This network consists of series connected chokes with capacitors connected at the junctions of the various chokes. In particular, each section of the delay line consists of at least one inductor and at least one capacitor, connected in a closed series circuit. A single section can be used for the present invention. A network of this type is shown in pages 10 and 11, chapter 6, in the text "Principles of Radar," published by McGraw Hill Co., Inc. 1946 (second edition). Circuits of this type are used for forming a square pulse in the driver stage of a radar modulator. In accordance with the invention, a circuit of this type is so adjusted that it will oscillate, whereby the circuit is initially charged for a short charging time from the pulsing circuit and thereafter (during the OFF time of the pulsing circuit, or modulator) provides an oscillating discharge which is connected to any suitable load, such as a fluorescent tube. It will be shown that the wave shape output of this novel modulator, while not completely sinusoidal, is satisfactory for driving gas discharge tubes, and would also be satisfactory for any application which does not require an accurate sinusoidal wave shape. The chokes used in the delay line oscillators may contain one or more windings to provide filament heating windings, and the like.

Moreover, the choke in the delay line oscillator may contain a secondary winding section connected in series with the fluorescent tube. This would then provide a high voltage in series with the tube where, however, this high voltage is not applied to any of the various semiconductor devices in the pulse forming circuit.

An important feature of the various circuits that can be constructed in accordance with the invention is that there is a significant a-c component in the voltage applied to the tube, if not a pure a-c voltage. In particular, in a current fed mode, to be described hereinafter, there is a pure a-c voltage input to the tube whether the energizing circuit is an a-c or d-c circuit. This has a significant advantage since most gas discharge lamps are most efficiently operated when an a-c voltage is connected to the lamp. While most gas discharge lamps can be operated from either d-c or a-c voltage, d-c voltage will cause a premature blackening or darkening at one end of certain types of gas discharge lamps, particularly fluorescent lamps. D-c operation is also less efficient than a-c operation. For example, lamp efficiency for d-c operation is about 70 percent of its efficiency at high frequency a-c operation. D-c operation will also cause decreased fluorescent tube life by 10 to 20 percent. Where d-c voltage is applied to mercury vapor lamps, there is a loss in life time because of overheating of one electrode. In some sodium vapor lamps, the lamps cannot be operated at all by d-c voltage. The main advantage of d-c operation is that it does not cause a stroboscopic effect. However, devices operated in accordance with the present invention are operated at sufficiently high frequency to eliminate any stroboscopic problem.

Accordingly, a primary object of this invention is to provide a novel energizing circuit for gas discharge tubes which eliminates the conventional ballast, and operates the tubes at a relatively high frequency.

Another object of this invention is to provide a novel drive circuit for gas discharge tubes which controllably modulates a sine wave at a given pulse repetition frequency and a given conduction time for each pulse.

Still another object of this invention is to operate a plurality of gas discharge tubes from an a-c circuit which is switched between the various tubes to establish a given pulse repetition frequency and conduction time for each tube.

Another object of this invention is to provide a novel common energizing circuit for a plurality of gas discharge tubes and for eliminating the ballast of the tubes.

A further object of this invention is to provide a novel, simple and inexpensive frequency converter or d-c to a-c converter which is formed of a modified pulse-forming network.

These and other objects of this invention will become apparent from the following description when taken in connection with the drawings, in which:

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

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 period.

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.

Referring first to FIG. 1, there is shown a circuit which illustrates the principle of the present invention 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 this impedance 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 could not build up to extremely high value, and thus the tube would operate satisfactorily while not burning out due to 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 have been an autotransformer, and could have been 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, and, accordingly, applies the pulse voltage shown in FIG. 3 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 connection 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.

In accordance with a further feature of the invention, 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.** In accordance with the invention, the pulse timing circuit is further provided with a suitable circuit for changing pulse conduction time in response to varying time 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.

In accordance with the present invention, this type circuit which shall be termed as oscillation network hereinafter, 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 $2\theta$ 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 $\theta$, 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 pulse **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 $2\theta$, and by making $T = \theta + t$, and $t$ approximately equal to $\theta$.

An important advantage of the circuit of FIG. **9** is that it provides an essentially pure a-c input of 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 pulse-forming network 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 characteristic 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** and **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 curcuit 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** (33ohms), **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 **111***a*, 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 six 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 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.

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 appending 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 and a gas discharge lamp having terminals; said voltage source, pulse modulator means and gas discharge lamp connected in series; said pulse modulator means being continuously alternately conductive and nonconductive throughout the entire operation of said gas discharge lamp and being permanently connected to said gas discharge lamp terminals, thereby to continuously apply voltage pulses of short duration less than about 100 microseconds to said gas discharge lamp, whereby said gas discharge lamp has a relatively high effective impedance; and a current limiting impedance means connected in series with said gas discharge lamp and said pulse modulator means.

2. A gas discharge lamp energizing circuit comprising, in combination: a voltage source, a pulse modulator means and a gas discharge lamp having terminals; said voltage source, pulse modulator means and gas discharge lamp connected in series; said pulse modulator means being continuously alternately conductive and nonconductive throughout the entire operation of said gas discharge lamp and being permanently connected to said gas discharge lamp terminals; thereby to continuously apply voltage pulses of short duration less than about 100 microseconds to said gas discharge lamp; and filament heater circuit means for heating the filaments of said gas discharge lamp; said filament heater circuit means including transformer means connected to said energizing circuit and tuned to the frequency of said pulse modulator means.

3. A gas discharge lamp energizing circuit comprising, in combination: a voltage source, a pulse modulator means and a gas discharge lamp having terminals; said voltage source, pulse modulator means and gas discharge lamp connected in series; said pulse modulator means being continuously alternately conductive and nonconductive and being permanently connected to said gas discharge lamp terminals, thereby to continuously apply voltage pulse of short duration less than about 100 microseconds to said gas discharge lamp; and a second gas discharge lamp, and switching means for sequentially and alternately connecting said pulse modulator means between said gas discharge lamp and said second gas discharge lamp.

4. A gas discharge lamp energizing circuit comprising, in combination: a voltage source, a pulse modulator means and a gas discharge lamp having terminals; said voltage source, pulse modulator means and gas discharge lamp connected in series; said pulse modulator means being continuously alternately conductive and nonconductive and being permanently connected to said gas discharge lamp terminals, thereby to continuously apply voltage pulses of short duration less than about 100 microseconds to said gas discharge lamp; control means connected to said pulse modulator means for adjustably controlling the pulse length of said pulses.

5. A gas discharge lamp energizing circuit comprising, in combination: a voltage source, a pulse modulator means and a gas discharge lamp having terminals; said voltage source, pulse modulator means and gas discharge lamp connected in series; said pulse modulator means being continuously alternately conductive and nonconductive and being permanently connected to said gas discharge lamp terminals, thereby to continuously apply voltage pulses to said gas discharge lamp; said phase modulator means being connected directly to said lamp by low impedance connection means; said pulse modulator means having a conduction time sufficiently short to limit the average current flow to said lamp to below a given value.

6. The device substantially as set forth in claim 4 which further includes coupling means for coupling said control means to said voltage source for varying said pulse length in accordance with variation in the voltage of said voltage source for regulating the output light of said gas discharge lamp.

7. The device substantially as set forth in claim 4 which further includes coupling means for coupling said control means to said voltage source for varying said pulse length in accordance with variation in the voltage of said voltage source for regulating the output light of said gas discharge lamp.

8. The circuit of claim 5 wherein said conduction time is less than about 10 microseconds.

9. The circuit of claim 7 wherein said conduction time is less than 100 microseconds.

10. A gas discharge lamp energizing circuit comprising, in combination: a voltage source, a pulse modulator means and a gas discharge lamp having terminals; said voltage source, pulse modulator means and gas discharge lamp connected in series; said pulse modulator means being continuously alternately conductive and nonconductive and being permanently connected to said gas discharge lamp terminals, thereby to continuously apply voltage pulses of short duration to said gas discharge lamp control means connected to said pulse modulator means for adjustably controlling the pulse repetition frequency of said pulses.

* * * * *

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,824,428 Dated July 16, 1974

Inventor(s) Joel S. Spira and Joseph Licata

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 12, line 28, "phase" should read --- pulse ---

Column 12, line 33, numeral "4" should read --- 10 ---

Column 12, line 47, numeral "7" should read --- 5 ---

Column 12, line 58, after "lamp" there should be a semicolon (;)

Signed and sealed this 27th day of May 1975.

(SEAL)
Attest:

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Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

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