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Electronic Ballast

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Abstract

An electronic ballast circuit can be used with an electric discharge lamp to obtain the necessary circuit conditions (voltage, current and waveform) for starting and operation. All fluorescent light sources require ballast for proper operation. The circuit interacts with the lighting mechanism itself to control, regulate and, ultimately, stabilize the light output of the lamp. Design of the circuit includes rectifier circuit, high frequency voltage converter circuit, and half bridge resonant output circuits. The circuit utilize transistors, diodes, capacitors, inductors, and resistors. It is cheap, very stable and to extend the lifetime of a fluorescent lamp.

Key words: Ballast, circuit components, circuit operation.

Introduction

Fluorescent lamps are a large family of light sources. There are three main types of fluorescent lamps: cold cathode, hot cathode, and electroluminescent. They all use phosphors stimulated by electrons to create light. Fluorescent lamp is a lamp with a glass discharge tube and fluorescent coating on the inside. The standard fluorescent lamp was developed for commercial use during the 1930's. The idea of hows fluorescent lamps were made was started around the 1880's and they were tested over the decades and finally they can be marketed. They are widely use in both outdoor and indoor, backlight for LCD displays, decorative lighting and signs.

A fluorescent lamp is a glass tube filled with an inert gas (usually argon) at low pressure. On each side of the tube tungsten electrode is located. The illumination in the fluorescent lamp was done by ionizing mercury vapor in a glass tube. This causes electrons in the gas to emit photons at UV frequencies. The UV light is converted into standard visible light using a phosphor coating on the inside of the tube. The ballast regulates AC power to the electrode. Old-modeled lamps used a starter to get the lamp going. Modern lamps use pulse start which is done by components within the ballast. There are basically two different designs of ballasts and they are known as magnetic ballast and electronic ballast. The magnetic ballasts use transformers to convert and control electricity. The electronic ballasts use semiconductors to limit power to a fluorescent lamp.

In this research, design of electronic ballast is designed and constructed. The basic structure of the electronic ballast is illustrated with a block diagram as shown in the figure 1. First, the ballast rectifies the AC power, and then it chops to make a high frequency for improved efficiency. The electronic ballast can be more precisely controlled power than magnetic ballast.

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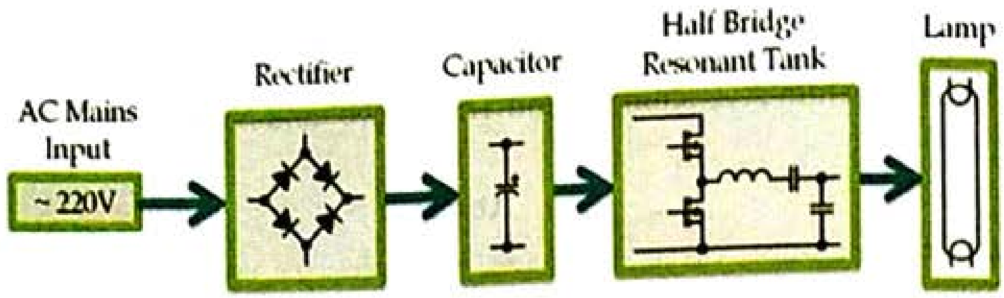

Figure 1. Block diagram of the electronic ballast

Fluorescent Lamps

Using the fluorescent lamps is most brilliant way of illuminating for houses and dwellings to remove darkness. Fluorescent lights, which offer a more energy efficient means of lighting homes and offices. In the mid-1930s when first fluorescent tube lights were introduced in the market, they were a total revelation. People were amazed to see their houses and offices lit as brightly as cool daylight.

A fluorescent lamp basically consists of a long glass gas discharge tube. Its inner surface is coated with phosphorous and is filled with an inert gas, generally argon, with a trace of mercury. The tube is then finally sealed at low pressure with two filament electrodes each at its both ends. These electrode filaments are used to preheat the tube and initiate a rapid conduction of electrons between the two end electrodes.

The process initially requires a relatively high amount of power. The energy also converts some of the mercury from a liquid to a glass. Electrons then collide with the gaseous mercury atoms, increasing the amount of energy. As electrons return to their original energy level, they begin to release light. However, the light they emit is ultraviolet, and not visible to the naked eye, so another step needs to take place before emitting the light.

That is why the tube was coated with phosphorous. Phosphors will emit light when exposed to light. When exposed to the ultraviolet light, the particles emit a white light. Once the conduction of electrons between the electrodes is complete, no more heating of the filaments is required and whole system works at a much lower current.

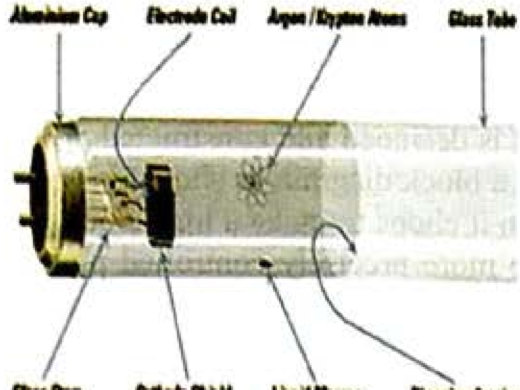

Figure 2. Basic structure of a fluorescent lamp

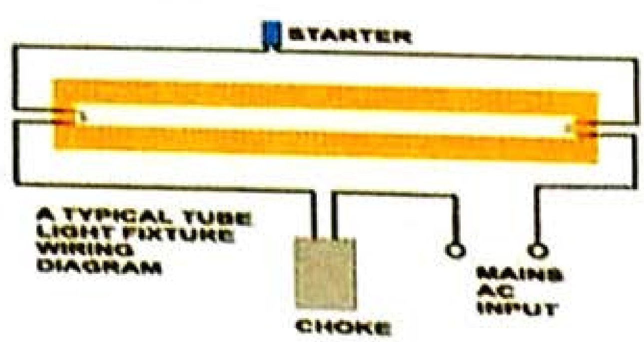

Figure 3. A typical tube light fixture wiring diagram

Figure 3 shows the system design of a tube light fixture consisting of a large heavy square "choke" or "ballast" and a small cylindrical "starter." The choke is in fact a large inductor. It consists of a long copper winding over iron laminations. An inductor by nature always has a tendency to throw back the stored current in it, every time the power through it is switched OFF. This principle of the choke is exploited in lighting a fluorescent tube light.

When an AC voltage is applied to a tube light fixture, the voltage passes through the choke, the starter, and the filaments of the tube. The filaments light up and instantly warm up the tube. The starter is made up of a dischargeable bulb with two electrodes next to it. When electricity passes through it an electrical arc is created between the two electrodes. This creates light, however the heat from the bulb causes one of the electrodes (a bimetallic strip) to bend, making contact with the other electrode. This stops the charged particles from creating the electrical arc that created light.

However, now that the heat from the light is gone, the bimetallic strip cools and bends away from the electrode, opening the circuit again. At this point, the ballast or choke "kick's back" it's stored current, which again passes through the filaments and ignites the tube light once again. If the tube does not sufficiently charge up, subsequent kicks are delivered by the choke due to rapid switching of the starter, so that finally the tube strikes. After this the choke only acts like a low impedance current limiter to the tube as long as the light is kept illuminated.

There is a common problem associated with these types of fixtures is humming or buzzing. The reason for this lies in the loosely fitted choke on to the fixture which vibrates in accordance with the 50 or 60 hertz frequency of our AC mains and creates a humming sort of noise. Tightening the choke's screws may instantly eliminate the problem.

The working principle of today's modern electronic ballasts is to avoid the use of starters for the preheating purpose. They are also very light in weight. These inhibit the initial flickering of the tube light as normally seen in the ordinary tube fixtures by changing the frequency of the mains power to a much higher 20,000 hertz or more. Moreover, electronic ballasts are very energy efficient.

Table 1. Advantages and Disadvantages of fluorescent lamps

Advantages	Disadvantages
Very high luminous efficiency	Contains toxic mercury vapour
Colour rendering is good to excellent	Quite sensitive to ambient temperature
Low cost and simple control gear	Light output drops in cold areas
Long lifetime, highly durable product	Light output drops in hotter luminaries
Even and glare-free light distribution	Flickering light on 50Hz magnetic ballasts
Can produce almost any shade of white	Lumen output decreases through lifetime
Dimmable with special ballasts	Very long tubes can be difficult to handle

Ballasts

In a fluorescent lighting system, the ballast regulates the current to the lamps and provides sufficient voltage to start the lamps. Without a ballast to limit its current, a fluorescent lamp connected directly to a high voltage power source would rapidly and uncontrollably increase its current draw. Within a second the lamp would overheat and burn out. During lamp starting, the ballast must briefly supply high voltage to establish an arc between the two lamp electrodes. Once the arc is established, the ballast quickly reduces the voltage and regulates the electric current to produce a steady light output.

Maintaining an optimum electrode temperature is the key to long lamp life. Thus, some ballast has a separate circuit that provides a low voltage to heat the lamp electrodes during lamp starting and typically during lamp operation.

To achieve full rated light output and rated lamp life from a fluorescent lighting system, ballast's output characteristics must precisely match the electrical requirements of the lamps it operates. Traditionally, ballasts are designed to operate a specific number (usually one to four) and type of lamp (such as a four - feet lamp) at a specific voltage. Thus, to find ballast compatible with a particular luminaries (light fixture), lamp type, lamp quantity, and line voltage must be known.

Electronic and Magnetic Ballasts

Electronic ballast uses solid state electronic circuitry to provide the proper starting and operating electrical conditions to power discharge lamps. Electronic ballast can be smaller and lighter than a comparably-rated magnetic one. Electronic ballast is usually quieter than a magnetic one, which produces a line-frequency hum by vibration of the transformer laminations.

Electronic ballasts are often based on SMPS topology, first rectifying the input power and then chopping it at a high frequency. Advanced electronic ballasts may allow dimming via pulse-width modulation or via changing the frequency to a higher value. Ballasts incorporating a microcontroller (digital ballasts) may offer remote control and monitoring via networks or simple analog control using a 0-10 V DC brightness control signal.

Discussion on Magnetic Ballast and Electronic Ballast

Fluorescent lamps require a ballast to stabilize the lamp and to provide the initial striking voltage required to start the arc discharge.

Discharge lamps are inductive loads and need high voltage initially to discharge the lamp. They also have negative resistance, meaning they are unable to regulate the amount of current that passes through them once the discharge starts. Small light sources can use passive components, such as a series resistor that limits the flow of current across its terminals. For high-powered lights, however, a resistor would waste a large amount of electricity, so a more complex regulator is required. These tasks are completed with the help of the ballast.

Electromagnetic ballasts (EM ballast) work on the principle of electromagnetic induction to provide the starting and operating voltages of a gas discharge light. Inside each is a coil of wire and an electromagnetic field that together transform voltage. Some also include an igniter for high-power applications. Typically EM ballast works in a switch-start circuit in which the inductor is referred to as the ballast (choke) and switch works as the starter.

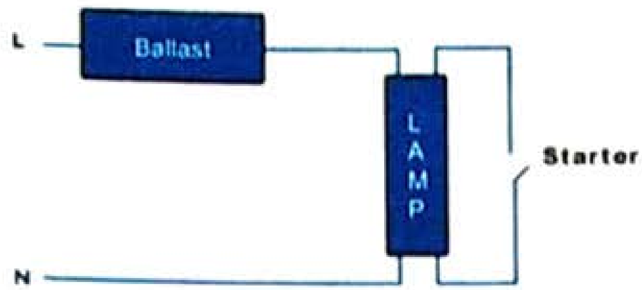

Figure 4. Operation of an electromagnetic ballast

1. Starter switch contacts are closed on application of the supply voltage.
2. Inductor current preheats the lamp cathodes by resistance heating.
3. Contacts open a few tenths of seconds later and lamp voltage rises sharply, the process repeats until the lamp strikes.
4. Inductor reactance regulates the lamp current.

Electronic ballast uses solid state circuitry to transform voltage, but unlike EM ballasts, it can also alter the frequency of power. High-frequency operation of >20 KHz increases the fluorescent lamp efficiency by 10% since the conversion rate of UV radiation increases. The advantage of this is that the lamp requires less input power for the same light output leading to an energy saving. Because it uses solid-state circuitry instead of magnetic coils, it is also more efficient and therefore runs cooler.

Electronic ballasts were first introduced as simple inverter ballasts. They perform the basic function of starting the lamp and controlling the lamp current. These ballasts were typically used in retrofit compact fluorescent lamps but suffered from problems of low power factor (around 0.5) and high THD (~120%).

Active power factor correction ballasts incorporate filters and active control circuits to correct the power factor closer to unity and also minimize the total harmonic distortion to >10%.

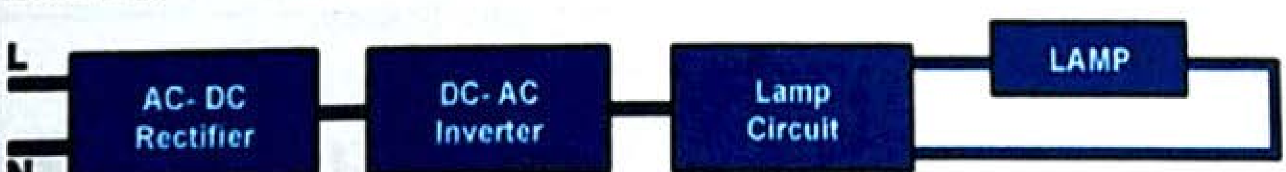

Figure 5. Inverter Electronic Ballast

An AC input is fed to AC-DC converter, which converts the AC voltage to DC. DC is inverted into high frequency AC using an inverter, which is fed to the lamp using lamp circuit.

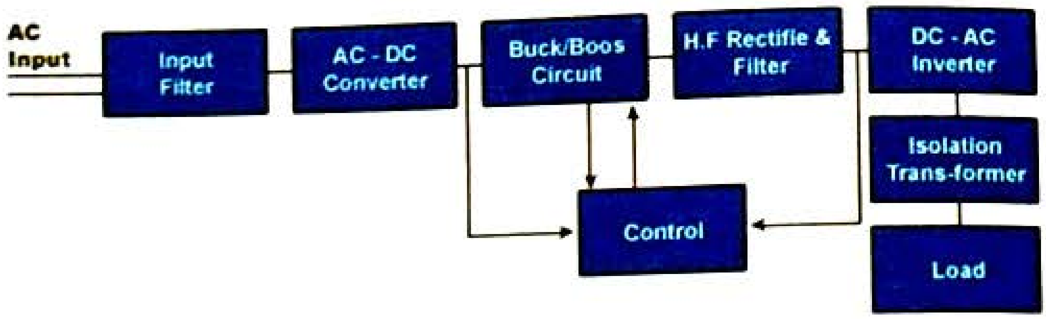

Figure 6. Electronic ballasts with active power factor correction

* A/C input is converted to DC using AC-DC converter and gives input to the active harmonic filter.
* Active harmonic filter comprises of Buck/Boost circuit along with HF rectifier and control circuit
* Filter maintains the voltage at its output constant at 400 V (DC).
* The output voltage of DC-AC inverter and wattage input to the lamp remains constant (for input line voltage variation 145V-275V).
* Constant wattage operation and constant light output is achieved.

Circuit Design

The fluorescent tube-light requires additional gear such as the copper ballast and starter for normal operation. These two are required to provide the initial high voltage for ionization and thereafter to limit the current through the tube to safe values. It has been observed that the illumination efficiency of the tube-light when it is excited by high frequency power source is higher than that when it is excited at the 50Hz line frequency.

Moreover, the power factor and the efficiency of the bulky copper ballasts are poor. Hence, electronic ballasts were developed to overcome these deficiencies. The electronics ballast circuit is light in weight, compact and has a high power factor. It starts up even at low voltage, and above all, it has a very high efficiency.

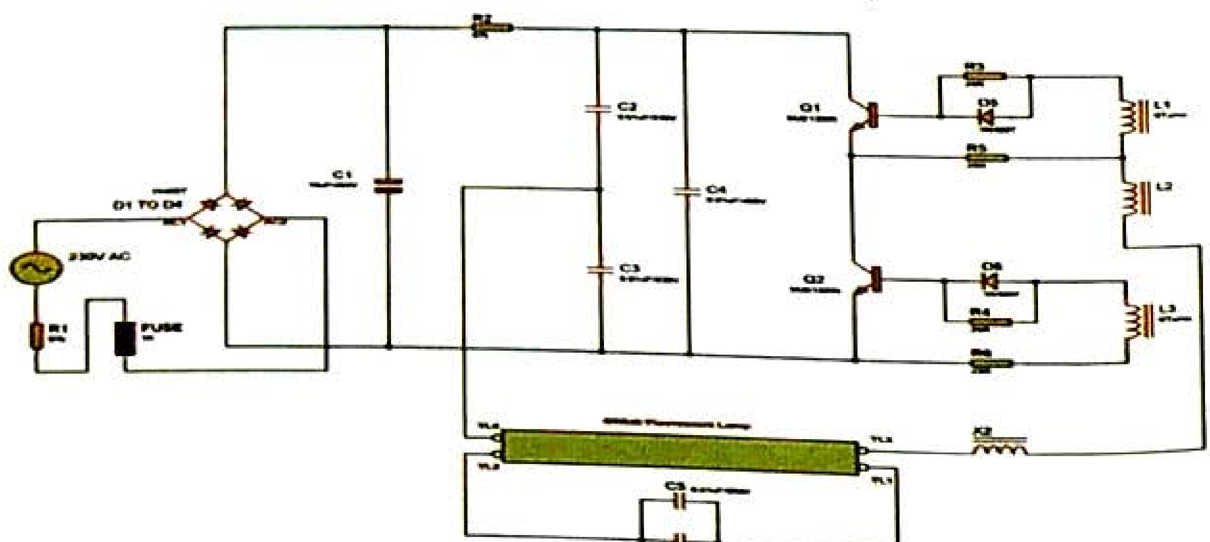

Figure 7. Schematic diagram of 40 watt electronic ballast design

The typical electronic ballast is a current fed oscillator in the half bridge configuration. Transistors T_1, T_2 and capacitors C_2, C_3 form the half bridge in the circuit electronic ballast for tube light. Diodes D_1 to D_4 and capacitors C_1 provides the required DC voltage for the circuit. Inductor X_2 regulates the current through the tube and also determines the frequency of operation of the electronic ballast. For the value shown, the operating frequency is typically 25 to 30 kHz, from R_2, and C_4 from the start-up circuit.

As capacitor C_4 charges up to approximately 35V, it provides a current pulse to the base of transistor T_2, setting the circuit into oscillation. The specifications of transformer X_1 and X_2 are given below:

X_1 = coil wound on ferrite ring as L1, L2 and L3 in 6 turns, 3 turns and 6 turns respectively wound by thin plastic coated copper wire. The different winding should show insulating in excess of 100 MΩ at a test voltage of 500V.

X_2 = 160 turns of 29 SWG enameled copper wire with a sheet of thin insulating paper between layers. The E-25 ferrite core is fixed with a small air gap of about 0.2mm produced by paper kept between the faces of the ferrite core.

The transistors may be sorted by their current gain. The transistor with the similar current gain can be used.

Listing of Components used in the Circuit

The lists of components used in the circuit are given below and they are available in the local market.

Table 2. List of components in the electronic ballast

Type of Component	Value of Component	Number of Quantity
Resistors	67kW	2
	25W	4
Fuse	1A	1
Capacitors	0.01uF/630V	2
	0.01uF/650V	2
	0.01uF/450V	1
	10uF/450V	1
Transistors	MJE13005	2
Diodes	1N4007	6
Inductor	L1, L3 (6Turns)	2
	L2 (3Turns)	1
	X2 (160Turns)	1

Circuit Construction

Construction of the circuit was made on a specially designed printed circuit board. The printed circuit board was a single sided printed circuit board and it is created by using carbon copy method. It is simple, the circuit layout can be made on a paper by manual hand drawing by measuring the components pain layouts with a ruler and draw the circuit lines on a paper. Then it is copied to an art paper by using a photo copier machine. The image on the art paper is carbon powders and it can be easily transported to the copper side of circuit board by ironing. Then the paper is removed and the carbon track lines are appeared on the copper layer. Then the circuit board is immersed in a copper etching solution. The etching took about 20 minutes to completely etch the whole printed circuit board. Then the carbon layer is removed by using thinner and the copper layer is ready to solder the components on the board.

The initial process is to insert the resistors and diodes in their position and soldered neatly. It is important to notice the anode and cathode side of diodes in their position. Then the two transistors are inserted in their position and soldered. Then the capacitors are also carefully inserted with correct polarity for electrolytic capacitors and soldered. The next step is to prepare for the inductor coil on a ferrite ring. There are three single wires with different plastic coating cut for about 2.5 inches and two 5 inches jumper wires. They are red, green and blue. They are turned on the ferrite ring with two 6 turns for L1 and L3, but for L2 only 3 turns are made. The coil terminals are inserted on the printed circuit board and soldered with correct terminals.

There is one more component on the board and it is the 160 turn inductor (X2). It is placed in its position and soldered. The last thing for the electronic ballast is power cable and fluorescent lamp cables. An ac plug with wire cable is used to connect with ac 220 line input voltage. The four white wires with fluorescent lamp terminals sockets are soldered on the output terminal of the circuit. The component side and soldering side of the constructed circuit board is illustrated in figure 8 and figure 9. At the soldering side of the circuit after soldering components, a green solder mask was coated to protect the erosion of solder joints.

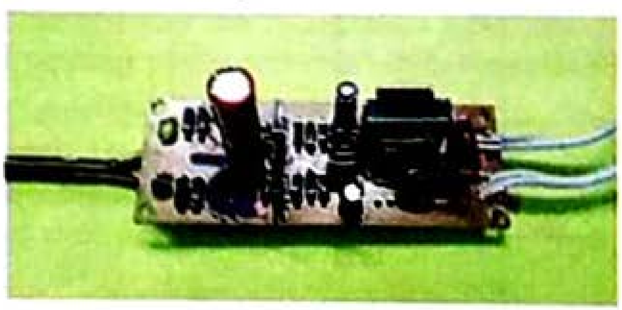

Figure 8. Components side of the electronic ballast

Figure 9. Soldering side of the electronic ballast

Circuit Operation

The design of the electronic ballast operates off the AC mains with a voltage of 230 Volts and voltages generated within the unit can reach 400 to 650 Volts. Therefore, extreme caution must be taking on while building, testing and using the constructed design. Moreover, it is required to house in a plastic or metal casing with perfect insulation for safety and long term use.

The schematic of the circuit is illustrated in previous chapter. The schematic of the unit conforms to that of a "Half-Bridge Resonant Converter". The AC mains input is fed at AC1-AC2 and full-wave rectified by diodes D1, D2, D3 and D4. The rectified output is filtered by the high-voltage capacitor C1 to form the DC supply voltage to the half-bridge converter.

A mid-point DC voltage is formed by the two capacitors C2 and C3. The half-bridge transistors Q1, Q2 effectively switch the load between the collector junction of Q2 and emitter junction of Q1. The effective load is a series combination of the base-drive toroid-transformer, resonant-inductor and florescent tube. The series-resonant frequency is determined by the 1.3mH inductor (X2) and the series combination of capacitors C5 and C6. The circuit resonates at a nominal 60 kHz.

The toroid transformer provides the base-drive to transistors Q1 and Q2 in the correct phase so that the transistors switch on-off alternately. Resistors R5 and R6 provide a dc-bias path for Q1 and Q2. R3 and R4 limit the base currents of Q1 and Q2. On initial start-up a very high AC voltage is impressed across the fluorescent tube terminals TL1-TL2 the tube ionizes and breaks down setting up the discharge between the terminals. Once this occurs a voltage of 80-100 volts across the tube is sufficient for generating the light output. This voltage and the current through the tube are regulated by the inductor L1.

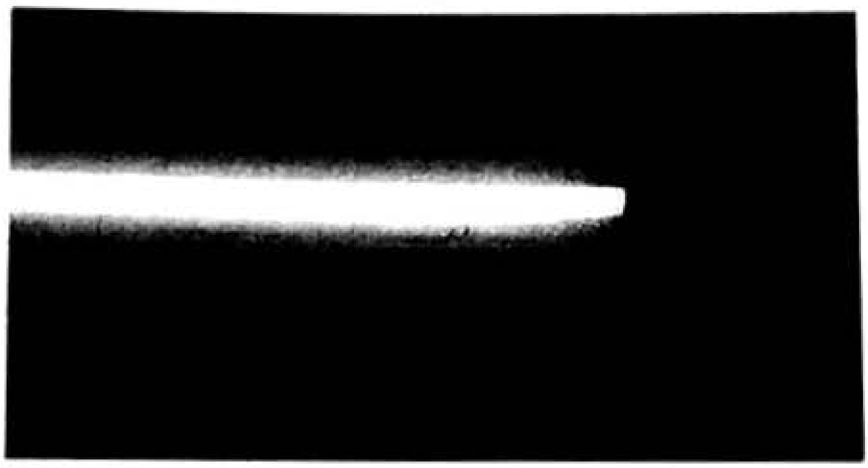

Figure 10. The fluorescent lamp generate stable illumination of white light by using constructed electronic ballast

Comparison between Magnetic and Electronic Ballasts

The below comparison is for a 40W T8 Linear Fluorescent Lamp operating on an Electromagnetic ballast and an Electronic Ballast with APFC (Active Power Factor Correction).

Table 3. Comparison between Magnetic and Electronic Ballasts

Parameter	Electromagnetic Ballast	Electronic Ballast
Operating frequency	50Hz (A/C power frequency)	>20KHz
Power Factor	0.5	>0.995
Total Harmonic Distortion	15-30%	<10%
Current drawn for lumen output of 2450	430mA	320mA
Lamp Wattage Consumption	36W	32W
Watt Losses	6-15W	3-4W

Conclusion

Several simple control circuits have been designed in market for various types of fluorescent lamps. But there are many different weak points on those products in the market. Most of the circuits cannot provide long term use. They are noisy. Heat was built in the ballast casing. But in this newly designed electronic ballast, it is light in weight, low power consumption, longevity of tube, low noise, and prolonged ballast life. Moreover, it can be constructed with locally available components. Brightness result of the lamp tube is stable and no flickering and dimming in experimental observations, since it is a high frequency circuit.

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