ELECTRONIC BALLAST

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Electronics)

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ABSTRACT

Nowadays, the development in technology causes some intelligent groups to create many ideas in producing something useful for human life. The increasing of electrical cost will give more advantages to the engineers to make research in producing the electrical equipments that can save electrical energy. One of application is electronic ballast. The electronic ballast is targeting the most of peoples because everyone needs the electrical energy for lighting system whether at home, office, school, mosque, factory and so on. The electronic ballast specially made to replace the conventional choke in fluorescent lamp. Electronic ballast can control the lamp power more easily and has higher efficiency since it uses the power semiconductor devices with better switching method. Even the cost for produce the electronic ballast is more expensive than conventional choke, it still has more advantage in lifetime operation because it is greater than conventional choke. By using the 240 VAC as a voltage source, the combination of L-C circuit will be acts as filter in electronic ballast circuit to eliminate the spikes and smoothes out the steps in the current waveform during start-up.. Furthermore, the introducing of IR2156 ballast controller IC in electronic ballast circuit can make the operation of lighting system will improved. The IR2156 IC has include the programmable preheat frequency, programmable preheat time and programmable over current protection and internal ignition ramp which can make sure the safety of this system is guaranteed. Consequently, the high frequency can obtained and the efficiency of lamp operation can improved. Therefore, everyone can save his or her money to pay the electricity bill since the electronic ballast used in fluorescent lamp

ABSTRAK

Perkembangan teknologi pada masa sekarang telah menyebabkan beberapa kumpulan yang bijak pandai untuk mencipta banyak idea untuk menghasilkan sesuatu yang boleh memberi manfaat kepada manusia. Kenaikan kos dalam bayaran bil elektrik telah menyebabkan jurutera membuat kajian untuk menghasilkan perkakasan elektrik yang berupaya menjimatkan penggunaan tenaga elektrik. Satu yang telah terhasil iaitu ballast elektronik. Ballast elektronik mensasarkan keseluruhan golongan manusia kerana setiap orang meggunakan tenaga elektik untuk system pencahayaan tidak kira sama ada di rumah, pejabat, sekolah, masjid, kilang dan sebagainya. Ballast elektronik khususnya dicipta untuk menggantikan cok yang biasanya digunakan di dalam lampu pendaflour semenjak lampu pendaflour yang menggunakan cok biasa memerlukan tenaga elektrik yang tinggi berbanding ballast elektronik. Ballast elektronik berupaya mengawal penggunaan kuasa lampu dengan lebih mudah dan lebih efisien semenjak ia menggunakan komponen-komponen semikonduktor dengan kaedah pensuisannya yang lebih baik. Meskipun kos yang diperlukan untuk meghasilkan ballast elektronik adalah lebih tinggi daripada cok biasa, namun ia masih mempunyai kelebihan kerana jangkayat operasinya adalah lebih lama dan lebih baik daripada cok biasa. Dengan menggunakan sumber voltan sebanyak 240 V melalui arus ulang-alik, kombinasi litar L-C yang disambungkan secara terus pada sumber voltan tadi berfungsi sebagai penapis di dalam litar elektik yang berupaya untuk menyingkirkan lebihan arus elektrik dan menstabilkan gelombang arus semasa lampu mula-mula menyala. Kesannya, frekuensi yang lebih tinggi dapat diperolehi di mana kecekapan di dalam operasinya meningkat. Oleh itu, setiap orang berupaya menjimatkan perbelanjaan mereka untuk membayar bil elektrik apabila mereka menggunakan ballast elektronik untuk lampu pendaflour.

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LIST OF ABBREVIATION

V	-	Voltage/Volt
I	-	Current
k	-	Kilo
W	-	Watt
EMI	-	Electromagnetic Interference
RFI	-	Radio Frequency
AC	-	Alternating Current
Hz	-	Hertz
IC	-	Integrated Circuit
PFC	-	Power Factor Correction
VAC	-	Alternate Current Voltage
C	-	Capacitor
L	-	Inductor
fps	-	frame per second
UVLO	-	Under Voltage Lockout
PH	-	Preheat
VCC	-	Common Collector Voltage
IGN	-	Ignition
CPH	-	Preheat Capacitor
CS	-	Current Sensing Input
CT	-	Timing Capacitor
HO	-	High side gate driver output
LO	-	Low side gate driver output
DC	-	Direct Current
Vrms	-	Voltage root mean square
Vpk	-	peak voltage

MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
THD	-	Total Harmonic Distortion
RDT	-	Dead time Resistor
RT	-	Timing Resistor
RPH	-	Preheat Resistor
u	-	micro
m	-	mili
s	-	second
Ω	-	Ohm
%	-	Percent
VDC	-	Direct Current Voltage
PCB	-	Printed Circuit Board
RCS	-	Current Sense Resistor
CRES	-	Resonant Capacitor

CHAPTER 1

INTRODUCTION

1.1 Background

This chapter explains about the overview of electronic ballast, the objectives of the project, project scopes and thesis outline. This project is suitable for lighting application.

1.2 Electronic Ballast Overview

Electronic ballast is ballast that uses semiconductor components to increase the frequency of fluorescent lamp operation, typically in the 20 – 40 kHz range rather than 50 Hz normally used in conventional ballast. The conventional ballast was used today is need a starter to ignite the lamp and fluorescent lamp will flick during the ignition process. This flicker is actually will cause the high starting current or in-rush current occurs during starting process. This event will consume more power demand during starting condition and consumers are necessary to pay the electricity bill for every month with high rate of value. Consequently, waste energy will occur in electrical energy and so, waste money for consumers.

However, electronic ballast needed to design for improving the lighting system of fluorescent lamp. Based of potential in electronic ballast, most of all problems at above can reduce or may eliminate. High frequency, which produces in electronic ballast, will improve the efficiency of lamp operation. The life of electronic ballast is longer than conventional ballast because the flicker effect is free and less noise in operation.

1.3. Objectives

The overall objective of this project is to produce the high frequency (20kHz – 40kHz) electronic ballast which is capable of achieving 0.95 power factor for use with 18 W fluorescent lighting systems. However, the objectives are to free from flickering in lighting system and reduce the noise such as Electromagnetic interference (EMI) and Radio Frequency Interference (RFI) so that the lamp's life can be longer. Other objectives also are to make the energy consumption in fluorescent tube light fittings and consume the electrical energy to consumers with low cost of operation and to avoid the need for starter to light up the fluorescent lamp.

1.4. Scope of Project

In this project, I need to design and construct electronic ballast for use with a fluorescent lamp. The type of fluorescent lamp that I will use is T8 / 18W tube because this type is very popular in use for most of the place like classroom, home, office, mosque, café and so on. The circuit design for my project should be match with electrical line voltage requirement and suitable with fluorescent lamp type. This requirement is so important because to prevent any explosion or leakage in electronic ballast.

The components that need to use in electronic ballast circuit also must have suitable rating and value for each circuit stage so that the circuit can be function. The 240 VAC supply will be use to supply the power in fluorescent lamp because the most of lighting system for fluorescent lamp today are using AC source as a supply.

1.5 Thesis Outline

Chapter 1 explains the background and overview of electronic ballast project. The project criterion is based on the 240VAC voltage source and 50 Hz that is used in Malaysia.

Chapter 2 focuses on the methodologies for the implementations and designing of electronic ballast. It gives a brief review and correlation of all methods in producing electronic ballast for T8 and 18-watt fluorescent tube.

Chapter 3 explains and discuss about the meaning of electronic ballast, how electronic ballast works, the advantages of electronic ballast and the detail of implementation of electronic ballast.

Chapter 4 discusses all the results obtained in analysis of project. All discussions are concentrating on the result and performance of overall project.

Chapter 5 discusses the conclusion of the overall project. This chapter also discusses the problem and the recommendation for this project.

CHAPTER 2

LITERATURE REVIEWS

2.1 Electronic Ballast Overview

Nowadays, electronic ballasts for fluorescent lamps are popular in many lighting systems. Typical electronic ballasts consist of two power stages. The first stage is a power factor corrector for regulating the dc-link voltage. The second stage is a half-bridge series resonant parallel-loaded inverter for ballasting the lamp. Driving of the inverter switches can be accomplished by two methods. The first is to use a self-oscillating circuit, in which a saturable transformer drives the switches. Typical switches are bipolar transistors. The second is to use a ballast integrated circuit (IC) and the switches are usually MOSFETs. The self-oscillating inverter is the dominant solution, because the circuit is simple, robust, and cost effective **[1]**.

Actually, electronic ballasts are basically switching power supplies that eliminate the large, heavy, 'iron' ballast and replace it with an integrated high frequency inverter / switcher. Current limiting is done by a very small inductor, which has sufficient impedance at the high frequency **[2]**. For simplify the circuit of electronic ballast and reduced its cost, some single-stage electronic ballasts have been proposed by integrating PFC circuit into the inverter stage to perform both functions of the PFC and a resonant inverter. By sharing the active power switch and the control circuit, the component count can be effectively reduced **[3].**

Electronic ballasts utilizing transistor inverters are in use for quite sometime and it is well known that energizing the lamp with a high frequency supply results in several advantages like increased efficacy, no flicker or stroboscopic effect, instant start even at low supply voltage, reduced heating load on air conditioning system and others **[4].** The high frequency electronic ballast usually consists of EMI filter, power factor corrector, high-frequency dc/ac inverter, and control circuit. When these circuits are simulated, a suitable model for the main element, fluorescent lamp, is critical.

2.2 Principles Of Operation

Figure **2.01** shows the overall schematic diagram of Unity Power Factor High Frequency Parallel Resonant Electronic Ballast circuit, which has self-base driver, and controller circuit. The circuit consists of full-wave rectifier and conventional push-pull inverter with parallel resonance circuit. Resonance occurs mainly through C_r and L_r. Its operation explained as follows. In the steady state, the resonant voltage ***Vc*** becomes sinusoidal waveform. This voltage continues to turn the **Ql(Q2)** on and simultaneously turn the ***Q2 (Q1)*** off in synchronization with the zero crossing points of the resonant voltage, and the zero voltage switching conditions of transistors are satisfied. In the driver circuit, diode bridge rectifier, which connected to the transformer leg 3, plays a role to supply the transistor base current steadily through proper filtering network. As a result, the square wave current flows into the bases of the transistors **[5].**

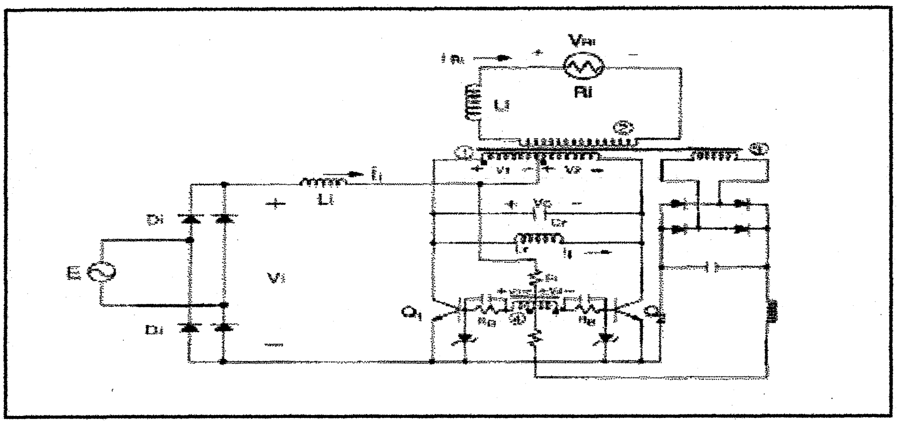

Figure 2.01: Schematic diagram of Unity Power Factor High Frequency Parallel Resonant Electronic Ballast

The new proposed single-switch single-stage electronic ballast circuit is shown in Figure 2. It includes a single-phase voltage supply, a lower conduction losses boost PFC circuit formed by L_{in}, S, C_1, a diode bridge rectifier formed by D3, D4, D5, and D6, two fast-recovery diodes DI and D2, a push-pull converter for high-frequency supply to the lamp formed by an isolated transformer, S, C1, Cs, Ls, Cp, a fast-recovery diode D7, and a fluorescent lamp. The power switch S operated at fixed frequency with a constant duty cycle of 50%. The boost PFC circuit operated in discontinuous conduction mode, the input current naturally follows the sinusoidal waveform of the input voltage, achieving unity power factor to the utility line **[3]**.

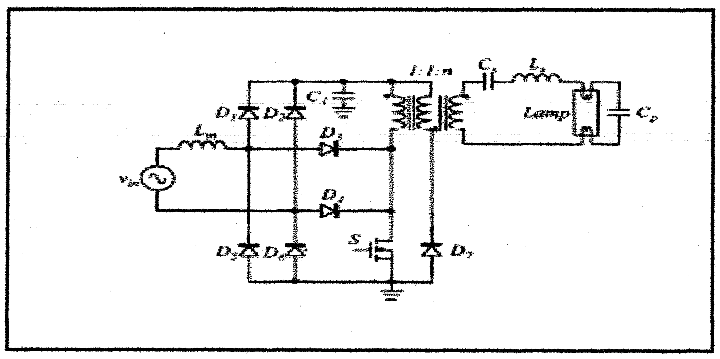

Figure 2.02 : A Novel Single-Switch Single-Stage Electronic Ballast With High Input Power Factor

2.3 Power Factor Control Methods [6]:

A typical active P.F.C. circuit supplies a regulated DC bus at higher voltage then the maximum peak voltage of the AC supply and uses a simple boost topology as shown in Figure 3. The boost topology of Figure 3 may be operated at constant high frequency with continuous inductor current or in the critical conduction mode where the inductor is allowed to discharge to zero energy in before initiating a new charge cycle.

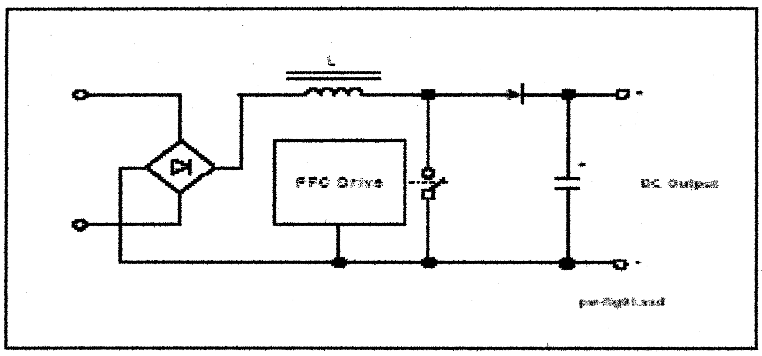

Figure 2.03 : Active PFC Circuit

Passive PFC circuit on Figure 2.04 operates at mains frequency (50 or 60Hz) using capacitors and iron cored inductors tuned to the line frequency in a low pass or band pass configuration. Unfortunately, the physical size and weight of these filters at mains frequency makes them unattractive, especially when one considers that the rest of the ballast circuitry can be smaller than the PFC components.

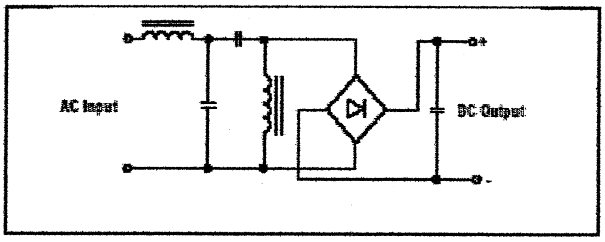

Figure 2.04: L-C Passive PFC Circuit

2.4 Square Wave Ballast [7]

Square wave ballasts eliminate the flicker problem. Square wave ballast maintains a virtually constant output of light over the whole AC cycle by squaring off the curves of the AC sine wave. The change over period is so brief that the light is virtually continuous. Square wave ballasts completely process and regulate the input power, and as a result, they can tolerate fairly wide voltage and Hertz rate discrepancies.

Typical 120V electronic ballast can take an input from 95V to 132V with out affecting the output signal and the fixture's color temperature. The refined signal also increases the light output by 6% to 8% and increases globe life as much as 20%.Unfortunately, the square wave causes the globe and igniter to buzz. The head becomes a resonating chamber, amplifying the noise and projecting it out toward the set and the microphones. To make the ballasts quiet when recording dialogue, electronic ballasts are fitted with a switch to change between flicker free operation and silent operation. In the silent mode, a special circuit electronically rounds off the sharp corners of the square wave, which eliminates the noise. In the silent mode, most square-wave ballasts provide flicker-free light at frame rates up to about 34 frames per second (fps), and in flicker-free mode, up to 10,000 fps.

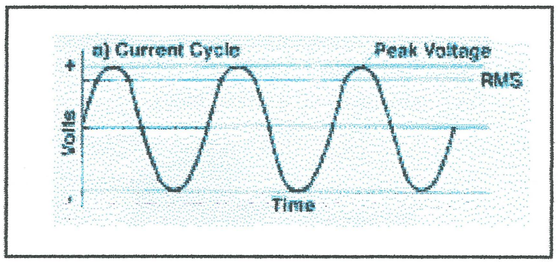

Figure 2.05 : The normal sinusoidal 60 Hz current cycle of magnetic ballast

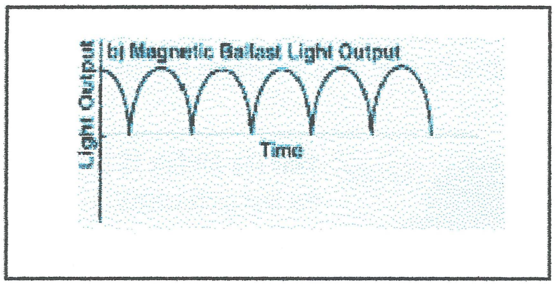

Figure 2.06 : Creates a fluctuating light output

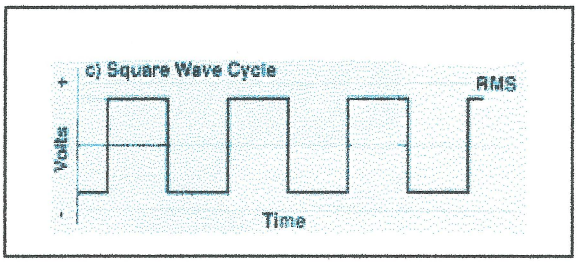

Figure 2.07:.Requirement that the camera frame rate be synchronized with the light fluctuations to obtain even exposure frame to frame.The refined square wave signal of electronic ballast

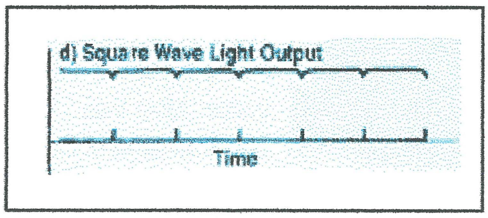

Figure 2.08: Creates virtually even light output

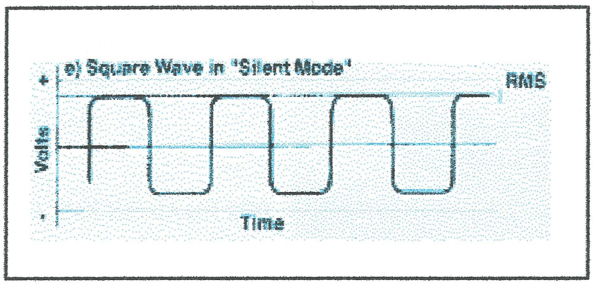

Figure 2.09 : Rendering the fixture flicker-free. The sharps corner of the normal square wave signal creates noise in the head. When operated in silent mode, the ballast electronically rounds off the corners of the square wave.

2.4 Electronic Ballast Analysis [8]

During Ignition:

The resonant capacitor C_u and inductor L_2 will provide enough high ac voltage during the start-up transient to make lamp ionization. The circuit can be described as four states of operation in one cycle,

State I(Figure 2.10)

The transistor M_2 is turned on at $t = t\,o$, with M_1 off because of the presence of L_1, M_2 is turn on with zero-current. C_2 is discharged to R_L. .These components will resonant for nearly half a cycle and then stops because ***D2*** and D_1 are reverse biased.

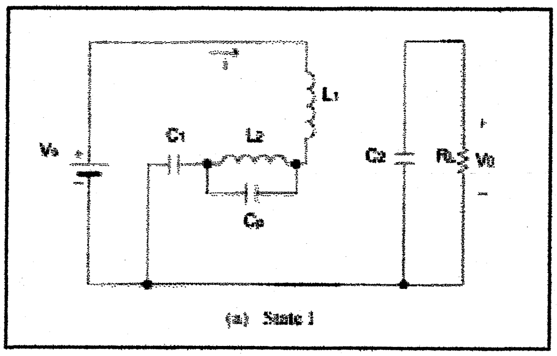

Figure 2.10 : Circuit analysis in state 1

State I1(Figure 2.11)

The device current and inductor current are zero. C_2 is still discharges to R_L, M_2 is switched off at zero current condition at t = t2 .

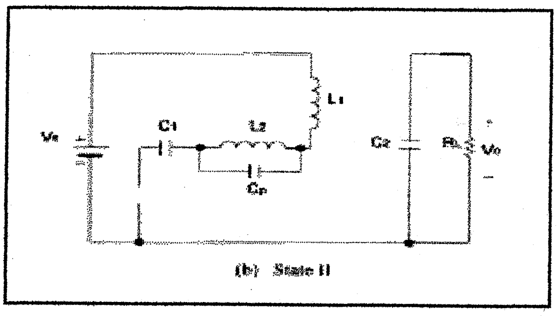

Figure 2.11 : Circuit analysis in state 2

State ***III (Figure 2.12)***

M_1 is turned on at t = t_2 with the zero current When R_L is large, the output voltage V_0 is a constant and can be looked as a voltage source. C_2 is charged by L_1. After i resonate back to zero value, D_1 and D_2 are in reverse biased and this state terminates.

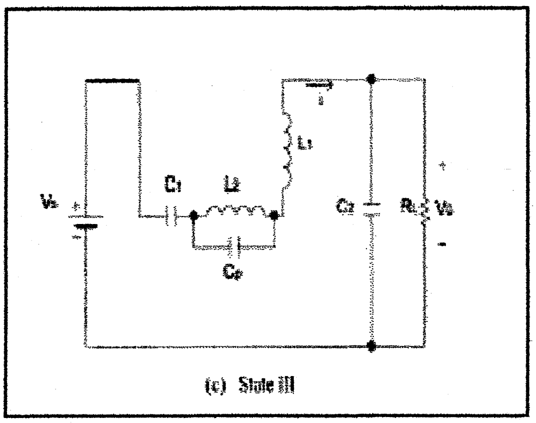

Figure 2.12 : Circuit analysis in state III

State ***IV(Figure 2.13)***

i is zero and C_2 is discharged to R_L . M_1 is turned off at zero-current when t = t_4.

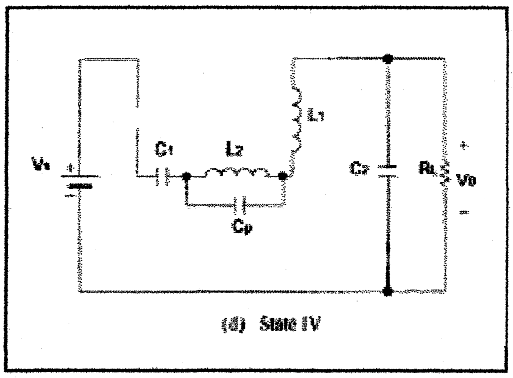

Figure 2.13 : Circuit analysis in state IV

2.5 Ballast Controller IC (IR2156) [9]

The IR2156 is a high voltage half-bridge gate driver with a programmable oscillator and state diagram to form a complete ballast control IC. The IR2156 features include programmable preheat time, programmable preheat and run frequencies, programmable dead time and programmable over-current protection. In electronic ballast, the IR2156 can be function in protection from failure of a lamp to strike, filament failures as well as an automatic restart function.

The IR2156 IC has five modes of operation in electronic ballast circuit. One of operation mode is under-voltage Lock-Out Mode (UVLO) that defined as the state the IC is in when VCC is below the turn-on threshold of the IC. This mode is function to maintain an ultra low supply current of less 200uA and to guarantee the IC is fully functional before the high and low side output drivers are activated.

The second mode in IR2156 is Preheat Mode (PH). This mode is defined as the state the IC is in when the lamp filaments are being heated to their correct emission temperature. This is necessary for maximizing lamp life and reducing the required ignition voltage. This IC enters preheat mode when VCC exceeds the UVLO positive-going threshold.

The other operation mode of IR2156 is Ignition Mode (IGN). This mode is defined as the state the IC is in when a high voltage is being established across the lamp necessary for igniting the lamp. The IR2156 will enter the ignition mode when the voltage on pin CPH exceeds 13V.

The next operation is Run Mode (RUN). In this mode, the ballast will enter the run mode when the lamp has successfully ignited. The run mode is defined as the state the IC is in when the lamp arc is established and the lamp is being driven to a given power level.

The last mode is Fault Mode (FAULT). In this mode, the IC will enters the fault mode when the voltage at the current sensing pin, CS exceed 1.3 volts at any time after the preheat mode and cause the both gate drivers outputs, HO and LO are latched in the low state. For this time, CPH is discharged to COM for resetting the preheat time and CT is discharged to COM for disabling the oscillator. The IC picture is shown in figure 2.14. For more information about IR2156 IC, refer to the appendix B.

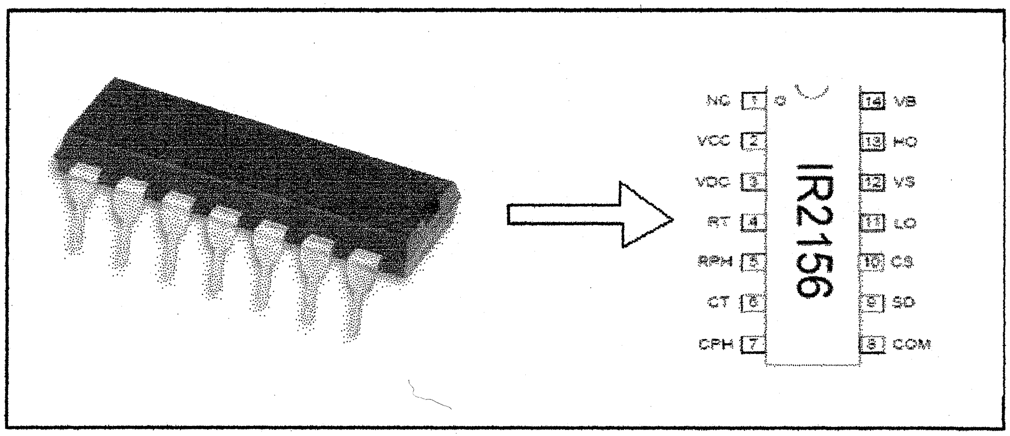

Figure 2.14: IR2156 IC

2.6 Fluorescent Lamp [10]

A fluorescent lamp is a gas-discharge lamp that uses electricity to excite mercury vapor in argon or neon gas, resulting in a plasma that produces short-wave ultraviolet light. Unlike incandescent lamps, fluorescent lamps always require a ballast to regulate the flow of power through the lamp. In common tube fixtures (typically 4 ft (120 cm) or 8 ft (240 cm) in length), the ballast is enclosed in the fixture. The main principle of fluorescent tube operation is based around inelastic scattering of electrons. Fluorescent lamps are negative resistance devices, so as more current flows through the electrical resistance of the fluorescent lamp drops, allowing even more current to flow. Connected directly to a constant-voltage mains power line, a fluorescent lamp would rapidly self-destruct due to the uncontrolled current flow. To prevent this, fluorescent lamps must use an auxiliary device, commonly called a ballast, to regulate the current flow through the tube. For operation from AC mains voltage, the use of simple inductor (also-called "magnetic ballast") is common. In countries that use 120 V AC mains, the mains voltage is insufficient to light large fluorescent lamps so the ballast for these larger fluorescent lamps is often a step-up autotransformer with substantial leakage inductance (so as to limit the current flow). Either form of inductive ballast may also include a capacitor for power factor correction.

In the past, fluorescent lamps were occasionally run directly from a DC supply of sufficient voltage to strike an arc. In this case, there was no question that the ballast must have been resistive rather than reactive, leading to power losses in the ballast resistor. In addition, when operated directly from DC, the polarity of the supply to the lamp must be reversed every time the lamp is started; otherwise, the mercury accumulates at one end of the tube. Nowadays, fluorescent lamps are essentially never operated directly from DC; instead, an inverter converts the DC into AC and provides the current-limiting function as described below for electronic ballasts.

Some fluorescent designs (*preheat lamps*) use a combination filament/cathode at each end of the lamp in conjunction with a mechanical or automatic switch that initially connect the filaments in series with the ballast and thereby preheats the filaments prior to striking the arc. These systems are standard equipment in 240 V countries, and generally use a glow starter. Before the 1960s, four-pin thermal starters and manual switches were also used. Electronic starters are also sometimes used with these electromagnetic ballast fittings. During preheating, the filaments emit electrons into the gas column by thermionic emission, creating a glow discharge around the filaments. Then, when the starting switch opens, the inductive ballast and a small value capacitor across the starting switch create a high voltage, which strikes the arc. Tube strike is reliable in these systems, but glow starters will often cycle a few times before letting the tube stay lit, which causes objectionable flashing during starting. The older thermal starters behaved better in this respect.

Once the tube is strucked, the impinging main discharge then keeps the filament/cathode hot, permitting continued emission. If the tube fails to strike, or strikes then extinguishes, the starting sequence is repeated. With automated starters such as glow starters, a failing tube will thus cycle endlessly, flashing repeatedly as the starter repeatedly starts the worn-out lamp and the lamp then quickly goes out as emission is insufficient to keep the cathodes hot, and lamp current is too low to keep the glow starter open. This causes visually unpleasant frequent bright flashing, and runs the ballast at above design temperature. Turning the glow starter a quarter turn anticlockwise will disconnect it, opening the circuit.

Electronic ballasts often revert to a style in between preheat and rapid-start styles: a capacitor (or sometimes an auto disconnecting circuit) may complete the circuit between the two filaments, providing filament preheating. When the tube lights, the voltage and frequency across the tube and capacitor typically both drop, thus capacitor current falls to a low but non-zero value. Generally, this capacitor and the inductor, which provides current limiting in normal operation, form a resonant circuit, increasing the voltage across the lamp so it can easily start.

There are three main failure modes currently:

1) Emission mix runs out
2) Failure of integral ballast electronics.
3) Failure of the phosphor :
    i. Tube runs out of mercury.
    ii. Phosphors and the spectrum of emitted light.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter focuses on the methodologies for the implementation of electronic ballast project to fluorescent lamp. My circuit project is designed base on half-bridge topology, which mostly used in European with input voltage of 240Vrms and 50Hz frequency.

Before looking at the detail of this project, I like to begin with brief review the relationship of all methods which I need to put into operation. Figure 3.1 shows the correlation between all of the methods of the project.

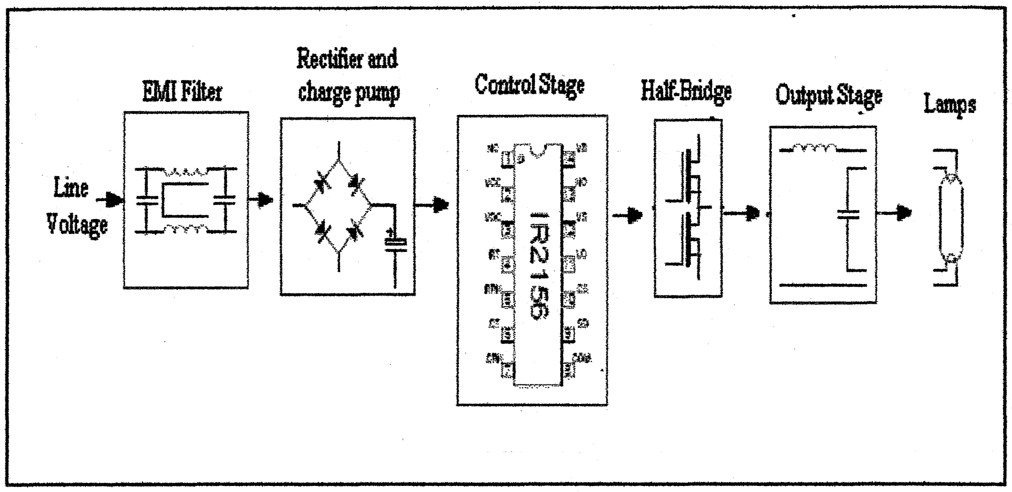

Figure 3.01 : Block diagram for electronic ballast project

From figure3.01, there were six main phases in order to construct the electronic ballast circuit. These six phases are filter, rectifier, control stage, half-bridge, output stage and fluorescent lamp as a load.

3.2 Filtering stage

In the first stage, the input voltage from the AC source with 240Vrms and 50 hertz frequency will flow into the circuit to generate the light of fluorescent lamp. To make sure the fluorescent tube is on, the maximum preheating voltage is about 250Vpk with preheating time around 1 second where the filament are required to strike the arc in ignition mode before the lamp can continuously in on-state. Consequently, it needs more power to ignite the lamp in start-up mode and the life of lamp ballast will be short.

Through this project, the filter stage is one of the important part in electronic ballast circuit. In this stage, I need to use the capacitor, varistor and common mode line filter (ELF-15N007A) which connected to the input line. Since the electronic ballast will generate the high frequency during its operation, the noise frequency signal will be existing in the air system such as during watching the television and listened the radio. The electromagnetic interference (EMI) is a type of noise that produced from high frequency signals during electronic ballast operation. For this reason, the electronic ballast circuit must have filter circuit in the first stage of circuit to avoid the problems occur during watching television and listened radio.

The common-mode line filter N-type (ELF-15N007A) is chosen in first stage of electronic ballast circuit because it can be used to suppress the conductive noise ranging from low to high frequencies generated in this circuit. The LC circuit will acts as filter to reduce the noise and electromagnetic field interference (EMI) in system because the presence of EMI and noise in the system will affect the performance of electronic device. At the same time, the function of varistor is to protect the circuit by absorbing surge voltage. The combination of varistor and LC filter will acts as an insulator at voltage below a predetermined level and the resistance decreases rapidly at voltages above a predetermined level. The combined device operates as an LC filter at low voltage and operates as a varistor at a high voltage.

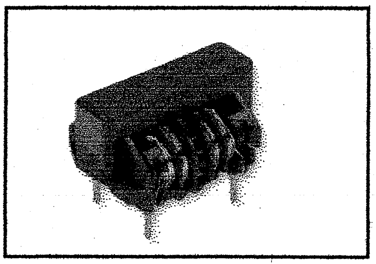

Figure 3.02: N-series common –mode line filter (ELF-15N007A) is used in filter circuit to filter the noise by attenuating the signal that appear identically on each of the wires going through the filter

3.3 Rectification stage

After the signal that was coming from the AC source was passing through the filtering stage, it will flow through the rectification stage for changing the alternating current (AC) mains line voltage to a direct current (DC) bus voltage. This stage is accomplished by using a full bridge rectifier with rating 1000V and 1A. Actually, the combination of filtering and rectification stage will be functioning to suppress the radio frequency interference (RFI) and voltage transients from the mains. The filter-rectifier circuit at the input can utilized to obtain a direct voltage from ac mains and then uses self-oscillating resonant high frequency inverter circuit to produce sinusoidal lamp voltage and current with high efficiency and minimum RFI problems. After that, the output DC voltage will smoothed by electrolytic capacitor. The supply resistor (RSUPPLY) has chosen to provide two times the maximum start-up current to guarantee ballast start-up at low line input voltage.

3.4 Control stage

An IR2156 ballast controller IC controls the full operation of electronic ballast circuit. The IR2156 is a ballast controller and half-bridge driver in one IC. The IR2156 features include programmable preheat time, programmable preheat and run frequencies, programmable dead time, and programmable over current protection. The power factor correction section contained in the IR2156 forms the control for boost topology circuit operating in critical conduction mode. This topology is designed to step-up and regulates the output DC bus while drawing sinusoidal current from the line (low THD) which is "in phase" with the AC input line voltage resulting in a high power factor.

Across the 2 MOSFETs MHS and MLS is a bootstrap diode DBOOT. This diode is called fast recovery diode (1N4937) that can be used for recovery time of 150ns and providing high efficiency at frequencies to 250 kHz. By providing a path for the inductive current, this device will clamp the spike voltage when MHS or MLS switches off. Since the dV/dt can be pretty high, DBOOT must has a fast turn-on time to make sure that the peak voltage will be clamped to a safe value. A bootstrap diode (DBOOT) and supply capacitor (CBOOT) comprise the supply voltage for the high side driver circuitry to guarantee that the high side supply is charged-up before the first pulse on pin HO.

3.5 High Frequency Oscillator (Half bridge)

In this project, the half-bridge circuit consist of 2 MOSFET transistors, resonant inductor, capacitors and diodes. From rectification stage, the switching regulator charges the electrolytic capacitor that acts as an energy reservoir. The voltage over the electrolytic capacitor is stabilised by adjusting the MOSFET current. Two MOSFET transistors are used to achieve the stability and reliability in operation.

The type of MOSFETs that were used in this operation are N-Channel type with high voltage rating (400V) that are called IRF720 because the breakdown voltage for standard line 230Vac nominal line must be more than 374V. This type has selected because the characteristics of IRF720 are fast switching, ease of paralleling, simple drive requirements, low on-resistance, and cost-effectiveness.

In this stage, when the half-bridge is oscillating, capacitor CSNUB, diodes DCP1 and DCP2 will form a snubber/charge pump circuit, which limit the rise, and fall time at the half-bridge output and also supplies the current to charge capacitor

CVCC2 to the VCC clamp voltage (approximately 15.6V) of IC1. When the rising under-voltage lockout threshold of IC1 reached, it starts to oscillate and drive MOSFET to boost and regulate the bus voltage to 400VDC. The power factor control starts only during preheat, so the bus is not yet boosted when the oscillator starts. Therefore, this will help to prevent the lamp flash at the start up.

In current mode drive, the steady-state current in the fluorescent tube is limited by the external inductance, LRES. The value of LRES is derived from the impedance one must set in series with the lamp to get the right output power. Depending upon the values of L and C, assuming the DC resistance R is negligible and the operating frequency is nominal, the current waveform will be truncated at the peak value either of the sine (worst case) or during the negative going slope. Obviously, in the second case, the turn off switching losses will be lower. The dynamic behaviour of the transistor must be stable to make sure that the frequency stays within the predicted limits.

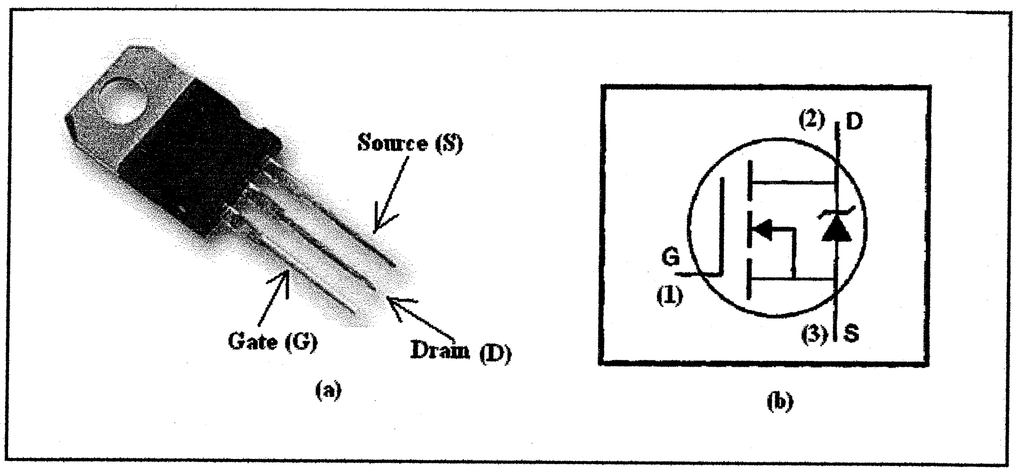

Figure 3.03: IRF720 half-bridge MOSFET (a) and its symbol (b)

3.6 Final Stage

When the circuit energized by turning on the power transistor, while the fluorescent tube is off, the circuit behaves as a series LC circuit (since lamp impedance is infinite low) with its own resonant frequency. This generates the necessary high voltage across the capacitor, permitting early ionisation of the medium inside the fluorescent lamp. During this period, the lamp current flows through the filament that is also in series with the capacitor, causing easy ionisation in the lamp. The magnitude of current is limited by the value of series inductor.

When the tube is fully ionised, the arc is struck, causing its impedance drop to a low value depending on the lamp characteristics. This increases the damping across the capacitor, shifting the resonant frequency. However, the lamp current keeps flowing through the filaments to extract maximum lamp life.

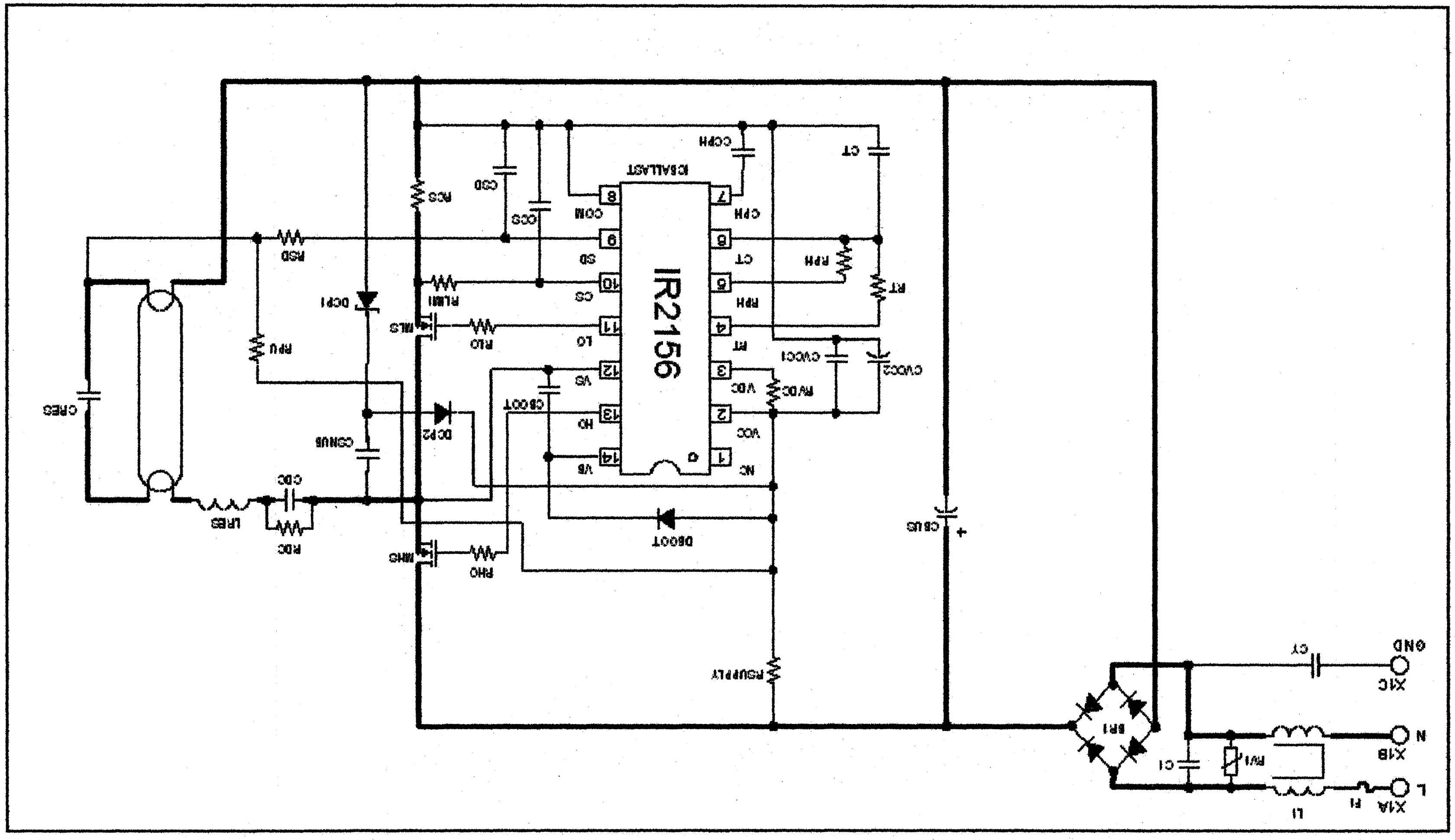

Figure 3.03 : The full circuit design of electronic ballast project

Table 3.1: Component List of Project

Q'tity	Type	Value	Rating	Tolerence	Reference
1	Bridge Rectifier	1 A	1000V		BR1
1	Capacitor	0.1 uF	275VAC		C1
3	Capacitor	0.1 uF	25V		CBOOT,CSD,CVCC1
1	DC Bus Capacitor	10 uF	350V		CBUS
1	Capacitor	0.38 uF	25V		CCPH
1	Capacitor	100 pF	25V		CCS
1	Capacitor	0.1 uF	400V		CDC
1	Resonant capacitor	4.7 nF	1500V	5%	CRES
1	Capacitor	1.5 nF	630V		CSNUB
1	Capacitor	470 pF	25V	1%	CT
1	Capacitor	2.2 uF	25V		CVCC2
1	Capacitor	0.01 uF	25V		CVDC
1	Y Capacitor	2.2 nF	250VAC		CY
1	Fast Recovery Diode	1N4937	600V / 1A		DBOOT
1	Zener Diode	18V	500mW		DCP1
1	Diode	1N4148			DCP2
1	Fuse	2A	250VAC		F1
1	Ballast Control IC	IR2156			IC BALLAST
1	Common-mode Line Filter	2x10mH	0.1A		L1
1	Resonant Inductor	1 mH	1.5 Apk	5%	LRES
2	MOSFET	IRF720			MHS, MLS
1	Current-sense resistor	1 Ohm		1%	RCS
2	Resistor	100KOhm			RDC, RSD
2	Resistor	20Ohm		5%	RHO, RLO
1	Resistor	1KOhm			RLIM1
1	Preheat Frequency Resistor	100KOhm		1%	RPH
1	Resistor	1MOhm			RPU
1	Resistor	1MOhm	400V		RSUPPLY
1	Oscillator timing resistor	22KOhm		1%	RT
1	Varistor	470V			RV1

3.7 Design Equation

3.7.1 Step 1: Program Dead – Time

The dead time between the gate driver outputs HO and LO is programmed with timing capacitor CT and an internal dead-time resistor RDT. The dead time is the discharge time of capacitor CT from 3/5VCC to 1/3VCC and is given as:

$t_{DT} = C_T \, . \, 2000$ [seconds]

$$C_T = \frac{t_{DT}}{2000} \quad \text{[Farads]}$$

3.7.2 Step 2: Program Run Frequency

The final run frequency is programmed with timing resistor RT and timing capacitor CT. The charge time of capacitor CT from 1/3VCC to 3/5VCC determines the on time of HO and LO gate driver outputs. The run frequency is therefore given as:

$$f_{RUN} = \frac{1}{2 \cdot C_T (0.6 \cdot R_T \div 2000)} \quad \text{[Hertz]} \qquad \text{or}$$

$$R_T = \frac{1}{1.12 \cdot C_T \cdot f_{RUN}} - 3333 \text{ [Ohms]}$$

3.7.3 Step 3: Program Preheat Frequency

The preheat frequency is programmed with timing resistors RT and RPH, and timing capacitor CT. The timing resistors are connected in parallel internally for the duration of the preheat time. The preheat frequency is therefore given as:

$$f_{PH} = \frac{1}{2 \cdot C_T \cdot \left(\frac{0.6 \cdot R_T \cdot R_{PH}}{R_T \div R_{PH}} \div 2000 \right)} \quad \text{[Hertz]} \quad \text{or}$$

$$R_{PH} = \frac{\left(\frac{1}{1.12 \cdot C_T \cdot f_{PH}} - 3333 \right) \cdot R_T}{R_T - \left(\frac{1}{1.12 \cdot C_T \cdot f_{PH}} - 3333 \right)} \quad \text{[Ohms]}$$

3.7.4 Step 4: Program Preheat Time

The preheat time is defined by the time it takes for the capacitor on pin CPH to charge up to 13 volts (assuming Vcc = 15 volts). An internal current source of 4.3μA flows out of pin CPH. The preheat time is therefore given as:

$t_{PH} = C_{PH} . 3.02e6$ [Seconds] or

$C_{PH} = t_{PH} . 0.331e\text{-}6$ [Farads]

3.7.5 Program Maximum Ignition Current

The maximum ignition current is programmed with the external resistor RCS and an internal threshold of 1.25 volts. This threshold determines the over current limit of the ballast, which can be exceeded when the frequency ramps down towards resonance during ignition and the lamp does not ignite. The maximum ignition current is given as:

$$I_{IGN} = \frac{1.25}{R_{CS}} \text{ [Amps Peak]} \qquad \text{or} \qquad R_{CS} = \frac{1.25}{I_{IGN}} \text{ [Ohms]}$$

components that are used in electronic ballast circuit such as Line filter, fluorescent tube and IR2156 IC.

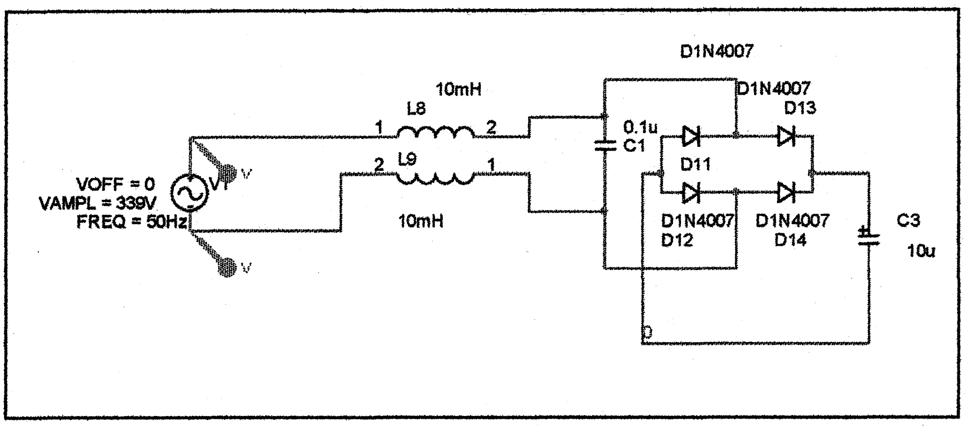

Figure 4.01: Simulation circuit test direct from main source 240VAC

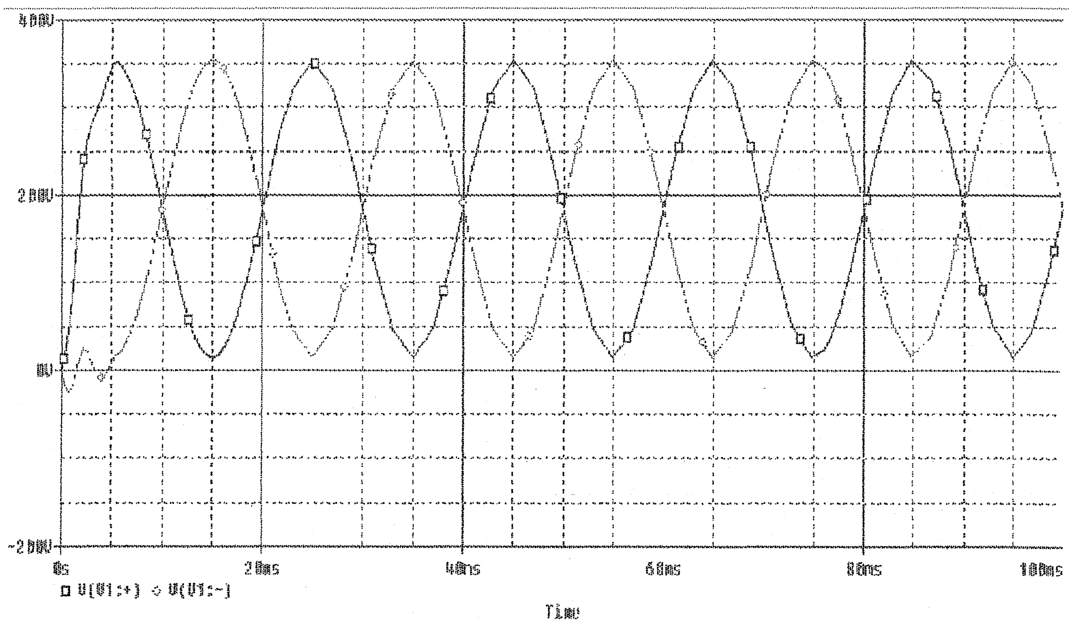

Figure 4.02: Waveform result from figure 4.1

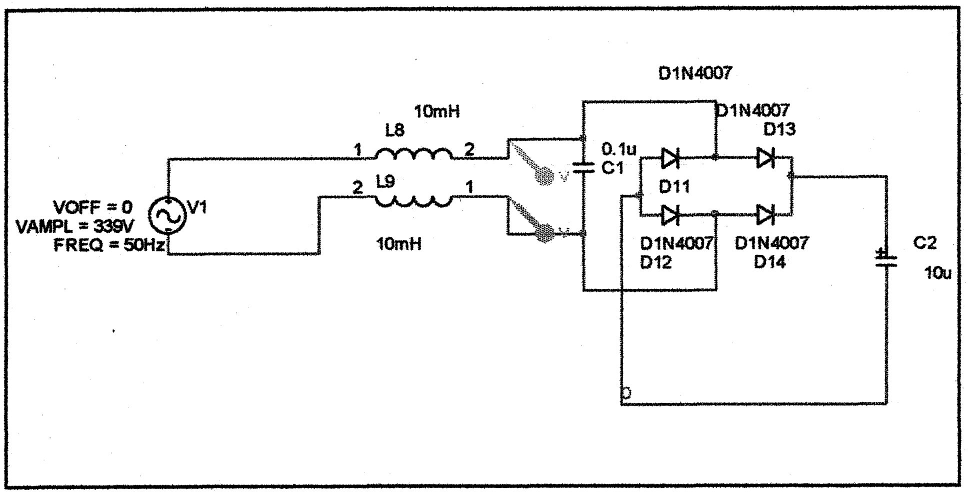

Figure 4.03: Simulation circuit analysis after EMI Filter

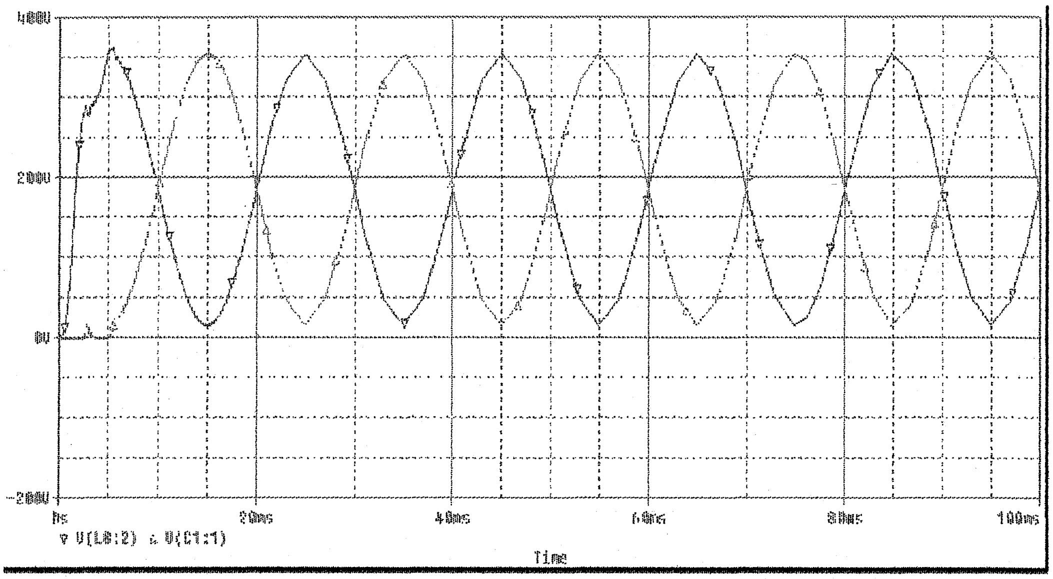

Figure 4.04: Waveform result from Figure 4.03

From the simulation results, the waveforms from figure 4.02 and figure 4.04 are look like the same but they have a little bit different at the early waveform where the waveform in figure 4.02 have more noise than figure 4.04.

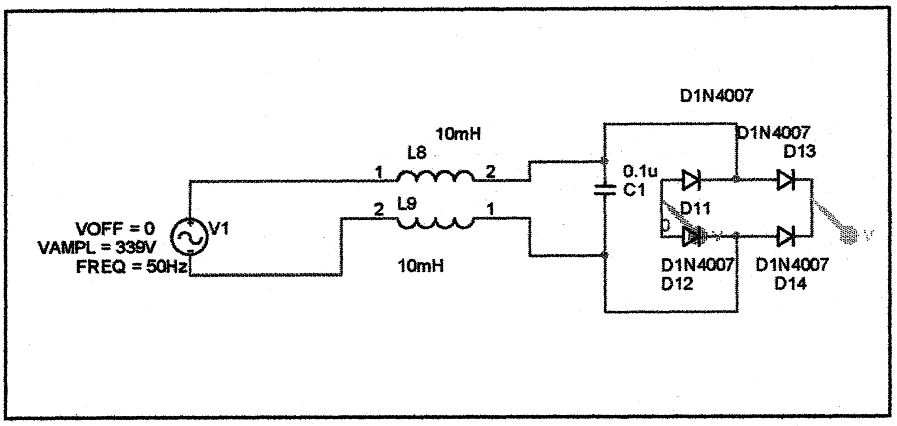

Figure 4.05: Simulation circuit after full bridge rectifier without electrolytic capacitor

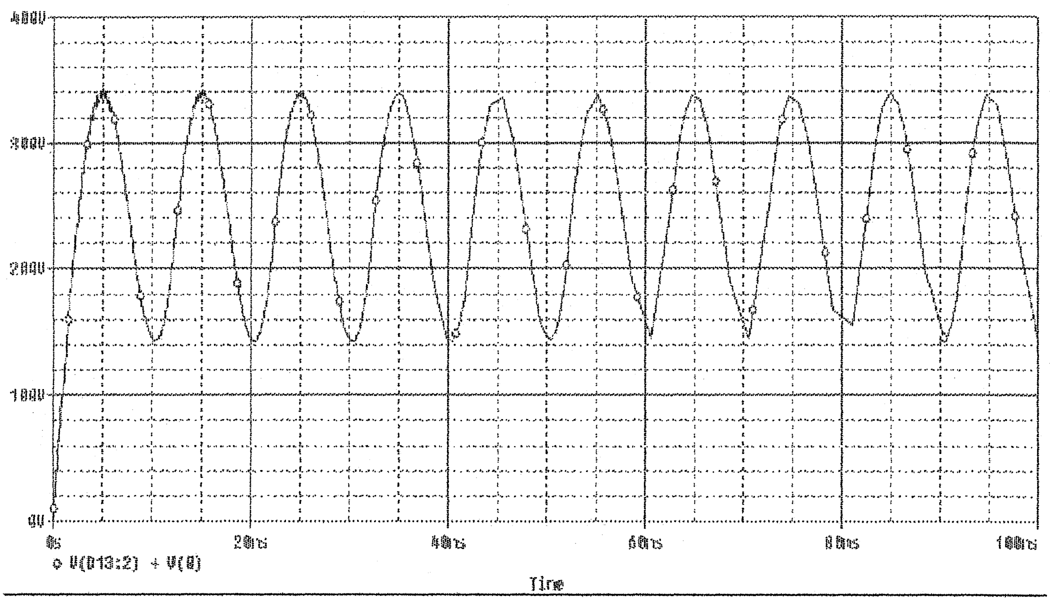

Figure 4.06: Waveform result from Figure 4.5 shows the non-smooth DC signal

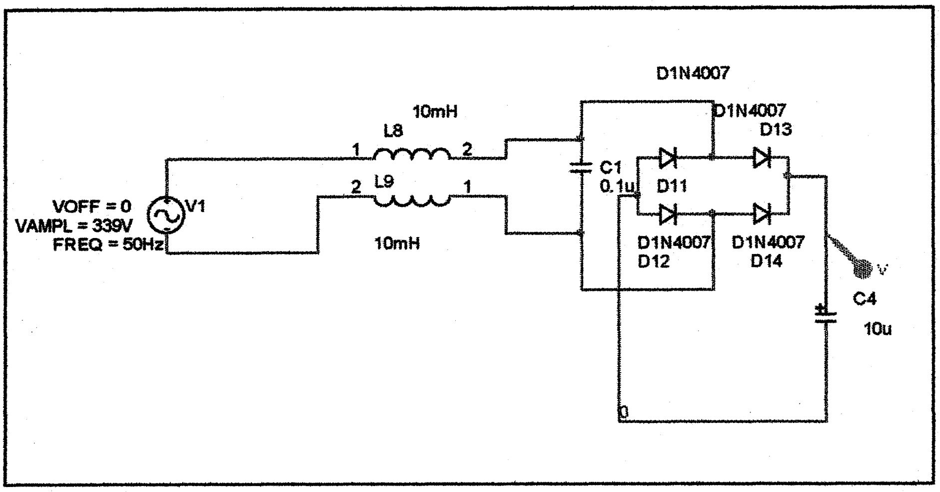

Figure 4.07: Simulation circuit with smoothing capacitor in rectification stage

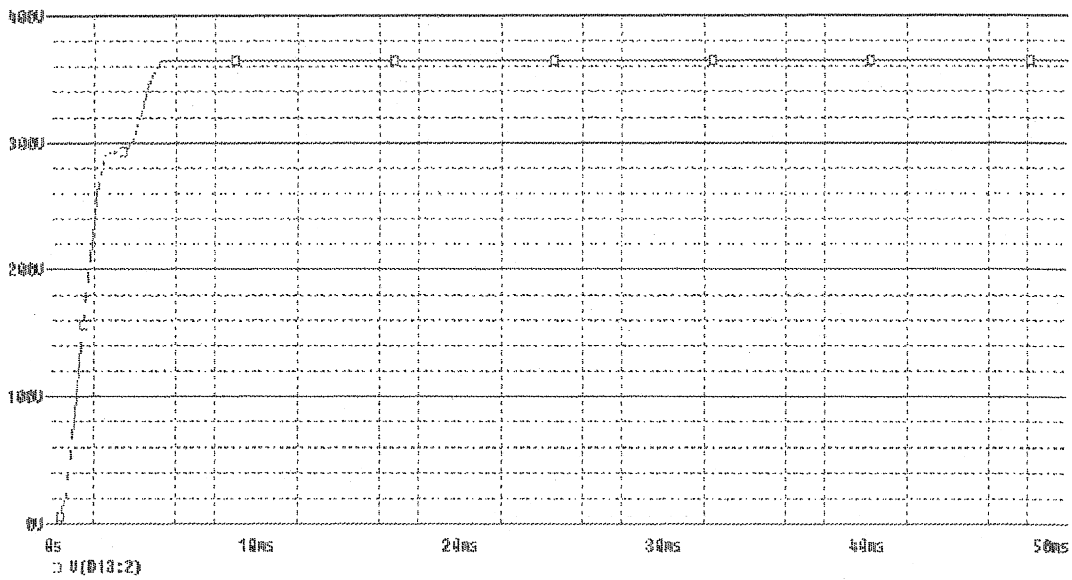

Figure 4.08: Waveform result from Figure 4.07 shows the smooth DC signal

From the figure 4.06, it shows that the DC waveform is not smooth because it looks likes sinusoidal waveform AC signal. The waveform in figure 4.08 shows the smooth DC signal when the electrolytic capacitor is applied. Unfortunately, the full circuit of my project cannot be simulate because the controller IC ballast, IR2156 is not exist in orcad library and also have no other equivalent components to replace that IC.

4.3 Hardware Testing

4.3.1 Circuit testing

This circuit can be tested by using multimeter and power scope. Our target is the 18W T8 type of fluorescent lamp will be light up without flicker during starting condition and no need for starter to on the tube.

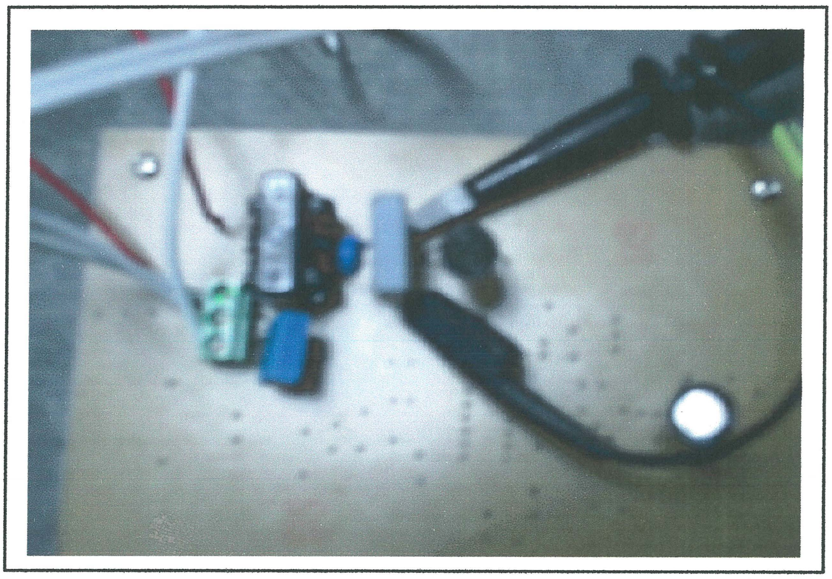

Figure 4.09: Circuit testing for filtering stage.

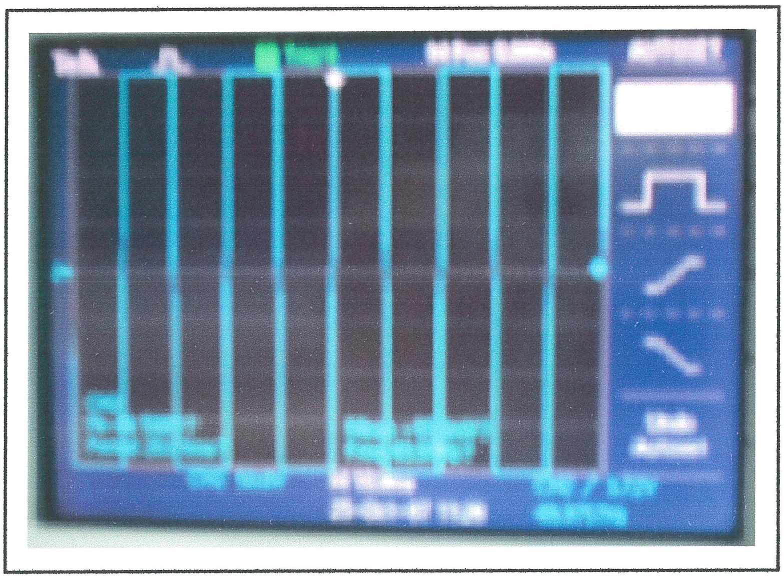

Figure 4.10: Waveform result for figure 4.09 from power scope

The data that I obtain from Figure 4.09 as shown in the table below:

Table 4.1: The data analysis from power scope in figure 4.09

Period	19.95 ms
Frequency	50.13 Hz
Peak-peak	508 V
Rise time	378.5 us
Mean	170 mV
Pos width	9.990 ms
Max	254V

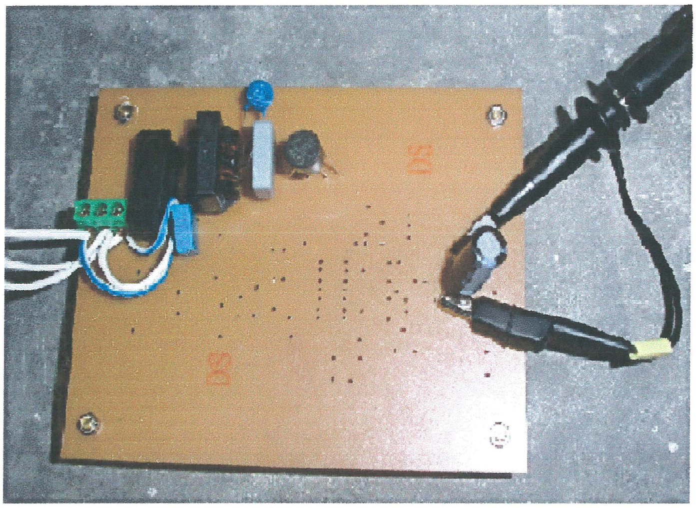

Figure 4.11: Circuit testing for rectifying stage

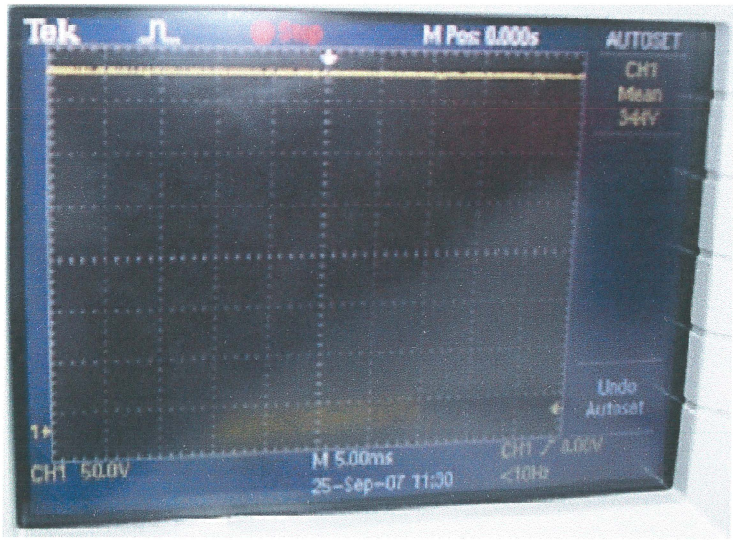

Figure 4.12: Waveform result for figure 4.11 from power scope

From the result above, the output voltage from power scope after rectifying stage is about 344VDC. When the circuit is tested with multimeter, the output voltage was about 332V. The output voltages were different because of resistant existence in multimeter.

4.3.2 Full Circuit analysis

The full circuit picture after constructing as shown in figure 4.13 below

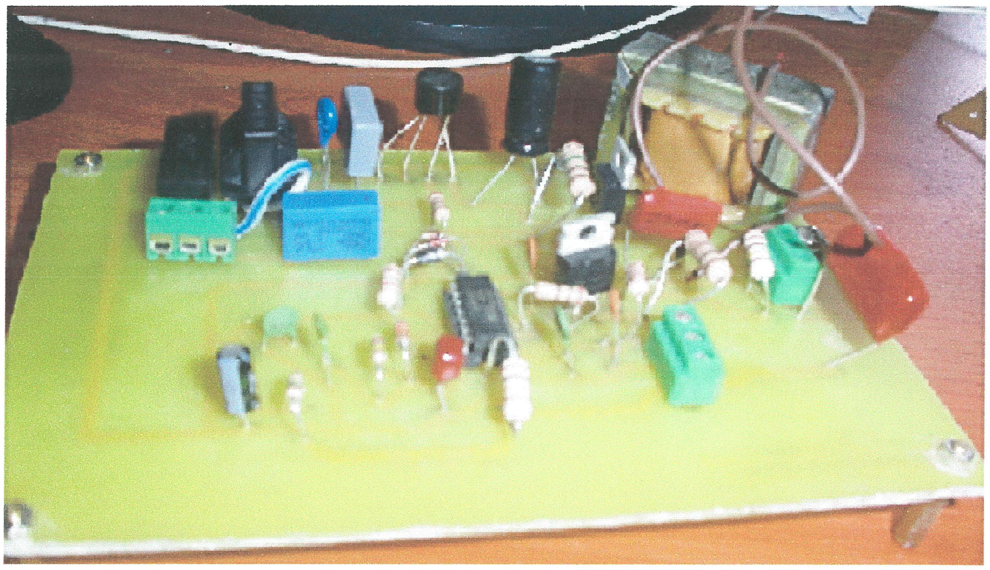

Figure 4.13: Full circuit picture before connected to 18W fluorescent lamp

The full circuit above designed based on PCB layout in Orcad 9.2 software as shown in figure 4.14

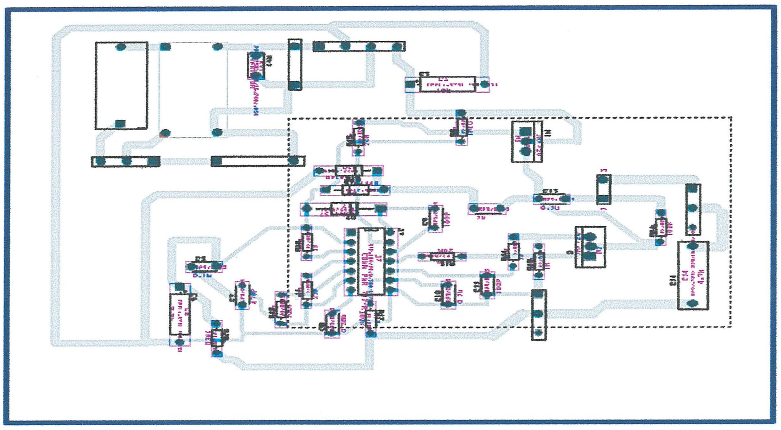

Figure 4.14: Layout of the PCB by using OrCAD Layout

After finishing circuit design, the circuit test can be making by connecting the full circuit with 18W fluorescent lamp. The result obtained as shown in Figure 4.15.

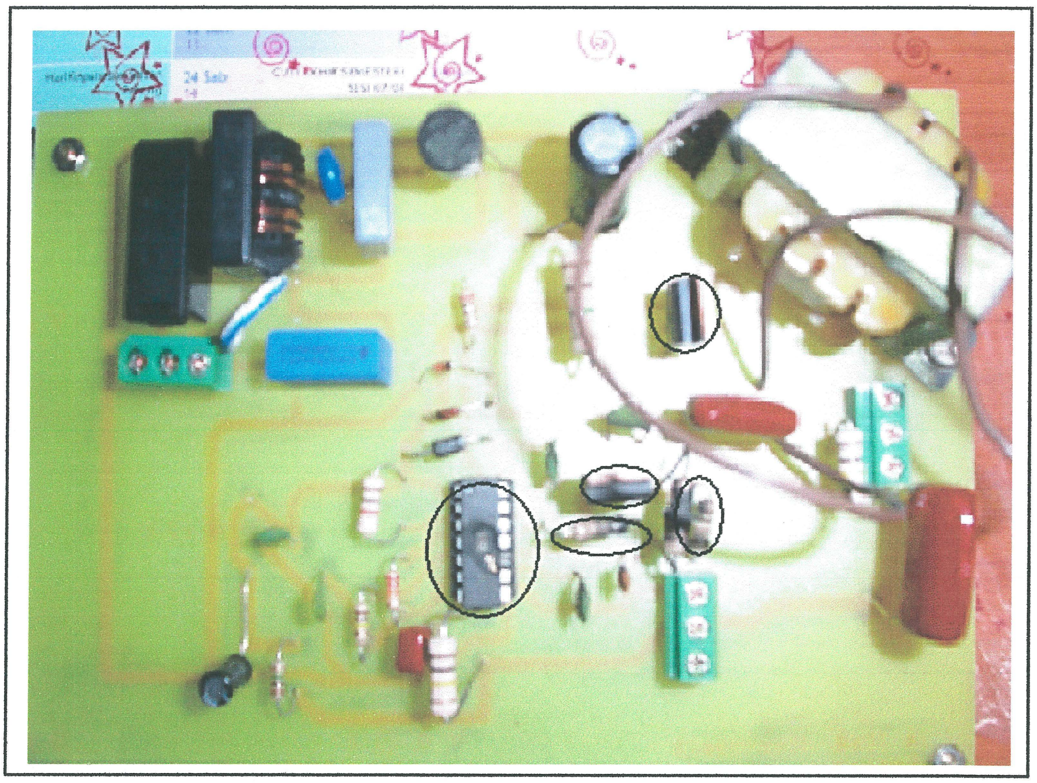

Figure 4.15: Damage at the components (in the circle)

From the picture above, there are a few components damage when the circuit connected to the fluorescent lamp. When the lamp fails to strike, the first component that must be damage is IR2156 IC controller because it is the main two part of all operation in electronic ballast. The both MOSFET IRF720 also can be damage because of hard switching has occurred in that circuit. Besides that, a current sense resistor, RCS also damage because this resistor is important part during preheats since the value of RCS can determine the peak current during ignition mode. Others damage component are RLO, RHO and CCPH.

From the damage, the main reason of circuit blow is the component tolerances are not correct. From the circuit, most of the resistors that I used are the type with 20% tolerances. The resistors, which need the correct tolerances in the circuit, are current sense resistor, RCS with 1% tolerance, Resistors RHO and RLO with 5% tolerance, preheat frequency resistor, RPH with 1% tolerance and oscillator timing resistor, RT with 1% tolerance. Others reason is the tolerances and type of capacitors like resonant capacitor, CRES with 5% tolerance and timing capacitor, CT with 1% tolerance. Unfortunately, the type of resonant capacitor and timing capacitor that I used in my project are not the actual type. One other reason that the circuit was failed is the value of timing resistor, RT is not match with IR2156 IC characteristics. The value of RT should be 40 kΩ but not 22 kΩ that I used in this circuit in order to obtain the run frequency of electronic ballast in range 37.6 kHz to 43.9 kHz. Based on calculation in chapter 3, the run frequency for 22 kΩ RT is about 75 kHz. This frequency is out of range and an error in IR2156 IC should be occurring because of not match with IC characteristics. We can refer the characteristics of IR2156 IC in appendix B

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From this project, the electronic ballast circuit that is constructed is to replace the conventional ballast for use in fluorescent lamp. The matching semiconductor components are important things that I need to take action in designing ballast circuit. An electronic ballast circuit must be contains an input filter circuit, rectifier, controller circuit, half-bridge and output stage circuit. IR2156 IC ballast controller that can control the voltage and current for preheat, ignition and run mode of fluorescent lamp controls the operation of electronic ballast. When electronic ballast project is complete, it can be used in lighting system by fluorescent lamp where the electrical power consumed by fluorescent tube is less rather than previous ballast because the high frequency ballast with high power factor will reduce the flickering in starting condition since it consume more power for electricity. Finally, the objective of this project cannot be achieved completely because of component tolerances error, different type and error value of components.

5.2 Recommendation For Future Work

For the future work, the electronic ballast circuit must be designed with correct component tolerance and should be match with IR2156 IC ballast so that the can't be damage soon. The component type such as resonant capacitor must be the real resonant capacitor because this component is one of important part in electronic ballast circuit since this capacitor connected directly to fluorescent lamp and replace starter connection. Lastly, the ultra fast recovery diode (10DF6) should replace the fast recovery diode (1N4937) in the circuit for more efficient system.

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[2] http://www.repairfaq.org/sam/flamp.htm#fb3

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[9] IR2156(S) & (PbF)
(http://www.ortodoxism.ro/datasheets/irf/ir2156.pdf)

[10] Fluorescent Lamp
http://en.wikipedia.org/wiki/Fluorescent_lamp

APPENDICES

APPENDIX A

PCB FABRICATION METHOD

Printed Circuit Board (PCB) is a mechanical assembly consisting of layers of fiberglass sheet laminated with etched copper patterns. It is used to mount electronic parts in a rigid manner suitable for packaging. It also known as a Printed Wiring Board (PWB).

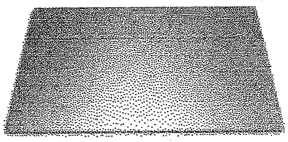


Figure A1::PCB board that available in the market

Draw the PCB Layout

The PCB layout can be draw manually or by using ORCAD 9.2 software with full edition. Firstly, the project must be designed by using orcad capture with full circuit. The components selected in the orcad capture must be exactly the true components that need to use in hardware fabrication. If the actual component is not exist in the arcad capture, we can choose the available component that was equivalent with the actual component.

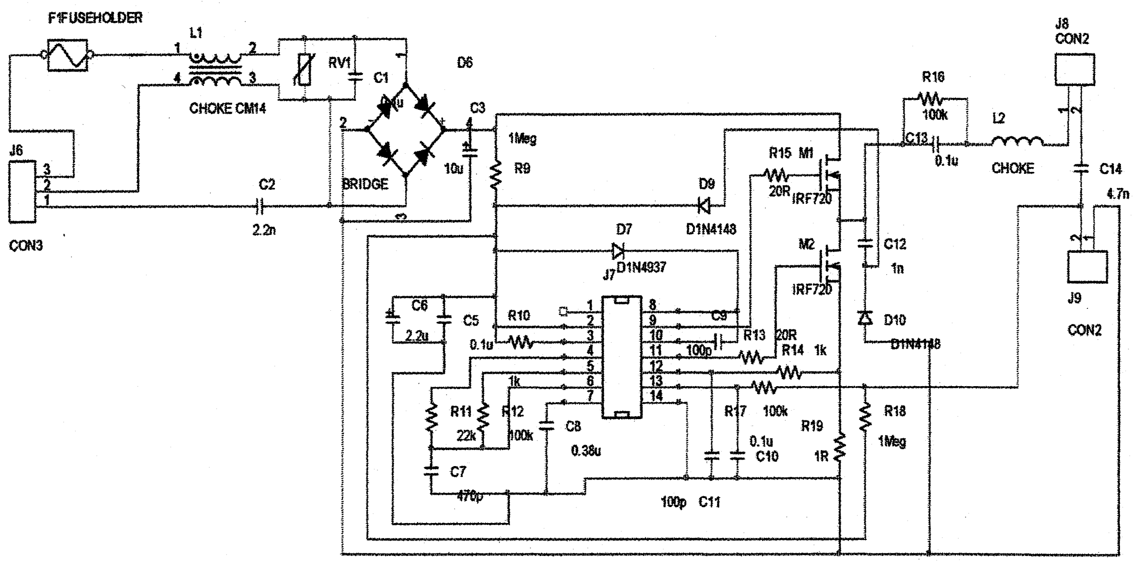


Figure A2: Full circuit schematic of electronic ballast with equivalent component in orcad Capture

ThiAfter the schematic in orcad capture was complete, the circuit must be transferred to the orcad layout program. From the orcad layout software, the actual footprint for every component in electronic ballast circuit can be identified to make sure the all size of footprints are same with the actual components. The actual size of every footprint can be measured via orcad layout and can be compared with size of actual components. The actual size for every component is the most important thing in making PCB layout so that the all components can be placed in the right ways on the PCB board. If the size of footprint is different from actual component, we can create the new footprint with suitable size in orcad layout. After that, all the components part will be route by autorouting or manual route method. The complete PCB layout is shown in figure A3.

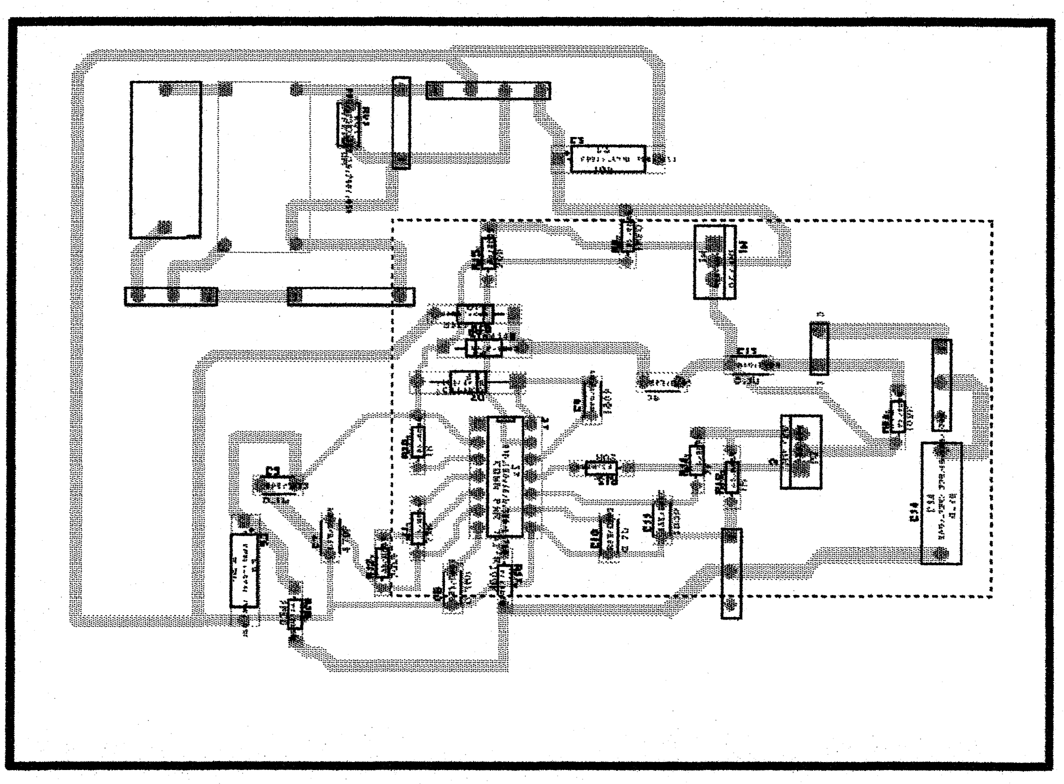


Figure A3: PCB layout with footprints view.

To transfer the PCB layout on the PCB board, we must eliminate the footprint view for the safety purpose. The ready PCB layout is shown in figure

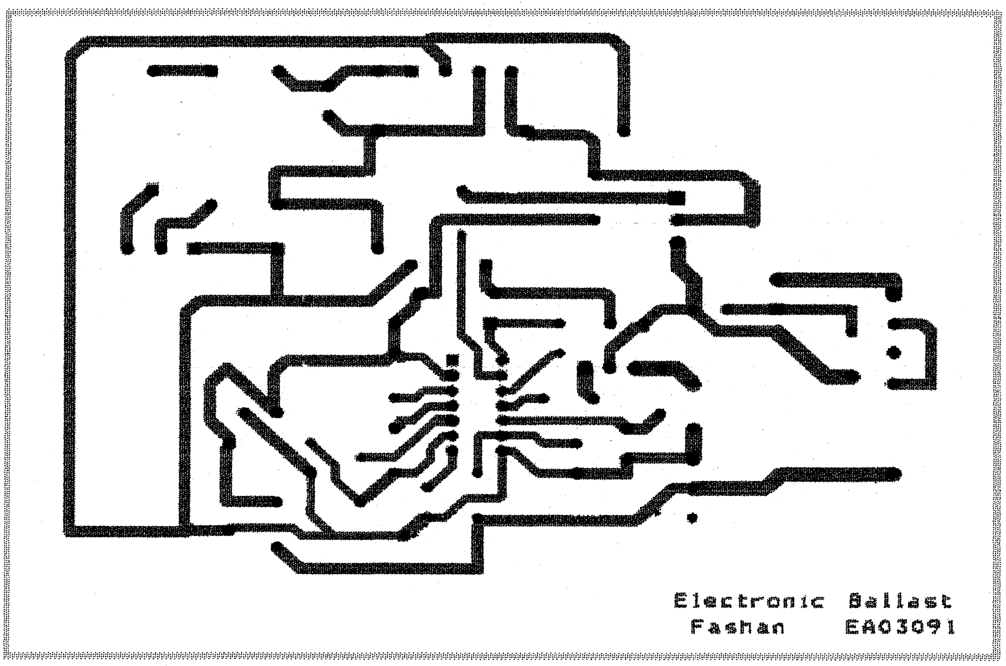


Figure A4: PCB layout with route line and hidden footprints

Tranferring image

After the routing process was complete, the image from orcad layout must be transferred by print out onto glossy photo paper. This type of paper must be printed by using laser jet printer type because it can produces a good solid black with no toner pinholes and good quality copier. After that, the glossy paper image printed must be lay face down over a cleaned circuit board blank and then iron it until the image from the paper will slide away leaving the toner on the board.

Etching Process

Etching is the process of chemically removing the unwanted copper from a plated board. This process is done by using boiling machine to boil the mixture of water and acid powder in order to remove the unwanted copper from a plate board. To complete tis process, it will take about two hours to remove the all unwanted copper

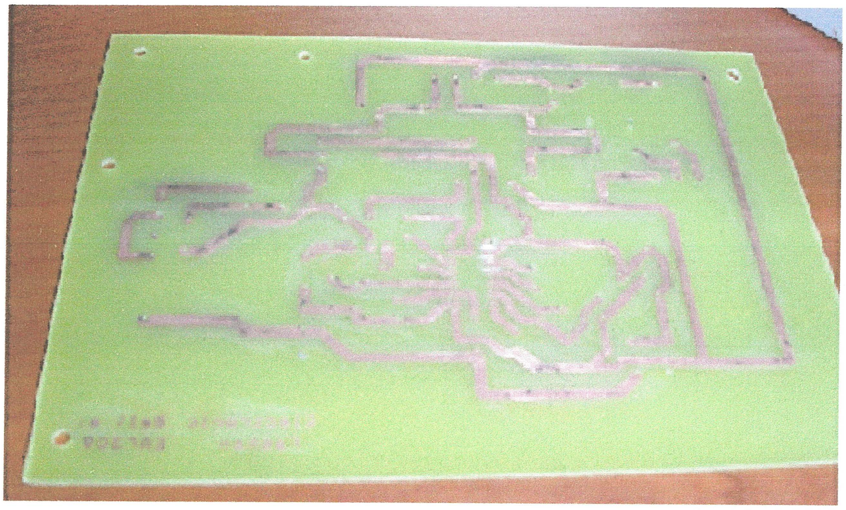


Figure A5: PCB board after the etching process

Drilling Process

After etching was complete, the board must be make the hole for placing the components on the board. The typical hole sizes for ICs, and resistors are about are 0.8 mm, larger diodes and capacitors are about 1.0mm and fuse holder is about 1.2mm to 1.5mm. After completing all the process, the all the components can be placing in PCB board with more easy

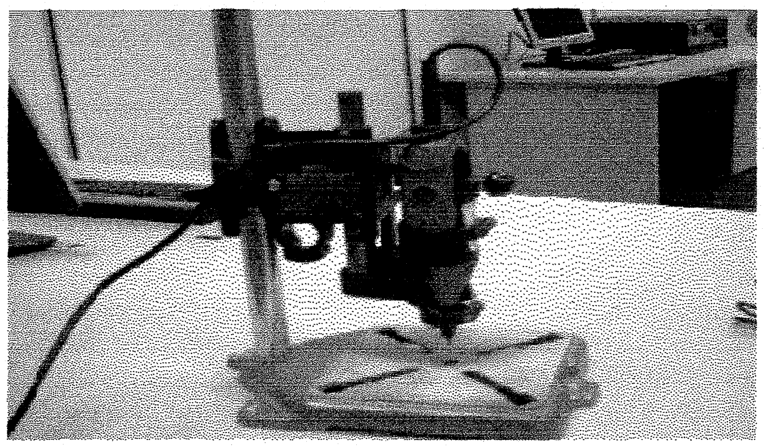


Figure A6: Drilling Machine

APPENDIX B

IR2156 DATASHEET

International
IOR Rectifier

Data Sheet No. PD60182-I

IR2156(S) & (PbF)

BALLAST CONTROL IC

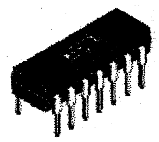
Features

- Ballast control and half-bridge driver in one IC
- Programmable preheat frequency
- Programmable preheat time
- Internal ignition ramp
- Programmable over-current threshold
- Programmable run frequency
- Programmable dead time
- DC bus under-voltage reset
- Shutdown pin with hysteresis
- Internal 15.6V zener clamp diode on Vcc
- Micropower startup (150μA)
- Latch immunity and ESD protection
- Also available LEAD-FREE (PbF)

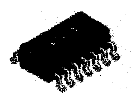
Description

The IR2156 incorporates a high voltage half-bridge gate driver with a programmable oscillator and state diagram to form a complete ballast control IC. The IR2156 features include programmable preheat and run frequencies, programmable preheat time, programmable dead-time, and programmable over-current protection. Comprehensive protection features such as protection from failure of a lamp to strike, filament failures, as well as an automatic restart function, have been included in the design. The IR2156 is available in both 14 lead PDIP and 14 lead SOIC packages.

Packages

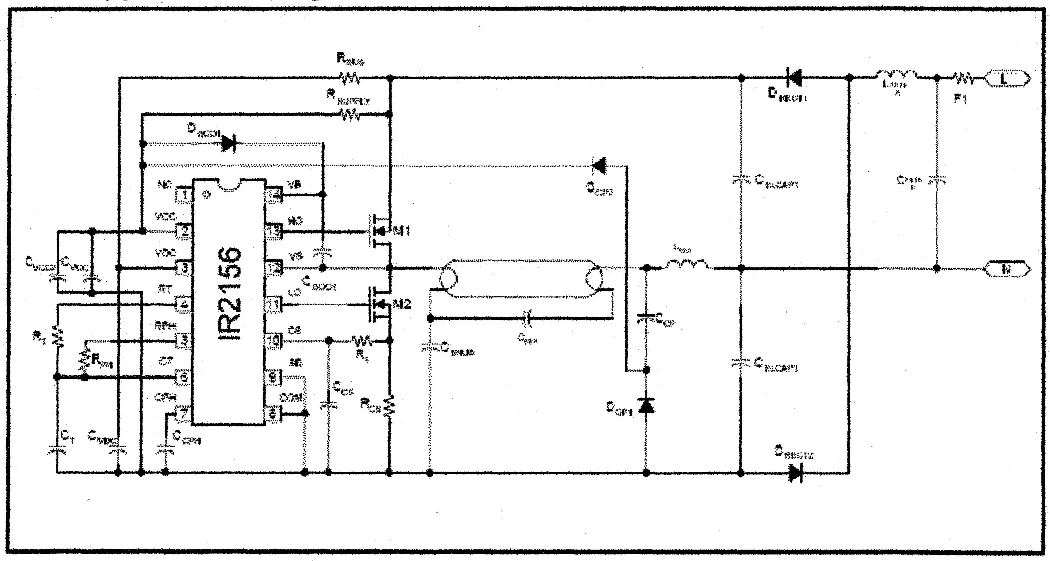


14 Lead PDIP



14 Lead SOIC (narrow body)

CFL Application Diagram



Absolute Maximum Ratings

Absolute maximum ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM, all currents are defined positive into any lead. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

Symbol	Definition		Min.	Max.	Units
V_B	High side floating supply voltage		-0.3	625	V
V_S	High side floating supply offset voltage		V_B - 25	V_B + 0.3	
V_{HO}	High side floating output voltage		V_S - 0.3	V_B + 0.3	
V_{LO}	Low side output voltage		-0.3	V_{CC} + 0.3	
I_{OMAX}	Maximum allowable output current (HO, LO) due to external power transistor miller effect		-500	500	mA
V_{VDC}	VDC pin voltage		-0.3	V_{CC} + 0.3	V
V_{CT}	CT pin voltage		-0.3	V_{CC} + 0.3	
I_{CPH}	CPH pin current		-5	5	mA
I_{RPH}	RPH pin current		-5	5	
V_{RPH}	RPH pin voltage		-0.3	V_{CC} + 0.3	V
I_{RT}	RT pin current		-5	5	mA
V_{RT}	RT pin voltage		-0.3	V_{CC} + 0.3	V
V_{CS}	Current sense pin voltage		-0.3	5.5	
I_{CS}	Current sense pin current		-5	5	mA
I_{SD}	Shutdown pin current		-5	5	
I_{CC}	Supply current (note 1)		-20	20	
dV/dt	Allowable offset voltage slew rate		-50	50	V/ns
P_D	Package power dissipation @ $T_A \le$ +25°C	(14 pin PDIP)	—	1.70	W
	$P_D = (T_{JMAX} - T_A)/Rth_{JA}$	(14 pin SOIC)	—	1.00	
Rth_{JA}	Thermal resistance, junction to ambient	(14 pin PDIP)	—	70	°C/W
		(14 pin SOIC)	—	120	
T_J	Junction temperature		-55	150	°C
T_S	Storage temperature		-55	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

Note 1: This IC contains a zener clamp structure between the chip V_{CC} and COM which has a nominal breakdown voltage of 15.6V. Please note that this supply pin should not be driven by a DC, low impedance power source greater than the V_{CLAMP} specified in the Electrical Characteristics section.

Recommended Operating Conditions

For proper operation the device should be used within the recommended conditions.

Symbol	Definition	Min.	Max.	Units
V_{BS}	High side floating supply voltage	V_{CC} - 0.7	V_{CLAMP}	V
V_{BSMIN}	Minimum required VBS voltage for proper HO functionality	5	V_{CC}	
V_S	Steady state high side floating supply offset voltage	-1	600	
V_{CC}	Supply voltage	V_{CCUV+}	V_{CLAMP}	
I_{CC}	Supply current	note 2	10	mA
C_T	CT lead capacitance	220	—	pF
I_{SD}	Shutdown lead current	-1	1	mA
I_{CS}	Current sense lead current	-1	1	
T_J	Junction temperature	-40	125	°C
I_{SDLK}	SD pin leakage current (@V_{SD}=6V)	—	125	µA
I_{CSLK}	CS pin leakage current (@V_{CS}=3V)	—	25	

Note 2: Enough current should be supplied into the VCC lead to keep the internal 15.6V zener clamp diode on this lead regulating its voltage, V_{CLAMP}.

Electrical Characteristics

V_{CC} = V_{BS} = V_{BIAS} = 14V +/- 0.25V, V_{VDC} = Open, R_T = 39.0kΩ, R_{PH} = 100.0kΩ, C_T = 470 pF, V_{CPH} = 0.0V, V_{CS} = 0.0V, V_{SD} = 0.0V, $C_{LO, HO}$ = 1000pF, T_A = 25°C unless otherwise specified.

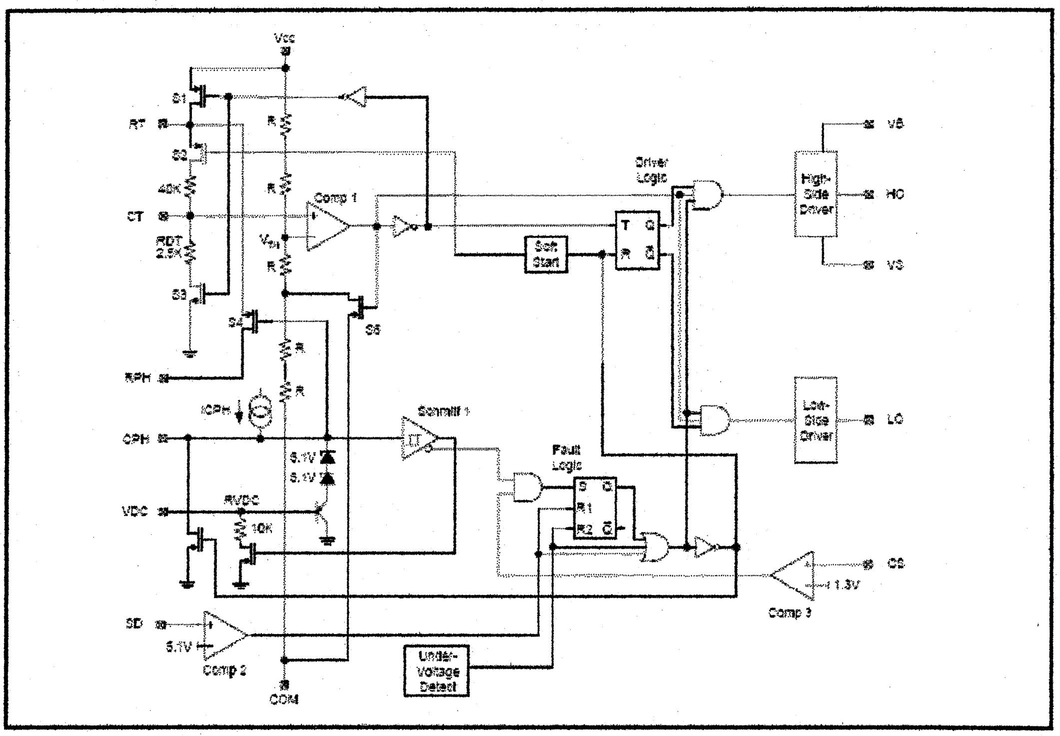
Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
Supply Characteristics						
V_{CCUV+}	Vcc supply undervoltage positive going threshold	10.5	11.5	12.5	V	Vcc rising from 0V
V_{CCUV-}	Vcc supply undervoltage negative going threshold	8.5	9.5	10.5		Vcc falling from 14V
V_{UVHYS}	Vcc supply undervoltage lockout hysteresis	1.5	2.0	3.0		
I_{QCCUV}	UVLO mode quiescent current	50	120	200	µA	V_{CC} = 11V
I_{QCCFLT}	Fault-mode quiescent current	—	200	470		SD = 5.1V, or CS > 1.3V
I_{QCC}	Quiescent V_{CC} supply current	—	1.0	1.5	mA	CT connected toCOM VCC =14V,RT=15kΩ
I_{QCC50K}	V_{CC} supply current, f = 50kHz	—	1.0	1.5		RT = 15kΩ C_T = 470 pF
V_{CLAMP}	V_{CC} zener clamp voltage	14.5	15.6	16.5	V	I_{CC} = 5mA
Floating Supply Characteristics						
I_{QBS0}	Quiescent VBS supply current	-5	0	5	µA	V_{HO} = V_S (CT = 0V)
I_{QBS1}	Quiescent V_{BS} supply current	—	30	50		V_{HO} = V_B (C_T = 14V)
I_{LK}	Offset supply leakage current	—	—	50	µA	V_B = V_S = 600V

Electrical Characteristics

$V_{CC} = V_{BS} = V_{BIAS} = 14V +/- 0.25V$, V_{VDC} = Open, $R_T = 39.0k\Omega$, $R_{PH} = 100.0k\Omega$, $C_T = 470$ pF, $V_{CPH} = 0.0V$, $V_{CS} = 0.0V$, $V_{SD} = 0.0V$, $C_{LO, HO} = 1000pF$, $T_A = 25°C$ unless otherwise specified.

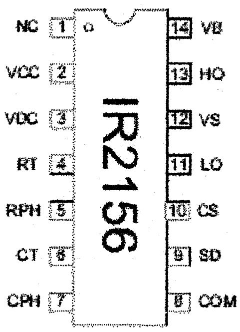
Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
Oscillator, Ballast Control, I/O Characteristics						
f_{osc}	Oscillator frequency	28	30	32	kHz	R_T=33.0kΩ, V_{VDC}= 5V V_{CPH} = Open (Guaranteed by design)
f_{osc}	Oscillator frequency	37.6	40	43.9	KHz	R_T=40k, R_{PH} = 100K C_T = 470pF
d	Oscillator duty cycle	—	50	—	%	
V_{CT+}	Upper C_T ramp voltage threshold	—	8.3	—	V	V_{CC} = 14V
V_{CT-}	Lower C_T ramp voltage threshold	—	4.8	—	V	V_{CC} = 14V
V_{CTFLT}	Fault-mode C_T pin voltage	—	0	—	mV	SD > 5.1V or CS >1.3V only CT CAP should beconnected to CT
t_{DLO}	LO output deadtime	—	2.0	—	usec	
t_{DHO}	HO output deadtime	—	2.0	—	usec	
R_{DT}	Internal deadtime resistor	—	3	—	KΩ	
Preheat Characteristics						
I_{CPH}	CPH pin charging current	3.6	4.3	5.2	µA	V_{CPH}=10V,CT=10V, VDC=5V
V_{CPHFLT}	Fault-mode CPH pin voltage	—	0	—	mV	SD > 5.1V or CS >1.3V
RPH Characteristics						
I_{RPHLK}	Open circuit RPH pin leakage current	—	0.1	—	µA	CT = 10V
V_{RPHFLT}	Fault-mode RPH pin voltage	—	0	—	mV	SD > 5.1V or CS >1.3V
RT Characteristics						
I_{RTLK}	Open circuit RT pin leakage current	—	0.1	—	µA	CT = 10V
V_{RTFLT}	Fault-mode RT pin voltage	—	0	—	mV	SD > 5.1V or CS >1.3V
Protection Characteristics						
V_{SDTH+}	Rising shutdown pin threshold voltage	—	5.1	—	V	
V_{SDHYS}	Shutdown pin threshold hysteresis	—	450	—	mV	
V_{CSTH}	Over-current sense threshold voltage	1.1	1.25	1.44	V	
t_{CS}	Over-current sense propogation delay	—	160	—	nsec	Delay from CS to LO
V_{CSPW}	Over-current sense minimum pulse width	—	135	—	nsec	V_{CS} pulse amplitude = V_{CSTH}+100mV
R_{VDC}	DC bus sensing resistor	7.5	10	14	kΩ	V_{CPH}>12V, VCT=0V VDC= 7V
$V_{CPH-VDC}$	CPH to VDC offset voltage	10.3	10.9	11.4	V	V_{CPH}=open,V_{VDC}=0V
Gate Driver Output Characteristics						
VOL	Low-level output voltage	—	0	105	mV	Io = 0
VOH	High-level output voltage	—	0	100	mV	VBIAS - Vo, Io = 0
tr	Turn-on rise time	—	110	150	ns	$C_{LO} = C_{HO}$ =1nF
tf	Turn-off fall time	—	55	100	ns	$C_{LO} = C_{HO}$ =1nF

Block Diagram



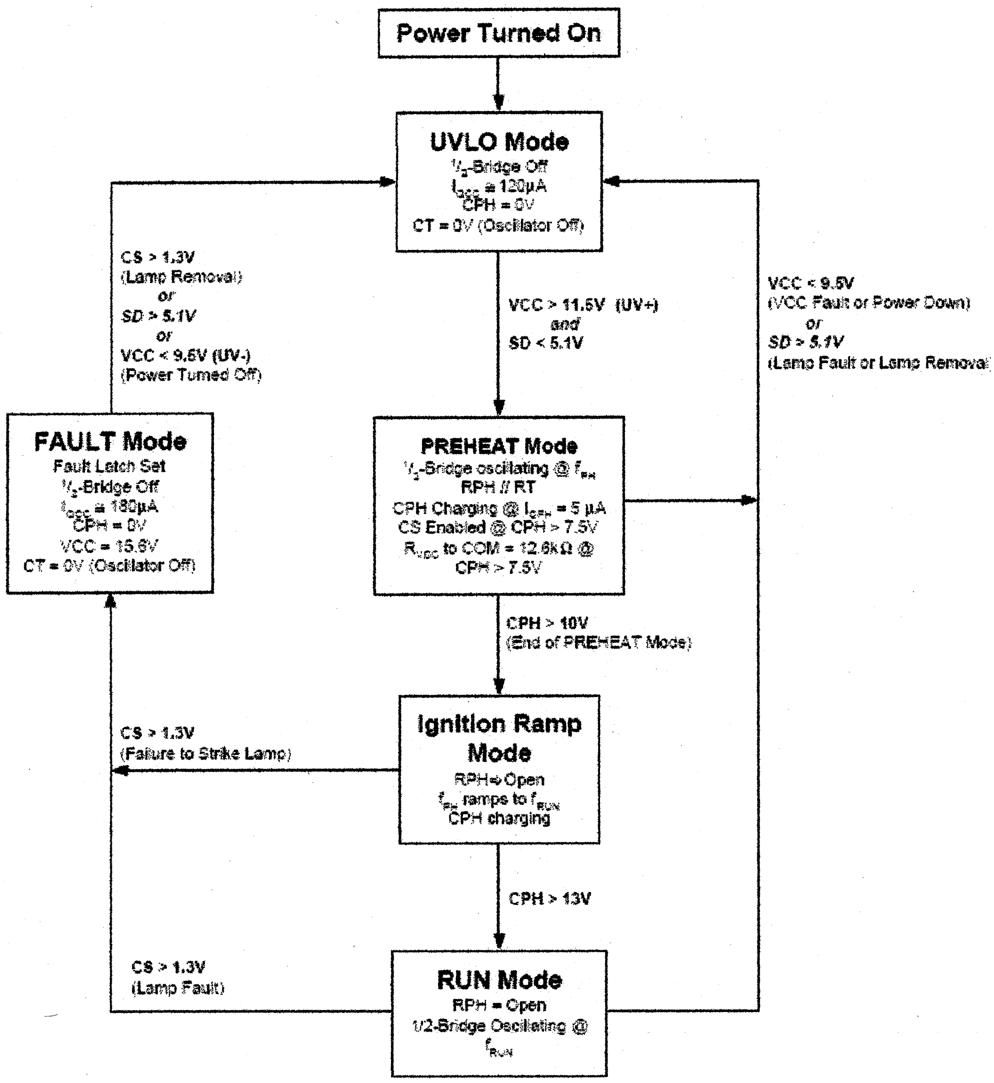
Lead Assignments & Definitions

Pin Assignments



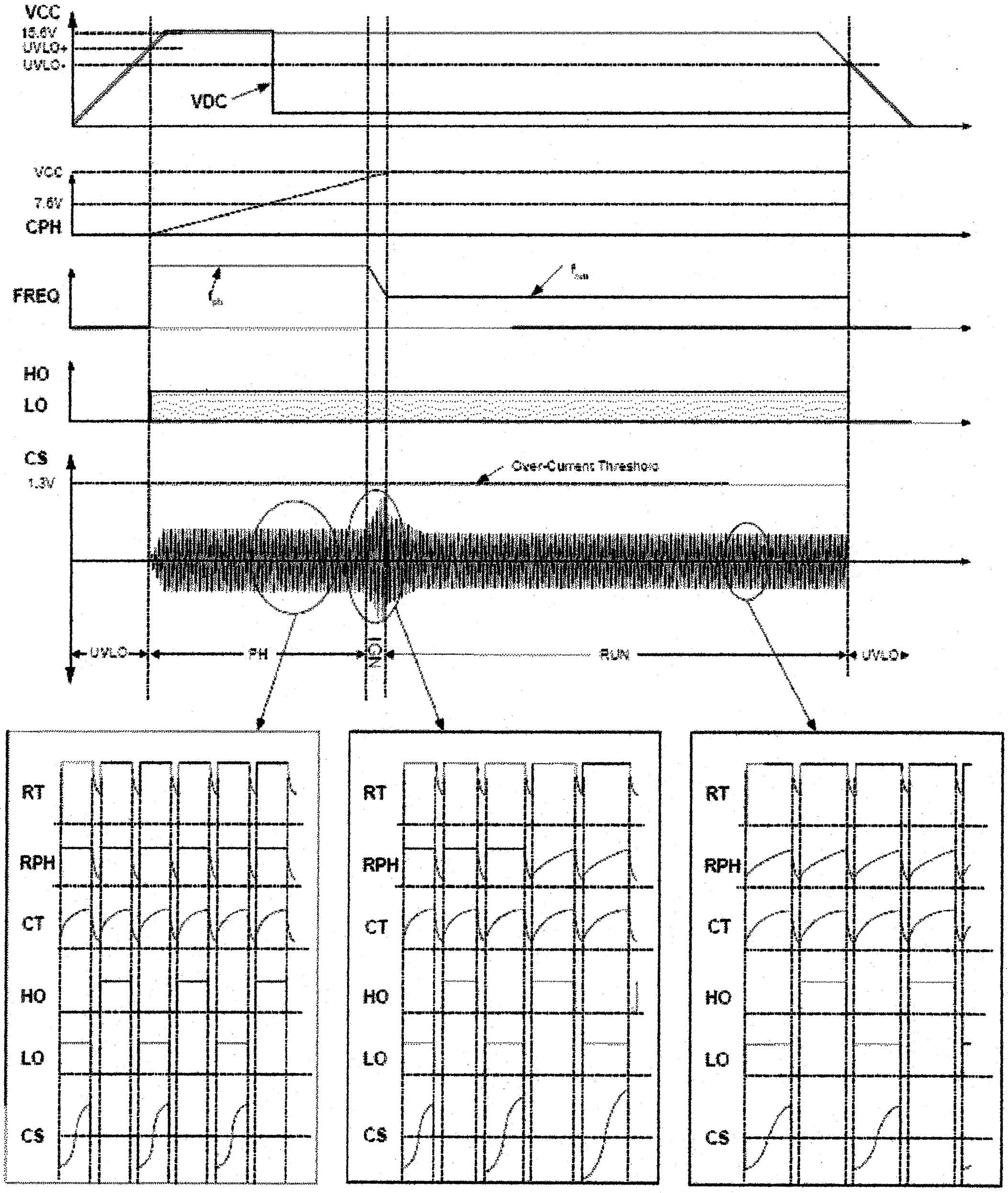
Pin #	Symbol	Description
1	NC	No connect
2	VCC	Logic & low-side gate driver supply
3	VDC	IC start-up and DC bus sensing Input
4	RT	Minimum frequency timing resistor
5	RPH	Preheat frequency timing resistor
6	CT	Oscillator timing capacitor
7	CPH	Preheat timing capacitor
8	COM	IC power & signal ground
9	SD	Shutdown input
10	CS	Current sensing input
11	LO	Low-side gate driver output
12	VS	High-side floating return
13	HO	High-side gate driver output
14	VB	High-side gate driver floating supply

State Diagram



Timing Diagrams

Normal operation



APPENDIX C

RESONANT INDUCTOR DATASHEET

International IOR Rectifier

INDUCTOR SPECIFICATION
TYPE : LRES (CURRENT MODE)

CORE SIZE: E20/10/6 (EF20) GAP LENGTH: 1.5 mm

BOBBIN: HORIZONTAL

CORE MATERIAL: Philips 3C85, Siemens N27 or equivalent

NOMINAL INDUCTANCE: 1 mH

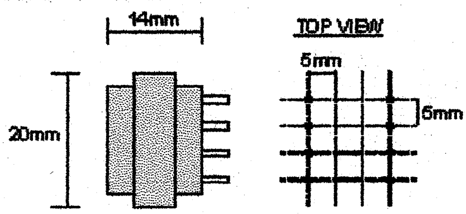
MAXIMUM CURRENT: 1.3 Apk

MAXIMUM CORE TEMPERATURE: 100 °C

WINDING	START PIN	FINISH PIN	TURNS	WIRE DIAMETER (mm)
MAIN			195	0.2

ELECTRICAL LAYOUT

PHYSICAL LAYOUT



TEST (TEST FREQUENCY = 50kHz)

MAIN WINDING INDUCTANCE: MIN mH MAX mH

MAIN WINDING RESISTANCE: MIN Ohms

NOTE : Inductor must not saturate at maximum current and maximum core temperature at given test frequency.

APPENDIX D

IRF720 DATASHEET

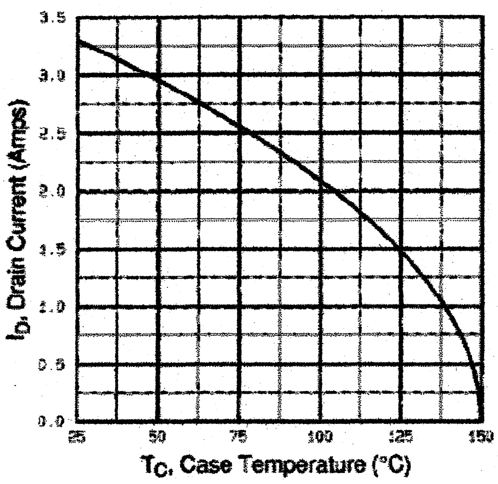


Fig 9. Maximum Drain Current Vs. Case Temperature

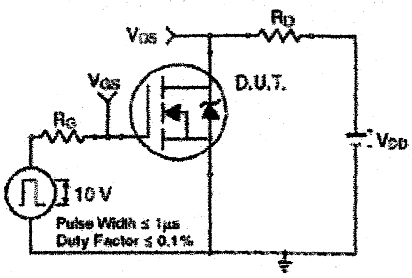


Fig 10a. Switching Time Test Circuit

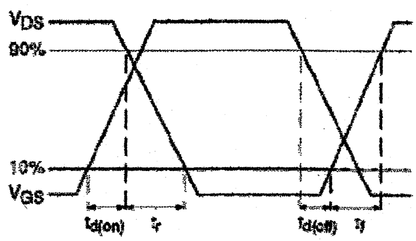


Fig 10b. Switching Time Waveforms

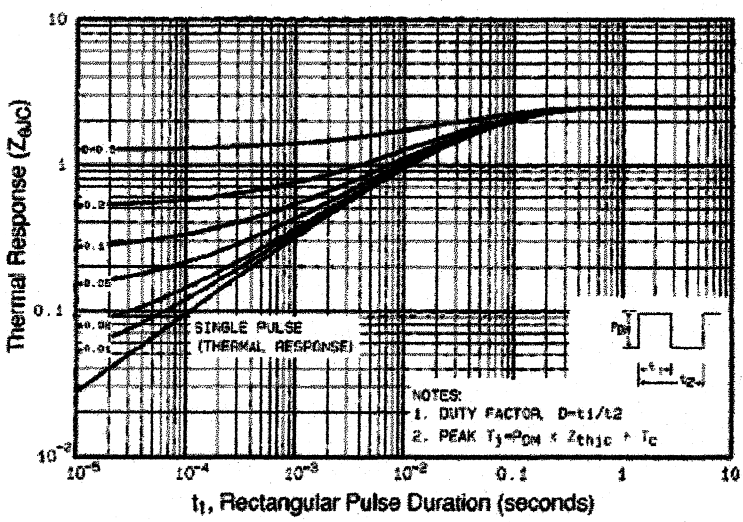


Fig 11. Maximum Effective Transient Thermal Impedance, Junction-to-Case

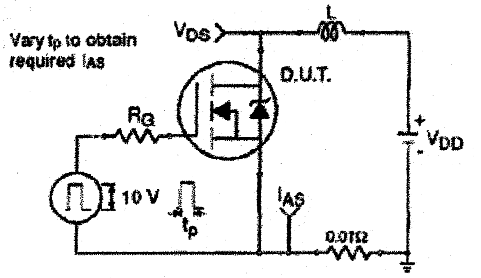


Fig 12a. Unclamped Inductive Test Circuit

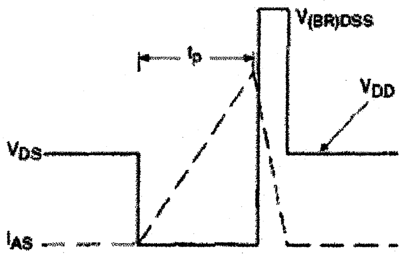


Fig 12b. Unclamped Inductive Waveforms

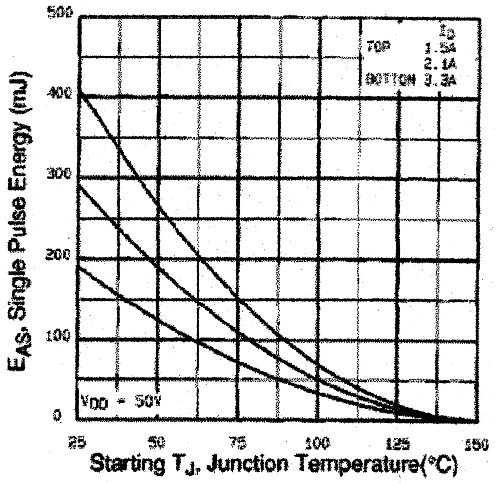


Fig 12c. Maximum Avalanche Energy Vs. Drain Current

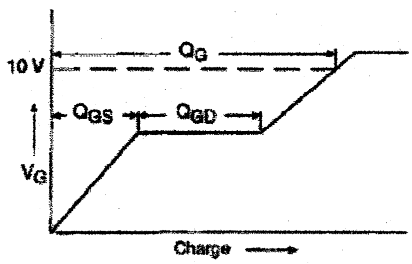


Fig 13a. Basic Gate Charge Waveform

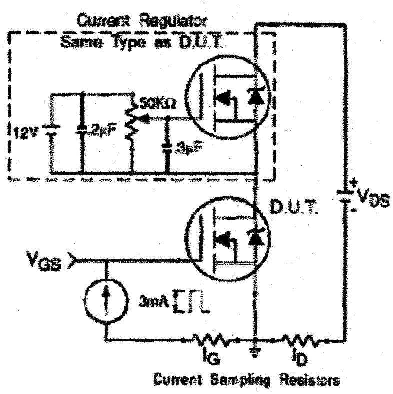


Fig 13b. Gate Charge Test Circuit

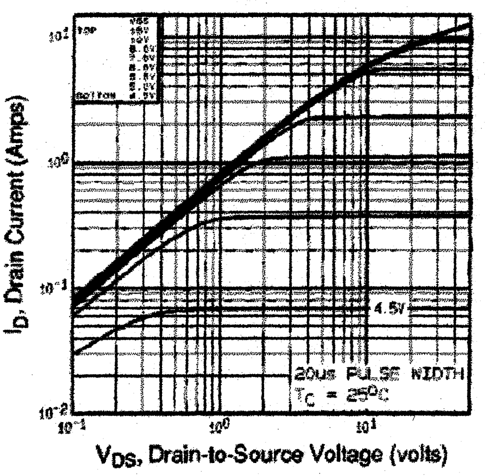


Fig 1. Typical Output Characteristics, T_C=25°C

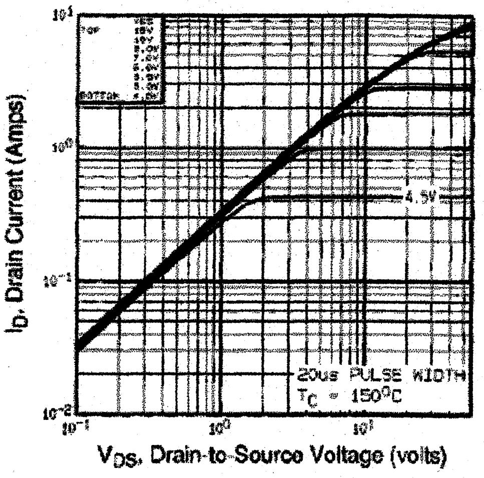


Fig 2. Typical Output Characteristics, T_C=150°C

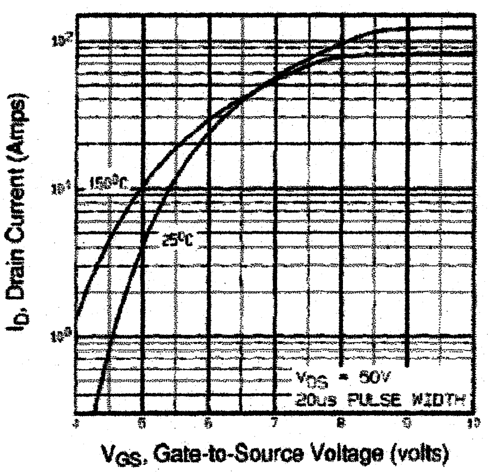


Fig 3. Typical Transfer Characteristics

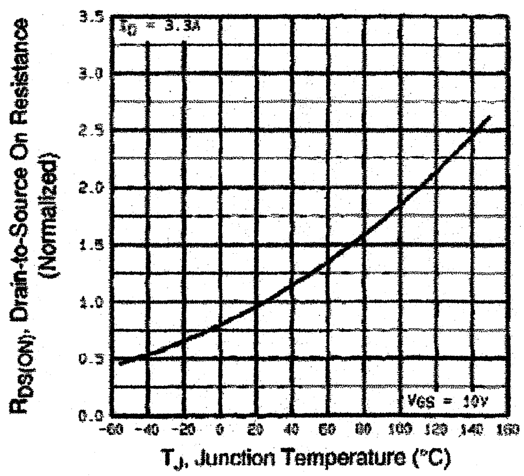


Fig 4. Normalized On-Resistance Vs. Temperature

IRF720

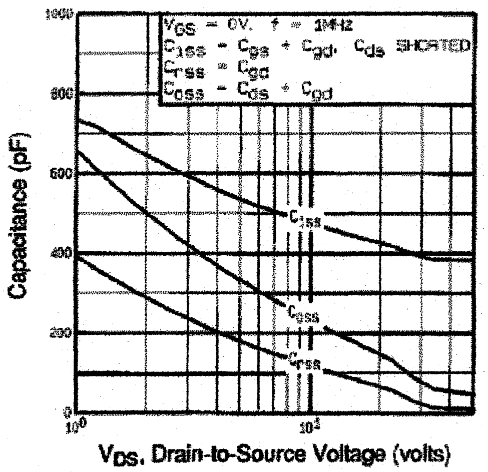


Fig 5. Typical Capacitance Vs. Drain-to-Source Voltage

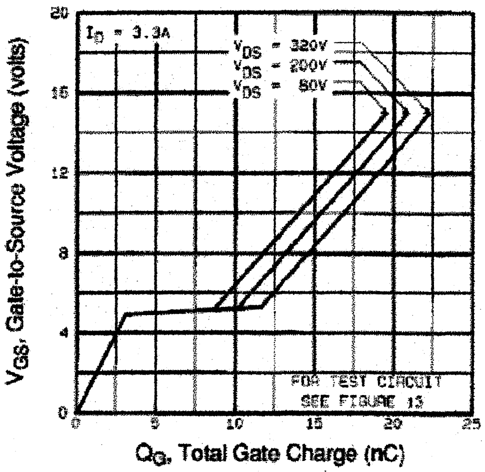


Fig 6. Typical Gate Charge Vs. Gate-to-Source Voltage

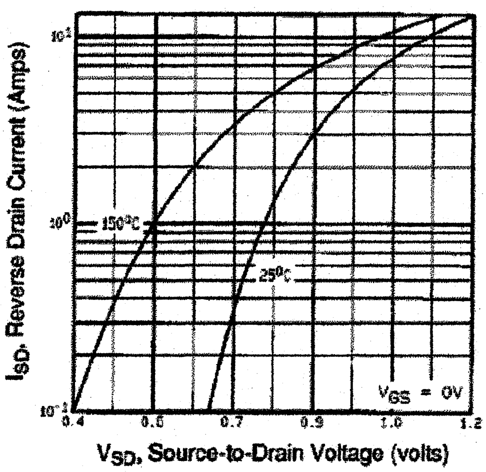


Fig 7. Typical Source-Drain Diode Forward Voltage

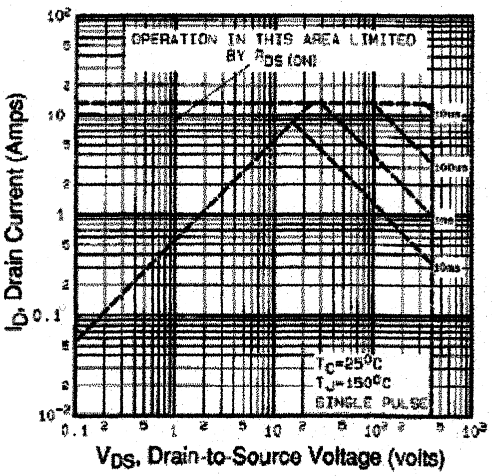


Fig 8. Maximum Safe Operating Area

APPENDIX E

COMMON MODE LINE FILTER DATASHEET

Panasonic Line Filters

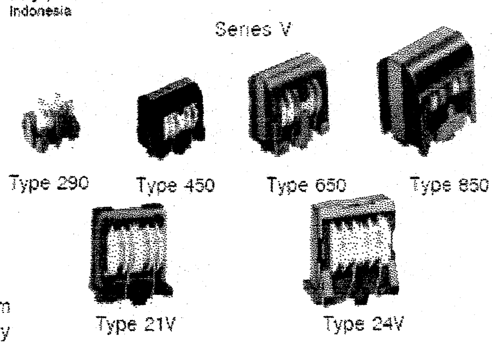
Line Filters

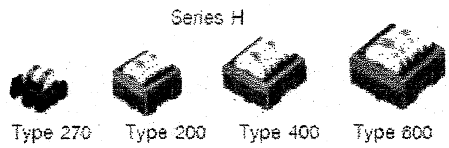
Japan
Singapore
Indonesia

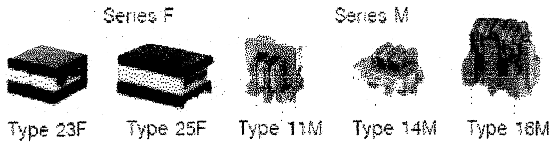
Series **V** **(Type 290, 450, 650, 850, 21V, 24V)**
Series **H** **(Type 200, 270, 400, 600)**
Series **F** **(Type 23F, 25F)**
Series **M** **(Type 11M, 14M, 16M)**
Series **N** **(Type 15N, 18N, 20N)**
Series **High N** **(Type 17N, 19N, 21N)**

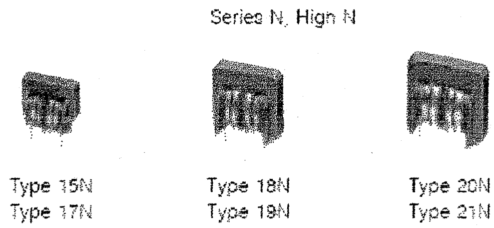
Line filters suppressing conductive noise ranging from low to high frequencies generated at power supply circuits of various electronic equipment

Industrial Property: Patents 22 (incl.pending)









■ Features

Series	Types	Features	
V	290, 450, 650, 850, 21V*, 24*	Vertical Structure	● Excellent attenuations in high frequency characteristics
H	200, 270, 400, 600	Horizontal Structure	● Decreasing greatly leakage flux
F	23F, 25F	Thin Structure	● 15 mm height max
M	11M, 14M, 16M	Small Structure	● Small size and lightweight
N	15N, 18N, 20N	Vertical Structure	● Suitable for high-density automatic insertion
High N	17N, 19N, 21N	High L Structure	● High inductance (same size with series N)

* Type 21V is developed product of Type 650. Type 24V is Type 850.

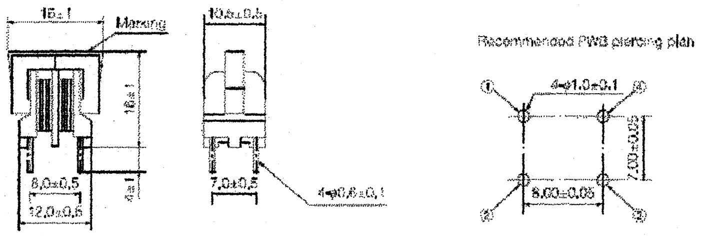
■ Recommended Applications
● CTV, VTR, Audios, PC, Facsimiles

Panasonic Line Filters

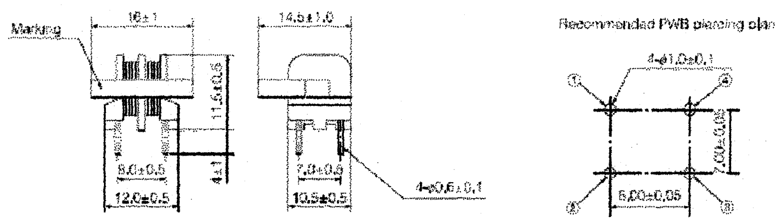
■ Dimensions in mm (not to scale)

Series M

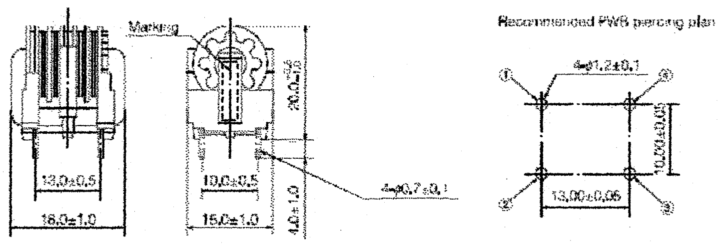
● Type 11M



● Type 14M

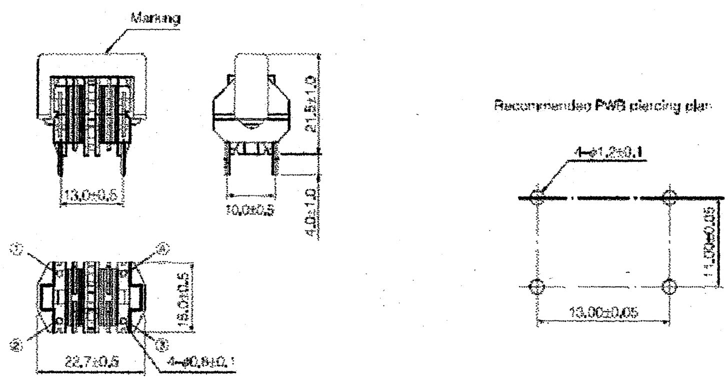


● Type 16M



Series N, High N

● Type 15N, 17N



Panasonic Line Filters

■ Explanation of Part Numbers

● V, H Series

1	2	3	4	5	6	7	8	9	10	11	12
E	L	F	1	8	D	2	9	0	A		
Product code			Series			Type (Style, Design No.)				Option 1	Option 2

● F, M Series

1	2	3	4	5	6	7	8	9	10	11	12
E	L	F	1	6	M	0	2	0	A		
Product code			Style		Series	Design No. (Current)			Option 1	Option 2	Option 3

● N, High N Series

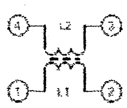
1	2	3	4	5	6	7	8	9	10	11	12
E	L	F	1	5	N	0	0	5	A		
Product code			Type		Series	Current			Option 1	Option 2	Option 3

■ Performance Characteristics

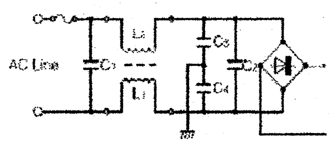
Item \ Series	V Serise				H Serise				F Series		M Series		N Serise			High N Series			Notes
Type	290	450	650/21V	850/24V	270	200	400	600	23F	25F	11M/14M	16M	15N	18N	20N	17N	19N	21N	
Operating Temperature	−20 °C to 105 °C (115 °C)								−20 °C to 115 °C										
voltage	AC 250 Vrms max																		
Current	Refer to "Examples"																		
Inductance	Refer to "Examples"																		
Dielectric Withstanding Voltage	AC 2 kV 1min																		
Temperature Rise	45 K max																		Resistance method
Applicable Safety Standards	** Denki Yonin*, UL, CSA, IEC																		

* The Electrical Appliance and Material Law of Japan
** Line filter does not acquire, only, the safety standards recognition

■ Connection Shematics

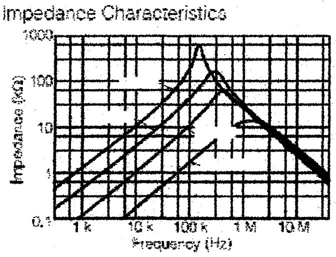


■ Circuit Example

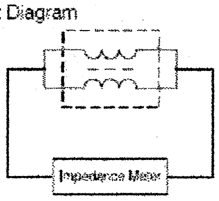


■ Impedance and Attenuation Characteristics (Typical)

● Impedance Characteristics



● Test Circuit Diagram



■ Current-Inductance (min.) Characteristics (Reference only)