NETAJI SUBHAS INSTITUTE OF TECHNOLOGY

WINTER TRAINING REPORT (EC-220)

POWER SUPPLY

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I would like to express my deep gratitude to my mentor, Prof. Dhananjay V. Gadre.

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I would also like to thank my seniors Gaurav Tyagi and Abhishek Pandey for their support and guidance throughout this project. It was with their help that the project was completed in time and had success.

Finally, I would like to thank my family and friends for their constant help and support.

ABSTRACT

The Winter Training organized by Prof Dhananjay V. Gadre on PCB design and fabrication was a new experience for the students all together. They were taught about the advancements in embedded technology as well as its importance in the first few days. Furthermore, the basics about electronics ranging from resistors to capacitors and the basic equipment required were discussed. Eventually we were taught about Power supplies and how they play an integral role in an electronic device.

During the latter days, the steps involved in building a PCB were taught to us. This included hands on experience with the software Eagle and basic steps required in PCB fabrication like printing, etching, drilling and soldering. All of this provided the students with the required knowledge for developing a Linear Variable Power Supply capable of supplying 3.4V-12V, 0.5A.

At the end of the training we were taught how to test our Power supply using an Active load and were also told about the importance and working of the Active load.

CONTENTS

CHAPTER 1

INTRODUCTION TO ELECTRONICS

Electronics is the science of how to control electric energy, energy in which the electrons have a fundamental role. Electronics deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive electrical components and interconnection technologies. Commonly, electronic devices contain circuitry consisting primarily or exclusively of active semiconductors supplemented with passive elements; such a circuit is described as an electronic circuit.

Working over Electronic Devices:

Basic Moto to design an Electronic Device:

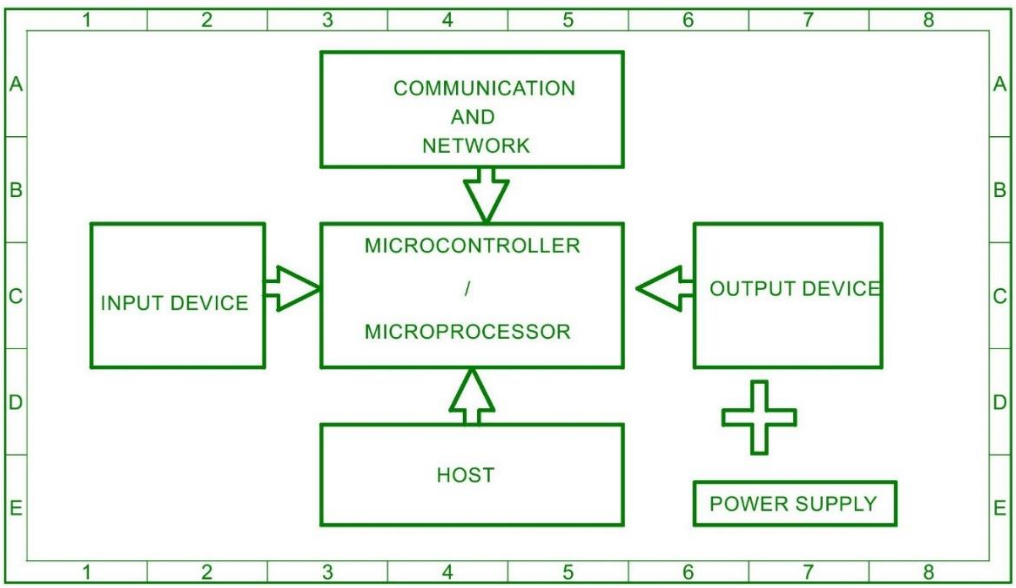


Figure 1.1: Basic Moto behind designing of an Electronic Device

According to above picture, we will be dealing for all the above so called components in flow chart.

- Microcontroller/Microprocessor
- Input Devices.
- Output Devices.
- Communication and Network
- Host

❖ Power Supply

1.1 MICROCONTROLLER/MICROPROCESSOR

HEART OF DEVICE

A **microcontroller** is a small computer (SoC) on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM.   A **microprocessor** is an electronic component that is used by a computer to do its work. It is a central processing unit on a single integrated circuit chip containing millions of very small components including transistors, resistors, and diodes that work together.

Microcontroller

Microprocessor

1.2 INPUT DEVICES

In computing, an **input device** is a peripheral (piece of computer hardware equipment) used to provide data and control signals to an information processing system such as a computer or information appliance. But electronically, definition changes to: devices which provide signals to process and mcu to perform some action on those signals are known as input devices. A List is presented here:

1. a switch (e.g. push-switch, micro switch)
2. a key pad
3. a Light Dependent Resistor (LDR)
4. a thermistor
5. a photodiode
6. a phototransistor
7. an opto-isolator
8. a proximity switch or reed switch.

1.3 OUTPUT DEVICES

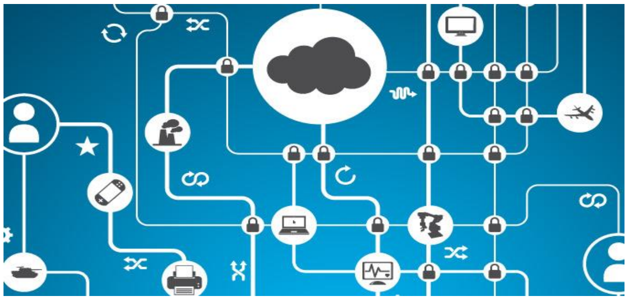
Devices which produces signals from input provided to them are known as output devices.

1. an LED
2. a lamp
3. a buzzer
4. a piezo
5. a motor or stepper motor
6. a solenoid
7. a relay
8. a seven-segment display.

1.4 COMMUNICATION AND NETWORK

A good system will have a communication network which transmits data or information at the fastest and most economical way possible.

E.g. A washing machine which sends a message to the maintenance personnel about an impending failure, or an egg tray with pressure sensors which gives a message to the user whenever the number of eggs are less than a minimum number in the tray and when the user is near a market, or in reality TV shows where 100-200 audience sitting in the set vote for something using electronic voting devices.



1.5 HOST

Devices which provide virtual instrumentation for our experiments like oscilloscopes, laptops, computers, phones etc. are known as hosts.

1.6 POWER SUPPLY

It has a lot of importance in the whole circuit. It is the only device which provide input power to our circuit to work efficiently.

CHAPTER 2

BASICS

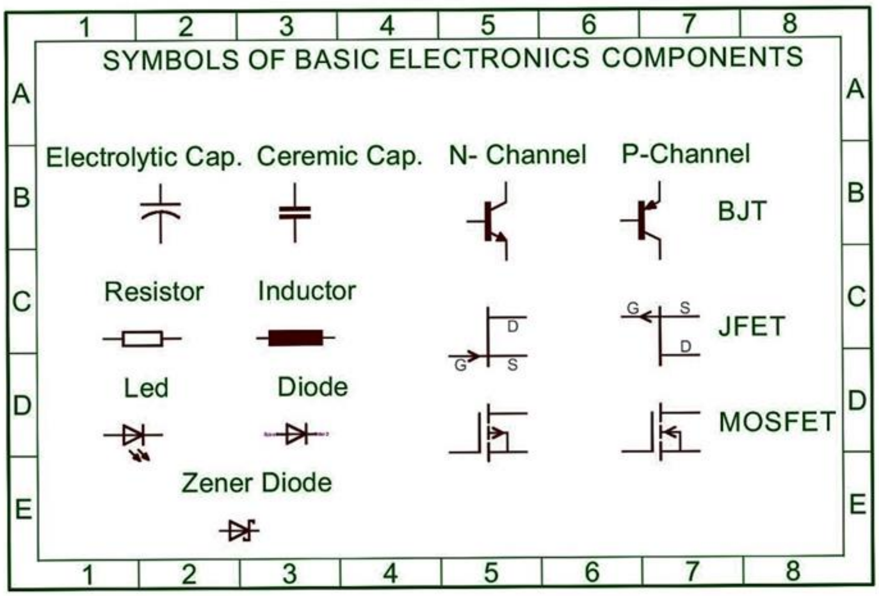


Figure 2.1: Symbols of basic electronics components

2.1 RESISTORS

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. Resistors act to reduce current flow, and, at the same time, act to lower voltage levels within circuits. In electronic circuits resistors are used to limit current flow, to adjust signal levels, bias active elements, terminate transmission lines among other uses.

A carbon film is deposited on an insulating substrate, and a helix is cut in it to create a long, narrow resistive path. Varying shapes, coupled with the resistivity of amorphous carbon (ranging from 500 to 800 $\mu\Omega$ m), can provide a wide range of resistance values. Compared to carbon composition they feature low noise, because of the precise distribution of the pure graphite without binding. Carbon film resistors feature a power rating range of 0.125 W to 5 W at 70 °C. The carbon film resistor has an operating temperature range of −55 °C to 155 °C.

Metal-oxide film resistors are made of metal oxides such as tin oxide. This results in a higher operating temperature and greater stability/reliability than Metal film. They are used in applications with high endurance demands.

Another type of resistors include wire wound resistors, an alloy of nickel, chromium and iron NICHROME. They possess high power capabilities and their tolerance is also very low.

Another use for a resistor is in as a thermistor. A thermistor is a type of resistor whose resistance varies significantly with temperature, more so than in standard resistors. They are broadly classifies as NTC (Negative Temperature Coefficient) or PTC (Positive Temperature Coefficient). It can be used to calculate the electronically realize the temperature of the surroundings.

The markings on a resistor are according to the color codes decided by the international council and are given in the appendix.

2.2 CAPACITORS

A capacitor (originally known as a condenser) is a passive two-terminal electrical component used to store energy electrostatically in an electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors (plates) separated by a dielectric (i.e. insulator). Capacitors are broadly divided in to electrolytic and non-electrolytic.

Non-electrolytic capacitors constitute ceramic capacitors. A ceramic capacitor is a non-polarized fixed capacitor made out of two or more alternating layers of ceramic and metal in which the ceramic material acts as the dielectric and the metal acts as the electrodes. They only work properly for low voltage values and hence aren't very economically viable.

Electrolytic capacitors are the most commonly used capacitors in electronics. They have a metallic anode covered with an oxidized layer used as dielectric. The second electrode is a non-solid (wet) or solid electrolyte. Electrolytic capacitors are polarized. Three families are available, categorized according to their dielectric.

- Aluminum electrolytic capacitors with aluminum oxide as dielectric
- Tantalum electrolytic capacitors with tantalum pent oxide as dielectric
- Niobium electrolytic capacitors with niobium pent oxide as dielectric.

The anode is highly roughened to increase the surface area. This and the relatively high permittivity of the oxide layer give these capacitors very high capacitance per unit volume compared with film or ceramic capacitors.

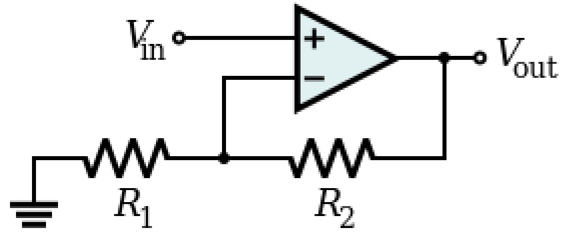
2.3 OPERATIONAL AMPLIFIERS

An operational amplifier ("op-amp") is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In this configuration, an op-amp produces an output potential (relative to circuit ground) that is typically hundreds of thousands of times larger than the potential difference between its input terminals.

These ideals can be summarized by the two "golden rules":

I. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

II. The inputs draw no current.



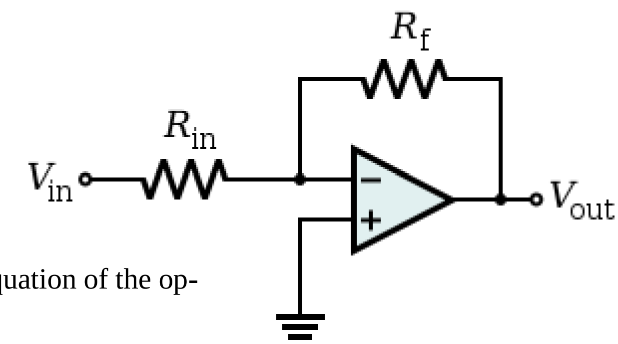
Non-Inverting Configuration

In a non-inverting amplifier, the output voltage changes in the same direction as the input voltage.

The gain equation for the op-amp is:

$$\mathbf{Vo/Vin = 1 + R2/R1}$$

Inverting Configuration



In an inverting amplifier, the output voltage changes in an opposite direction to the input voltage.

As with the non-inverting amplifier, we start with the gain equation of the op-amp:

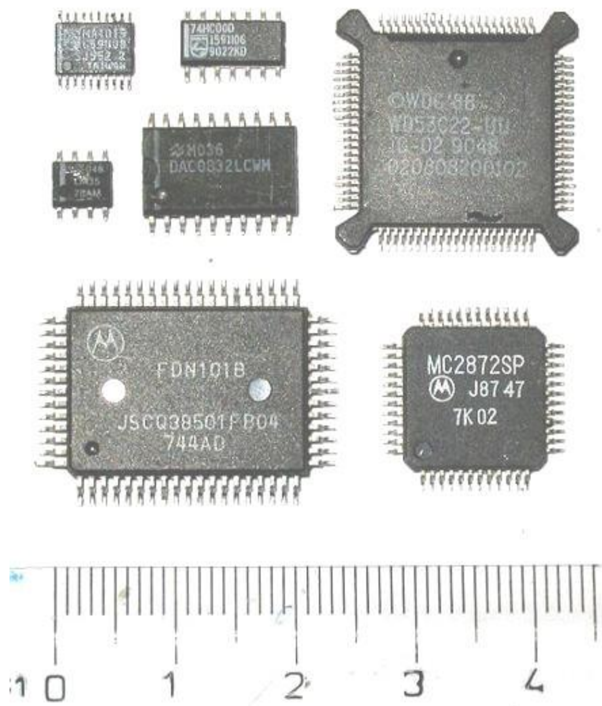
$$\mathbf{Vo/Vin = -R2/R1}$$

2.4 SURFACE MOUNTED TECHNOLOGY

SMD - Surface Mount Device. Surface-mount technology (SMT) is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit boards (PCBs). An electronic device so made is called a surface-mount device (SMD).

A Surface Mounted Technology (SMT) component is usually smaller than its through-hole counterpart because it has either smaller leads or no leads at all. It may have short pins or leads of various styles, flat contacts, and a matrix of solder balls (BGAs), or terminations on the body of the component. The main advantages of SMT over the older through-hole technique are:

- Smaller components. As of 2012 smallest was 0.4 × 0.2 mm (0.016 × 0.008 in: 01005). Expected to sample in 2013 are 0.25 × 0.125 mm (0.010 × 0.005 in, size not yet standardized)
- Much higher component density (components per unit area) and many more connections per component.
- Lower initial cost and time of setting up for production.
- Fewer holes need to be drilled.

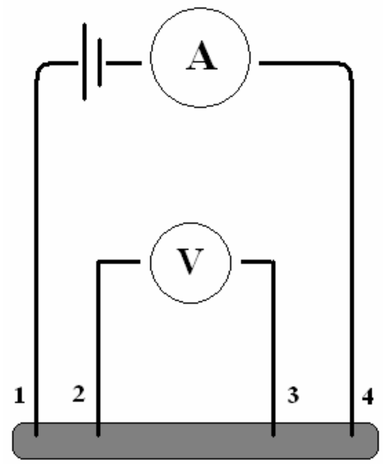


2.5 MEASURING DEVICES

MULTIMETER

A multi meter or a multi tester, also known as a VOM (Volt-Ohm meter or Volt-Ohm-milli ammeter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter would include basic features such as the ability to measure voltage, current, and resistance. Analog multimeters use a microammeter whose pointer moves over a scale calibrated for all the different measurements that can be made. Digital multimeters (DMM, DVOM) display the measured value in numerals, and may also display a bar of a length proportional to the quantity being measured.

4 PROBE METHOD



Four-terminal sensing (4T sensing), 4-wire sensing, or 4-point probes method is an electrical impedance measuring technique that uses separate pairs of current-carrying and voltage-sensing electrodes to make more accurate measurements than the simpler and more usual two-terminal (2T) sensing. Four-terminal sensing is used in some ohmmeters and impedance analyzers, and in wiring for strain gauges and resistance thermometers. Four-point probes are also used to measure sheet resistance of thin films.

2.6 DATASHEETS

A datasheet or spec sheet is a document that summarizes the performance and other technical characteristics of a product, machine, component (e.g., an electronic component), material, a subsystem (e.g., a power supply) or software in sufficient detail to be used by a design engineer to integrate the component into a system. Typically, a datasheet is created by the component/subsystem/software manufacturer and begins with an introductory page describing the rest of the document, followed by listings of specific characteristics, with further information on the connectivity of the devices. In cases where there is relevant source code to include, it is usually attached near the end of the document or separated into another file.

The basic parts of a datasheet are:

- Manufacturer's name, product number and name
- Notable device properties
- Short functional description
- Pin connection diagram
- Recommended operating conditions (as absolute minimum and maximum ratings)
- DC specifications (various temperatures, supply voltages, input currents, etc.)
- AC specifications (various temperatures, supply voltages, frequencies, etc.)
- Physical details showing minimum/typical/maximum dimensions, contact locations and sizes
- Test circuit
- Ordering codes for differing packages and performance criteria
- Application recommendations, such as required filter capacitors, circuit board layout, etc.

A sample LM723 datasheet is attached in the appendix

CHAPTER 3

EAGLE CAD

Easily Applicable Graphical Layout Editor

3.1 INTRODUCTION

EAGLE (Easily Applicable Graphical Layout Editor) by CadSoft is flexible and expandable CAD software with schematic capture, PCB layout, auto router and CAM program widely used since 1988.

EAGLE is popular among hobbyists because of its freeware license and rich availability of component libraries on the web.

3.1.1 Schematic Editor

In this we can create circuit schematics in the symbolic form. The various commands used in this are:

- INFO - Shows information about an object (component, signal, trace, etc.)
- MOVE - Allows components to be moved (same as schematic.)
- GROUP - Groups a collection of objects into a "group" that can be manipulated.
- DELETE - Delete an object. Items created in schematics need to be deleted there.
- SMASH - Separate the text labels of a part from the part itself, so they can be moved independently.
- BREAK - Add a corner to a line (or trace.)
- ROUTE - Turn an air wire into a trace.
- LINE - Draw lines (usually in non-copper layers. ROUTE is for drawing copper.
- VIA - Create a hole and pad associated with some signal.
- HOLE - A hole that isn't associated with a signal, i.e. for mounting.

- RATSNEST – Re computes air wires and polygons, example after components have been moved.
- CHANGE - Changes an object's properties.
- RIPUP - Changes a routed trace back to an air wire.
- TEXT - Add text
- POLYGON - Create a polygon (actually, we'll use a text command.)
- DRC - Invoke the Design Rule Check and parameter setting.

3.1.2 Board Layout Editor

Up in the file menu, there's a "Switch to board" selection. If we do that from a bare schematic, it will offer to create the board from the schematic for us (say "yes"), and then leave us sitting in the Board Editor.

The various commands used in board layout editor are:

- AIR WIRES - All the signals you created in the schematic are currently air wires; thin yellow lines that are drawn in the shortest possible way, crossing each other as needed. They stay connected to component pins even when you move the component around.
- RATSNEST – Re computes and redraws these after you move things around (and, say, make two connected pins closer together than they used to be.)
- ROUTING - A signal consists of turning an air wire into an actual copper trace on some layer(s) of the board, and positioning that trace so that it doesn't short against other traces on the same layer of the board.
- AUTOROUTE - Invokes the AutoRoute.

3.2 FEATURES OF EAGLE

3.2.1 General

• Maximum drawing area 64 x 64 inches
• Resolution 1/10.000 mm (0.1 microns)
• Mm or inch grid
• Up to 255 layers, user definable colors

• Command files (Script files)
• C-like User Language for data import and export
• Simple library editing
• Library browser with powerful search function
• Support of technology feature (e.g. 74L00, 74LS00.)
• Generation of graphics output as well as manufacturing and testing output with the CAM processor or the help the User Language.

• Printouts via the OS's printer drivers.
• Partlist generation with database support (import_bitmap.ulp)
• Drag & Drop in the Control Panel.
• Automatic backup function.

3.2.2 Layout Editor

• Full SMD support.
• Full multilayer support (16 signal layers).
• Design Rule Check for board layouts (checks e.g. overlaps, measures of pads or tracks).
• Copper pouring (ground plains).
• Package variants support.

3.2.3 Schematic Module

• Up to 99 sheets per schematic.
•Forward & Back Annotation between schematic and board.
• Automatic board generation.
• Automatic generation of supply signals.
• Electrical Rule Check (error check in the schematic and consistency check between schematic and layout).

3.2.4 AutoRoute Module

• Fully integrated into basic program
• Uses the layout's Design Rules
• Change between manual and automatic routing at any time.
• Rip Up and Retry algorithm.
• User-Definable strategy by cost factors.
• Routing grid down to 0.02 mm (about 0.8 mil).
• No placement restrictions.
• Up to 16 signal layers (with user definable preferred directions).
• Up to 14 supply layers.
• takes into consideration various signal classes (wire width, minimum distances).

3.3 EXAMPLE SCHEMATIC

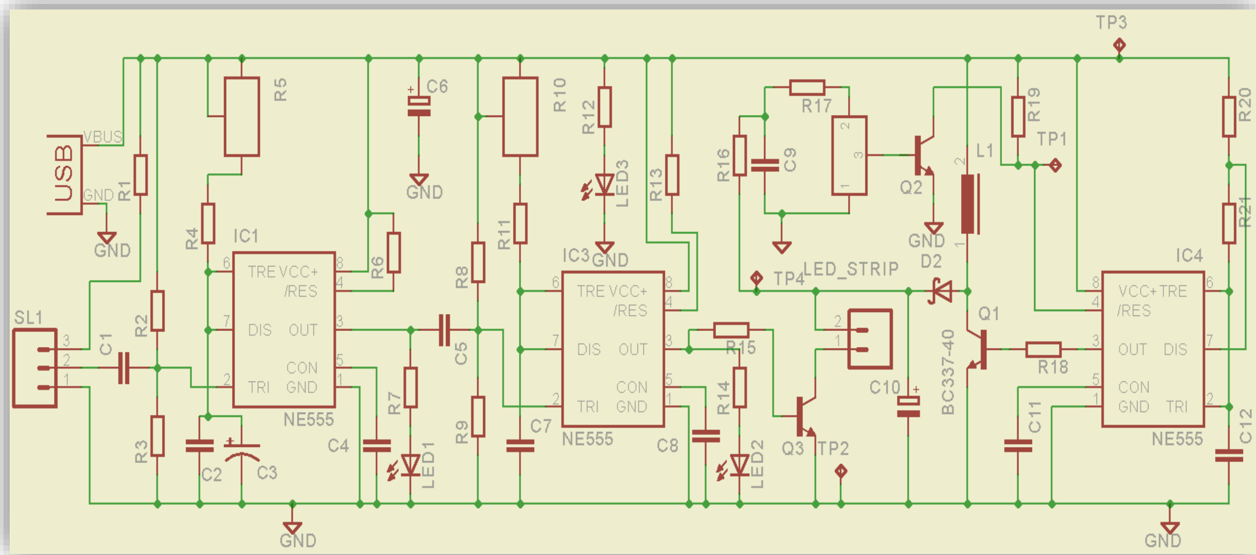


Figure 3.1: A 555 timer based Capture Drop Circuit.

3.4 EXAMPLE BOARD LAYOUT

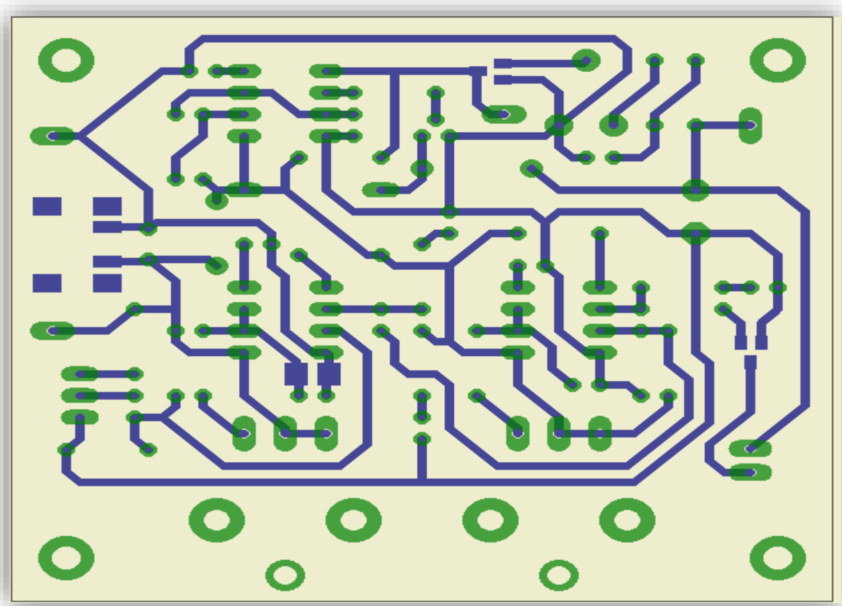


Figure 3.2: Board layout of the circuit

CHAPTER 4

AUDACITY

Audio Editor and Recorder

Audacity is open source software, easy-to-use, multi-track audio editor and recorder for Windows, Mac OSX, GNU/Linux and other operating systems. The interface is translated into many languages. You can use Audacity to:

- Record live audio.
- Record computer playback on any Windows Vista or later machine.
- Convert tapes and records into digital recordings or CDs.
- Edit WAV, AIFF, FLAC, MP3 and OggVorbis sound files.
- AC3, M4A/M4R (AAC), WMA and other formats supported using optional libraries.
- Cut, copy, splice or mix sounds together.
- Numerous effects including change the speed or pitch of a recording.

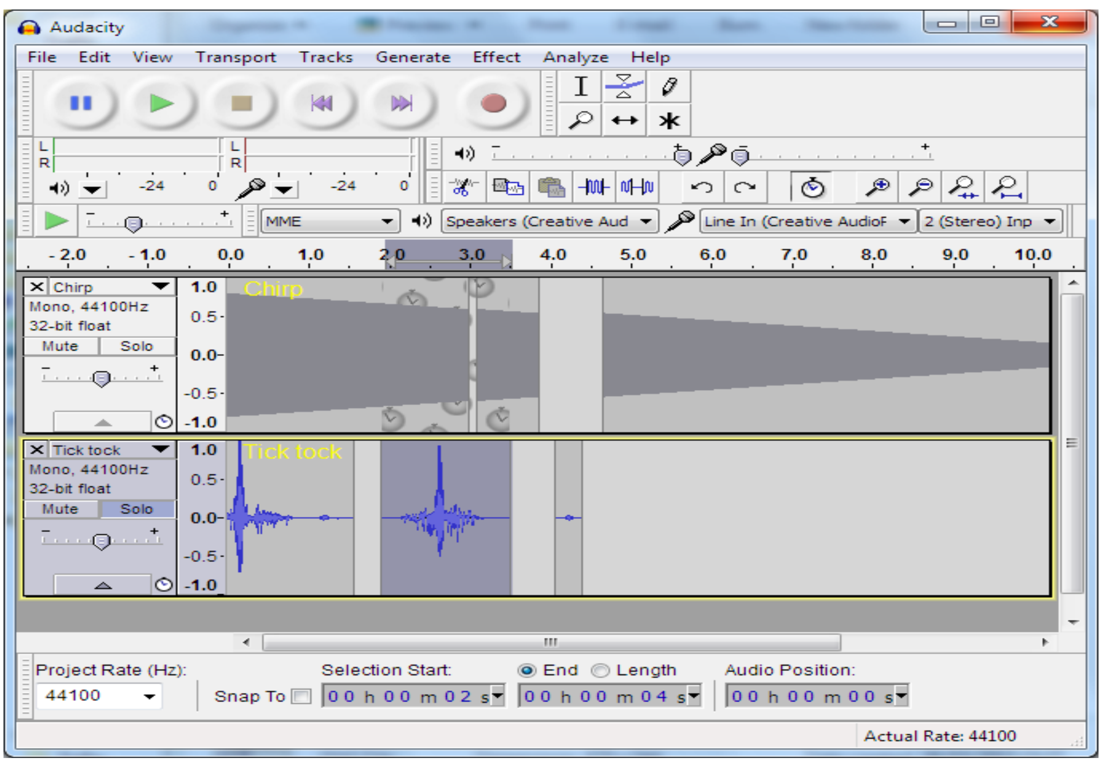


Figure 4.1: Audacity running on Windows

CHAPTER 5
POWER SUPPLIES

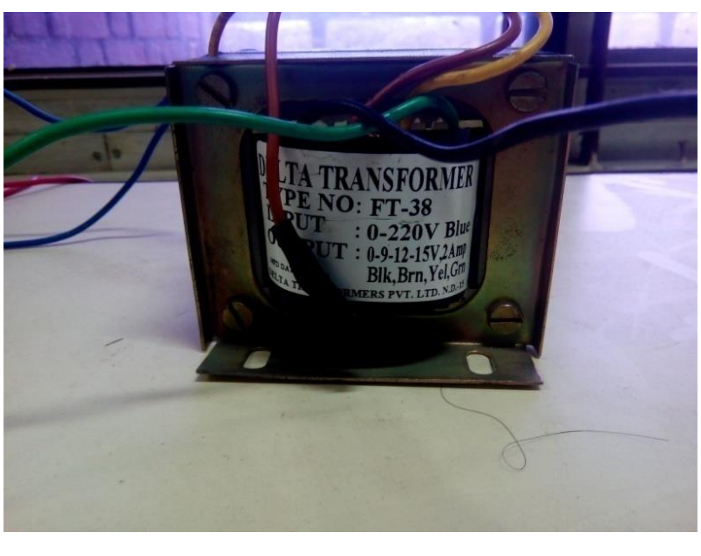
5.1 INTRODUCTION

A power supply is an electronic device that supplies electric energy to an electrical load. The primary function of a power supply is to convert one form of electrical energy to another; as a result, power supplies are sometimes referred to as electric power converters. Converting electric power means changing DC to AC or AC to DC or changing voltages etc.
Nowadays, almost all electronic equipment includes a circuit that converts ac supply into dc supply. The part of equipment that converts ac into dc is called DC power supply. In general at the input of the power supply there is a power transformer. It is followed by a rectifier (a diode circuit), a smoothing filter and then by a voltage regulator circuit.
From the block diagram, the basic power supply is constituted by four elements viz a transformer, a rectifier, a filter, and a regulator put together. The output of the dc power supply is used to provide a constant dc voltage across the load.

5.2 BASIC PARTS OF POWER SUPPLY

5.2.1 Transformer

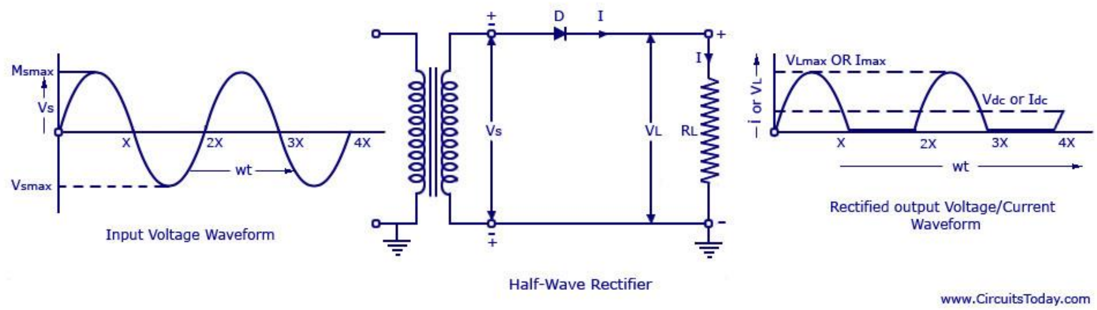
Transformer is used to step-up or step-down (usually to step-down) the-supply voltage as per need of the solid-state electronic devices and circuits to be supplied by the dc power supply. It can provide isolation from the supply line (an important safety consideration). It may also include internal shielding to prevent unwanted electrical noise signal on the power line from getting into the power supply and possibly disturbing the load.



5.2.2 Rectifier

Rectifier is a device which converts the sinusoidal ac voltage into either positive or negative pulsating dc. P-N junction diode, which conducts when forward biased and practically does not conduct when reverse biased, can be used for rectification *i.e.* for conversion of ac into dc. The rectifier typically needs one, two or four diodes. Rectifiers may be either **half-wave rectifiers** or full-wave rectifiers (centre or **bridge**) type.

- Half Wave Rectifier



A simple Half Wave Rectifier is nothing more than a single pn junction diode connected in series to the load resistor. If you look at the above diagram, we are giving an alternating current as input. Input voltage is given to a step down transformer and the resulting reduced output of transformer is given to the diode 'D' and load resistor RL. The output voltage is measured across load resistor RL.

From the theory part, you should know that a pn junction diode conducts current only in 1 direction. In other words, a pn junction diode conducts current only when it is forward biased. The same principle is made use of in a half wave rectifier to convert AC to DC. The input we give here is an alternating current. This input voltage is stepped down using a transformer. The reduced voltage is fed to the diode 'D' and load resistance RL. During the positive half cycles of the input wave, the diode 'D' will be forward biased and during the negative half cycles of input wave, the diode 'D' will be reverse biased. We take the output across load resistor RL. Since the diode passes current only during one half cycle of the input wave, we get an output as shown in diagram. The output is positive and significant during the positive half cycles of input wave. At the same time output is zero or insignificant during negative half cycles of input wave. This is called **half wave rectification.**

- Full Wave Bridge Rectifier

A Full wave rectifier is a circuit arrangement which makes use of both half cycles of input alternating current (AC) and converts them to direct current (DC). We have seen that a half wave rectifier makes use of only one half cycle of the input alternating current. Thus a full wave rectifier is much more efficient than a half wave rectifier. This process of converting both half cycles of the input supply (alternating current) to direct current (DC) is termed full wave rectification.

The working & operation of a full wave bridge rectifier is pretty simple. The circuit diagrams and wave forms we have given below will help you understand the operation of a bridge rectifier perfectly. In the circuit diagram, 4 diodes are arranged in the form of a bridge. The transformer secondary is connected to two diametrically opposite points of the bridge at points A & C. The load resistance R_L is connected to bridge through points B and D.

During the first half cycle

During first half cycle of the input voltage, the upper end of the transformer secondary winding is positive with respect to the lower end. Thus during the first half cycle diodes D1 and D_3 are forward biased and current flows through arm AB, enters the load resistance R_L, and returns back flowing through arm DC. During this half of each input cycle, the diodes D_2 and D_4 are reverse biased and current is not allowed to flow in arms AD and BC.

During the second half cycle

During second half cycle of the input voltage, the lower end of the transformer secondary winding is positive with respect to the upper end. Thus diodes D_2 and D_4 become forward biased and current flows through arm CB, enters the load resistance R_L, and returns back to the source flowing through arm DA. Thus the direction of flow of current through the load resistance R_L remains the same during both half cycles of the input supply voltage.

5.2.3 Filter and Regulator

The output voltage from a rectifier circuit has a pulsating character i.e., it contains unwanted ac components (components of supply frequency *f* and its harmonics) along with dc component. For most supply purposes, constant direct voltage is required than that furnished by a rectifier. To reduce ac components from the rectifier output voltage a filter circuit is required.

Thus filter is a device which passes dc component to the load and blocks I ac components of the rectifier output. Filter is typically constructed from reactive circuit I elements such as capacitors and/or inductors and resistors. The magnitude of output dc voltage may vary with the variation of either the input ac voltage or the magnitude of load current. So at the output of a rectifier filter combination a voltage regulator is required, to provide an almost constant dc voltage at the output of the regulator. The voltage regulator may be constructed from a Zener diode, and or discrete transistors, and/or integrated circuits (ICs). Its main function is to maintain a constant dc output voltage. However, it also rejects any ac ripple voltage that is not removed by the filter. The regulator may also include protective devices such as short-circuit protection, current limiting, thermal shutdown, or over-voltage protection.

5.3 TYPES OF POWER SUPPLY

Power Supplies can be classified on the basis of following characteristics:

5.3.1 Functional

- **Regulated Power Supply:** It is one that maintains constant output voltage or current despite variations in load current or input voltage.
- **Unregulated Power Supply:** It is one that does not maintain constant output voltage or current.
- **Adjustable Power Supply:** Output voltage or current can be programmed by mechanical controls or by means of a control input.
- **Adjustable Regulated Power Supply:** It is both adjustable and regulated.
- **Isolated Power Supply:** It has a power output that is electrically independent of its power input.

5.3.2 Mechanical

- **Bench Power Supply:** It is used in standalone desktop unit used in applications such as circuit test and development.
- **Open Frame Power Supply:** It has a partial mechanical enclosure.
- **Rack Mount Power Supply:** It is built so that it can fit into the racks in standard electronic equipment.

5.3.3 Power Conversion Method

- **Linear Power Supply**

It regulates the output voltage by dropping excess voltage in a series dissipative component. They use a moderately complex regulator circuit to achieve very low load and line regulation. They also have very little ripple and very little output noise. They process the input power directly, with all active power conversion components operating in their linear operating regions. Typical applications are:

- Low noise amplifiers
- Automatic test equipment
- Signal processing
- Laboratory equipment
- Data acquisition
- Control circuits

- **Switched Power Supply**

The transistor operates in the cut off and saturated region. The voltage of a switched mode power supply constantly oscillates and the circuitry uses this to decide when to connect and disconnect

from the source. As it stays in the cut off and saturated region, the static power dissipation is minimal, though dynamic power dissipation is significant. It has a higher efficiency than linear power supply but is considerably more complex. It suffers from low noise immunity. This type of power supply is used in most electronic gadgets like Laptops, mobile phones etc.
It is of 3 types-

- ***Buck- Buck*** converter produces a DC output in a range from 0V to just less than the input voltage.

- ***Boost- Boost*** increases the input (battery) voltage to a level required to drive a load at the desired current level.

- ***Buck Boost*** converter is a type of switched mode power supply that combines the principles of the Buck Converter and the Boost converter in a single circuit. Like other SMPS designs, it provides a regulated DC output voltage from either an AC or a DC input.

5.4 POWER SUPPLY CHARACTERISTICS

There are various factors that determine the quality of the power supply like the load voltage, load current, voltage regulation, source regulation, output impedance, ripple rejection, and so on.
Some of the characteristics are briefly explained below:

- ***Output Impedance*** – A regulated power supply is a very stiff dc voltage source. This means that the output resistance is very small. Even though the external load resistance is varied, almost no change is seen in the load voltage. An ideal voltage source has an output impedance of zero.

- ***Source/Line Regulation*** – In the block diagram, the input line voltage has a nominal value of 230 Volts but in practice, here are considerable variations in ac supply mains voltage.
  Since this ac supply mains voltage is the input to the ordinary power supply, the filtered output of the bridge rectifier is almost directly proportional to the ac mains voltage. The source regulation is defined as the change in regulated output voltage for a specified rage of lie voltage.

- ***Load Regulation*** – The load regulation or load effect is the change in regulated output voltage when the load current changes from minimum to maximum value.

  Load regulation = V_{no}-load – V_{full}–load
  V_{no}-load – Load Voltage at no load.
  V_{full}-load – Load voltage at full load.

From the above equation we can understand that when V_{no}-load occurs the load resistance is infinite, that is, the out terminals are open circuited. V_{full}-load occurs when the load resistance is of the minimum value where voltage regulation is lost.

- ***Minimum Load Resistance*** – The load resistance at which a power supply delivers its full-load rated current at rated voltage is referred to as minimum load resistance.

  Minimum Load Resistance = V_{full}-load / I_{full}-load

The value of I $_{full}$-load, full load current should never increase than that mentioned in the data sheet of the power supply.

- ***Ripple Rejection*** – Voltage regulators stabilize the output voltage against variations in input voltage. Ripple is equivalent to a periodic variation in the input voltage. Thus, a voltage regulator attenuates the ripple that comes in with the unregulated input voltage. Since a voltage regulator uses negative feedback, the distortion is reduced by the same factor as the gain.

5.5 CONVERSION OF INPUT POWER TO OUTPUT POWER

Conversion of input power to output power involves following steps.

5.3.1 **Rectification**

A rectifier circuit is a circuit which converts AC input power into DC output power. Presently a semi-conductor junction rectifier is used.

Transformers are attached to the rectifier circuit to bring the alternating current (A.C) voltage down to the required level. With the help of the transformer, the alternating current (A.C) voltage can be increased or decreased with a small amount of power loss. Moreover, transformers also help in increasing the safety of the equipment being used. PN diodes are also used for the rectification process along with the transformers. PN diodes help in getting a better rectification of current. The diodes are generally attached in a separate circuit having one, two, or four diodes.

The output result is a unidirectional direct current, smooth in quality. A single rectifier can only produce a half-wave rectification, which though unidirectional, is not continuous in flow and has several ripples in it. In order to reduce these ripples in the direct current, a capacitor is used. Thus, a capacitor helps in smoothing the alternative current (A.C) voltage after the rectification process.

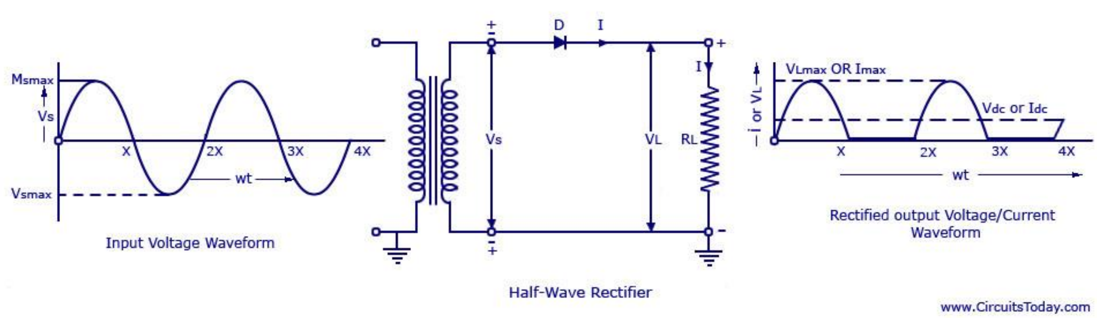


Figure 5.1: Half Wave Rectifier

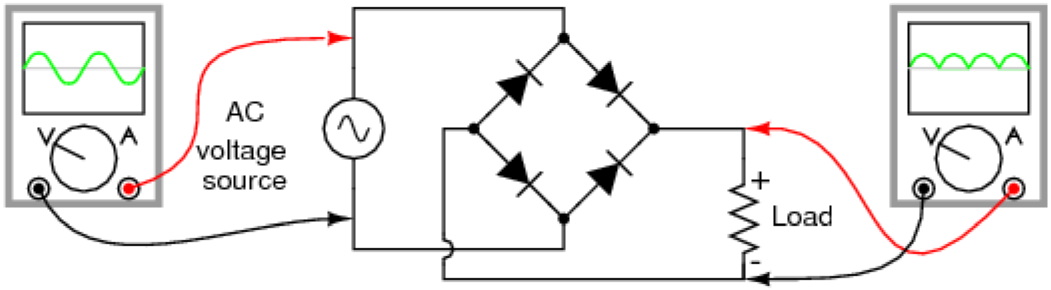


Figure 5.2: Bridge Rectifier

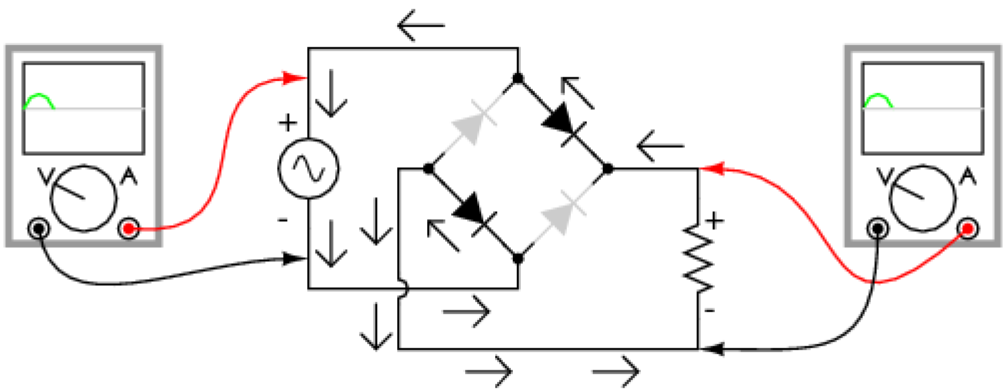


Figure 5.2 (a): Bridge Rectifier for positive half cycle

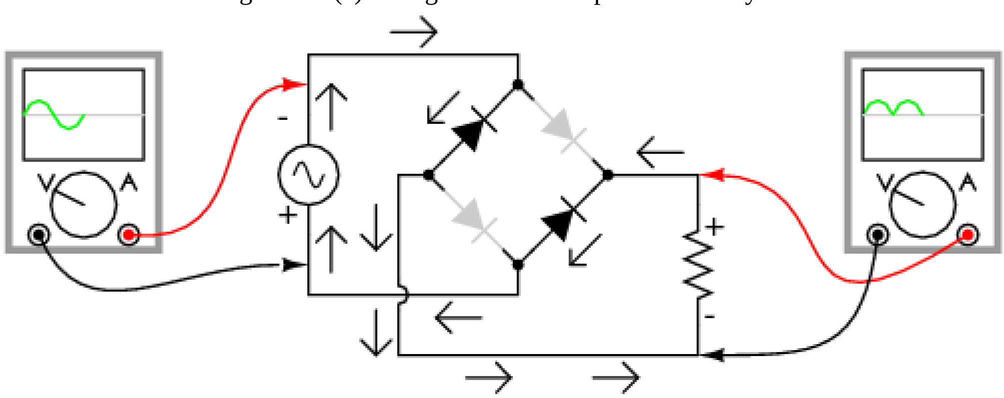


Figure 5.2(b): Bridge Rectifier for negative half cycle

5.3.2 **Filtering**

The R-C filter circuit is used to reject input noise. Smoothing capacitor helps reduce the ripples in the circuit which converts the pulsating DC output after rectification to a constant DC voltage. The other capacitor is the reservoir capacitor. An electrolytic capacitor is used as a reservoir capacitor.

It acts as a temporary storage for the power supply output current. The reservoir capacitor is large electrolytic, usually of several hundred or even a thousand or more microfarads, especially in mains frequency PSUs. This very large value of capacitance is required because the reservoir capacitor, when charged, must provide enough DC to maintain a steady PSU output in the absence of an input current; i.e. during the gaps between the positive half cycles when the rectifier is not conducting.

A combined reservoir capacitor and low pass filter it is possible to remove 95 percent or more of the AC ripple and obtain an output voltage of about the peak voltage of the input wave.

To obtain a ripple free constant dc supply we need to apply appropriate valued capacitor. This value of capacitor is obtained by input voltage that we get from transformer. In this case we opted for a step down transformer which provides output of 12 V. The peak is obtained at value of about 12*1.414=16.8 V.

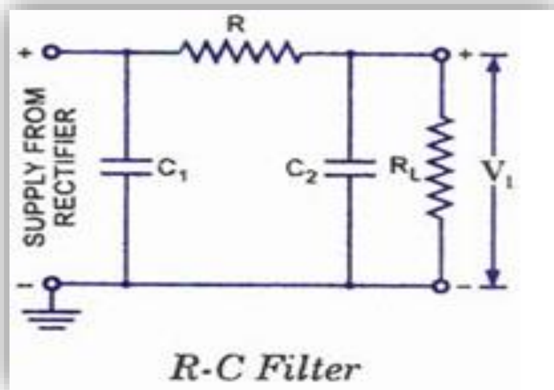


Figure 5.3: Filter circuit

Generally, the available values of capacitors are 16 V, 25V; etc. This type of zener arrangement for regulated supply is used for circuit using small supply current. Zener diode provides constant voltage only for the case of constant current and temperature. Hence we need to provide constant current to zener diode in order to provide constant reference voltage. So this configuration was not used for designing the regulated voltage circuit.

As far as power efficiency is required, we observe high power loss.
Assuming current through zener is 1A, where output is 5.1V value of resistor required is (17-5.1)/1 = 12, here power loss is obtained as 17-5.1=12W.The efficiency of power supply is very low; hence it is not a good power supply design.

Some other short comings of using the above circuit:

- V_{out} is settable to a precise value.
- For widely varying load current a high rated zener is required to handle dissipation at low load current.

5.6 SHORT CIRCUIT PROTECTION

In this circuit, all current passes through the base emitter junction of the transistor. Such high amounts of current passing through the circuit can lead to excessive heating of the circuit. It can also lead to transistor meltdown. Hence we use a simple current-limiter circuit to protect transistor Q1. The entire load current is routed through R2. A voltage difference will exist across R2.

When the load current exceeds a predetermined safe value, the voltage drop across R2 will forward bias Q2 and cause it to conduct. Since Q2 is a silicon transistor, the voltage drop across R1 must exceed 0.6 V to turn Q2 on. Therefore, R2 is chosen for a value that provides a drop of 0.6 V when the maximum safe load current is drawn. R2 protects the base-emitter junction of Q2 from current transients or from destruction in the event Q1 fails under short-circuit conditions. When Q2 turns on, some of the current through the base of Q1 flows through Q2, thereby depriving Q1 of some of its base current.
This action depending upon the amount of Q1 base current at a precise moment cuts off Q1 conduction to some degree, thus limiting the current through it.

Disadvantage- The voltage drop across R2 which will lead to the IV curve to be slightly decreasing.

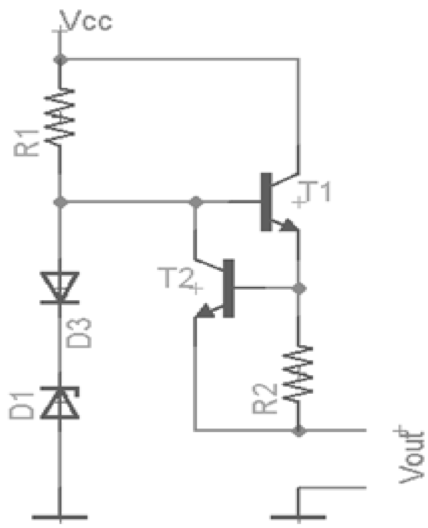


Figure 5.4: Basic circuit for Short Circuit Protection

5.7 POWER SUPPLY USING OPERATIONAL AMPLIFIERS

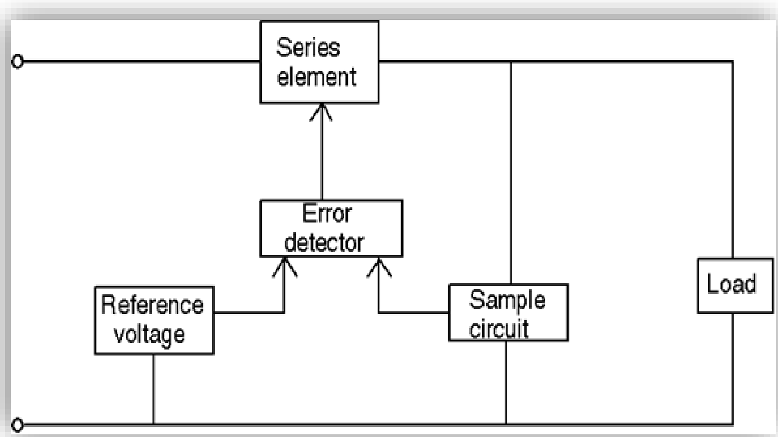


Figure 5.5: Block diagram of Power Supply using Operational Amplifier

This voltage regulator consists of four blocks:

- ***Series element:*** this block gets its input from error signal to maintain constant output voltage.
- ***Sample circuit:*** this part takes the sample from output voltage and provides it to the error detector.

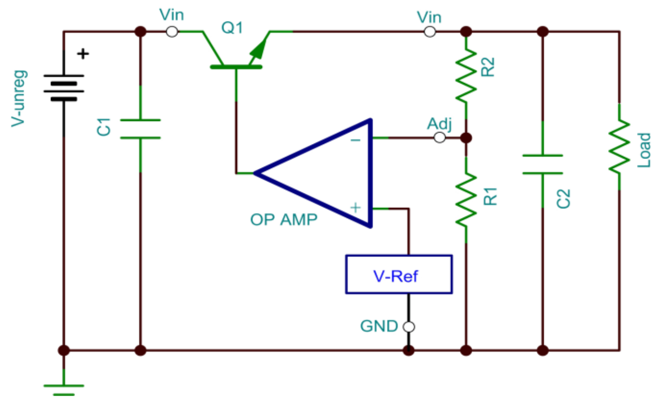


Figure 5.6: Basic circuit of a Regulated Power Supply

- ***Reference voltage:*** this block provides reference voltage to error detector to be compared with voltage provide by sample circuit.
- ***Error detector:*** this block gets input from reference and sample circuit which are then compared and give the error signal to the series element, so as to control output.

CHAPTER 6

PCB FABRICATION

6.1 PCB (Printed Circuit Board)

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate.

Advantages: -The circuit board fabrication cost (PCB cost) is lower with mass quantity production. Electronic circuit characteristics will be maintained without introducing parasite capacitance with a proper circuit board design. Component wiring and assembly can be mechanized in a circuit board manufacturing facility. Also, Chances of miss wiring or short-circuited wiring are minimized.

6.2 TYPES OF PRINTED CIRCUIT BOARDS

There are three types of PCB: -

1) **Single Sided Board**

This is the least complex of the Printed Circuit Boards, since there is only a single layer of substrate. All electrical parts and components are fixed on one side and copper traces are on the other side.

2) **Double Sided Board**

This is the most common type of board, where parts and components are attached to both sides of the substrate. In such cases, double-sided PCBs that have connecting traces on both the sides are used. Double-sided Printed Circuit Boards usually use through-hole construction for assembly of components.

3) **Multi Layered Board**

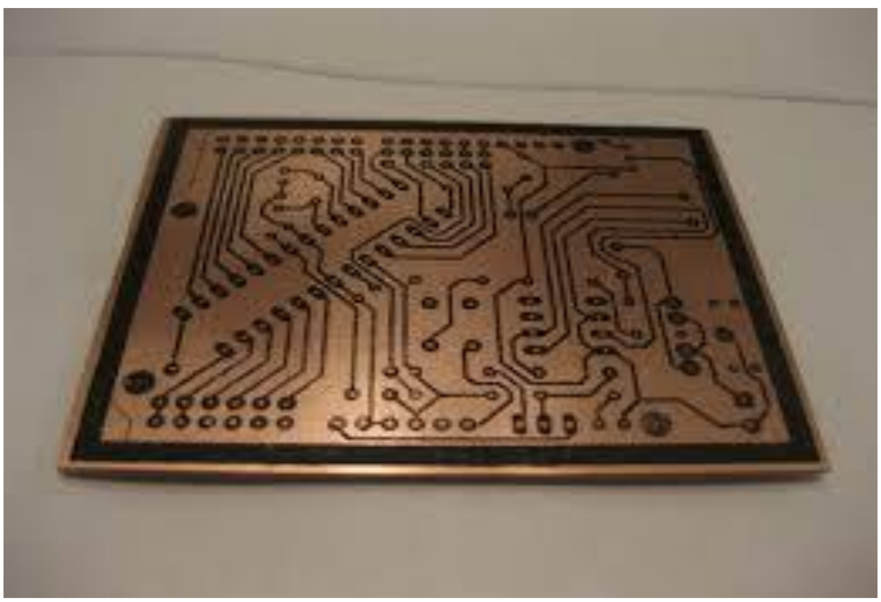
Multi layered PCB consists of several layers of substrate separated by insulation. Most common multilayer boards are: 4 layers, 6 layers, 8 layers, and 10 layers. However, the total number of layers that can be manufactured can exceed over 42 layers. These types of boards are used in extremely complex electronic circuits.

6.3 PCB FABRICATION METHODS

1) TONER TRANSFER METHOD

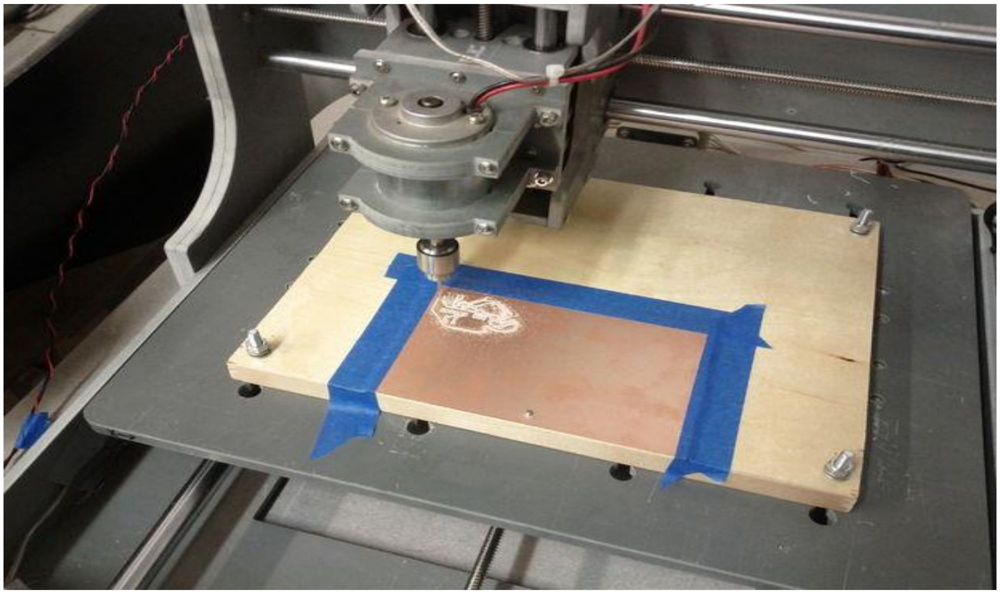
Steps involved: -

1) Take the print-out of board layout on a Glossy Magazine paper.
2) Invert the printed circuit on copper clad and irons it uniformly for about 5 minutes.
3) Put the combo in a water tub and gently remove the paper from it. The resultant is a copper board with black tracks of toner on it.
4) Put it in small container containing $FeCl_3$ and stir occasionally for about 15-20 minutes until exposed copper has been removed.
5) Use a kitchen scrub to remove toner off the tracks. Now we have a printed circuit board with fine copper tracks on it.
6) Spray an anti-oxidant on it so as to prevent copper from oxidation. Now we have our PCB complete.
7) Drill it and solder components on it.
8) Test the power supply for various load voltages and currents.



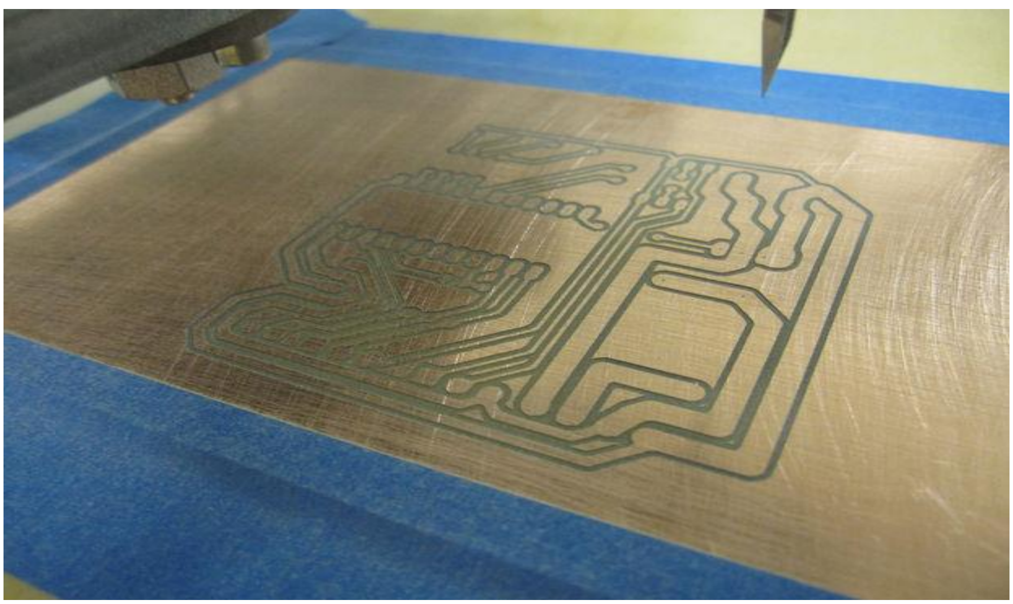
2) PCB MAKING USING CNC MACHINE

The whole PCB fabrication process is carried out by the CNC machine. You just need to program it with the help of software. Circuit making, drilling, cutting etc. are all performed by the machine



I) CNC MACHINE

II) PCB made by CNC machine

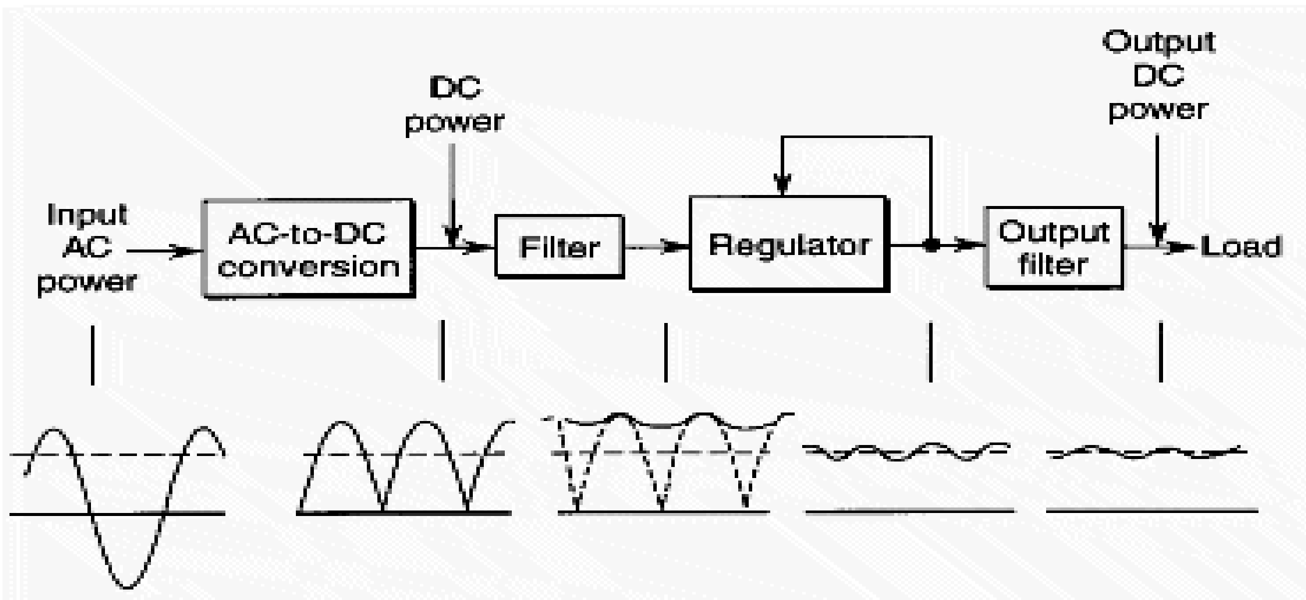


CHAPTER 7

CASE STUDY: Power Supply Using LM723

7.1 DESIGNING OF LINEAR POWER SUPPLY

BLOCK DIAGRAM



Different stages involved in the designing of the power supply are:

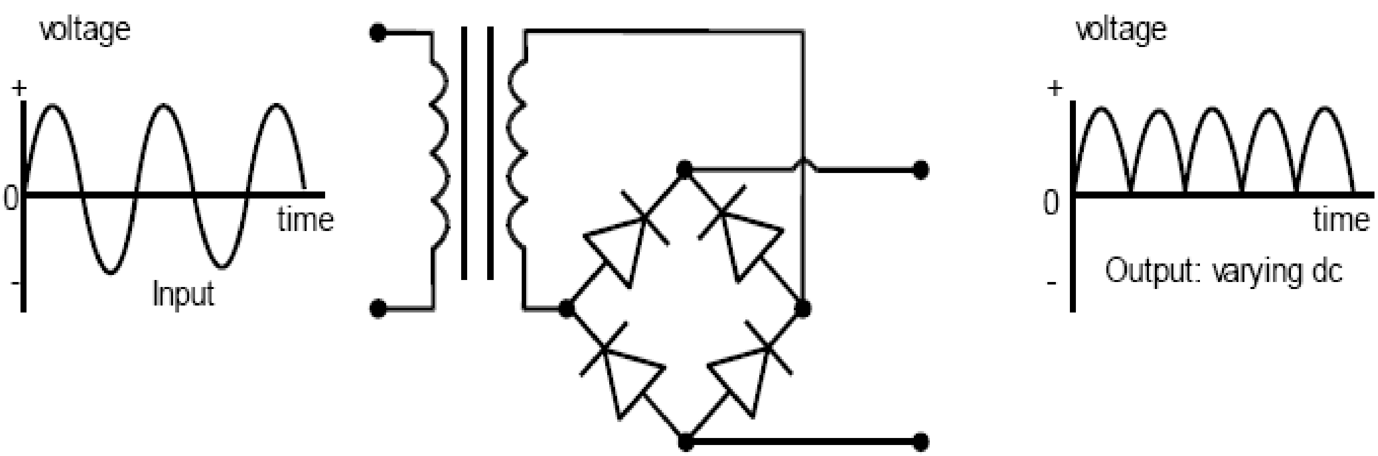
1. Stepping Down the AC Mains Supply
2. Rectification of the AC
3. Adequate filtering of the rectified output
4. Regulation of the output
5. Short-Circuit Protection
6. Delivery of the output

1) Stepping Down the AC mains

The Ac Mains 220 V was stepped down with the help of a step down transformer of appropriate rating; let’s say 0-12V, which can provide a maximum DC voltage of
12 x1.414 =16.97V.

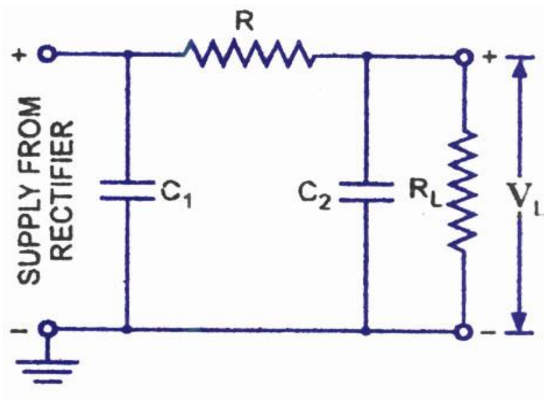
2) Rectification of AC

There were a few options of rectifiers available like half wave, full wave, and bridge. We went for a bridge as it does not require a centre tapped transformer and allows exploitation of the complete range of the transformer.

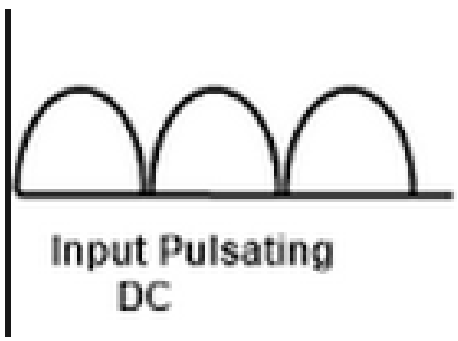


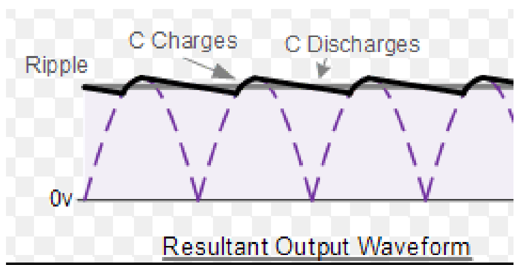
3) Filter Action

Electronic filters are electronic circuits which perform signal processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones, or both. The R-C filter circuit as given in figure is used to reject input noise. By deliberate design R is kept much larger than XC1 at the ripple frequency. So the ripples are dropped across series resistor R instead of across the load resistor RL. Typically R is kept at least 10 times greater than XC2; this means that each section reduces the ripples by a factor of at least 10.



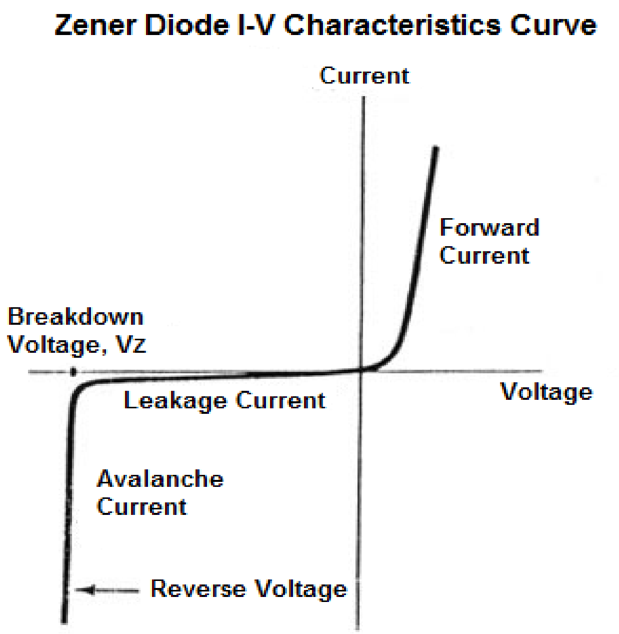
R-C Filter



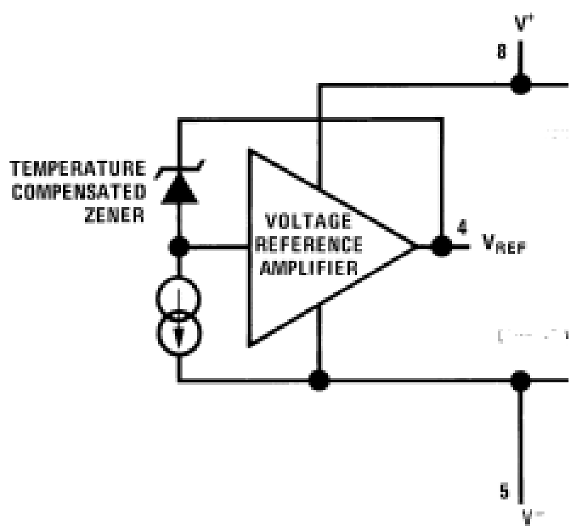


4.A) Zener Diode as voltage regulator

A Zener diode can be used as a voltage regulator. It is connected in reverse bias mode to act as a voltage regulator. The current-voltage (I-V) characteristics show that the voltage remains constant over a range of input voltage and thus helps in regulation.



Here, In IC LM-723, we have a temperature controlled Zener diode whose output voltage does not vary with temperature. We have connected it in series with a current source so that the current across the Zener diode does not vary and the Zener diode can provide a fixed output voltage (VREF).

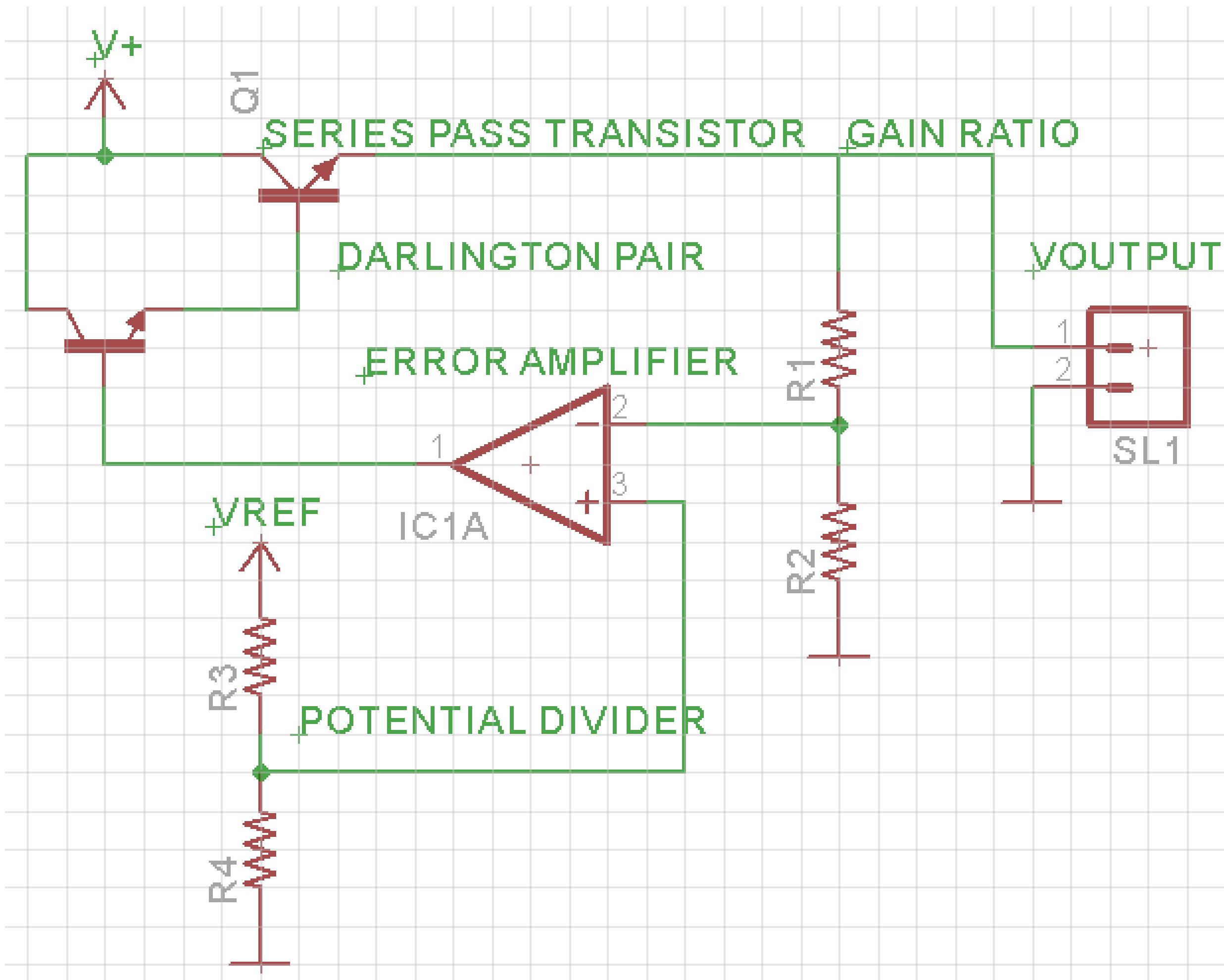


4.B) The error amplifier and series pass transistor

VREF is varied suitably with the help of a potential divider and fed to the non-inverting terminal of the error amplifier. The output of the op-amp is connected to a Darlington pair as the output current of the op-amp is very low. The Series pass transistor's collector is connected to V+ and emitter to the load (with short circuit protection) as shown in the figure. The inverting terminal of the Op-amp is connected to the output through a gain provider circuit.

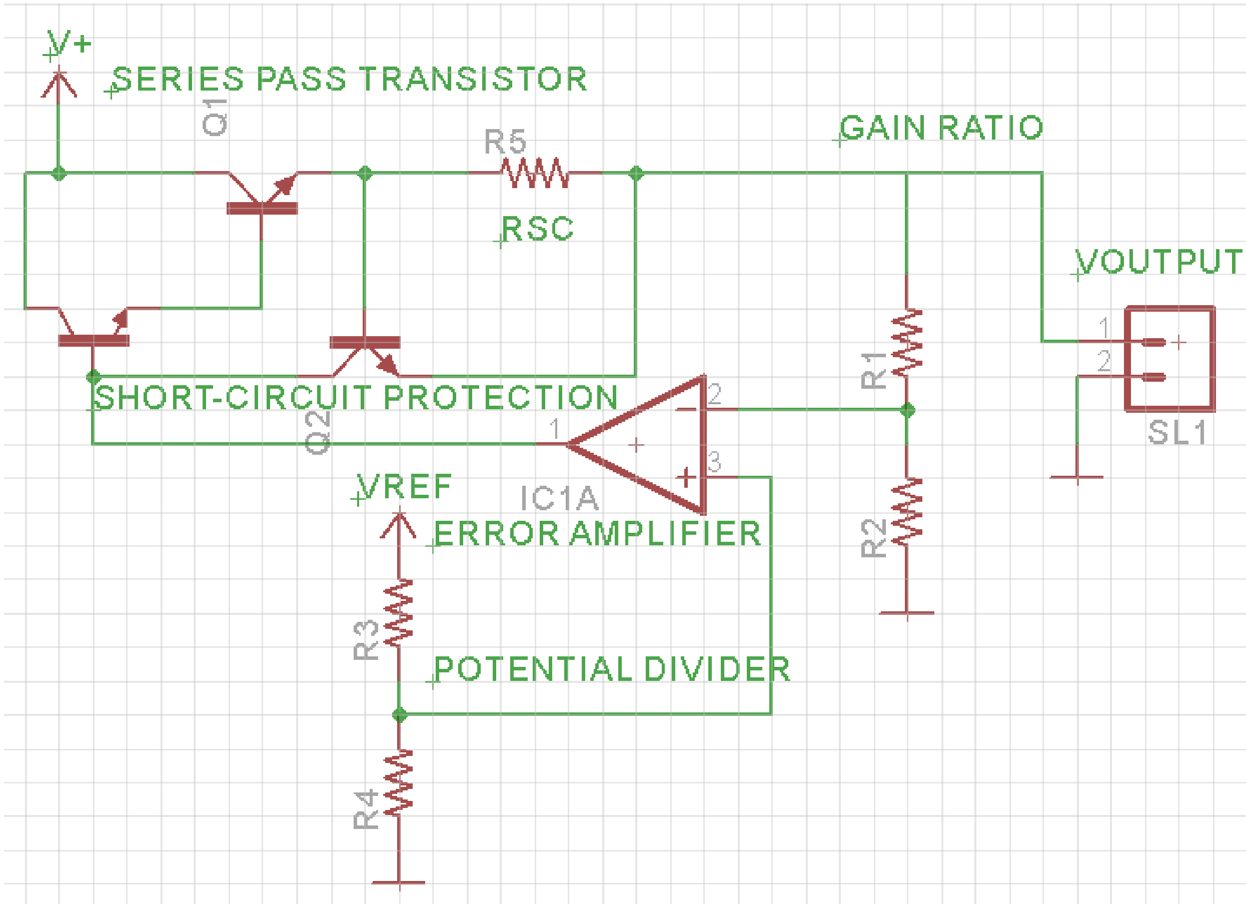
The op-amp has a property of forcing its output voltage to vary so as to keep same voltage at its inverting and non-inverting terminal. As the voltage on the non-inverting terminal is VREF it will try to keep the same voltage on the inverting terminal and therefore keep the output voltage constant depending on the value of VREF and the Gain potential divider.

As the load changes, the value of voltage on the op-amp's inverting terminal changes, but it wants to keep it constant as long as VREF on the non-inverting terminal is not varied, So therefore it forces its output voltage to change and correspondingly change the current through the Series pass transistor so as to keep the output at a constant voltage on changing load. That is why the op-amp is known as the error amplifier as it checks on the difference of voltage at its inverting and non-inverting terminal and changes the output accordingly so that the output voltage does not vary.



5) Short Circuit Protection

Now consider the situation where the output is shorted. The voltage at the inverting terminal of the op-amp will become zero and VREF on the non-inverting terminal. The op-amp will force the Series pass transistor to pass a large amount of current through it in order to make the voltage on the two terminals equal. This will lead to huge power dissipation in the transistor and it can eventually damage the transistor and the circuit. Therefore, it is necessary to give short circuit protection. The circuit with short-circuit protection is shown in figure:



The Short-Circuit protection is given with the help of transistor Q2 and Resistor RSC. When the load is shorted, there will be an increase in current through RSC and correspondingly the voltage drop across RSC will switch on the transistor Q2 which in turn will drain the base current going in the Darlington pair and hence protect it from damage. But as the current through the Darlington pair decreases, the voltage drop across RSC will also decrease and the transistor Q2 will again be cut-off. It will transit between off and on. In steady state it will just be on. The value of Short-Circuit resistance RSC can be found out using the formula: $RSC=V_{be}/I_{max}$.

6) Regulated Output

The regulated output has to be delivered via some means to power some or the other devices/appliances/circuits. This was done by installing a two pin standard connector which was left open circuited. To keep an eye on the output of the dc voltage, we installed a Led in parallel with the output.

LOAD REGULATION: The ability of output voltage to remain constant over a wide range of change in load current. In other Words, the load regulation is defined as the ratio of change in the output voltage with respect to change in load current. The slope of output curve is load regulation.

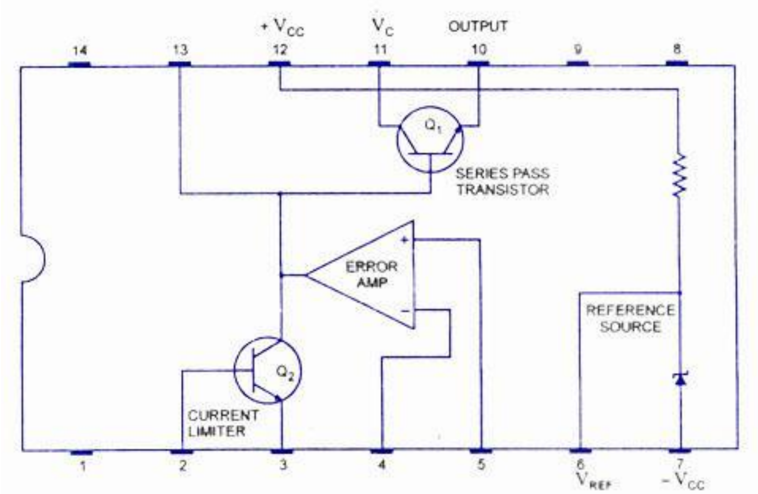
%Load Regulation = $\Delta Vout/\Delta Iout$

LINE REGULATION: It is the ratio of change in output voltage to change in input voltage at a constant load.

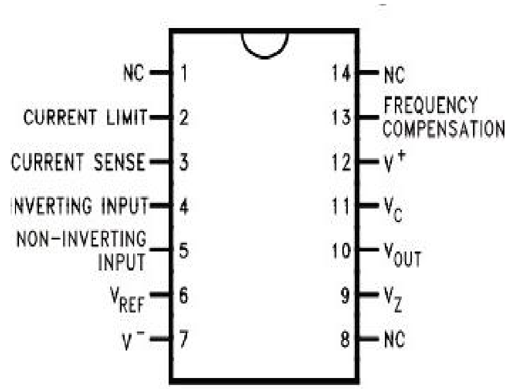
%Line regulation = $\frac{\Delta Vout}{Vin\,(\max)-Vin(\min)}$

7.2 IC LM723

As we have seen above, the regulator circuit requires a lot of components to work properly.



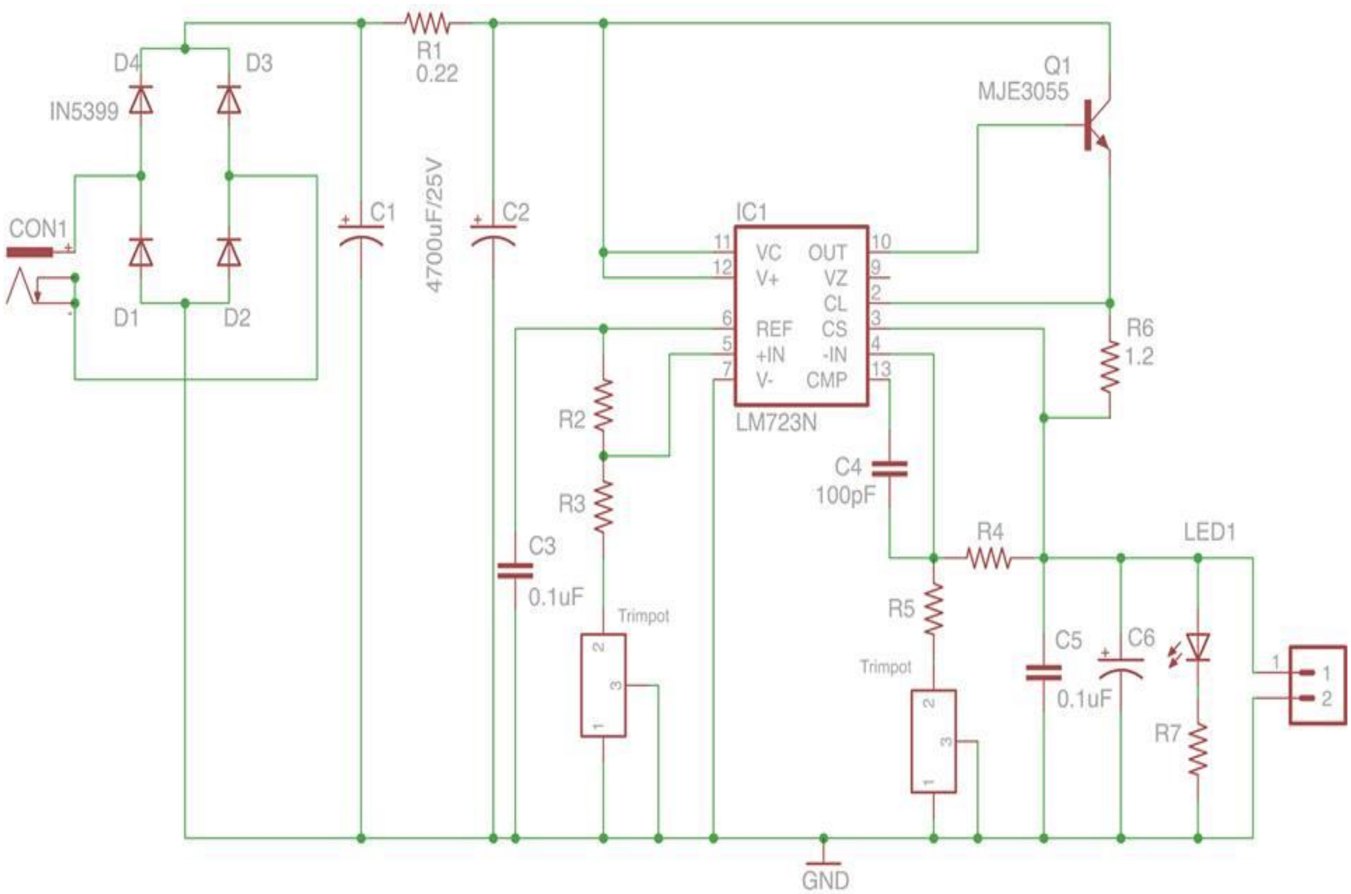
But, we have an IC LM723, which has most of the above components bundled in it. The Zener Input configuration, Op-amp, and Short Circuit Protection is bundled in itself, thereby reducing the size and labour and also increasing the reliability of the circuit. The device can be connected to operate as a positive or negative voltage regulator with an output voltage ranging from 2 V to 37 V, and output current levels up to 150 mA. The maximum supply voltage is 40 V, and the line and load regulations are each specified as 0.01%.



The rectified and filtered ac signal is used to power LM 723. The 6th pin of this IC is V_{ref}. It provides the reference voltage the reference voltage of 7.15. The 5th and 4th pins are non- inverting and inverting terminal of comparator respectively.

As the 6th pin provides with a reference voltage of 7.15 volts, we need to employ a voltage divider if we want a voltage level of less than 7.15 volt, let's say 5V.

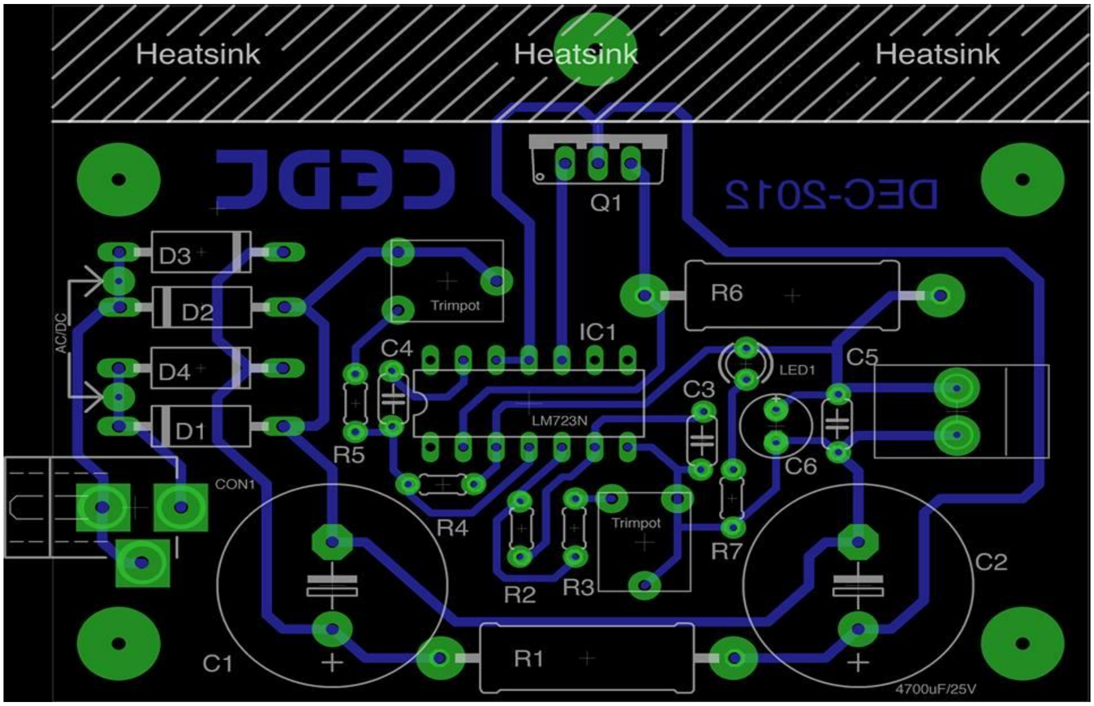
7.3 SCHEMATIC



Use of Capacitors

In the above circuits, capacitors have been used at some places in parallel with load resistor. These capacitors are known as frequency compensators. The transients that may occur due to noise during the operation of power supply may also result in phase change and the negative feedback could be changed to positive feedback. To avoid that, capacitors are used.

Board Layout



7.4 DEVELOPMENT OF POWER SUPPLY (TONER TRANSFER METHOD)

STEP 1: TAKING PRINT

- After making and designing the circuit on eagle take the print of the mirror image of the circuit on a glossy paper. The mirror image is taken in order to get the print of the circuit on board right after following the remaining steps.

STEP 2: PREPARING THE SURFACE

- A copper clad board of width 1.6mm is used in this process. Copper clad boards have oxide layer deposited on their surface because of reaction with oxygen and moisture present in the surroundings. These impurities prevent conduction of current and further reaction of copper in the subsequent processes.
- In order to remove this oxide layer present on the board sand paper is used. It is necessary to remove the oxide layer so that after using the toner ink, rest of the copper can be removed to make the circuit work. The sand paper should be used very wisely and carefully. There are

various types of sand paper available in the market depending upon their use and coarseness. Therefore the sand paper selected for this purpose should not be much coarser, and must be fine enough to remove the oxide layer from the surface. The rubbing should be done in single direction from one end to another moving sideward. The pressure applied should be uniform throughout in order to get a lustrous surface of copper on copper clad board. The surface this process should be shinny and even so that it does prevent the current flow.

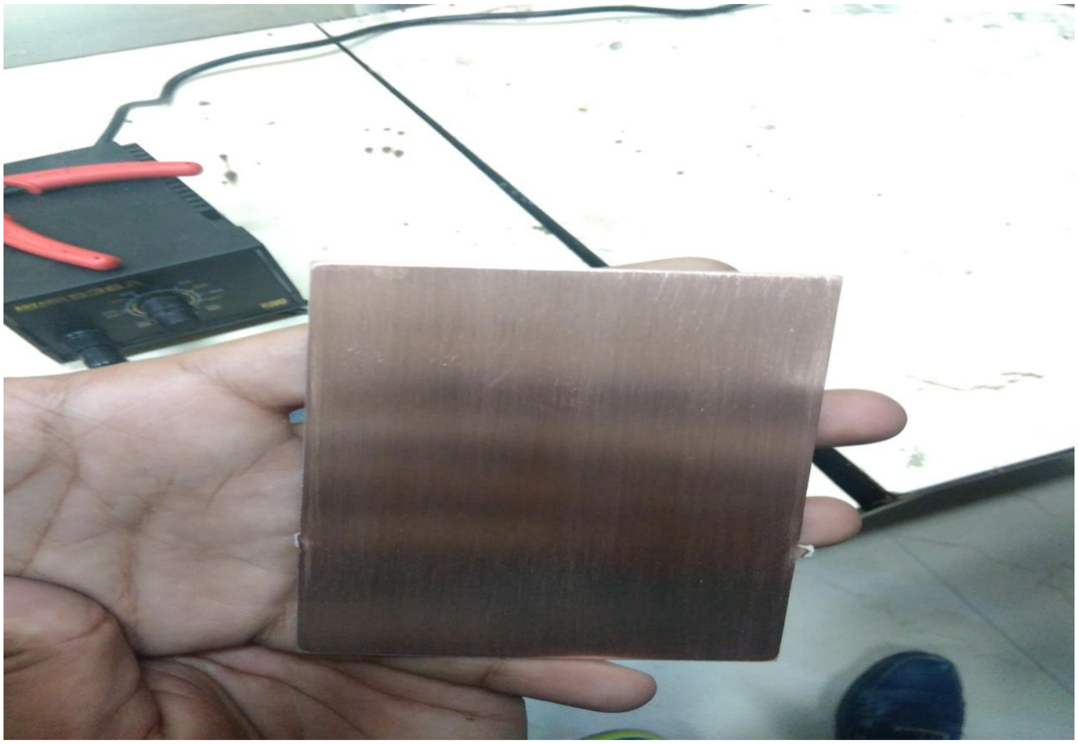


Figure 7.1: Copper clad after removing oxide layer

STEP 3: INK TRANSFER

- After getting rid of the oxide layer the circuit is printed on the board with the help of toner ink and heat. The glossy paper on which the print is taken is kept on the board with its inked side facing towards the copper surface. For transferring the ink from the paper to the board heat is used. This is done with help of ordinary iron used at home. The temperature is kept constant around 160 C. One has to keep in mind two basic rules during the process.

1. The pressure applied while pressing must be uniform.

2. The heat applied should also be uniform.

The board should not move while pressing. It should be holded with the help of thumb on one side and with fingers on the other side. A piece of cloth or heat insulating material should be used for holding purpose as the board gets very hot. The time required for fully transferring the ink on the board varies depending on the board size. After heating the ink gets transferred to board.

Figure 7.2: Printing of circuit on copper clad.

STEP 4: REMOVAL OF PAPER

- After the process of pressing and heating the board is kept aside to cool down. After 5-7 minutes the paper is removed from the surface. The paper is not peeled of instantly from the surface. Instead the board is kept in a water bath so that the paper is easily removed. The paper is rubbed off from the surface with the help of fingers after 5 minutes of soaking. Rubbing should be done gently without using any sharp object such as nails to prevent the ink from getting removed.

- Before moving on further one should make sure that the ink is properly placed on the board. All tracks, pads should be properly placed and inked. If the ink gets displaced from their respective places it has to repaired, then and there. A marker is used to make and complete the erased tracks and pads in order to repair them. If there are shorted tracks or pads, they are removed by using a pointed object like compass or a mounting needle.

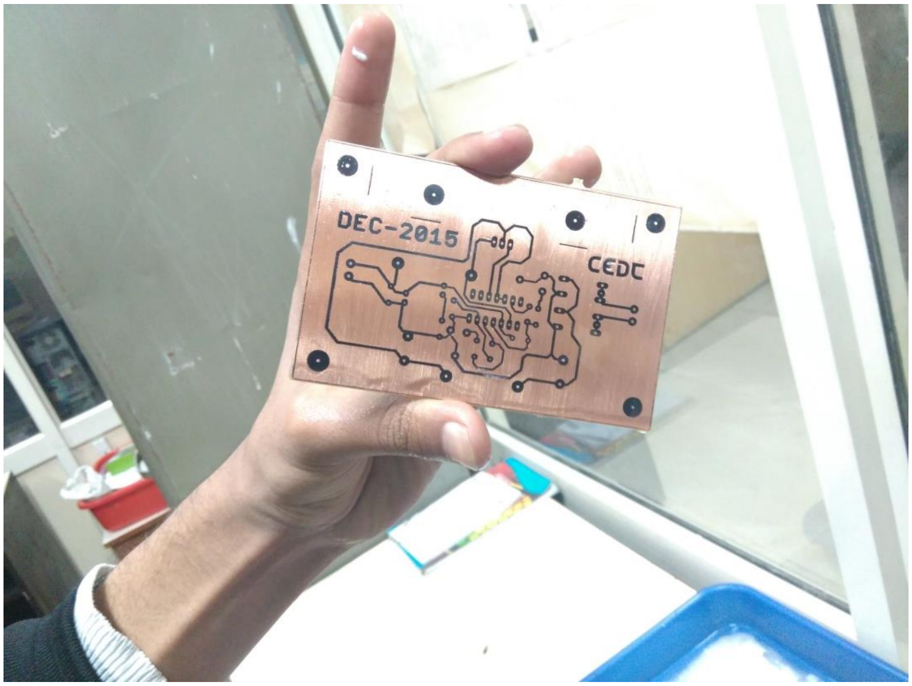


Figure 7.3: Copper clad with printed circuit

STEP 5: ETCHING

- The process of etching is one of the major step towards making the pcb. It is used to remove the excess copper from the board which is present around the inked paths. The inked board is placed in bucket containing a chemical reagent. The chemical agent used is ferric chloride. It reacts with the copper exposed to it and remove it. The process takes around 15-20 minutes for its completion depending upon the level of saturation. The chemical agent used is very harmful for the body and the clothes. Therefore, proper gloves and precautions should be used.

Figure 7.4: ETCHING – Removing excess copper from PCB using $FeCl_3$ solution

STEP 6: REMOVING THE INK

- When the excess copper is removed by etching, the ink remains on the board above the tracks. The ink has to be removed in order to make the paths conducting. The ink is removed with help of soap and scrubber. After removing the ink, the board is washed with water and checked for any remaining spots of ink. If there are any spots, they are removed and the process gets completed.

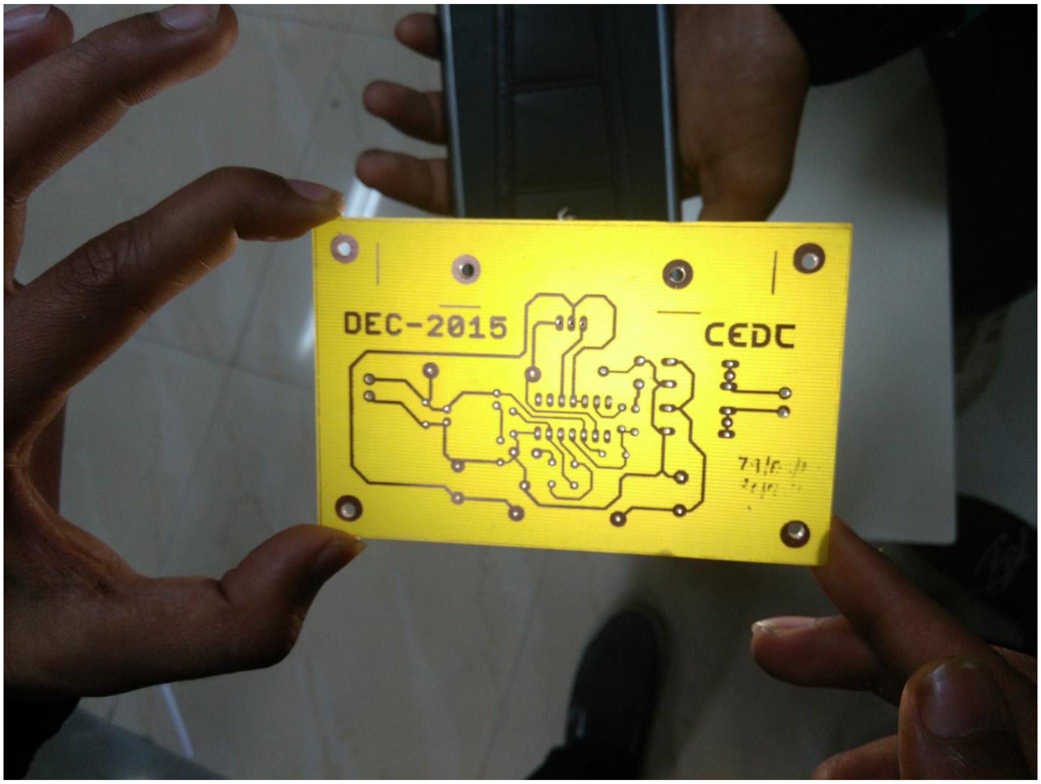


Figure 7.5: PCB after removing excess ink

STEP 7: ACRYLIC SPRAYING

- When the ink is completely removed, the board is sprayed with acrylic. It is done in order to prevent the copper present in the circuit from reacting with the oxygen and moisture present in air. The coating of acrylic does not react with copper and acts as a protective layer between the copper and surroundings. It is then left for 10-15 minutes to get dry.
- After following these steps the pcb gets ready to be drilled for placing the necessary components.

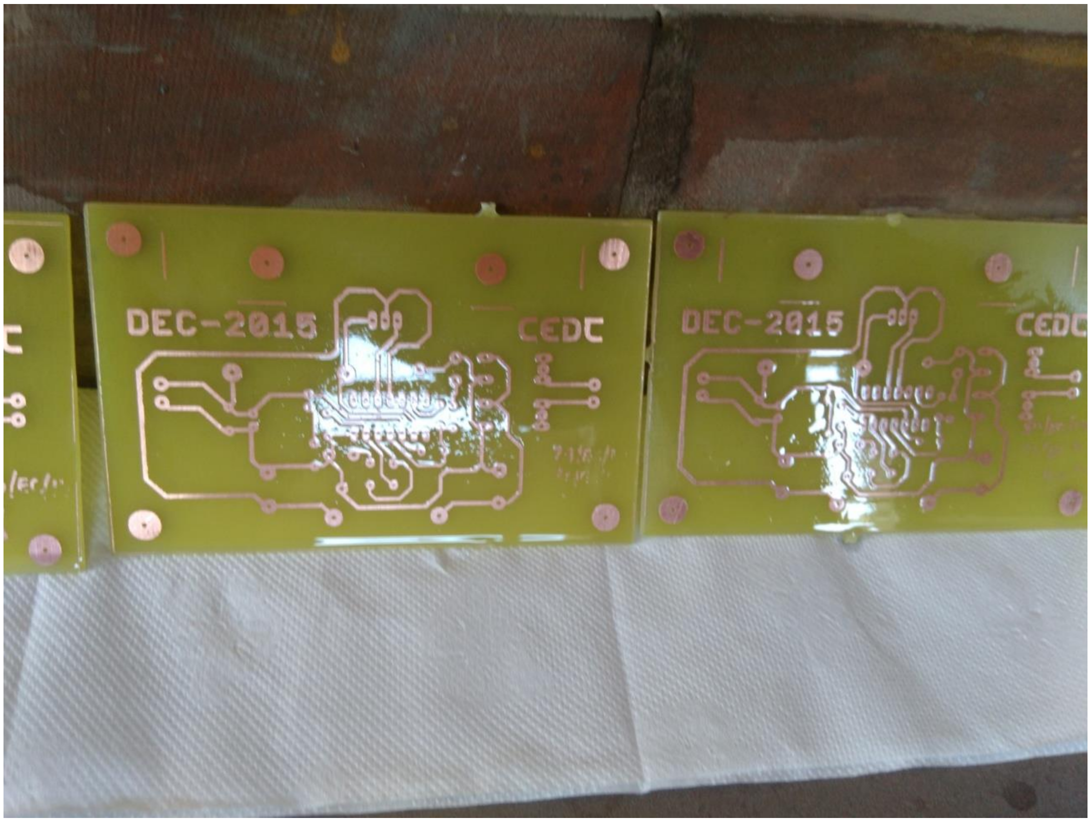


Figure 7.6: Drying of PCB using acrylic spray.

STEP 8: DRILLING

- Drilling is done on pcb with the help of drilling machine in order to make holes for the soldering components on it. Different drilling bits having different diameters are used to make holes according to component requirements. During drilling process make sure that the pcb do not move while the bit is inserted in the board else the drill bit can break. The machine handled is gently pushed down in a single move. The holes should be done in the center of the pad. Drilling machine works at a very high speed and therefore care must be taken during drilling process.
- HSS drilling bits ranging from 0.7mm to 3mm in diameter is used during drilling.
- Now the pcb is ready for the components to be placed and soldered.

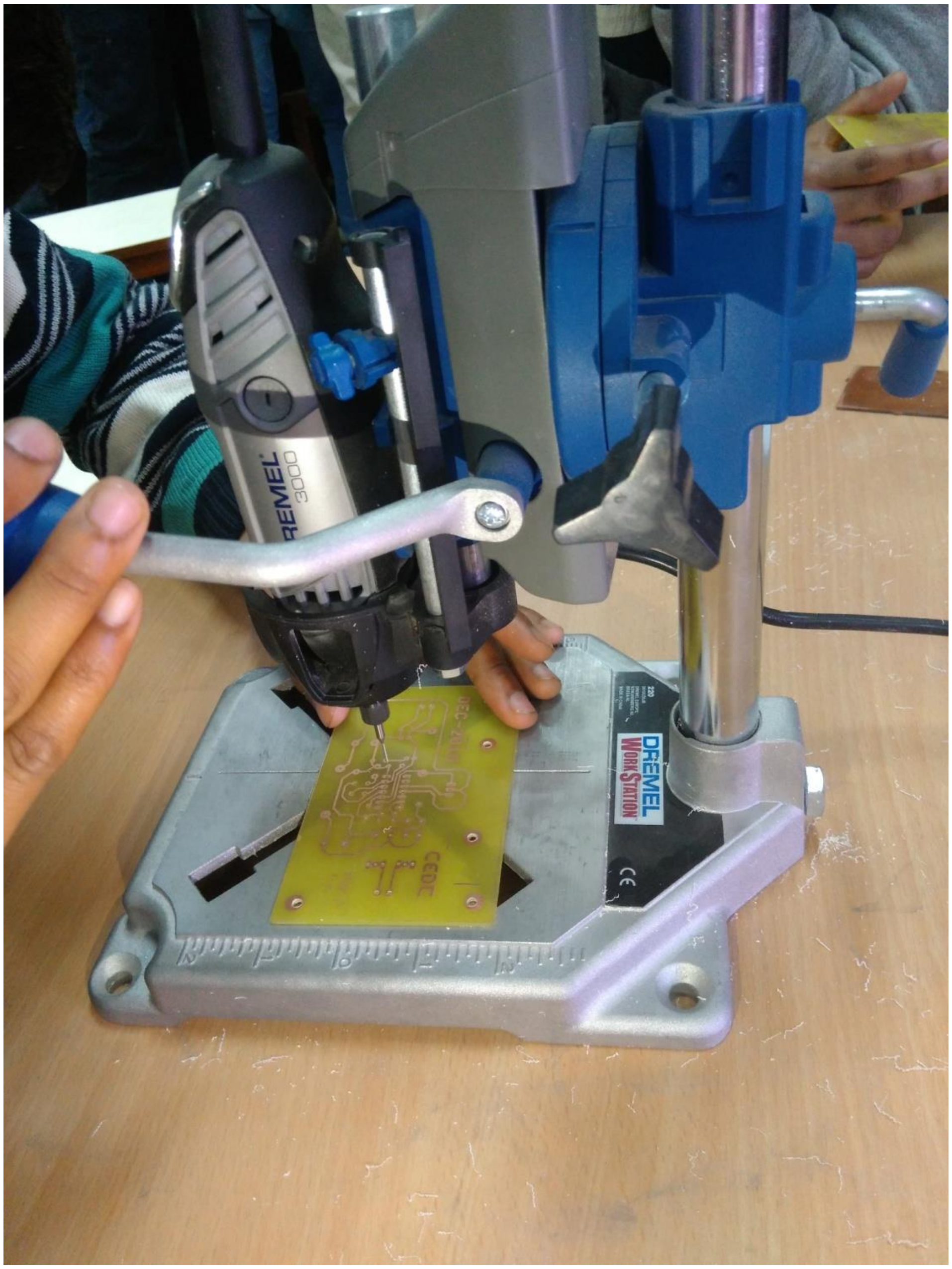


Figure 7.7: Drilling of PCB

STEP 9: SOLDERING

- First the board is placed on the screws at four corners in order to make it stable and making the soldering process quick and easy. All the components are placed on the board according to the board layout. The components are soldered in order of their height profile.
- First of all, the smd components are placed if any. After that the components are placed in increasing order of their height.

- There certain points and precautions which are to kept in mind while soldering the components on the board. These are:-
- Adjust the temperature of the solder around 350 C and keep the soldering station at a proper place depending upon the ease of accessing the iron.
- Wet the sponge provided at the soldering station with water.
- Don’t overheat the solder joint by placing the iron for a longer time while soldering leds as they tend to get damage very easily.
- While soldering components at compact regions make sure that the soldering bead is not slanted much, as it may lead to short circuit.
- The soldering iron should be cleaned repeatedly with the wet sponge in order to remove the extra solder present on the solder bead.
- The ICs should be placed and soldered carefully.

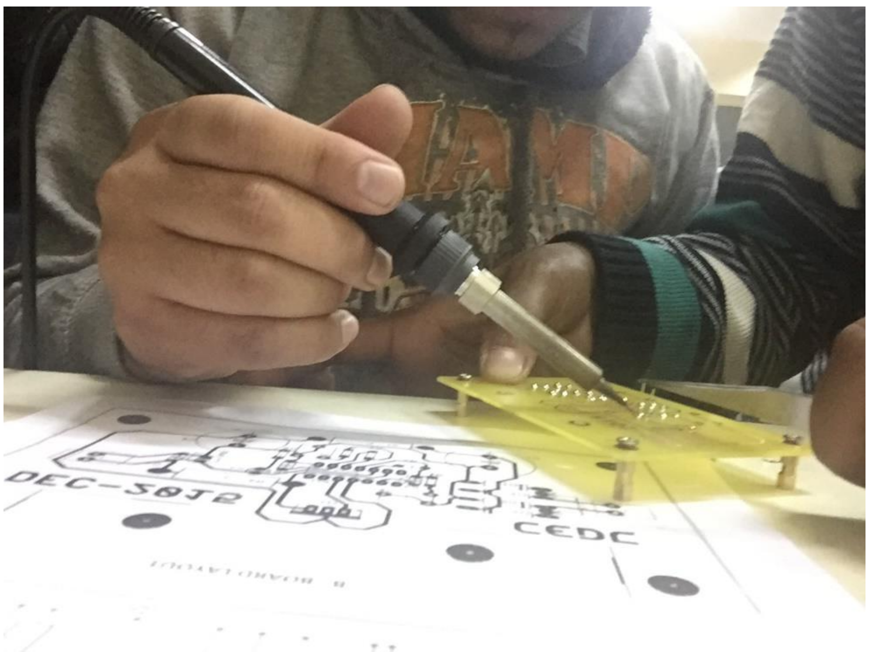


Figure 7.8: Soldering of Electronic Components on PCB

COMPLETED POWER SUPPLY

Figure 7.9 (a): Top view of Fabricated Power Supply

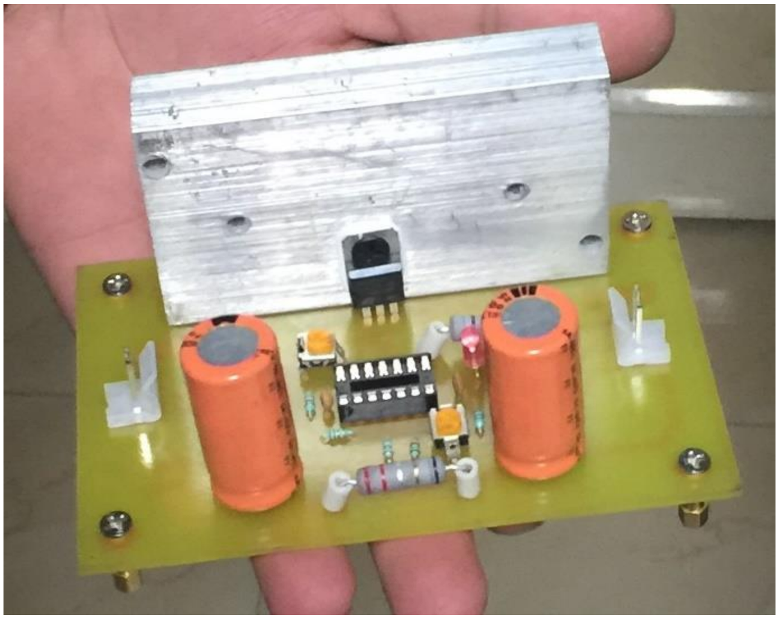


Figure 7.9 (b): Diagonal view of Fabricated Power Supply

7.5 TESTING OF POWER SUPPLY

ACTIVE LOAD

One way of testing the power supply would be to get a large number of resistors of different values and for each value of resistance, calculate the output voltage and current. But this is a very tedious process and also much time consuming.

Second way is with the help of an Active load. The circuit is shown in figure:-

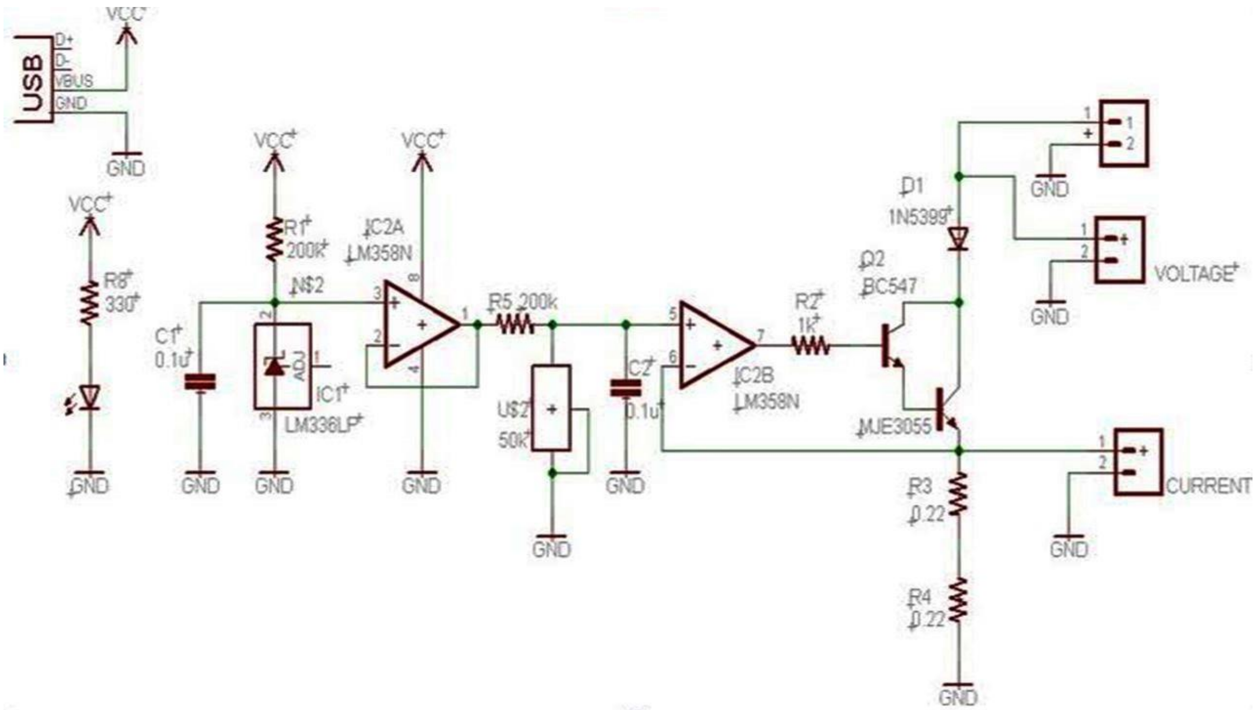


Figure 7.10: Schematic of Active Load PCB

By changing the value of VREF, the voltage at the inverting terminal and hence across the resistor R2 changes, therefore the current through R2 changes (VREF/R2). This current is being drawn from the power supply and therefore effectively the current drawn from the supply is being varied. At each value of VREF, measure the current sense and voltage sense with the help of a multimeter.

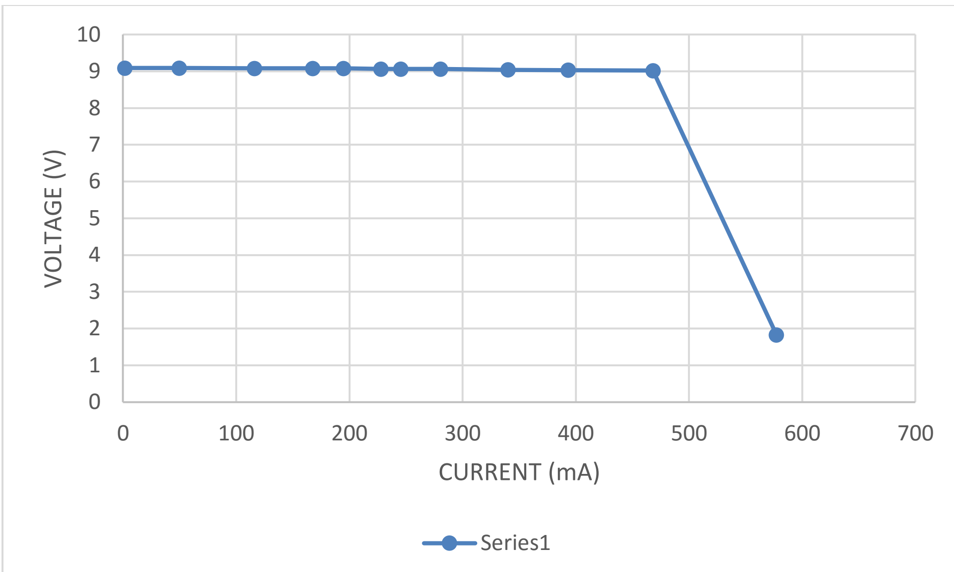
7.6 OBSERVATIONS

S.no	V Sense(Volts)	I SENSE(V/0.44)(mA)
1.	9.09	1.5909
2.	9.09	49.54
3.	9.08	116.13
4.	9.08	167.5
5.	9.08	194.72
6.	9.06	227.95
7.	9.06	245.45
8.	9.06	280.45
9.	9.04	340.01
10.	9.03	393.40
11.	9.02	468.18
12.	1.83	577.27

7.7 GRAPH

X-Axis: Current (mA)

Y-Axis: Voltage (V)



Load Regulation=$\Delta Vout/\Delta Iout$

= (9.09-9.02)/ (468.18-1.59)

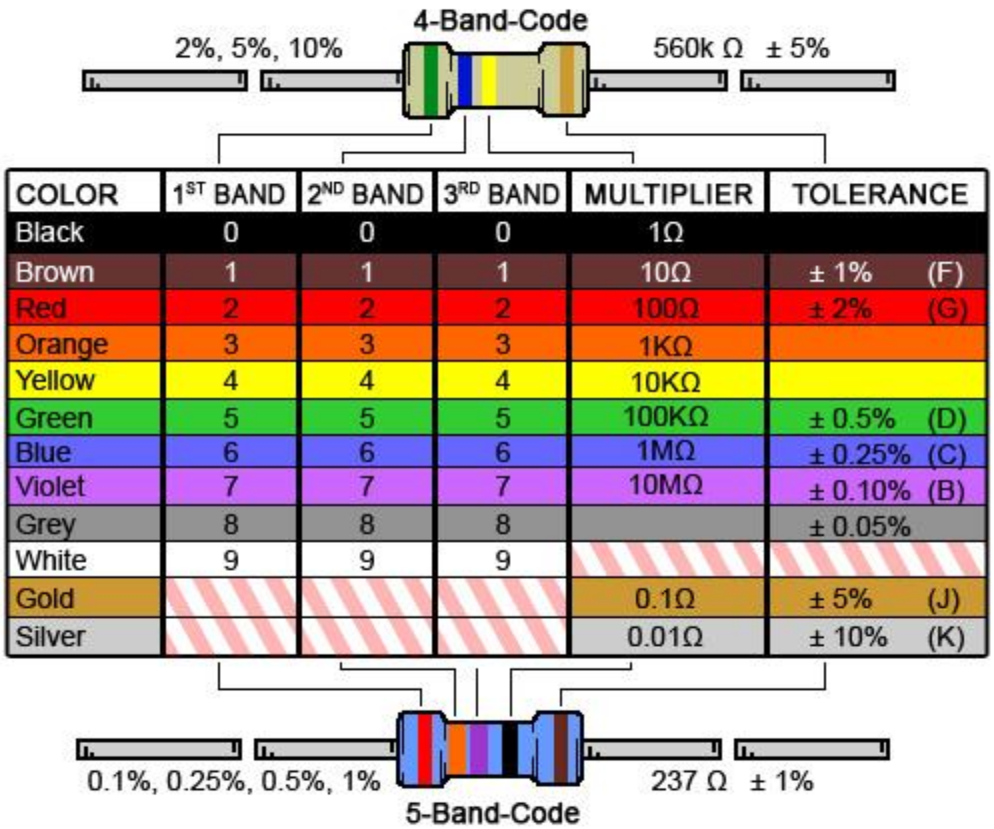
=<u>0.015002%</u>

Power Supply has been designed with a Load Regulation of <u>0.015002%</u>

APPENDIX

A.1

Resistor Color Codes



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

A.2 LM723 Datasheet

LM723/LM723C Voltage Regulator

Check for Samples: LM723, LM723C

FEATURES

- 150 mA Output Current Without External Pass Transistor
- Output Currents in Excess of 10A Possible by Adding External Transistors
- Input Voltage 40V Max
- Output Voltage Adjustable from 2V to 37V
- Can be Used as Either a Linear or a Switching Regulator

DESCRIPTION

The LM723/LM723C is a voltage regulator designed primarily for series regulator applications. By itself, it will supply output currents up to 150 mA; but external transistors can be added to provide any desired load current. The circuit features extremely low standby current drain, and provision is made for either linear or foldback current limiting.

The LM723/LM723C is also useful in a wide range of other applications such as a shunt regulator, a current regulator or a temperature controller.

The LM723C is identical to the LM723 except that the LM723C has its performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Connection Diagram

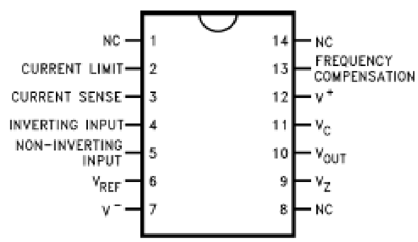
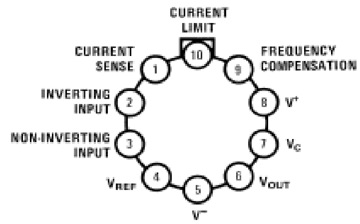


Figure 1. Top View
CDIP Package or PDIP Package
See Package J or NFF0014A



Note: Pin 5 connected to case.

Figure 2. Top View
TO-100
See Package LME

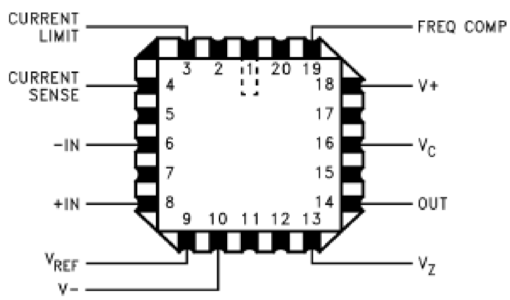
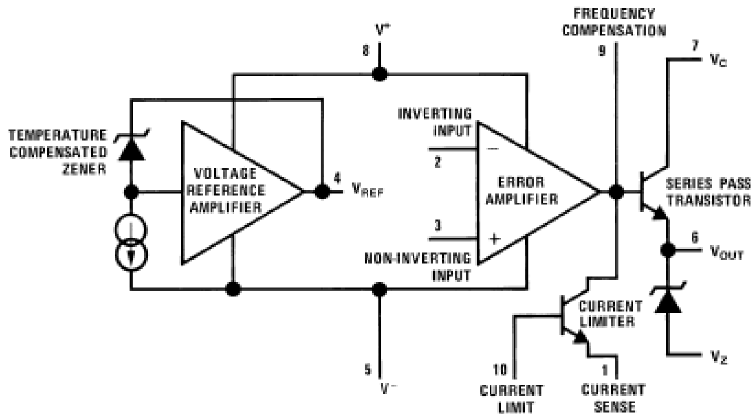


Figure 3. Top View
See Package NAJ0020A

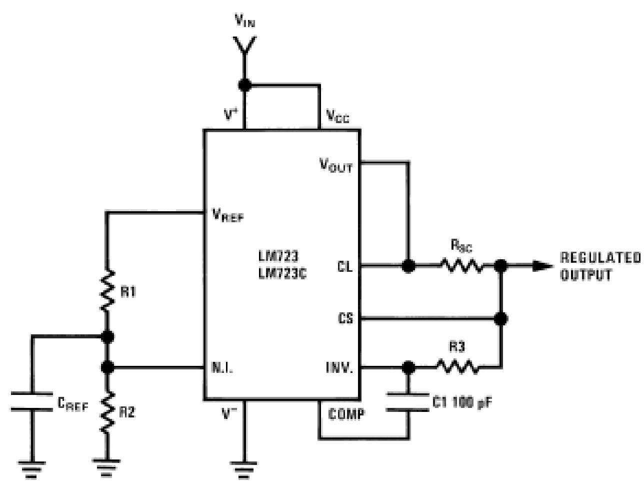
Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

Equivalent Circuit*



*Pin numbers refer to metal can package.

Typical Application



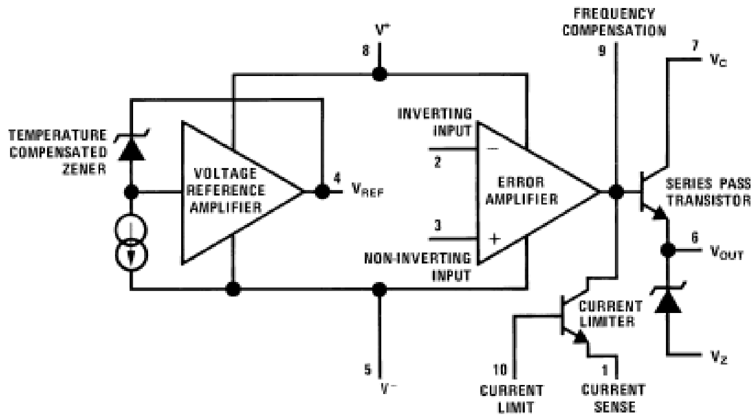
Note: $R3 = \frac{R1\ R2}{R1 + R2}$

for minimum temperature drift.

Typical Performance	
Regulated Output Voltage	5V
Line Regulation (ΔV_{IN} = 3V)	0.5mV
Load Regulation (ΔI_L = 50 mA)	1.5mV

Figure 4. Basic Low Voltage Regulator (V_{OUT} = 2 to 7 Volts)

Equivalent Circuit*



*Pin numbers refer to metal can package.

Typical Application

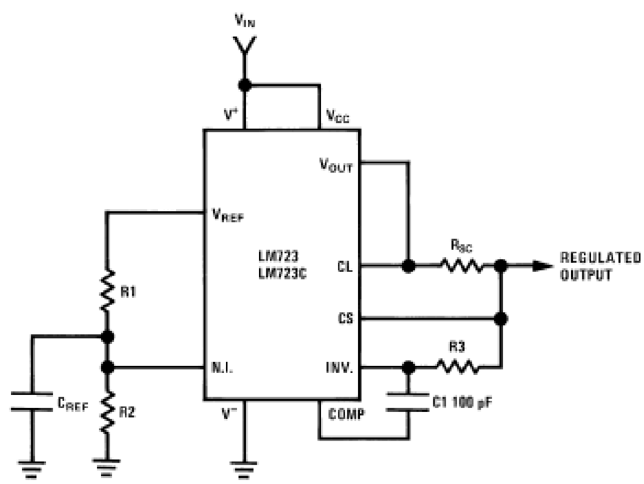


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Figure 4. Basic Low Voltage Regulator (V_{OUT} = 2 to 7 Volts)

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM723CH	ACTIVE	TO-100	LME	10	500	TBD	Call TI	Call TI	0 to 70	(LM723CH ~ LM723CH)	Samples
LM723CH/NOPB	ACTIVE	TO-100	LME	10	500	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM	0 to 70	(LM723CH ~ LM723CH)	Samples
LM723CN/NOPB	ACTIVE	PDIP	NFF	14	25	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	0 to 70	LM723CN	Samples
LM723H	ACTIVE	TO-100	LME	10	500	TBD	Call TI	Call TI	-55 to 150	(LM723H ~ LM723H)	Samples
LM723H/NOPB	ACTIVE	TO-100	LME	10	500	Green (RoHS & no Sb/Br)	Call TI	Level-1-NA-UNLIM	-55 to 150	(LM723H ~ LM723H)	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.