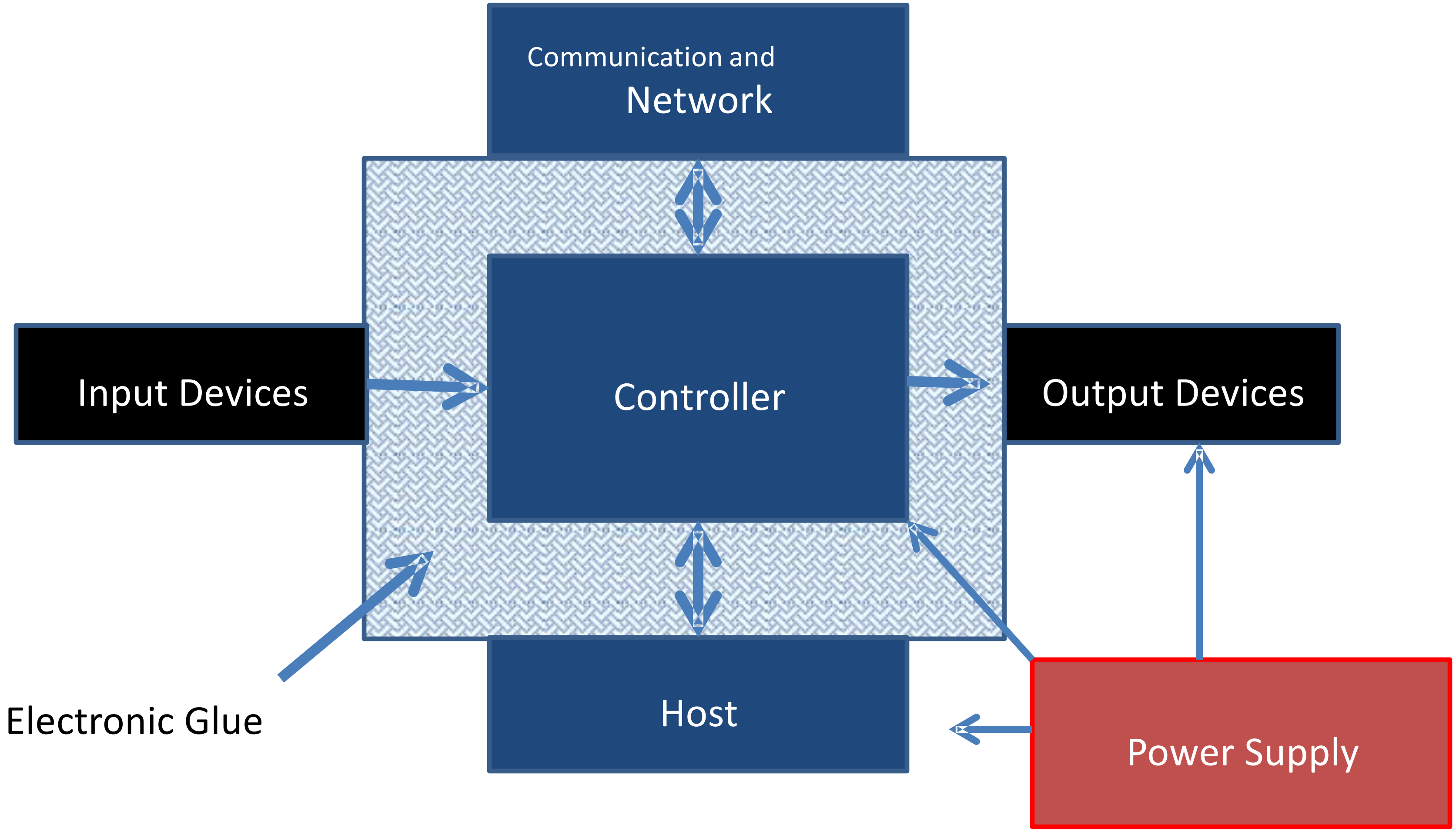
6-Box Model: Power Supply

EHDD U-3

6-Box Model

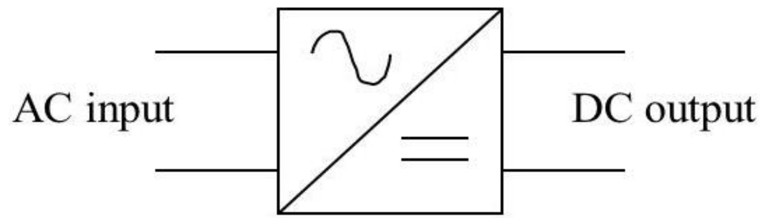

Communication and
Network
Input Devices
Controller
Output Devices
Electronic Glue
Host
Power Supply

Power Supply

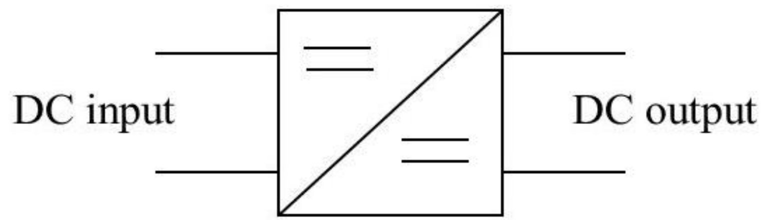
Types of interfaces:

- dc-dc: dc-dc converter
- ac-dc: rectifier
- dc-ac: inverter
- ac-ac: cycloconverter (used less often)

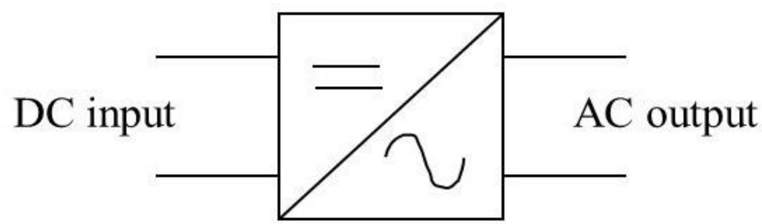
AC to DC: RECTIFIER



DC to DC: CHOPPER



DC to AC: INVERTER



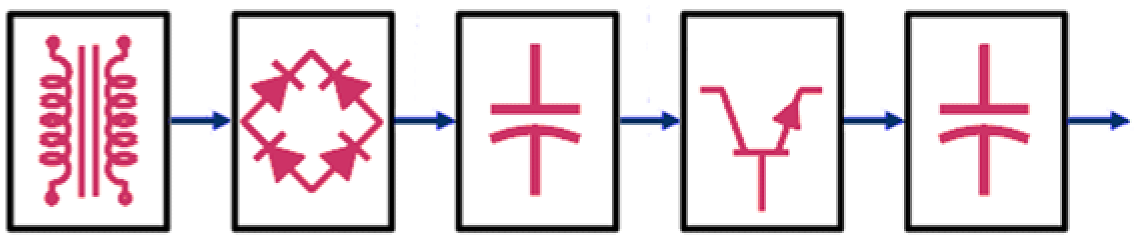
Power Supply

- Around 95% of the electronic equipments are powered from low voltage DC supplies.
- The source will be either a battery or a power supply converting AC mains into one or more low voltage DC supplies.
- Electronic components require a DC supply that is **well regulated**, has **low noise characteristics** and provides a **fast response to load changes**.

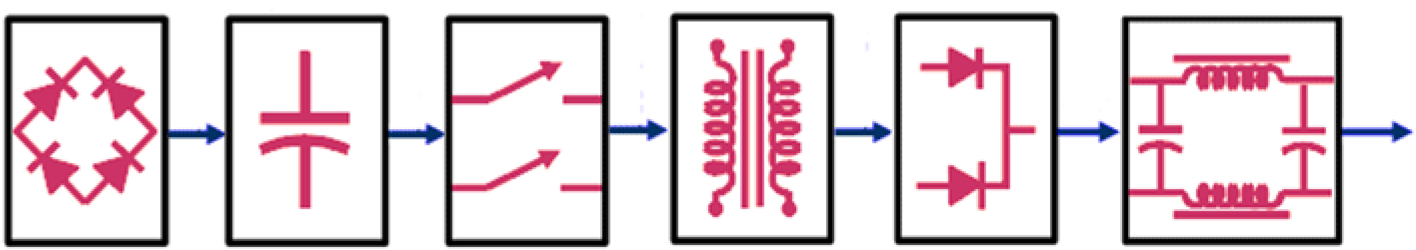



DC Regulated Power Supply

Linear topology



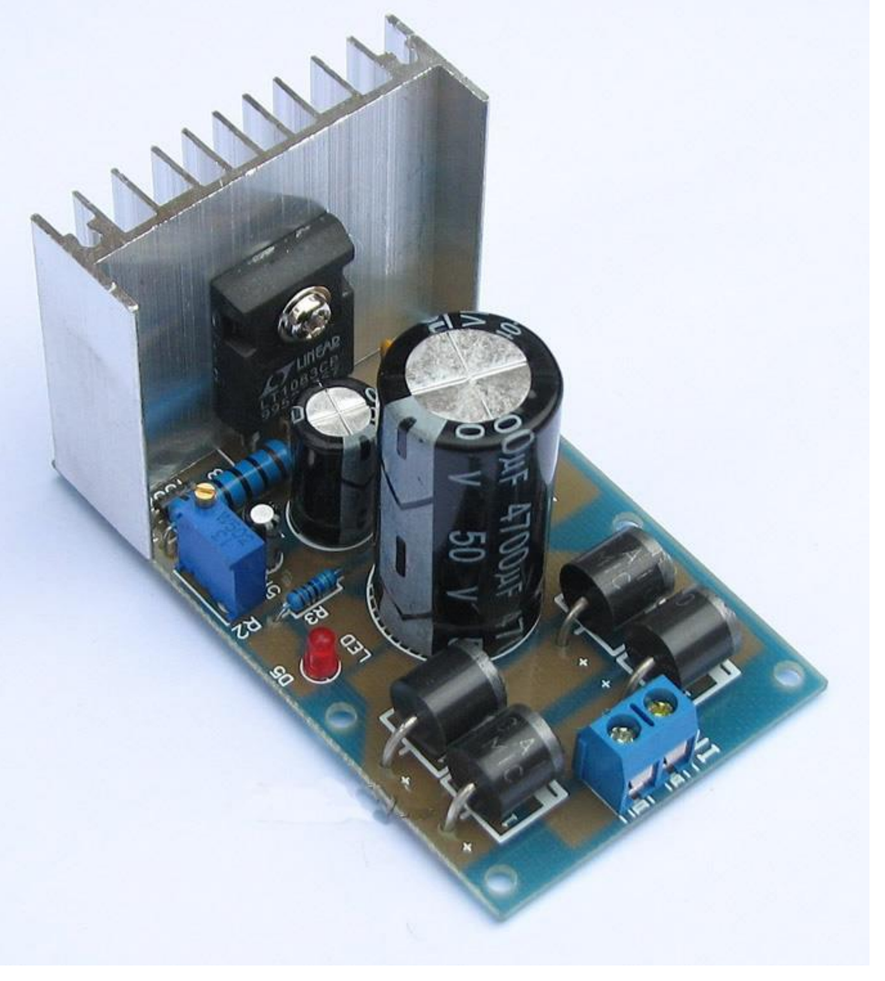
Switched mode (SMPS)



DC Regulated Power Supply

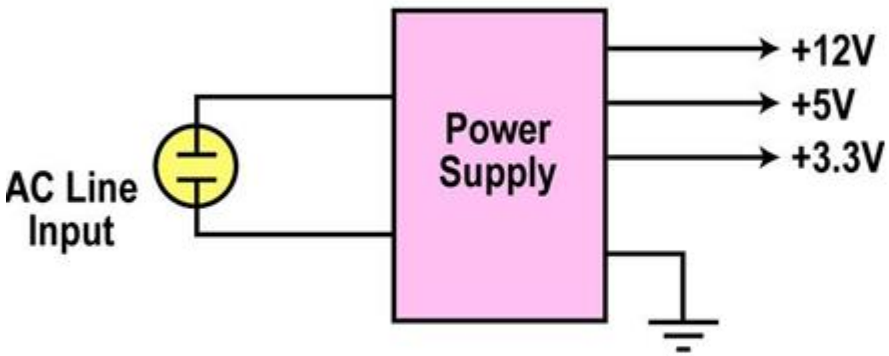
Power Supply	Linear	SMPS
Size	Large and Heavy	Small and Light
Efficiency	30-40%	70-95%
Complexity	Simple	Complex
EMI	Low Noise	Filtering Required
Cost	High (Due to Material)	Low

Linear Power Supply



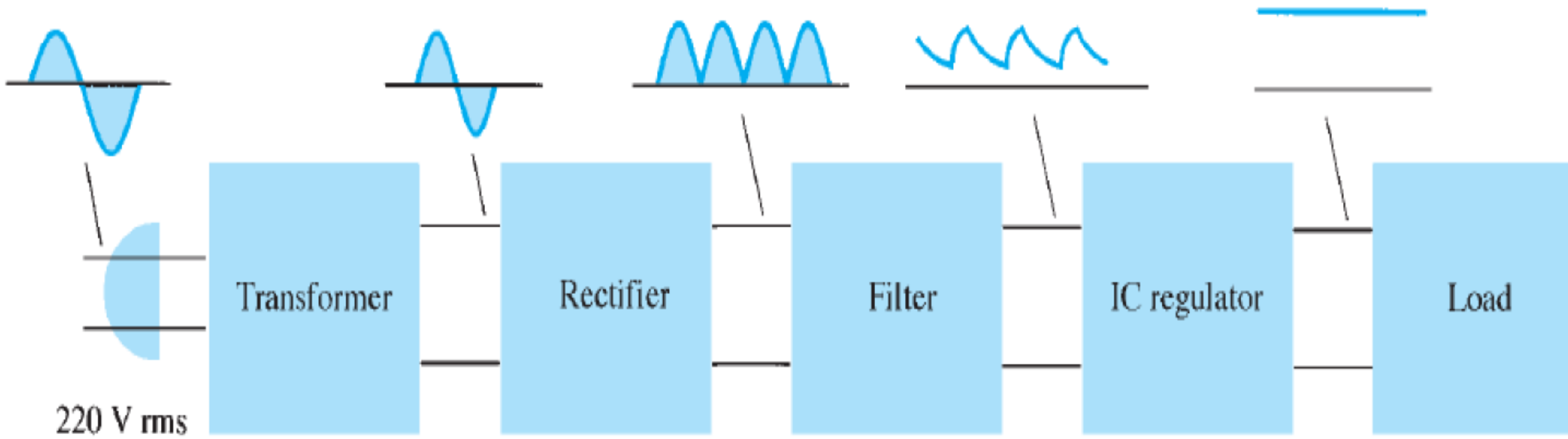
Linear Power Supply Characteristics

- The input is the 230 volt, 50 Hz AC.
- The power supply converts the AC into DC and provides one or more DC output voltages.
- Some modern electronic circuits need two or more different voltages.
- Common voltages are 48, 24, 15, 12, 9, 5, 3.3, 2.5, 1.8, 1.5, 1.2 and 1 volts.
- A good example of a modern power supply is the one inside a PC that furnishes 12, 5, 3.3 and 1.2 volts.



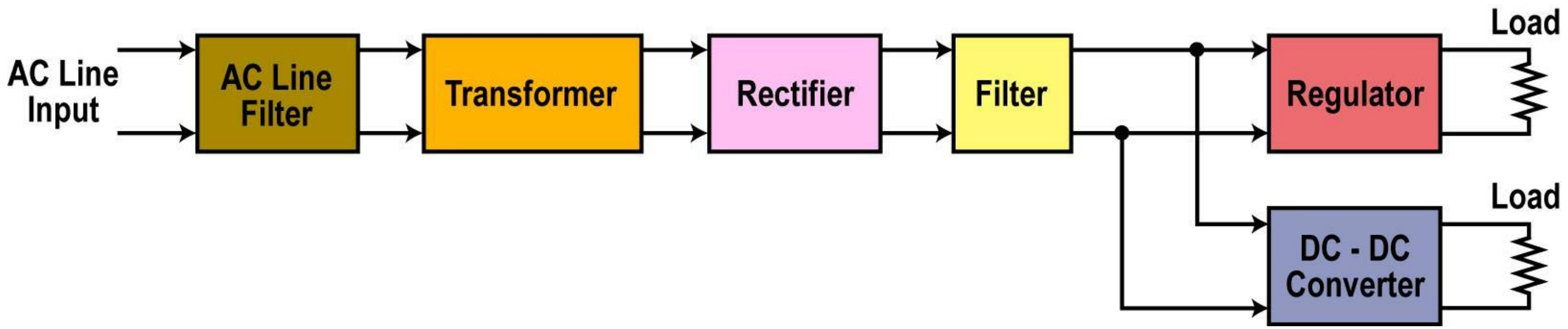
Components of a Power Supply

- Main circuits in most power supplies.



1. The AC voltage, typically 220 V RMS, is connected to a transformer, which steps that ac voltage down to the level for the desired dc output.
2. A diode rectifier then provides a full-wave rectified voltage, which is initially filtered by a basic capacitor filter to produce a dc voltage.
3. A regulator circuit can use this dc input to provide a dc voltage that **remains constant if input or load changes.**

Transformer



- A transformer is commonly used to step the input AC voltage level down or up. Most electronic circuits operate from voltages lower than the AC line voltage so the transformer normally steps the voltage down by its turns ratio to a desired lower level.
- For example, a transformer with a turns ratio of 20 to 1 would convert the 230 volt 50 Hz input sine wave into a 11.5 volt sine wave.

Rectifier

- The rectifier converts the AC sine wave into a pulsating DC wave.
- There are several forms of rectifiers used but all are made up of diodes.
- Rectifier types and operation will be covered later.

Filter

- The rectifier produces a DC output but it is pulsating rather than a constant steady value over time like that from a battery.
- A filter is used to remove the pulsations and create a constant output.
- The most common filter is a large capacitor.

Regulator

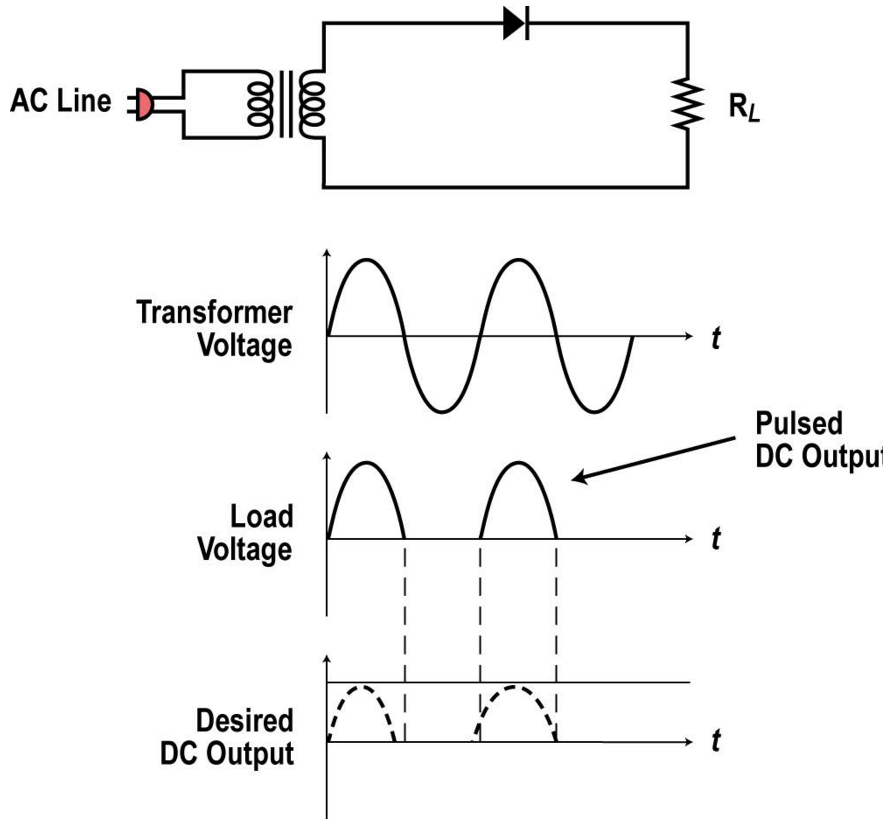
- The regulator is a circuit that helps maintain a fixed or constant output voltage.
- Changes in the load or the AC line voltage will cause the output voltage to vary.
- Most electronic circuits cannot withstand the variations since they are designed to work properly with a fixed voltage.
- The regulator fixes the output voltage to the desired level then maintains that value despite any output or input variations.

DC-DC Converter

- Most modern power supplies also contain one or more DC-DC converters
- Modern electronics often demand different voltages to function.
- A DC-DC converter changes one DC voltage to another, higher or lower DC voltage.
- A DC-DC converter is used with a power supply to prevent the need for a second AC-DC supply.

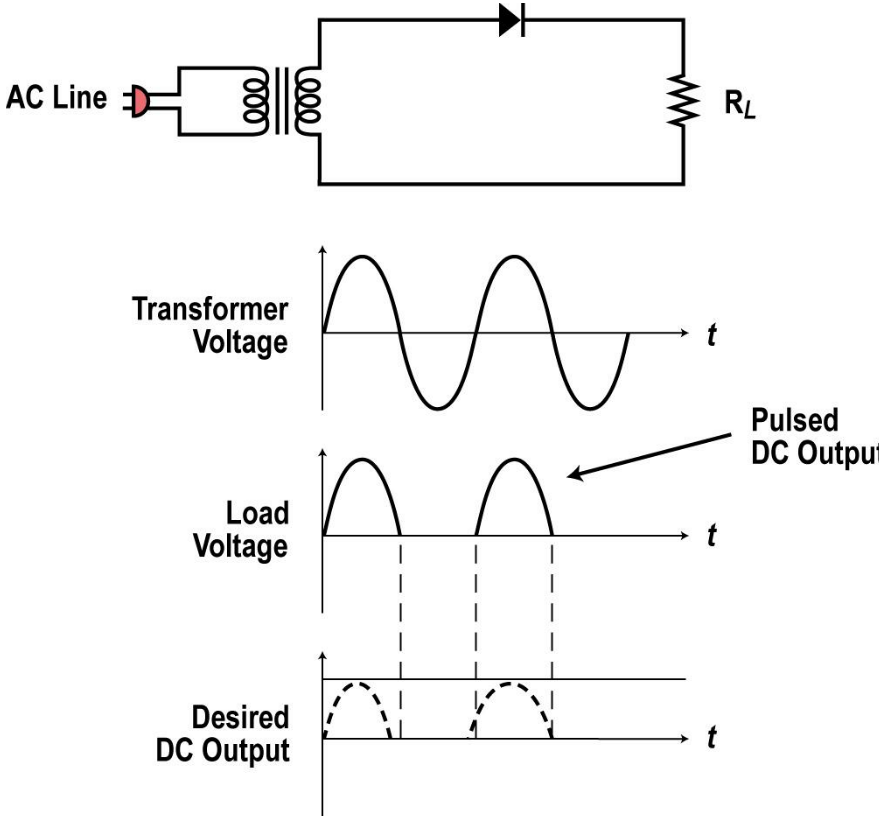
How Rectifiers Work

- The simplest form of rectifier is the half wave rectifier shown.
- Only the transformer, rectifier diode, and load (R_L) are shown without the filter and other components.
- The half wave rectifier produces one sine pulse for each cycle of the input sine wave.
- When the sine wave goes positive, the anode of the diode goes positive causing the diode to be forward biased. The diode conducts and acts like a closed switch letting the positive pulse of the sine wave to appear across the load resistor.



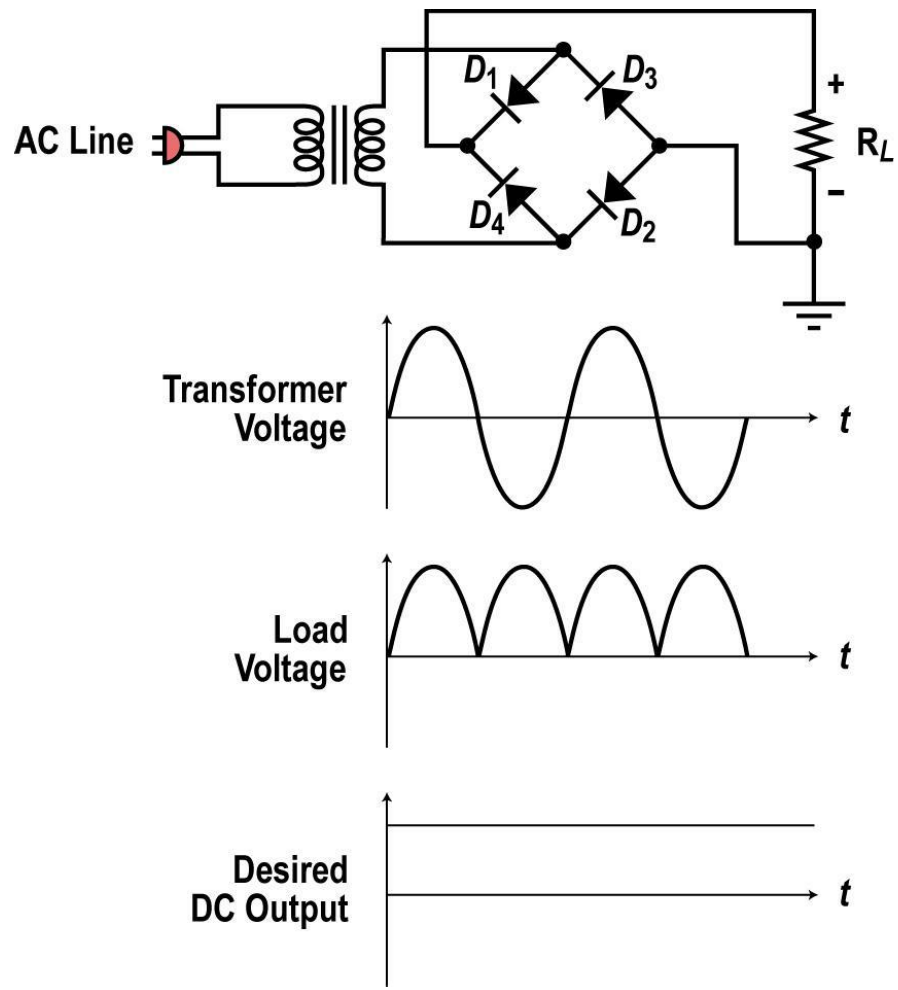
How Rectifiers Work (continued)

- When the sine wave goes negative, the diode anode will be negative so the diode will be reverse biased and no current will flow.
- No negative voltage will appear across the load. The load voltage will be zero during the time of the negative half cycle.
- See the waveforms that show the positive pulses across the load. These pulses need to be converted to a constant DC.

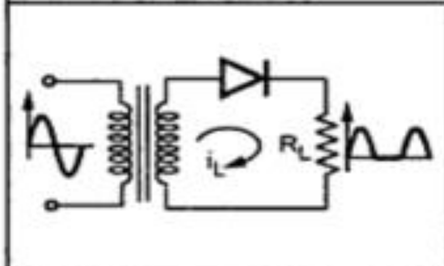
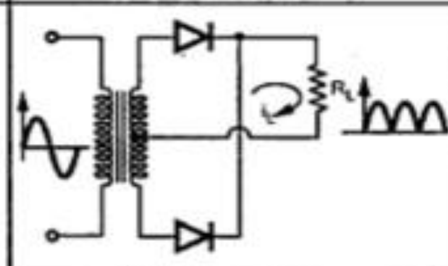
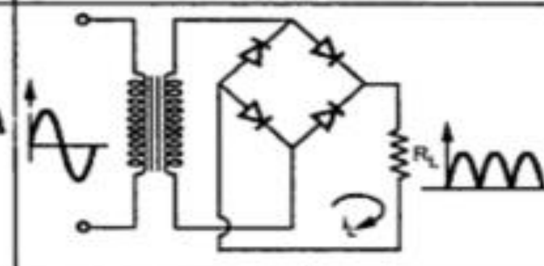


Bridge Rectifier

- Another widely used rectifier is the bridge rectifier. It uses four diodes.
- This is called a full wave rectifier as it produces an output pulse for each half cycle of the input sine wave.
- On the positive half cycle of the input sine wave, diodes D1 and D2 are forward biased so act as closed switches appearing in series with the load.
- On the negative half cycle, diode D1 and D2 are reverse biased and diodes D3 and D4 are forward biased so current flows through the load in the same direction.



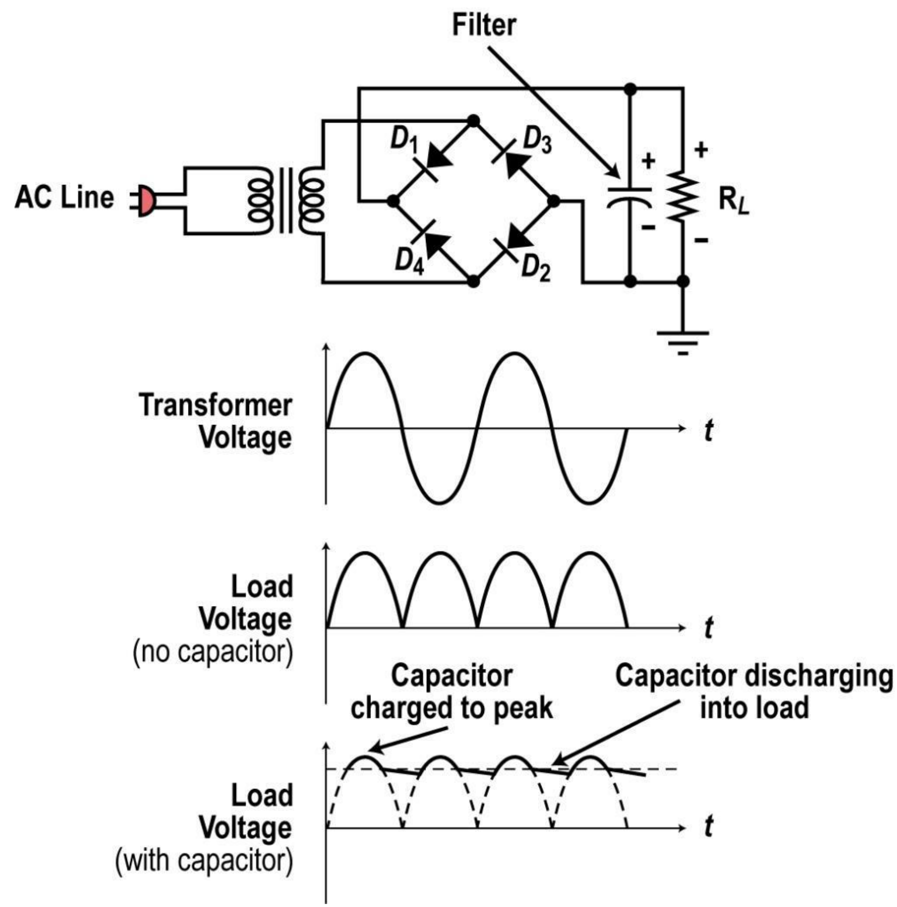
Rectifiers Types

Circuit diagrams		
Half wave	Full wave	Bridge
		

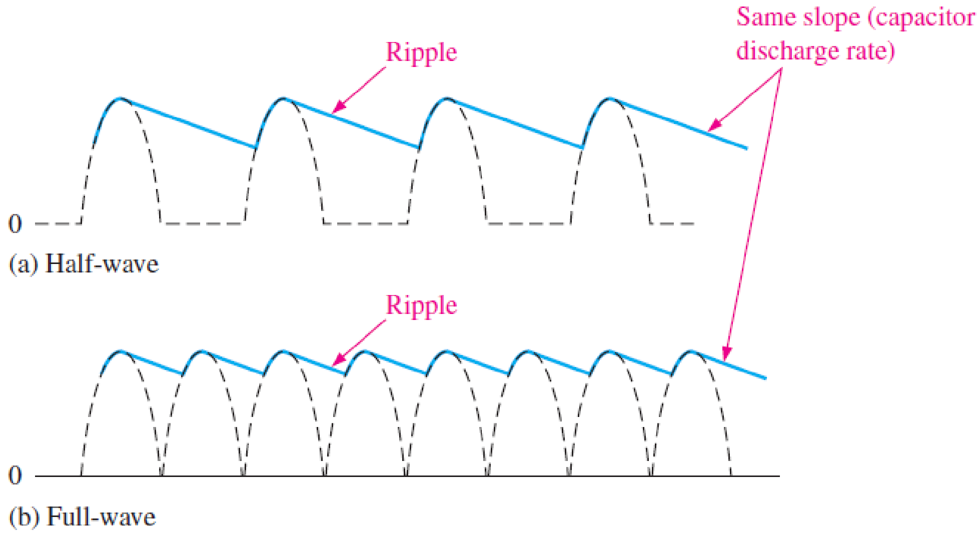
Sr. No.	Parameter	Half wave	Full wave	Bridge
1.	Number of diodes	1	2	4
2.	Average D.C. current (I_{DC})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
3.	Average D.C. voltage (E_{DC})	$\frac{E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$
4.	R.M.S. current (I_{RMS})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
5.	D.C. power output (P_{DC})	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4}{\pi^2} I_m^2 R_L$	$\frac{4}{\pi^2} I_m^2 R_L$
6.	A.C. power input (P_{AC})	$\frac{I_m^2(R_L + R_f + R_s)}{4}$	$\frac{I_m^2(R_f + R_s + R_L)}{2}$	$\frac{I_m^2(2R_f + R_s + R_L)}{2}$
7.	Maximum rectifier efficiency (η)	40.6 %	81.2 %	81.2 %
8.	Ripple factor (γ)	1.21	0.482	0.482
9.	Maximum load current (I_m)	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + 2R_f + R_L}$
10.	PIV rating of diode	E_{sm}	$2\ E_{sm}$	E_{sm}
11.	Ripple frequency	50 Hz	100 Hz	100 Hz
12.	T.U.F.	0.287	0.693	0.812

How the Filter Works

- A large capacitor is connected across the load resistor. This capacitor filters the pulses into a more constant DC.
- When the diode conducts, the capacitor charges up to the peak of the sine wave.
- Then when the sine voltage drops, the charge on the capacitor remains. Since the capacitor is large it forms a long time constant with the load resistor. The capacitor slowly discharges into the load maintaining a more constant output.
- The next positive pulse comes along recharging the capacitor and the process continues.



Ripple



Ripple Factor The **ripple factor** (***r***) is an indication of the effectiveness of the filter and is defined as

$$r = \frac{V_{r(pp)}}{V_{DC}}$$

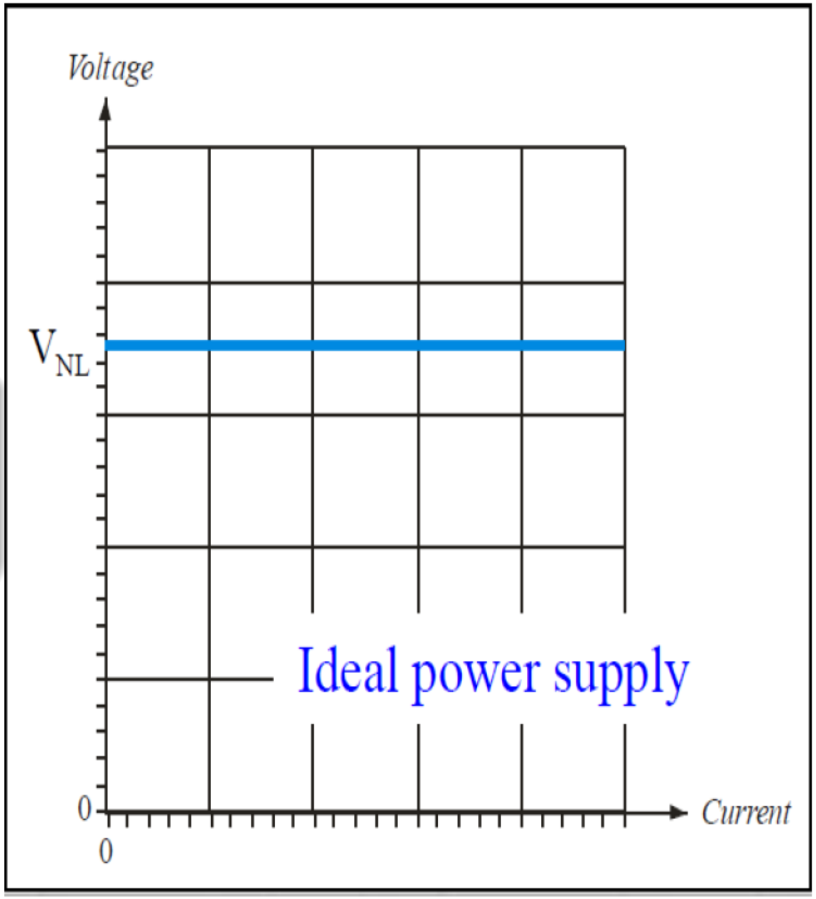
$$V_{r(pp)} \cong \left(\frac{1}{fR_L C}\right) V_{p(rect)}$$

$$V_{DC} \cong \left(1 - \frac{1}{2fR_L C}\right) V_{p(rect)}$$

The Regulator

- Most regulators are ICs .
- These are feedback control circuits that actually monitor the output voltage to detect variations.
- If the output varies, for whatever reason, the regulator circuit automatically adjusts the output back to the set value.
- Regulators hold the output to the desired value.
- Since ripple represents changes in the output, the regulator also compensates for these variations producing a near constant DC output.

Ideal Power Supply



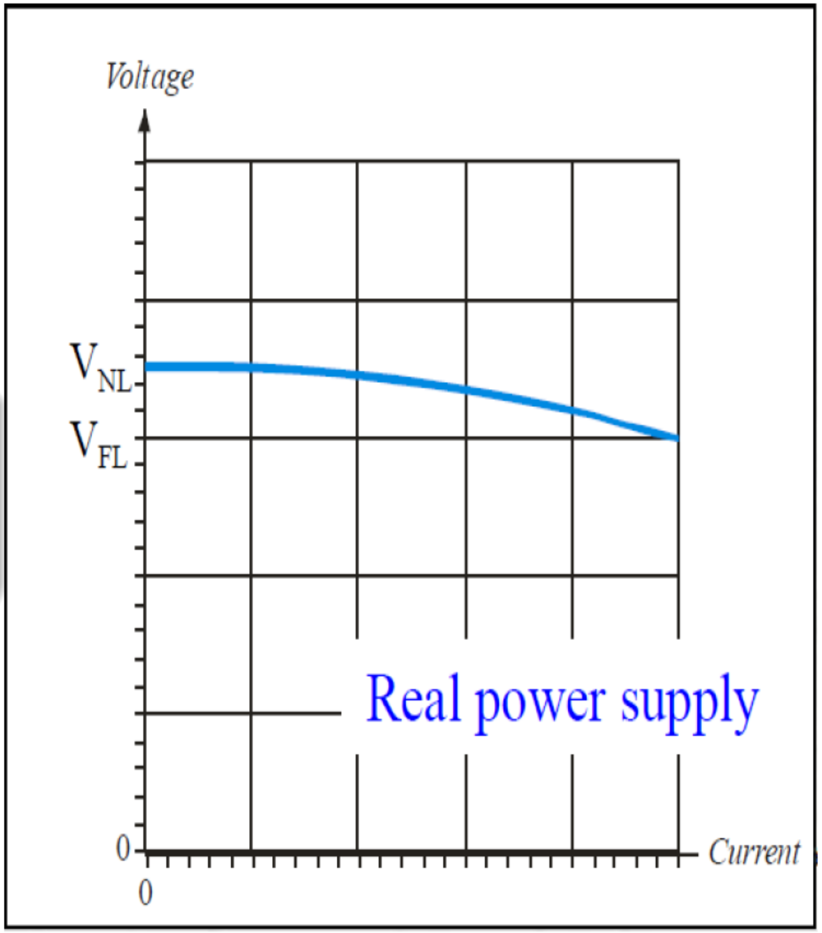
Ideal Power Supply:

It provides a constant dc voltage despite changes to the input voltage or load conditions.

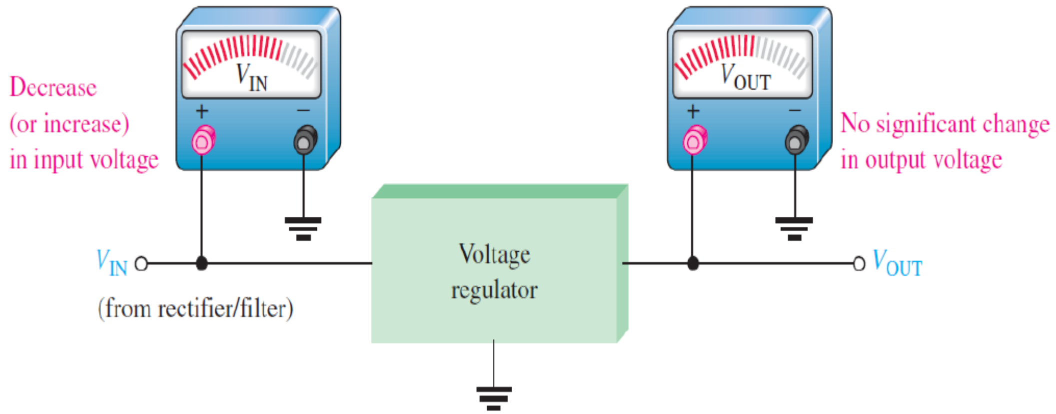
Real Power Supply

Real Power Supply:

The output voltage of a real power supply changes under load or line (input) change.



The Regulator

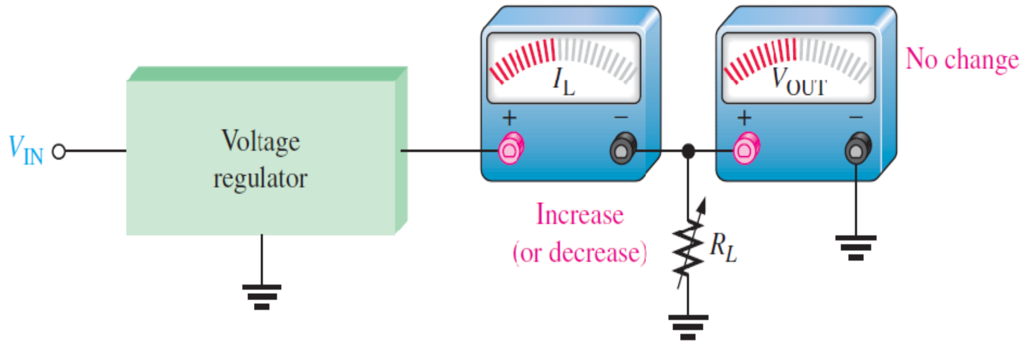


Line Regulation:

It is the percentage change in the output voltage for a given change in the input voltage. It can be expressed in units of $(\%/V)$.

$$\text{Line regulation} = \frac{(\Delta V_{OUT}/V_{OUT})100\%}{\Delta V_{IN}}$$

The Regulator



Load Regulation:

It is the percentage change in output voltage for a given change in load current.
One way to express load regulation is as a percentage change in output voltage from no-load (NL) to full-load (FL).

$$\text{Load regulation} = \left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right)100\%$$

The Regulator

Regulator circuit	Advantage	Disadvantage
Zener Diode	Less parts Simpler construction	Low Current
Series Regulator	Higher current capability Simple to design	Inefficient
Three Terminal Regulator	Simplest design for end user Fewest parts Lowest output noise and ripple	Less efficient Higher currents require larger packages
Switching Regulator	Small size Light weight Higher efficiency Minimum power drop.	More complicated Large number of components

Voltage Regulation

1. Line regulation: To maintain constant output voltage when the input voltage varies. Line regulation is defined as the percentage change in the output voltage for a given change in the input voltage.

$$Line\ regulation = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}}\right)\times 100\%$$

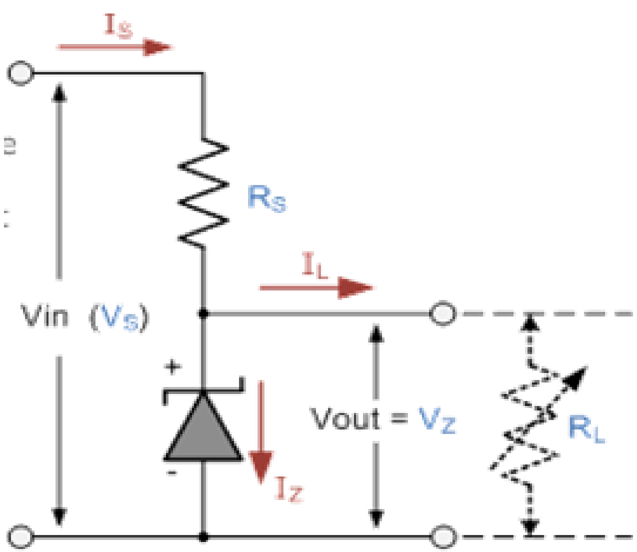
$$Line\ regulation = \frac{\left(\Delta V_{OUT} / V_{OUT}\right)\times 100\%}{\Delta V_{IN}}$$

2. Load regulation: To maintain constant output voltage when the load varies. Load regulation is defined as the % change in the output voltage from no-load (V_{NL}) to full-load (V_{FL}).

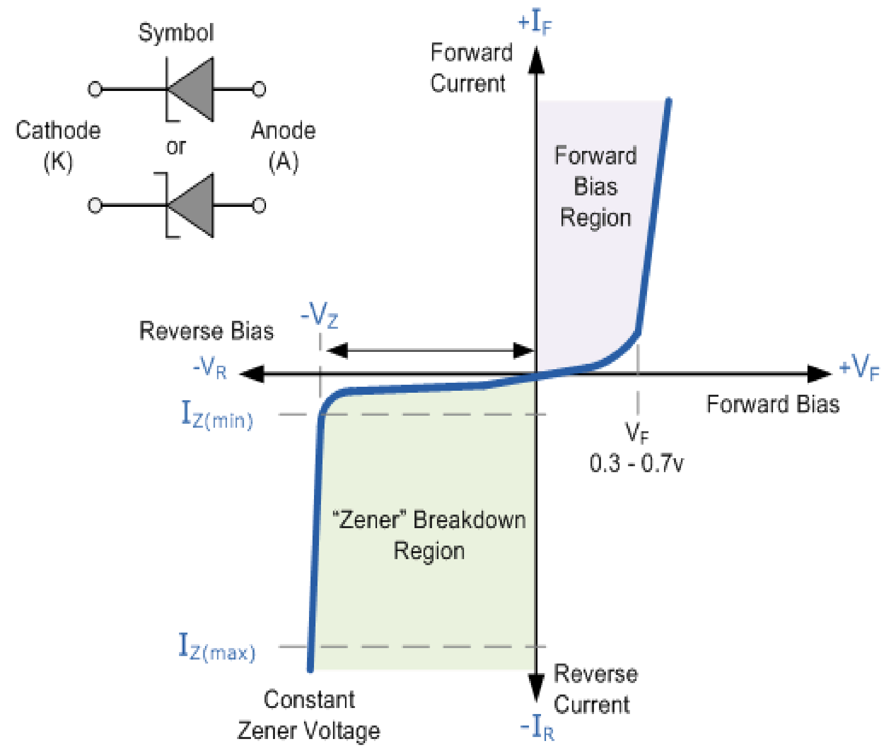
$$Load\ regulation = \left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right)\times 100\%$$

Zener Diode Shunt Regulator

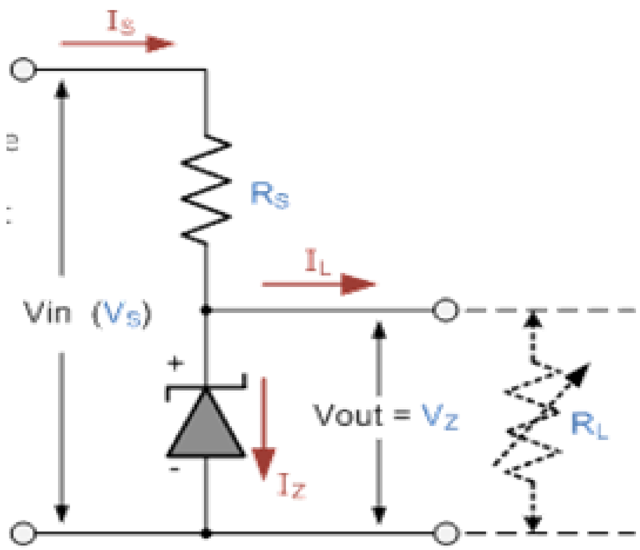
- For low current power supplies - a simple shunt voltage regulator can be made with a resistor and a Zener diode.
- Zener diodes are rated by their breakdown voltage $\mathbf{V_Z}$ (1.24 – 200V, ±5-10%), maximum power $\mathbf{P_Z}$ (typically 250mW-50W) and minimum $\mathbf{I_Z}$ (in µA).



http://www.electronics-tutorials.ws/diode/diode_7.html



Zener Diode Shunt Regulator



$$R_S = \frac{V_S - V_Z}{I_Z}$$

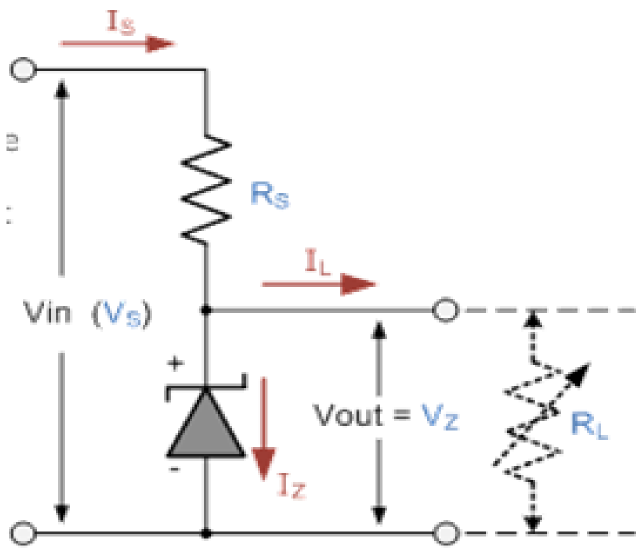
$$I_L = \frac{V_Z}{R_L}$$

$$I_Z = I_S - I_L$$

Line Regulation

Vs increases, Is increases, Iz increases, Vz/Vout Constant

Zener Diode Shunt Regulator



$$R_S = \frac{V_S - V_Z}{I_Z}$$

$$I_L = \frac{V_Z}{R_L}$$

$$I_Z = I_S - I_L$$

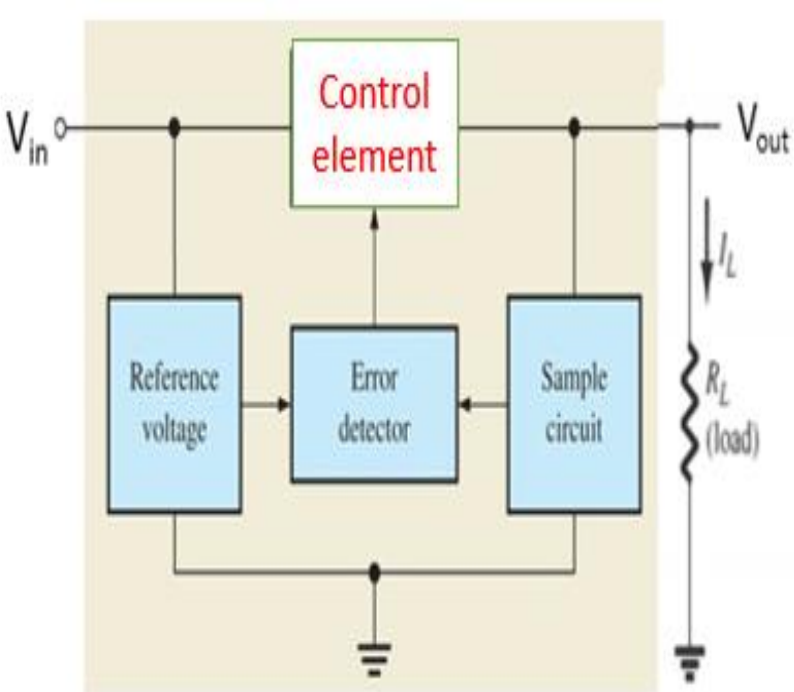
Load Regulation

IL increases, Iz decreases, Vz/Vout Constant

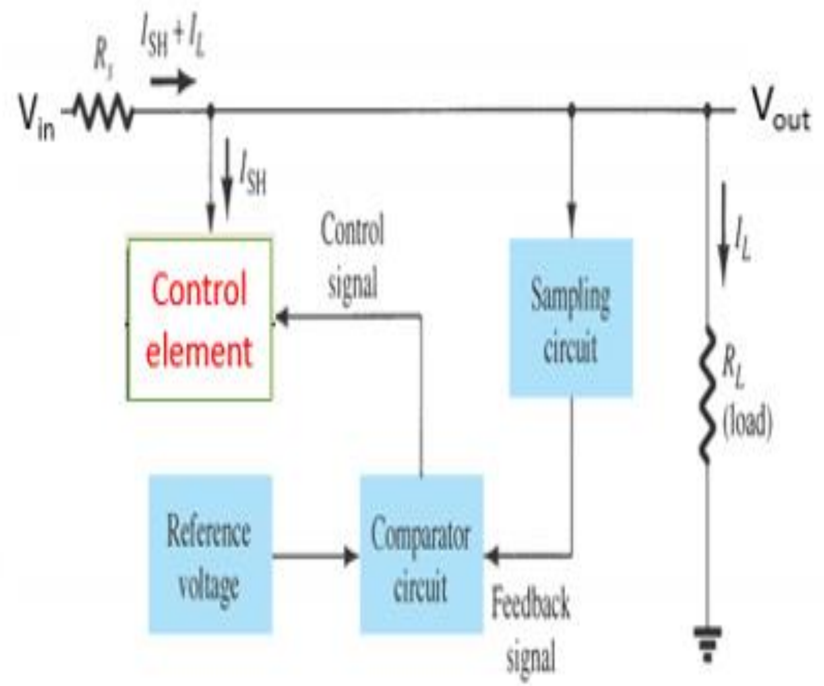
The Basic Linear Regulator

- The linear regulator is a DC-DC converter to provide a constant voltage output without using switching components.
- The linear regulator is very popular in many applications for its low cost, low noise and simple to use.
- Two basic types of linear regulator are the **series regulator** and the **shunt regulator:**
  - **Series regulator:** Control element of series regulator is connected in series with load.
  - **Shunt regulator:** Control element of the shunt regulator is connected in parallel with the load.

The Basic Linear Regulator

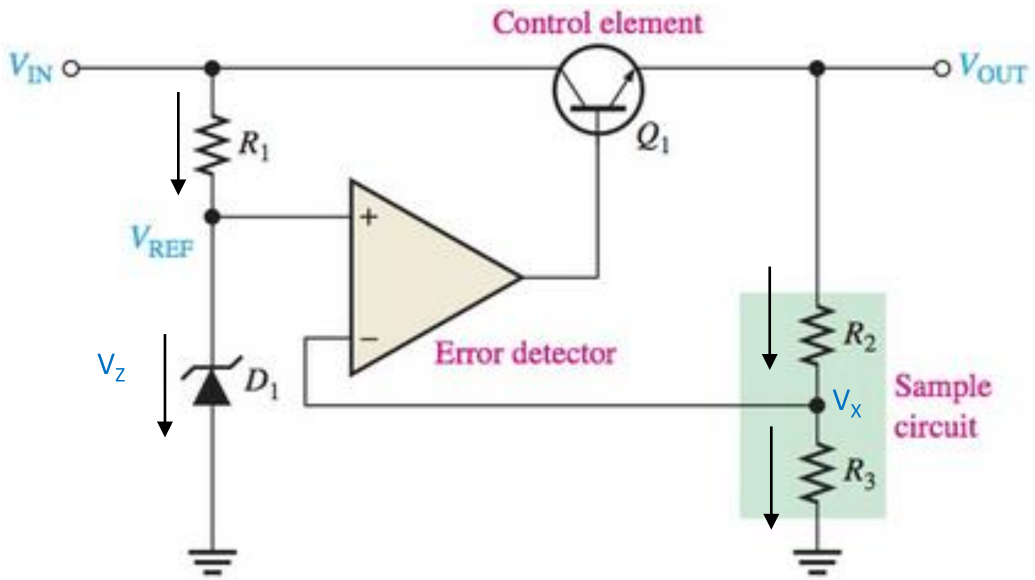


Series regulator



Shunt regulator

Series Linear Regulator

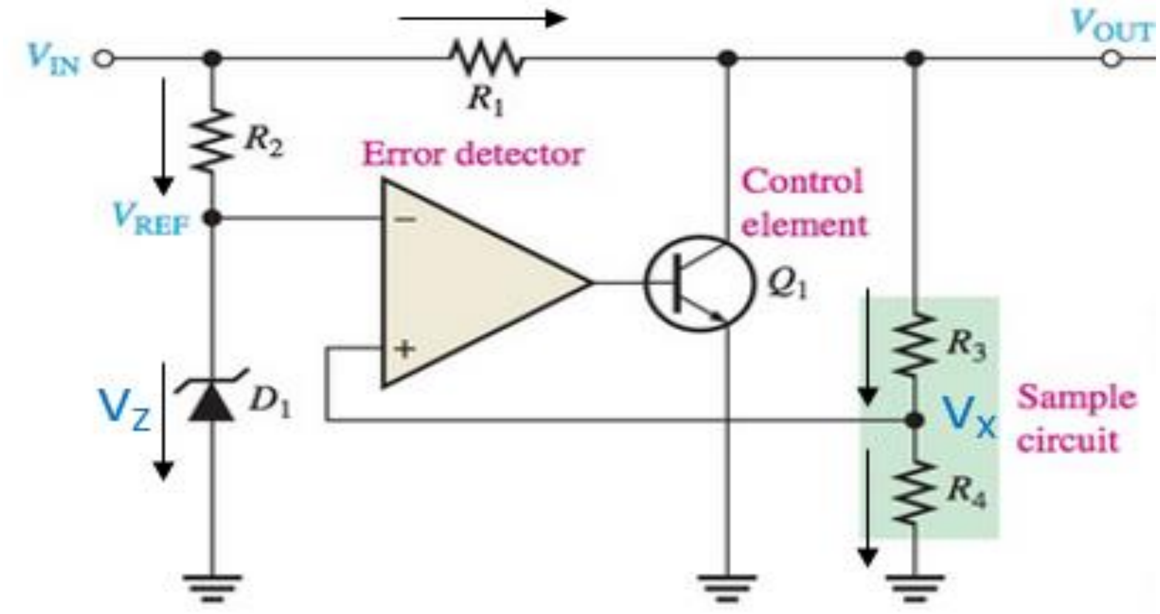


$\mathbf{I_{R1} = (V_{in} - V_{REF}) / R_1 = I_Z}$ ($I_+ = 0 = I\_$ Op-Amp)

$\mathbf{R_1 = (V_{in} - V_{REF})^2 / P_{R1}}$

$\mathbf{I_{R2} = I_{R3} = V_{OUT}/(R_2+R_3)}$ ($I_+ = 0 = I\_$ Op-Amp)

Shunt Linear Regulator

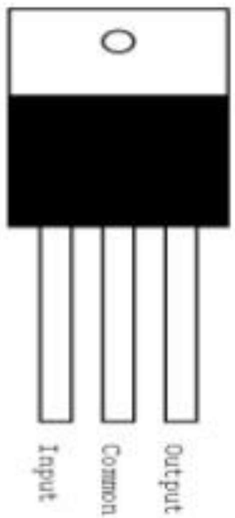


$\mathbf{I_Z = (V_{IN} - V_Z)/R_2 = I_{R2}}$
$\mathbf{I_{Z(max)} = (P_Z / V_Z)}$
$\mathbf{R_1 = (V_{IN} - V_{OUT})/I_{R1}}$
$\mathbf{I_{R1(max)} = (V_{in} - 0)/R_{R1}}$ (when $V_{OUT} = 0$)
$\mathbf{I_{R3} = V_{OUT}/(R_3 + R_4) = I_{R4}}$

IC Regulator

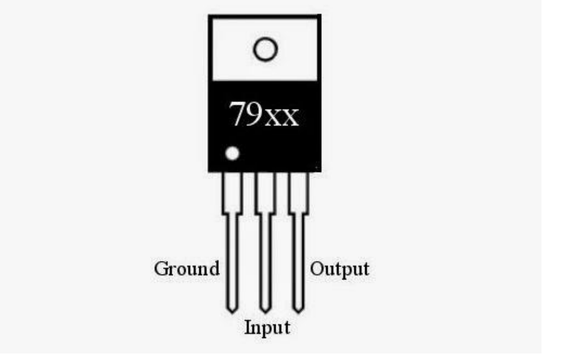
78XX basic features

IC No	Voltage
7805	5V
7806	6V
7808	8V
7809	9V
7810	10V
7812	12V
7815	15V
7818	18V
7824	24V



- **Features**
- 3 terminal positive voltage regulator with nine voltage options
- High Output Current - typically 1.5A
- Short circuit current limit - 750mA at 5v
- Max input voltage = 35v
- Minimum Input Voltage = V_{out} + 2.5

IC Regulator

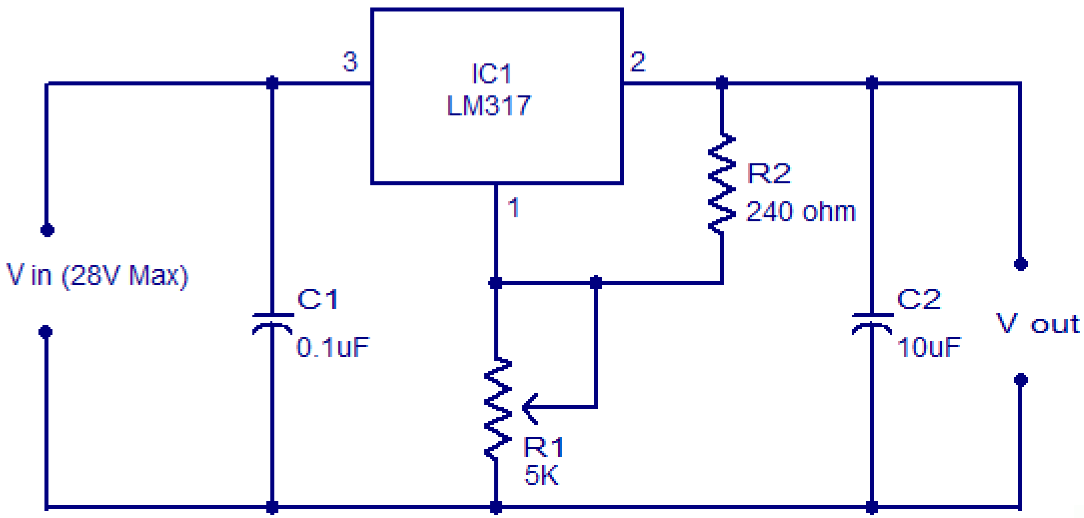


Features of 79XX

IC No	Voltage
7902	-2V
7905	-5V
7905.5	-5.2V
7906	-6.2V
7908	-8V
7912	-12V
7915	-15V
7918	-18V
7924	-24V

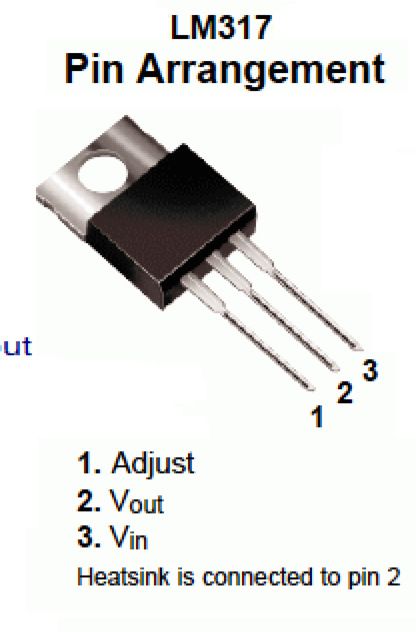
- Same as that of 78XX series except that 79XX series are negative regulators
- They are available in same seven voltage options with two extra voltage options,-2V and -5.2V.

IC Regulator



Typical adjustable regulator using LM317 www.circuitstoday.com

Vout = 1.25V (1+ (R2/R1)) + (I adj x R2)



Linear Regulators Advantages

- Low number of components makes linear power supplies very cost-effectiveness overall and space savings (unless heat sink is used).
- Simplicity and low complexity design makes linear power supplies more reliable.
- No switching noise and low output voltage ripple makes linear power supplies best suitable for applications where noise-sensitivity is essential.
- Low output voltage ripple
- The linear regulator is free of any switching noise, having ripple rejection capability and its low voltage noise, which makes the linear regulator of choice in such noise-averse applications as audio-visual, communication, medical, and measurement devices.

Linear Regulators Disadvantages

- The linear regulator can be very efficient only if V_O is close to V_{IN}.
- The linear regulator (LR) has another limitation, which is the minimum voltage difference between V_{IN} and V_O. When V_O is too close to V_{IN}, the LR may be unable to regulate output voltage anymore.
- The linear regulators that can work with low headroom ($V_{IN} – V_O$) are called low dropout regulators (LDOs).
- The linear regulator or an LDO can only provide step-down DC/DC conversion.
- Typical design may require a heat sink.
- These disadvantages to linear power supplies include size, high heat loss, and lower efficiency levels
- It requires a large transformer and other large components to handle the power. Using larger components increases the overall size and weight of the power supply

LINEAR REGULATORS APPLICATIONS

There are many applications in which linear regulators provide superior solutions to switching supplies:

1. **Simple/low cost solutions**. Linear regulator or LDO solutions are simple and easy to use, especially for low power applications with low output current where thermal stress is not critical. No external power inductor is required.
2. **Low noise/low ripple applications**. For noise-sensitive applications, such as communication and radio devices, minimizing the supply noise is very critical.
3. **Low dropout applications**. For applications where output voltage is close to the input voltage, LDOs may be more efficient than an SMPS.

Linear Power Supply: Case Study

5v regulated DC supply

To build a 5v regulated DC supply from 230 AC

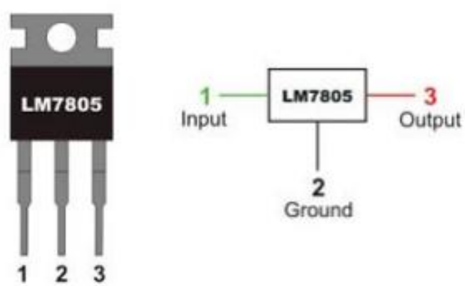
This circuit mainly consists a step down Transformer, a Full wave bridge rectifier and a 5V voltage regulator IC (7805).

We can divide this circuit into four parts: (1) Step down AC voltage (2) Rectification (3) Filtration (4) Voltage Regulation.

Linear Power Supply: Case Study

Step 1: The selection of regulator IC
we are designing for the 5V output voltage, we will select the LM7805 linear regulator IC.

Refer voltage, current and power ratings of the selected regulator IC.
This is done by using the datasheet of the regulator IC.



Ratings

- Input voltage range 7V- 35V
- Output voltage range $V_{Max=5.2V}$, $V_{Min=4.8V}$
- Current rating $I_c = 1A$

- The datasheet prescribes to use a 0.1µF capacitor at the output side to avoid transient changes in the voltages due to changes in load.
- Use a 0.1µF at the input side of the regulator to avoid ripples if any.

Linear Power Supply: Case Study

Step 2: The selection of transformer

- The minimum input to our selected regulator IC is 7V (as per datasheet).
- So, we need a transformer to step down the main AC to at least this value.
- But, between the regulator and secondary side of the transformer, there is a diode bridge rectifier too.
- The rectifier has its own voltage drop across it i.e. 1.4V.
- We need to compe

$$V_{secondary} = 7V + 1.4V$$
$$V_{secondary} = 8.4V (Peakvalue)$$

This means we should select the transformer with a secondary voltage value equal to 9V or at least 10% more than 9V.

we can select a transformer of **current rating 1A** and secondary voltage of 9V. As the regulator IC has a current rating of 1A, we cannot pass more current then this value.

Linear Power Supply: Case Study

Step 3: The selection of diodes for bridge

When selecting a diode for the bridge circuit, consider the **output load current, and maximum peak secondary voltage** of the transformer i-e 9V in our case.

We can select IN4001 diode because it has the **current rating of 1A** more than our desire rating, and **peak reverse voltage of 50V**.

Peak reverse voltage is the voltage a diode can sustain when it is reverse biased.

Linear Power Supply: Case Study

Step 4: The Selection of smoothing capacitor and calculations

While selecting a proper capacitor filter consider, its **voltage, power rating, and capacitance value.**

The **voltage rating** is calculated from the secondary voltage of a transformer.
Rule of thumb is, the capacitor voltage rating must be at least 20% more than the secondary voltage.

So, if the secondary voltage is 13 V (Peak value for 9V), then your capacitor voltage rating can be 50V.

Linear Power Supply: Case Study

Step 4: The Selection of smoothing capacitor and calculations

Capacitance value. It depends upon the output voltage and the output current.

$$C = \frac{I_o}{2\Pi f V_o}$$

Io = Load current i.e. 500mA in our design, Vo = Output voltage i.e. in our case 5V,

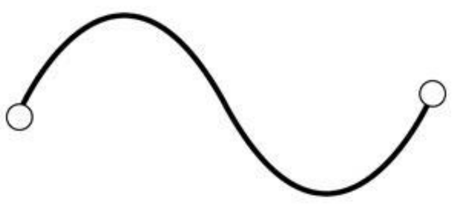
f = Frequency i.e 50Hz

$$C = \frac{500mA}{2 \times \Pi \times 50 \times 5} = 3.1847 \times 10^{-4}$$

Linear Power Supply: Case Study

Step 5: Making the power supply safe

Every design must have a safety feature to protect it from burning. Similarly, our simple supply must have a one i.e. the input fuse.
The input fuse will protect our supply in case of overloading.



DC Regulated Power Supply circuit : 5V, 1A

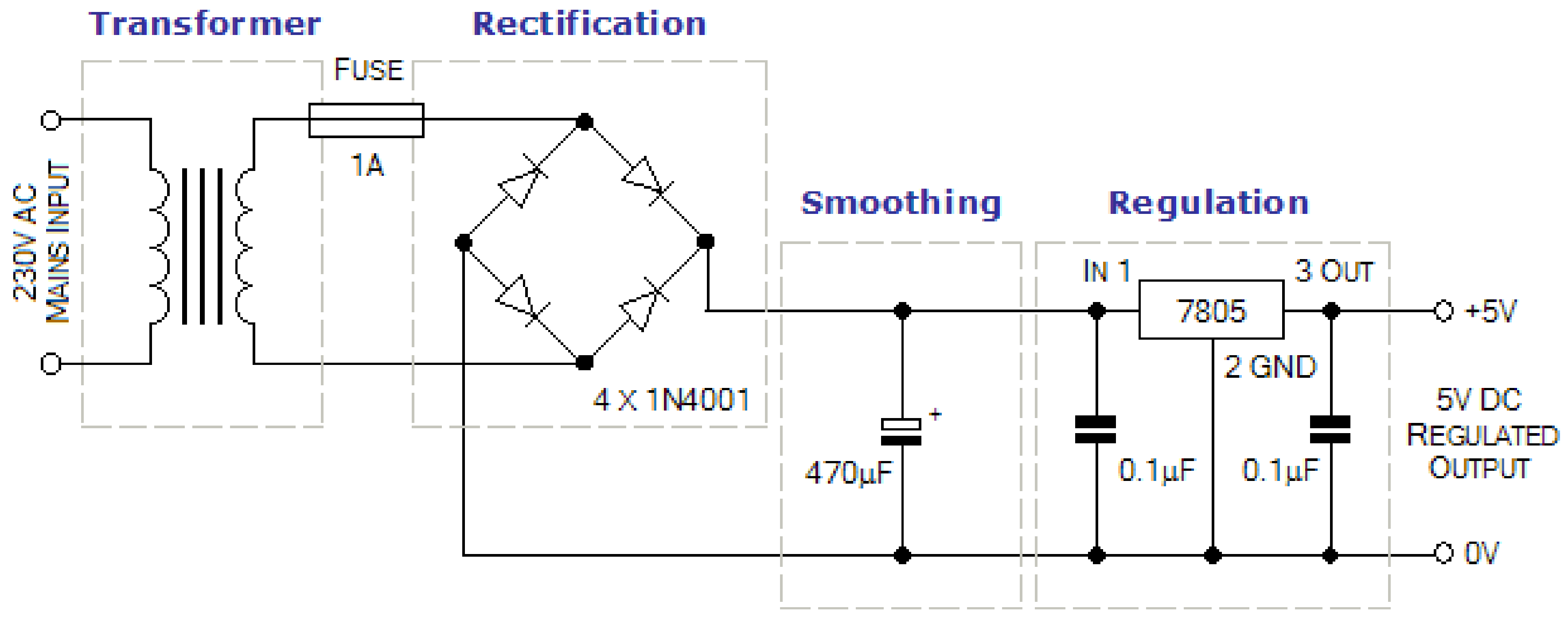
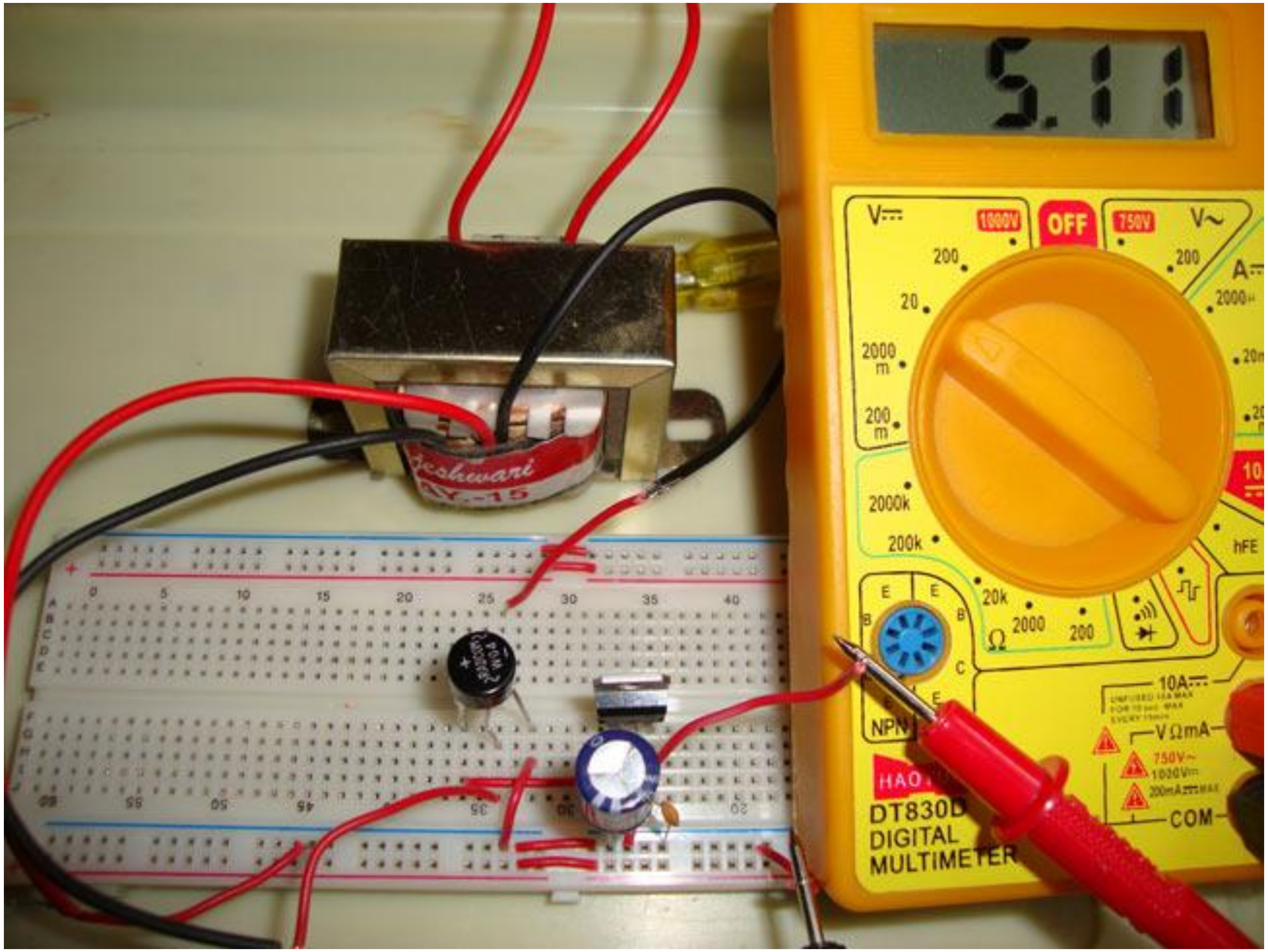
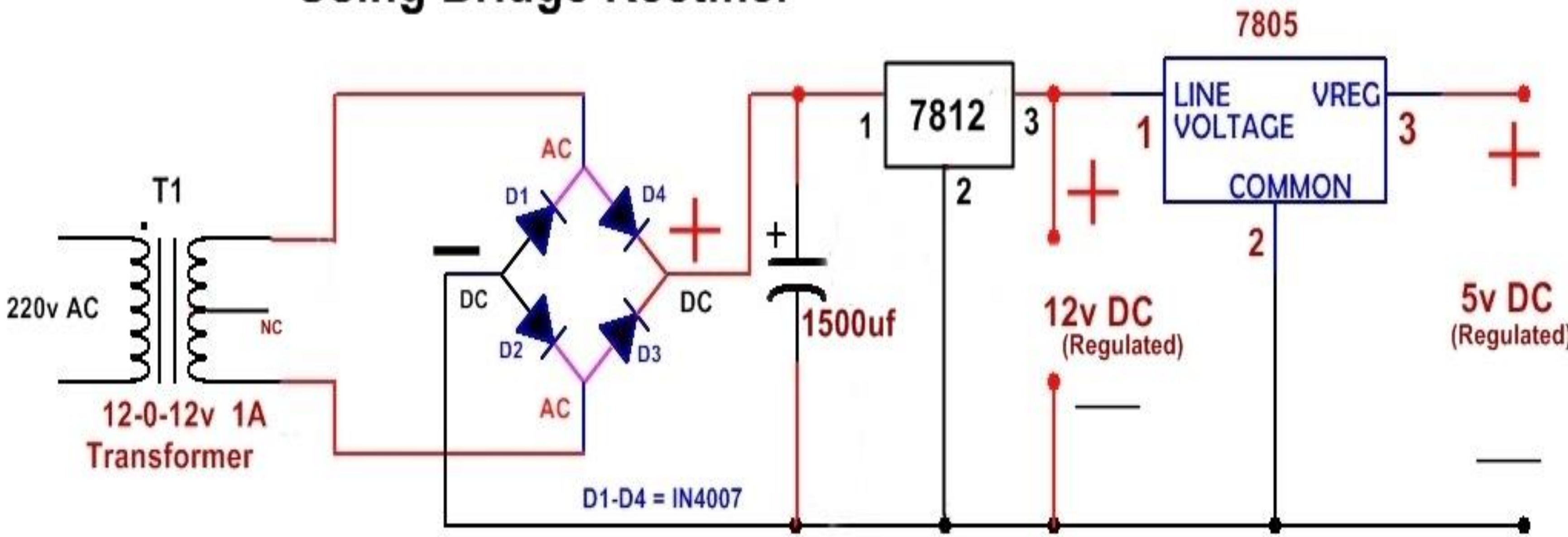


Figure 4: A simple 5V DC regulated power supply system

Linear Power Supply: Case Study



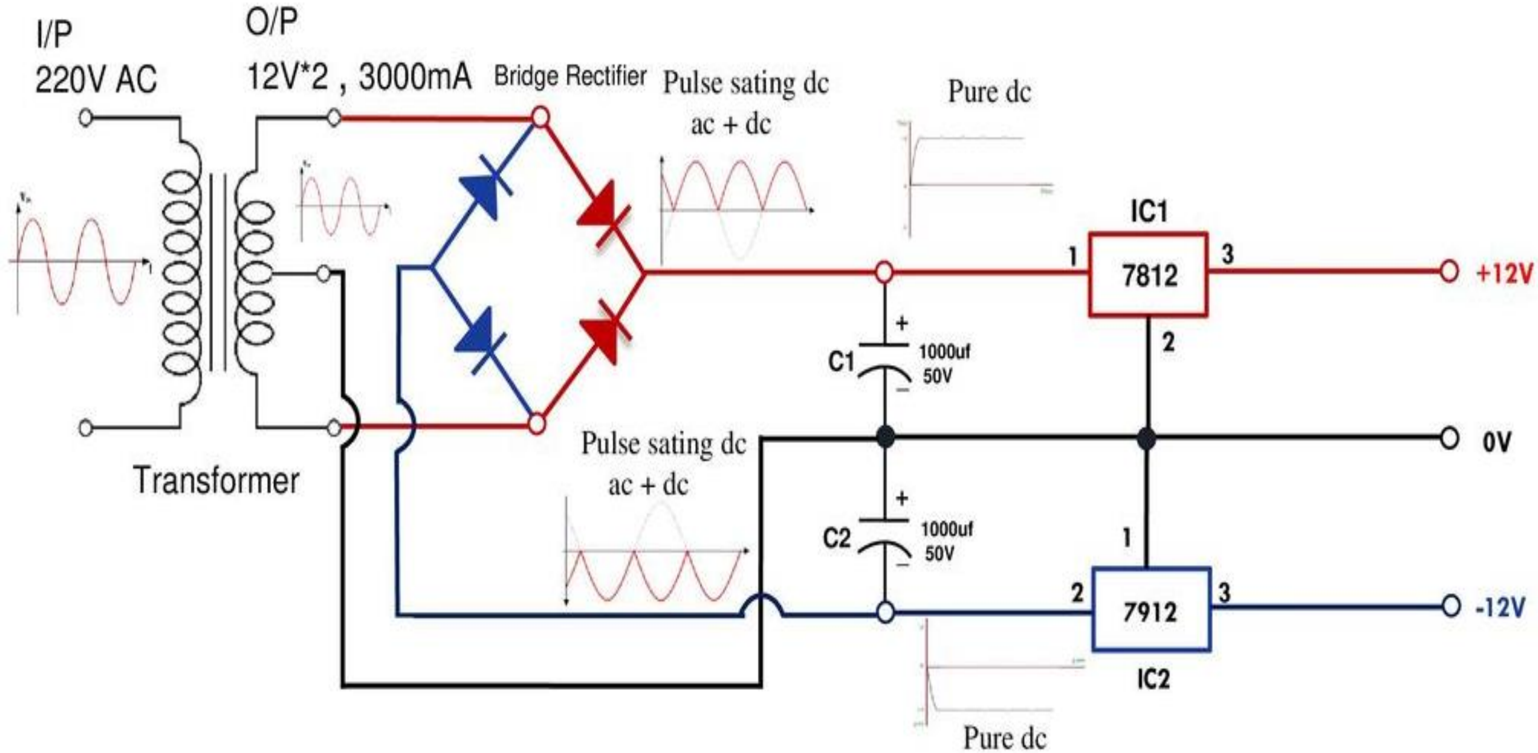
220/230v AC to 12V DC, 5V DC Converter Circuit Using Bridge Rectifier



NC = No connection

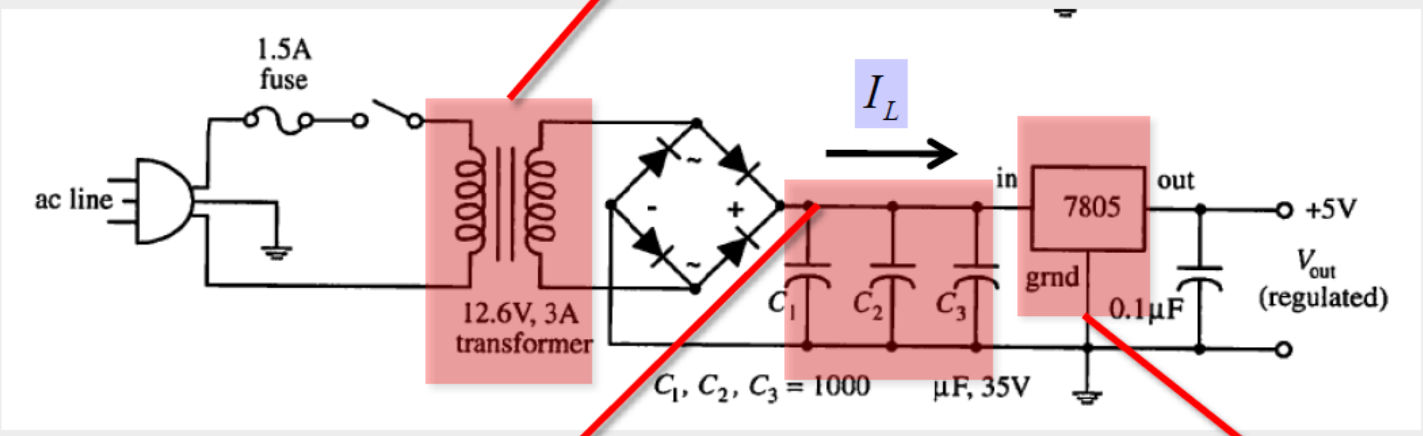
circuitspedia.com

DC Regulated Power Supply circuit : Dual 12 V



Issue in Linear Power Supply

Bulky, expensive transformer



Ripple voltage is $V_{pp} \leq \dfrac{I_L}{2fC}$

Where f is the line frequency (50/60 Hz)

Thus for good pre regulation, need large C (bulky, \$\$\$)

Linear regulator, often dissipates significant power and need expensive heat sinks.

SMPS: Switch Mode Power Supply

SMPS: Switch Mode Power Supply

- SMPS is a type of Power Supply Unit (PSU) that uses some kind of switching devices to transfer electrical energy from source to load.

- Usually the source is either AC or DC and the load is DC

- The most common application of an SMPS is the power supply unit of a computer. Switching Mode Power Supply (SMPS) has become a standard type of power supply unit for electronic devices because of their **high efficiency, low cost and high power density**.

SMPS: Switch Mode Power Supply

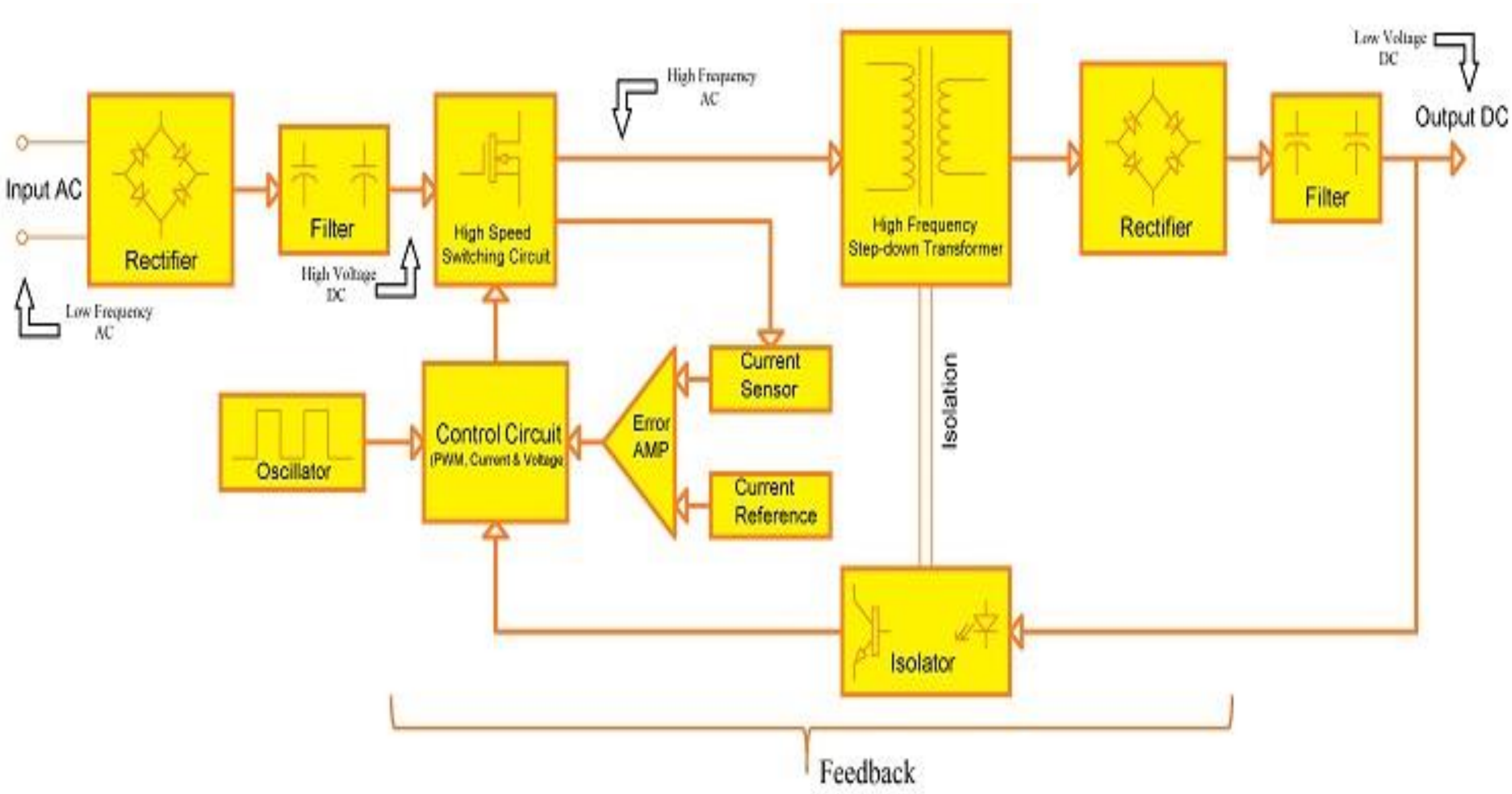
Specification	***Linear***	***SMPS***
Efficiency	Typical efficiency of 30-40%	Typical efficiency of 60-95% can be achieved with good design
Output Voltage	Always less than Input	Can be more or less than Input
Regulation Method	By dissipating excess power	By varying duty cycle of PWM
Circuit Complexity	Less complex; consists of regulator and filter as main components	Very complex; consists of switching element, high frequency transformer, rectifiers and filters, feedback circuit
Noise and Interference	Less electronic noise at output and mild high frequency interference	High interference and noise due to frequent switching od current
Size and weight	Bulky because of transformer and heat sink	No transformer at input but requires a tiny high frequency transformer
Applications	Low power, simple and low cost systems	High power, complex and stable power requirements

SMPS: Switch Mode Power Supply

The main design types in SMPS are:

- **AC to DC**
  - where AC mains is given as input and we get a regulated DC at the output,
- **DC to DC Step up converter**
  - where an input DC voltage is stepped up i.e. output voltage is greater than input
- **DC to DC Step down converter**
  - where the input DC voltage is stepped down i.e. output voltage is less than or equal to input voltage.
  - In case of DC to DC SMPS systems, the input DC is usually given from a battery

SMPS: Switch Mode Power Supply



SMPS: Switch Mode Power Supply

- Convert input AC to High Voltage DC and convert this High Voltage DC to High Voltage, High Frequency Square Wave (AC).
  - This High Voltage and Frequency AC is converted to Regulated DC.
  - Square Wave Oscillator and High Speed Electronic Switch (like a MOSFET) are responsible for converting DC to High Frequency AC.
- By converting the input AC or DC (after rectifying and filtering the AC) to High Frequency AC,
  - the size and price of the components like inductors, transformers and capacitors can reduced
  - they can be smaller and cheaper.
- As the High Frequency AC signal generated at the switch is a square wave, the output voltage can be regulated with the help of Pulse Width Modulation (PWM).
- There is a voltage feedback through an isolator circuit to the control circuit
- With this feedback, the duty cycle of the PWM from the oscillator can be varied and hence the output is perfectly regulated.

SMPS: Switch Mode Power Supply

•A sample current from the High Frequency AC (signal after the switch) and a reference current are compared and given to the control circuit and hence provides an over current protection.

•Also note that the output DC is completely isolated from the input mains and even the feedback signal is isolated with the help of an Opto coupler.

•Driving the Switching Transistor (MOSFET) with square wave ensures that the power dissipation is very less when compared to the Transistor being operated as a series pass transistor in Linear Regulated Power Supplies.

•Since there is a High Frequency AC Signal in the SMPS, there is a chance of high frequency harmonics and as a result, SMPS is more susceptible to RF Interference.

SMPS Topologies

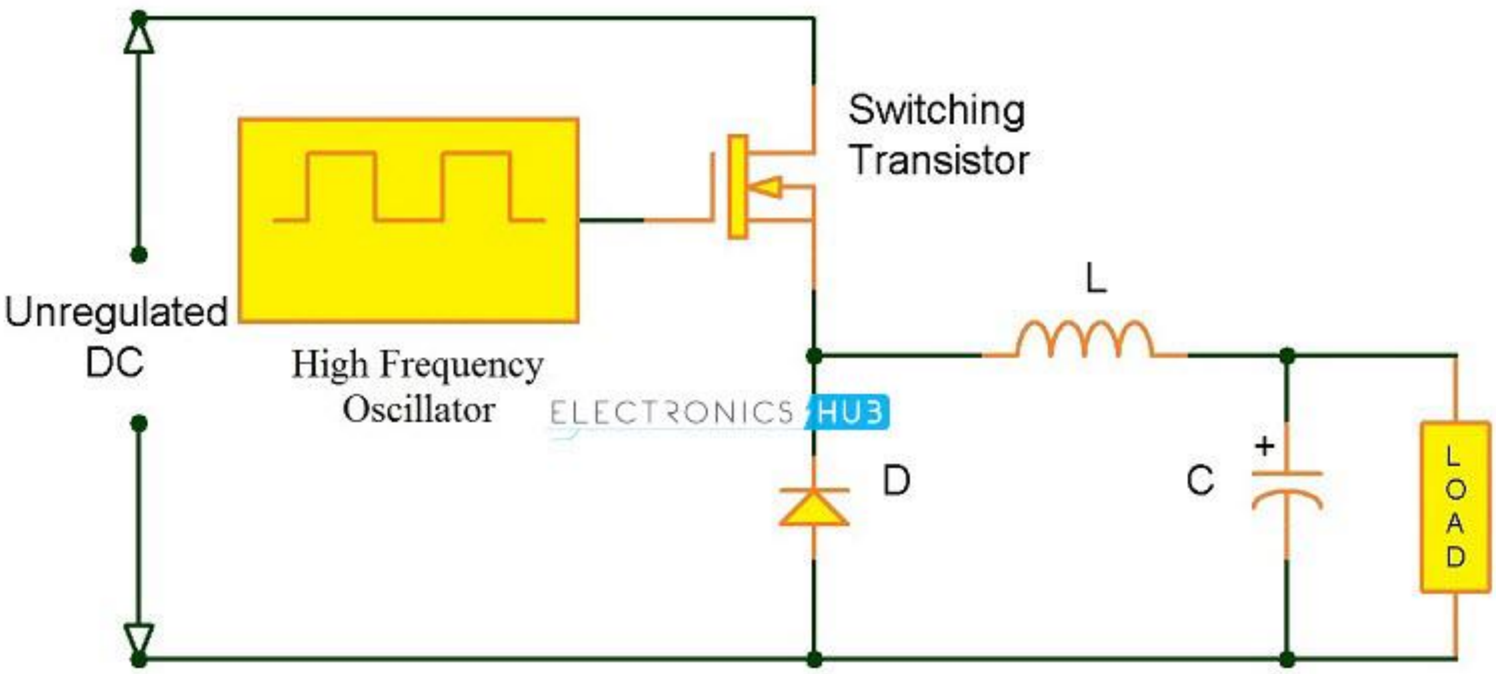
SMPS can be classified into two types based on its circuit topology:

- Non-isolated Converters
  - a type of SMPS Topology where the switching circuit and output are not isolated i.e. they have a common terminal.
  - The three basic and important types in Non – isolated SMPS are:
    - Buck Converter or Step – down Converter
    - Boost Converter or Step – up Converter
    - Buck – Boost Converter

- Isolated Converters.
  - Uses a transformer as an isolator between the switching element and output.
  - Depending on the transformer's turns ratio, the output voltage can be higher or lower than the input.
  - The two important Isolated Topology based SMPS converters are:
    - Flyback Converter
    - Forward Converter

SMPS Topologies

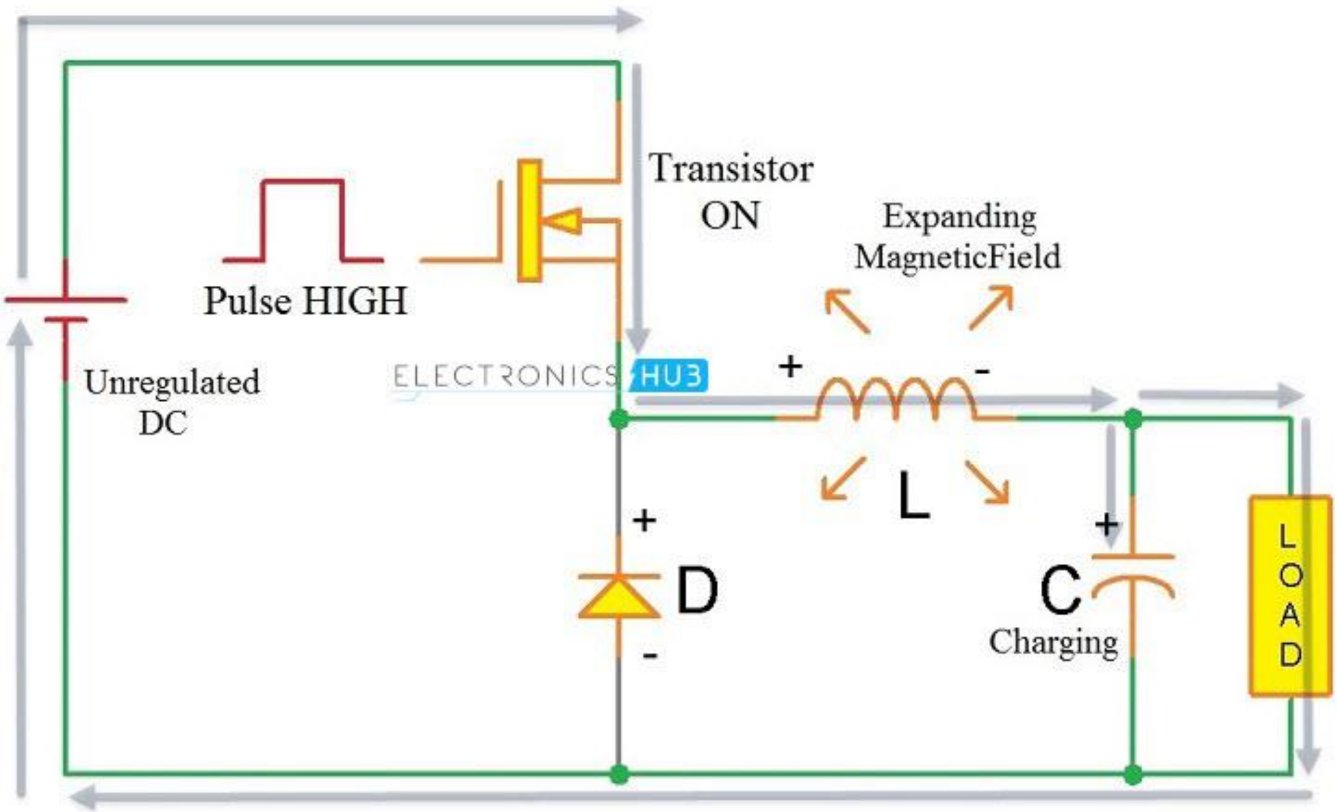
Buck Converter or Step – down Converter



Buck Converter

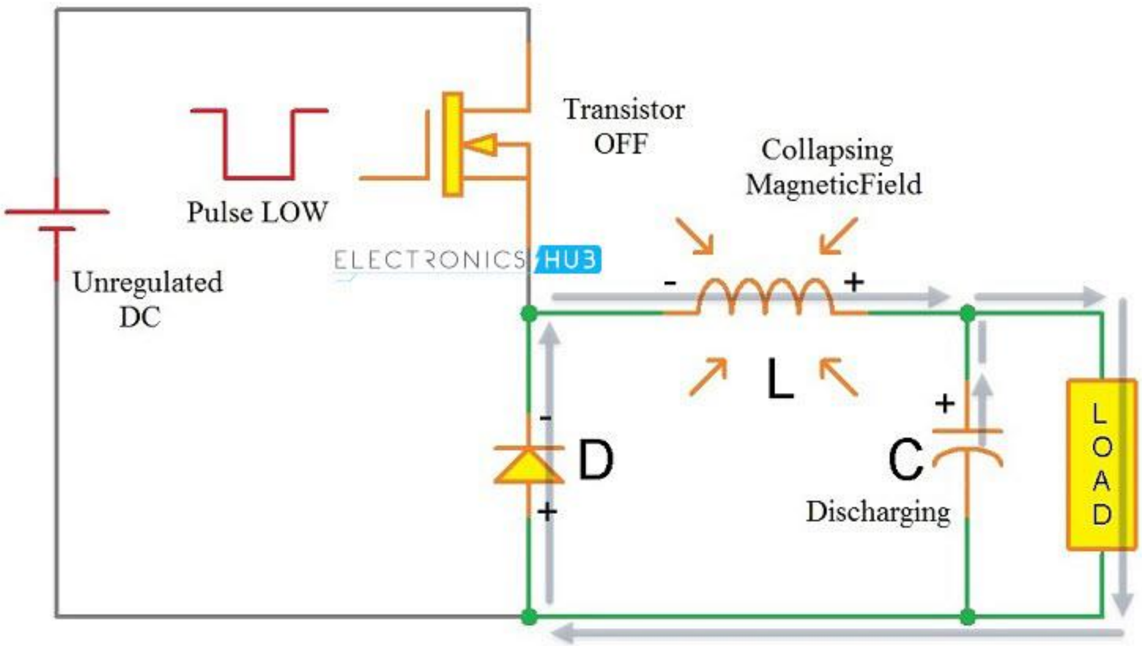
SMPS Topologies

Buck Converter or Step – down Converter



SMPS Topologies

Buck Converter or Step – down Converter



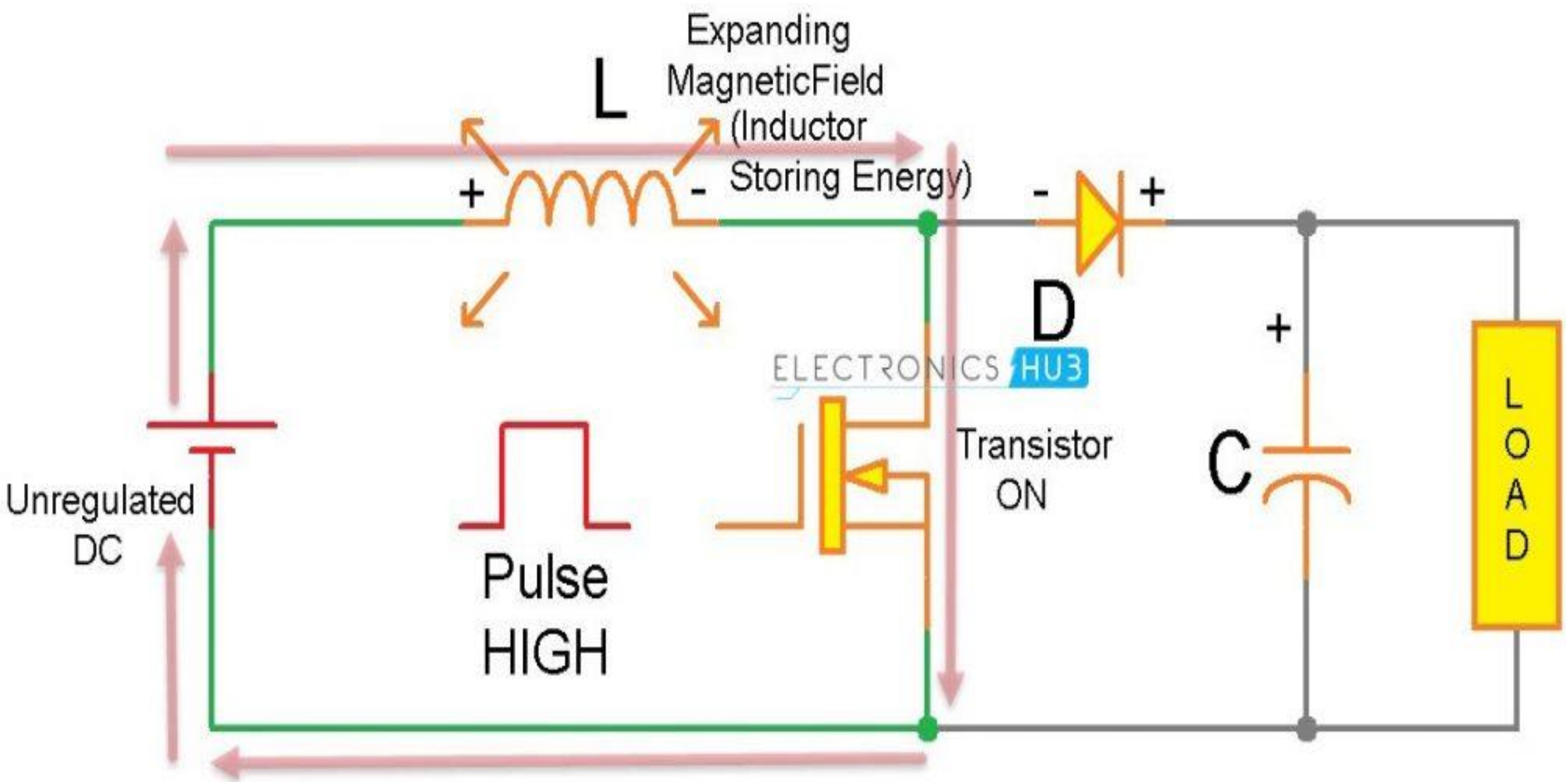
$$D = \frac{t_{ON}}{(t_{ON} + t_{OFF})} = \frac{t_{ON}}{\text{Total Time}} = \frac{t_{ON}}{T}$$

$$\therefore D \approx \frac{V_{OUT}}{V_{IN}} \quad \text{or} \quad V_{OUT} = D V_{IN}$$

$$V_{OUT} = \frac{t_{ON}}{(t_{ON} + t_{OFF})} \times V_{IN}$$

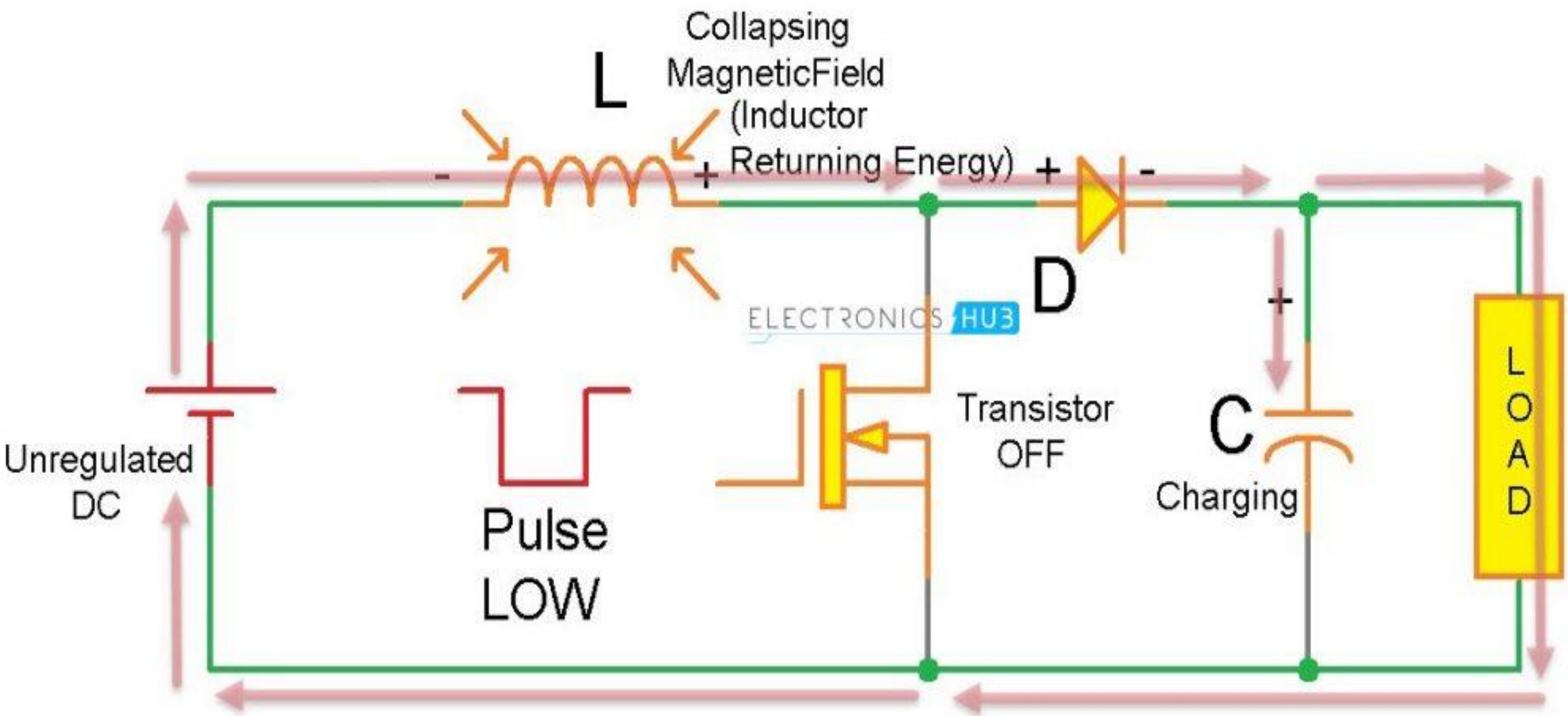
SMPS Topologies

Boost Converter or Step – up Converter



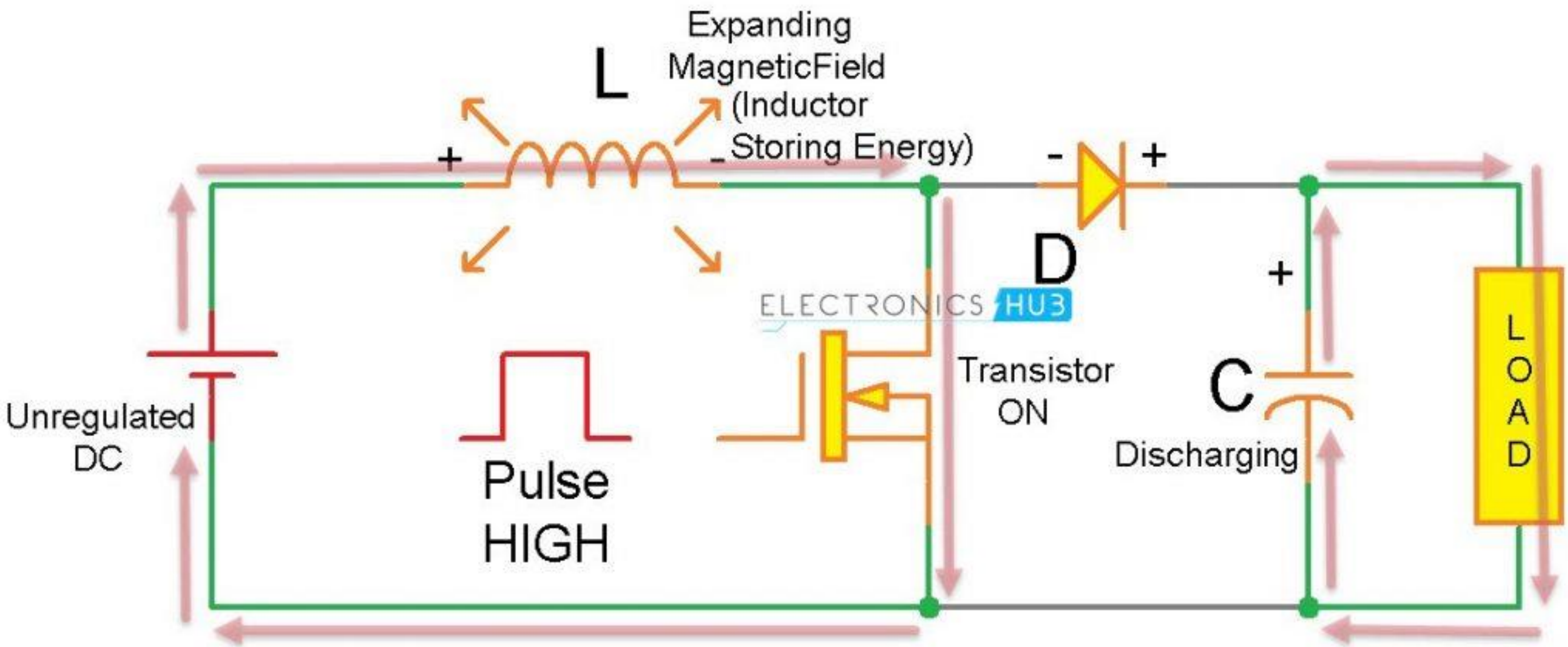
SMPS Topologies

Boost Converter or Step – up Converter



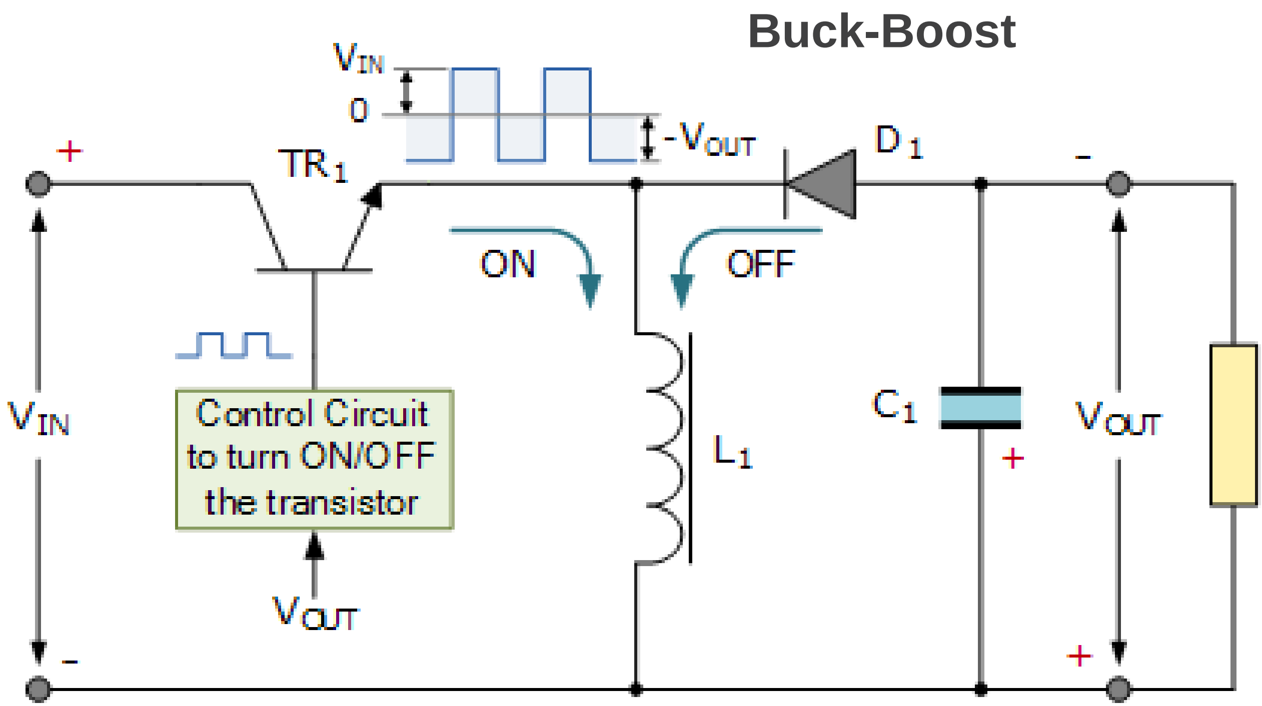
SMPS Topologies

Boost Converter or Step – up Converter



$$V_{OUT} = V_{IN} \frac{1}{(1 - \text{duty cycle})} = V_{IN} \left(\frac{1}{1 - D} \right)$$

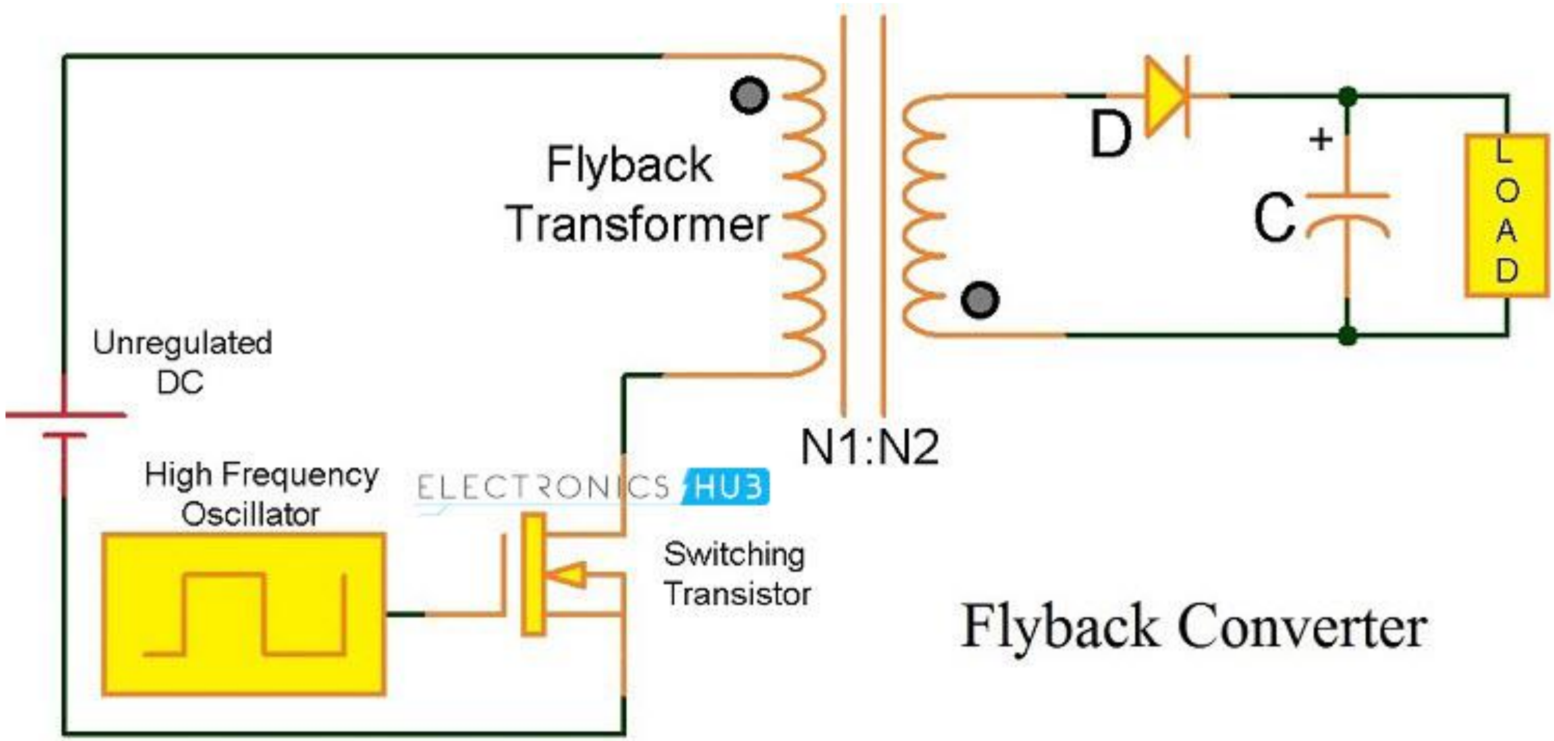
SMPS Topologies



$$V_{OUT} = V_{IN}\left(\frac{D}{1-D}\right)$$

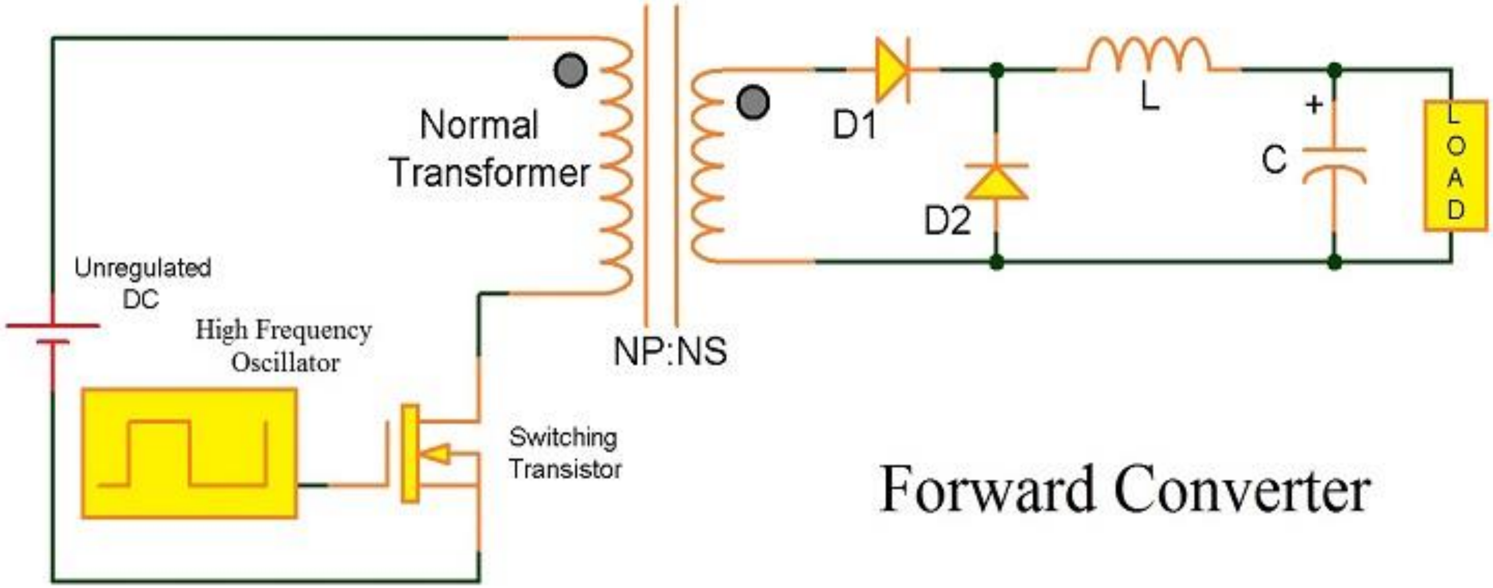
- Switch is "ON" - energy is delivered into the inductor by the DC supply
- Switch is "OFF", the energy stored previously in the inductor is switched to the output (through the diode), and none comes directly from the input DC source.
- The result is that the magnitude of the inverted output voltage can be greater or smaller (or equal to) the magnitude of the input voltage based on the duty cycle.

SMPS Topologies



The output voltage in Flyback Converter can be higher or lower than the input voltage and is dependent on the turns ratio of the primary and secondary of the transformer.

SMPS Topologies



The output voltage of the Forward Converter is dependent on the transformer turns ratio as well as the duty cycle of the Pulse Width Modulator. The output voltage is given by

VOUT = VIN x D x NS/NP

SMPS Topologies

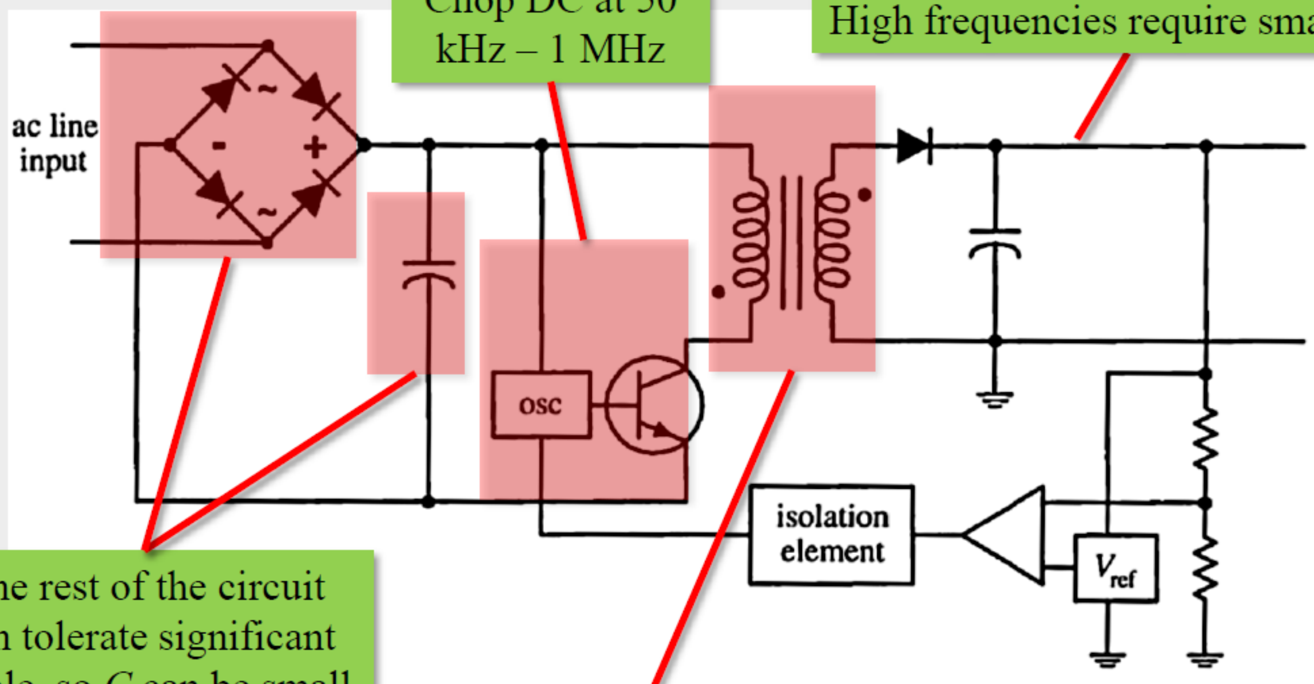
Non isolated	Buck converter	Vi>Vo
	Boost converter	Vi<Vo
	Buck –boost	Vi> (or <)Vo
isolated	Fly back	<200w
	forward	<300w
	Push pull	<500w
	Half bridge	<1kw
	Full bridge	<2kw

SMPS: Switch Mode Power Supply

Ripple voltage is $V_{pp} \le \dfrac{I_L}{2fC}$

High frequencies require small C

Chop DC at 50 kHz – 1 MHz



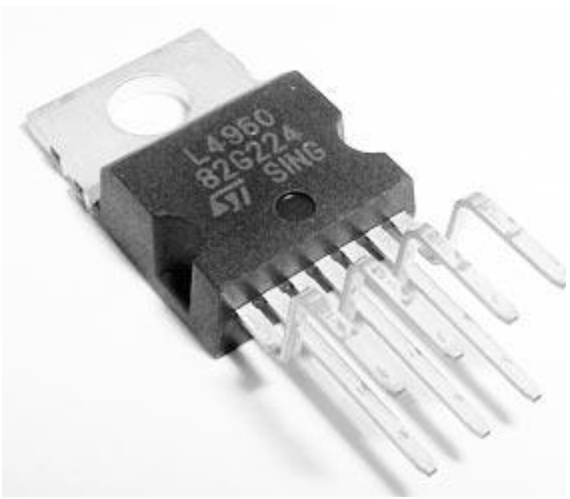
The rest of the circuit can tolerate significant ripple, so C can be small

Recall the universal transformer equation

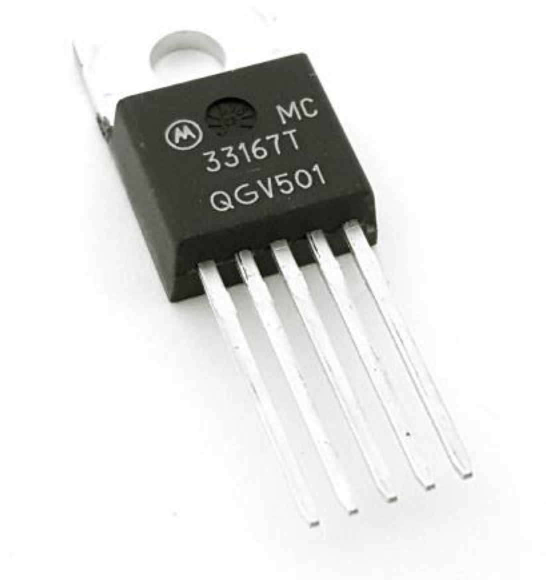
$$E_{rms} = \frac{2\pi f N a B_{peak}}{\sqrt{2}} \approx 4.44\, f N a B$$

High frequencies require smaller transformers

Switching Regulator ICs



L4960 2.5A Power Switching Regulator IC ST Microelectronics



MC33167T 5.5A 40V Step Up Step Down Switching Voltage Regulator Motorola

Step Down Switching Voltage Regulator TI

SMPS: Switch Mode Power Supply

Case Study: 12V 15W SMPS Power Supply Design

Design Considerations

Input Specification
For India, the input AC is available in 220-230 volt, for the USA it is rated for 110 volts. There are also other nations which use different voltage levels.
SMPS can be used in any country and could provide a stable output of full load if the voltage is between 85-265V AC

Output Specification
The SMPS could provide **15W output**.
It is 12V and 1.25A.
The targeted **output ripple** is selected as less the **30mV pk-pk at 20000 Hz bandwidth**.

Case Study: 12V 15W SMPS Power Supply Desig

Input and Output Protection Features

- The most common input protection is **Surge Protection** and **EMI filters**.
- Surge protection protects the SMPS from input surges or **AC overvoltage**.
- EMI filter protects the SMPS from EMI generation across the input line.

- Output protection includes **short circuit protection**, **over-voltage protection** and **over current protection**.
- This SMPS design will also include all of these protection circuits.

Case Study: 12V 15W SMPS Power Supply Desig

Selection of the Power Management IC

Every SMPS circuit requires a Power Management IC also known as switching IC or SMPS IC.

Our Design requirements are

- 15W output. 12V 1.25A with less than 30mV pk-pk ripple at full load.
- Universal input rating.
- Input surge protection.
- Output short circuit, over voltage and over current protection.
- Constant voltage operations.

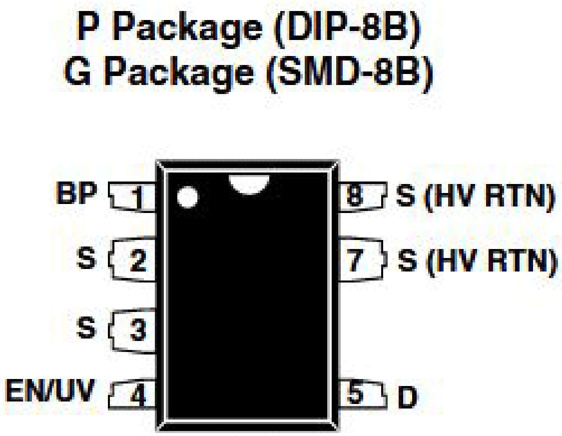
Power integration is a semi-conductor company that has a wide range of power driver ICs in various power output ranges.

Case Study: 12V 15W SMPS Power Supply Design

OUTPUT POWER TABLE				
PRODUCT[3]	230 VAC ±15%		85-265 VAC	
	Adapter[1]	Open Frame[2]	Adapter[1]	Open Frame[2]
TNY263 P or G	5 W	7.5 W	3.7 W	4.7 W
TNY264 P or G	5.5 W	9 W	4 W	6 W
TNY265 P or G	8.5 W	11 W	5.5 W	7.5 W
TNY266 P or G	10 W	15 W	6 W	9.5 W
TNY267 P or G	13 W	19 W	8 W	12 W
TNY268 P or G	16 W	23 W	10 W	15 W

Based on the requirements and availability we have decided to use the **TNY268P from tiny switch II families**.

Case Study: 12V 15W SMPS Power Supply Design

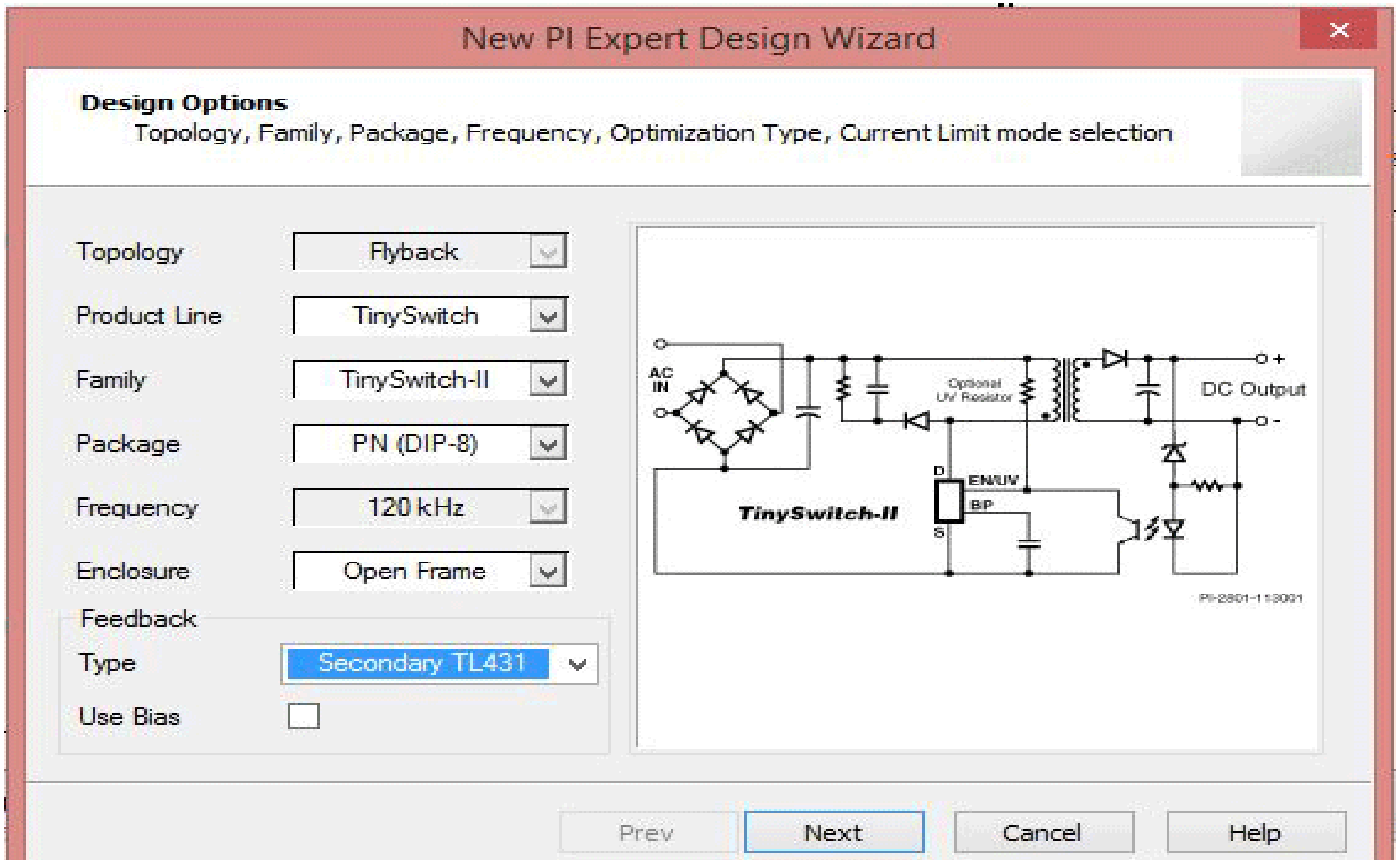


- DRAIN (D) Pin: Power MOSFET drain connection.
- BYPASS (BP) Pin: Connection point for a 0.1 µF external bypass capacitor for the internally generated 5.8 V supply.
- ENABLE/UNDERVOLTAGE (EN/UV) Pin: This pin has dual functions: enable input and line undervoltage sense.
- SOURCE (S) Pin: Control circuit common, internally connected to output MOSFET source

Case Study: 12V 15W SMPS Power Supply Design

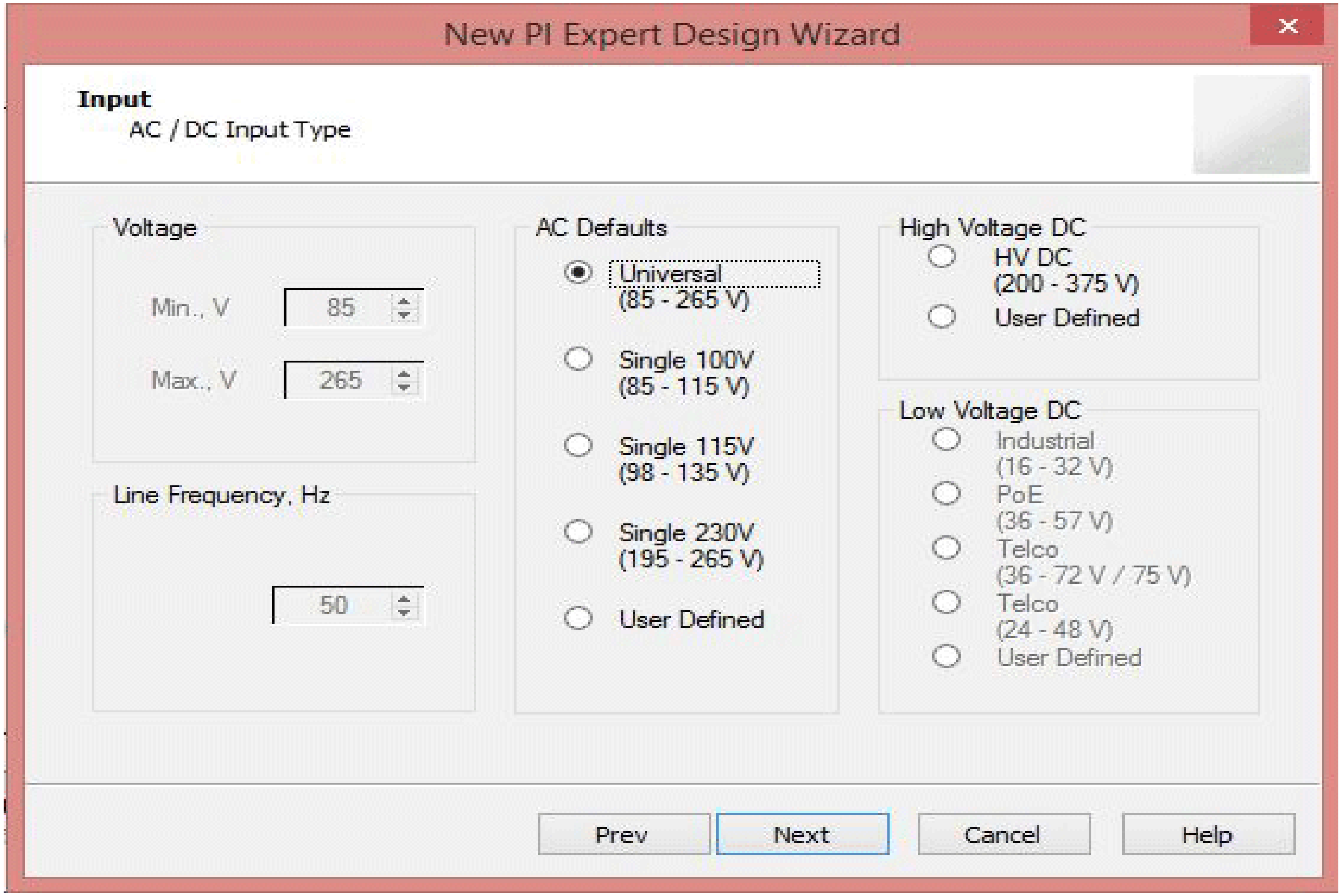
The best way to build the circuit is to use Power integration's PI expert software.

Step -1: Select the **Tiny switch II** and also select the desired package. We selected the DIP package. Select the Enclosure type, Adapter or Open Frame. Here Open Frame is selected.



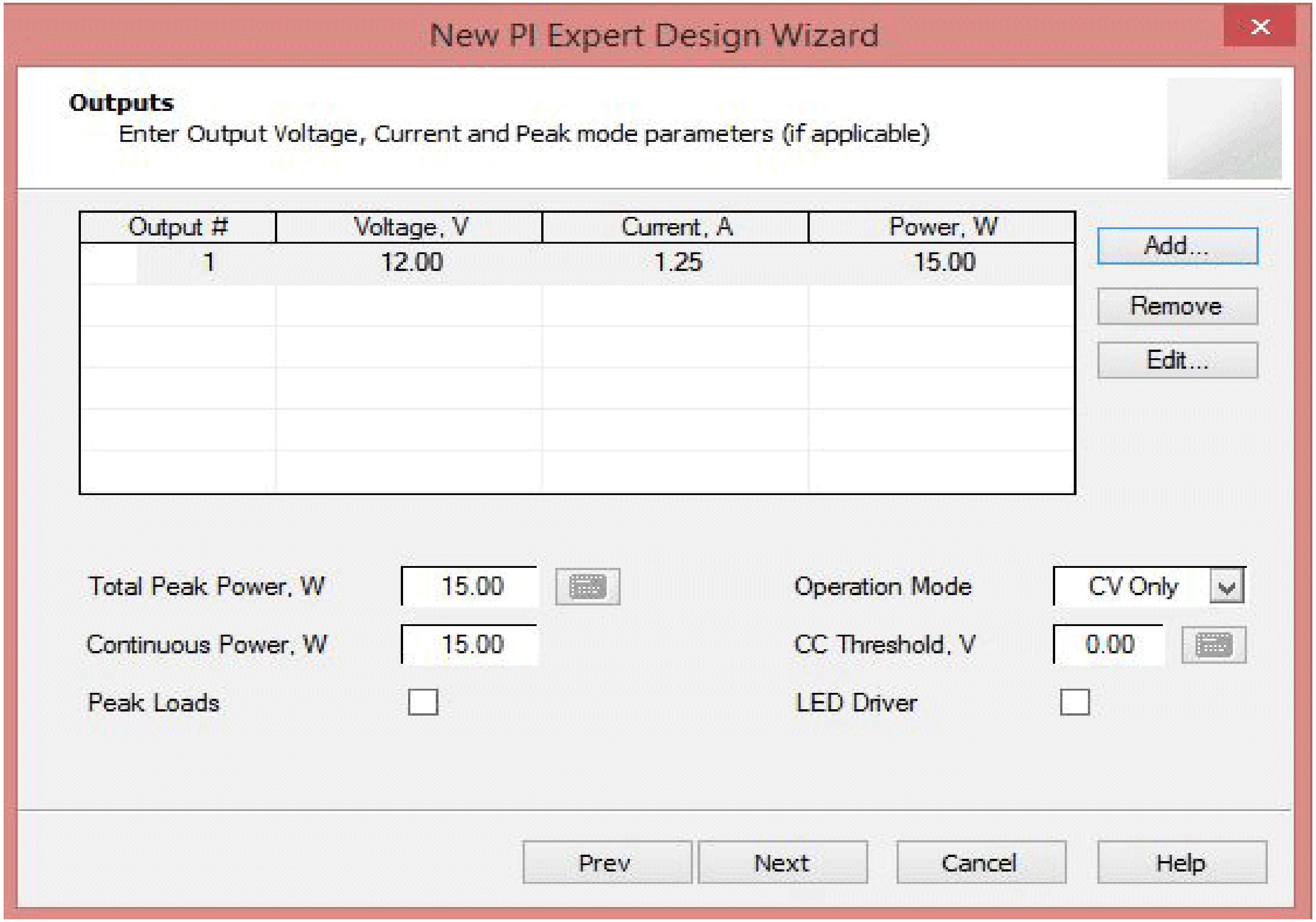
Case Study: 12V 15W SMPS Power Supply Desig

Step-2: Select the input voltage range. As it will be a universal input SMPS, the input voltage is selected as 85-265V AC. Line Frequency is 50 Hz.



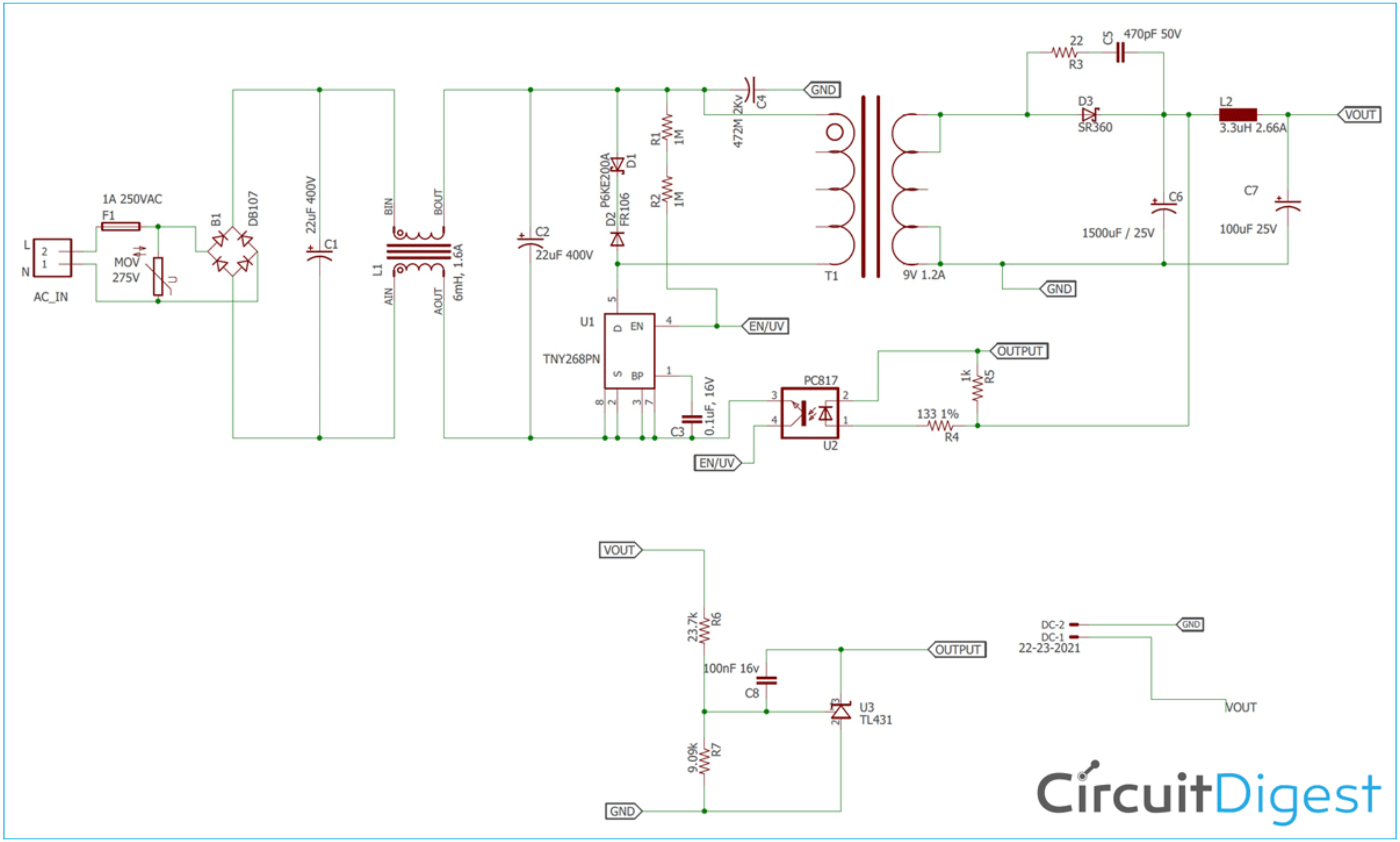
Case Study: 12V 15W SMPS Power Supply Desig

Step- 3:



Case Study: 12V 15W SMPS Power Supply Design

Everything is done in three easy steps, and the schematic is generated.



Case Study: 12V 15W SMPS Power Supply Desig

The circuit has the following sections

1.Input surge and SMPS fault protection

2.AC-DC conversion

3.PI filter

4.Driver circuitry or Switching circuit

5.Under-voltage lockout protection.

6.Clamp circuit

7.Magnetics and galvanic isolation

8.EMI filter

9.Secondary Rectifier and snubber circuit

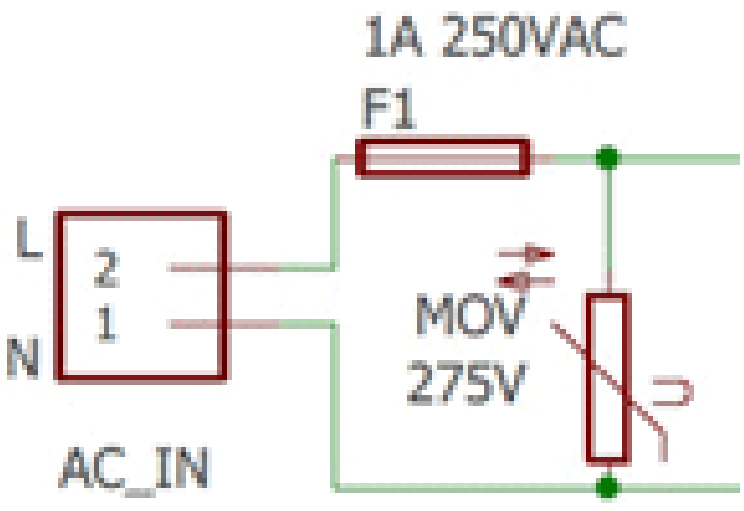
10.Filter Section

11.Feedback section.

Case Study: 12V 15W SMPS Power Supply Design

Input surge and SMPS fault protection

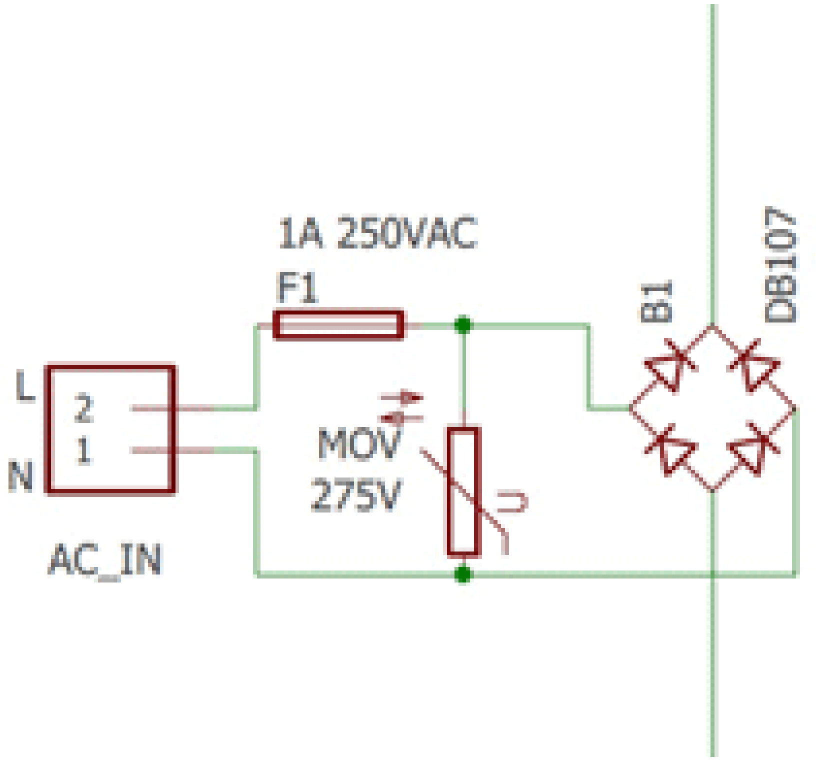
- This section consists of two components, F1 and RV1.
- F1 is a 1A 250VAC slow blow fuse
- RV1 is a 7mm 275V MOV (Metal Oxide Varistor).
- During a high voltage surge (more than 275VAC), the MOV became dead short and blows the input Fuse.
- However, due to the slow blow feature, the fuse withstands inrush current through the SMPS.



Case Study: 12V 15W SMPS Power Supply Design

AC-DC conversion

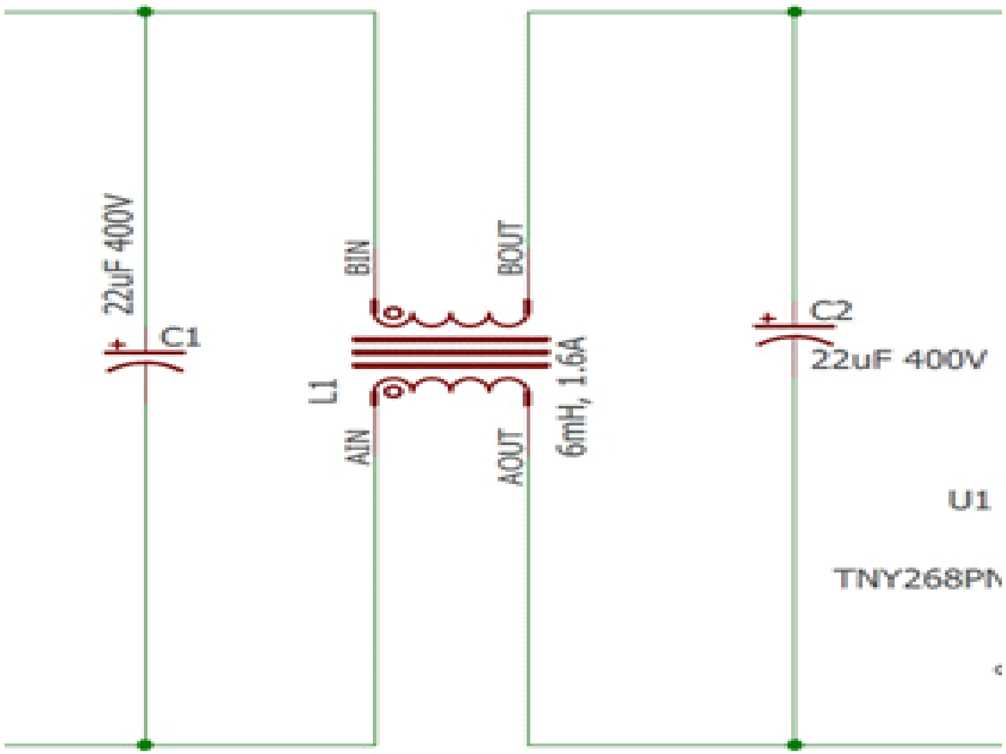
- These four diodes (inside DB107) make a full bridge rectifier.
- The diodes are 1N4006, but standard 1N4007 can do the job perfectly



Case Study: 12V 15W SMPS Power Supply Design

PI filter

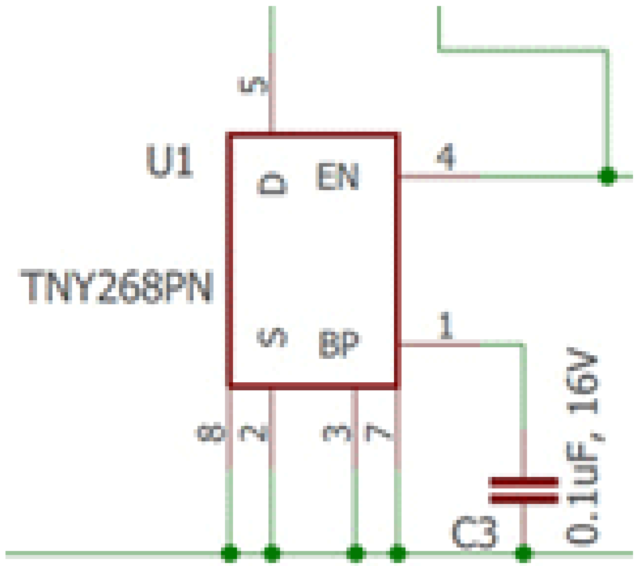
- PI filter is designed in such a way to reduce the **common-mode EMI rejection**.
- This section is created using C1, C2, and L1. C1 and C2 are 400V 22uF capacitors.
- The L1 is a common mode choke that takes differential EMI signal to cancel both.



Case Study: 12V 15W SMPS Power Supply Design

Driver circuitry or switching circuit

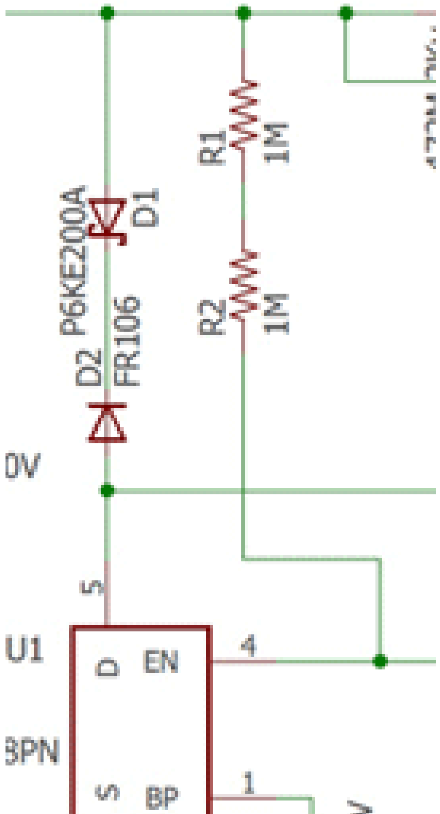
- It is the heart of an SMPS.
- The transformer's primary side is controlled by the switching circuit TNY268PN.
- The switching frequency is 120-132khz.
- U1 is the main driver IC TNY268PN.
- The C3 is the **bypass capacitor** which is needed for the working of our driver IC.



Case Study: 12V 15W SMPS Power Supply Design

Under-voltage lockout protection

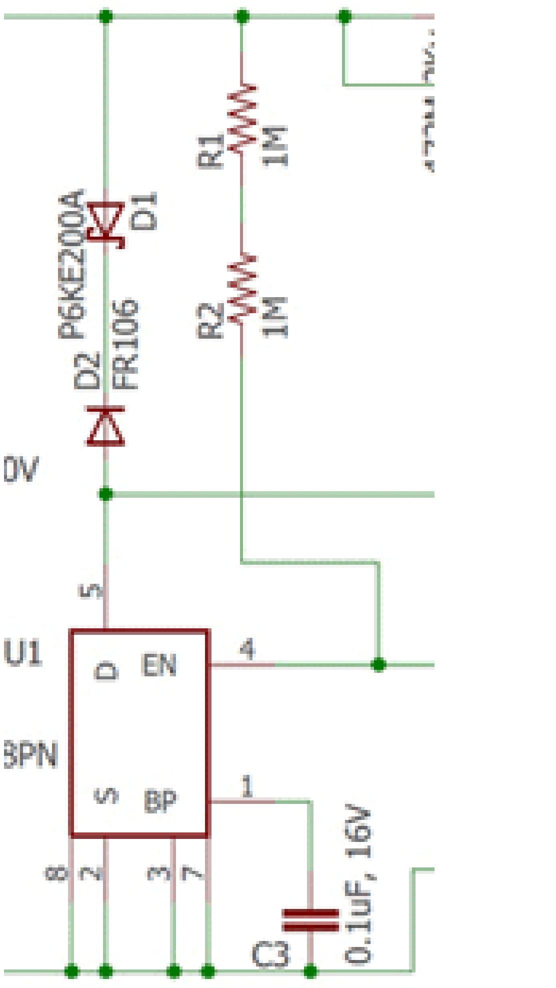
- Under-voltage lockout protection is done by the sense resistor R1 and R2.
- It is used when the SMPS goes into the auto-restart mode and sense the line voltage.



Case Study: 12V 15W SMPS Power Supply Design

Clamp circuit

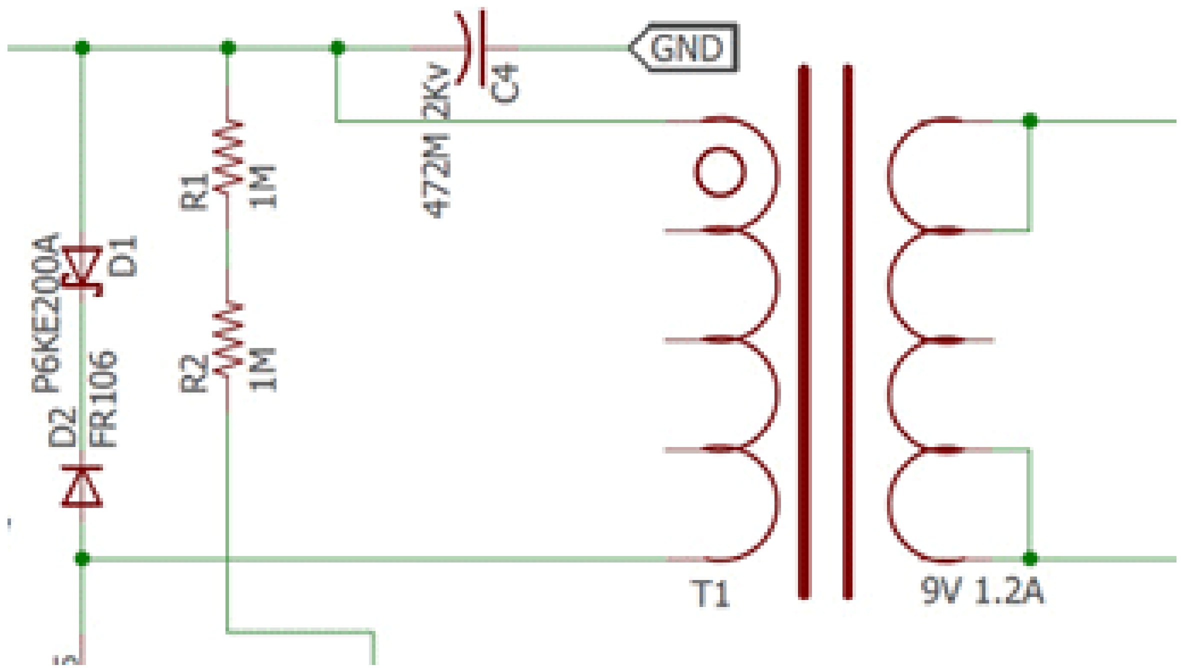
- D1 and D2 are the clamp circuit.
- D1 is the **TVS diode** and D2 is **an ultra-fast recovery diode**.
- The transformer acts a huge inductor across the power driver IC TNY268PN.
- Therefore during the switching off-cycle, the transformer creates high **voltage spikes** due to the **leakage inductance** of the transformer.
- These high-frequency voltage spikes are suppressed by the diode clamp across the transformer.
- UF4007 is selected due to the ultra-fast recovery and P6KE200A is selected for the TVS operation.



Case Study: 12V 15W SMPS Power Supply Design

Magnetics and galvanic isolation

The transformer is a ferromagnetic transformer and it not only converts the high voltage AC to a low voltage ac but also provide galvanic isolation.

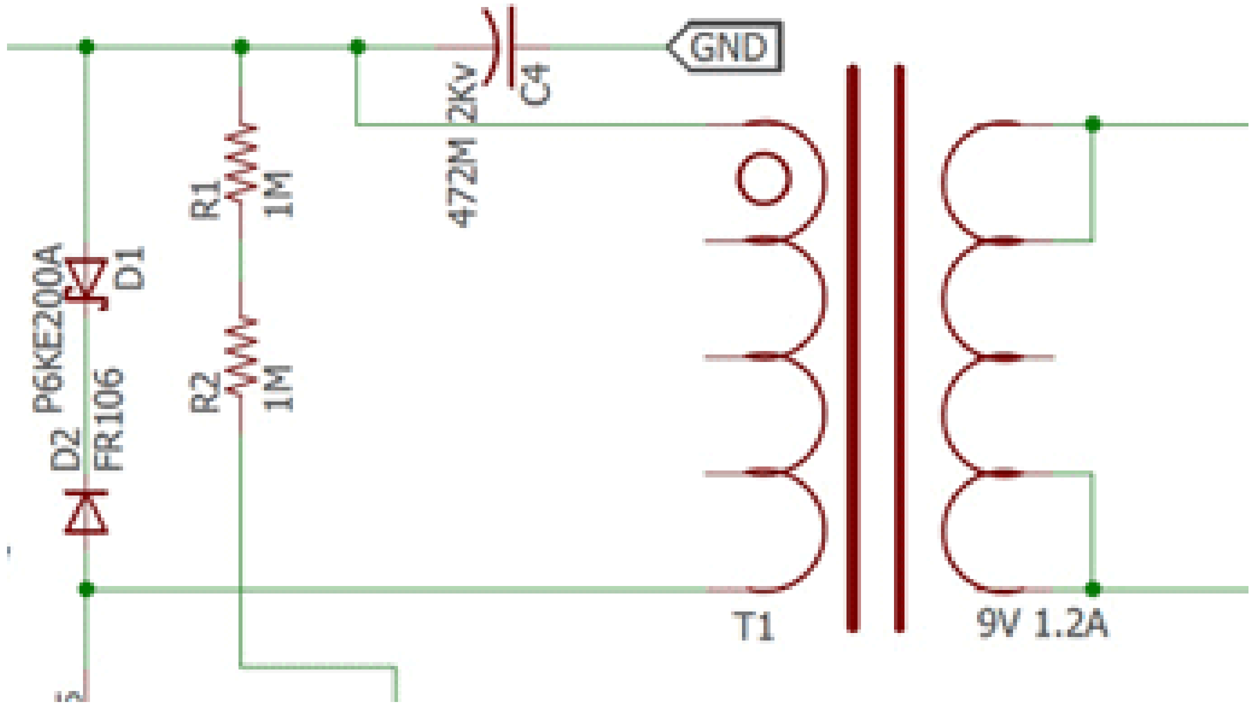


Case Study: 12V 15W SMPS Power Supply Design

EMI filter

EMI filtering is done by the C4 capacitor.

It increases the immunity of the circuit to reduce the high EMI interference.



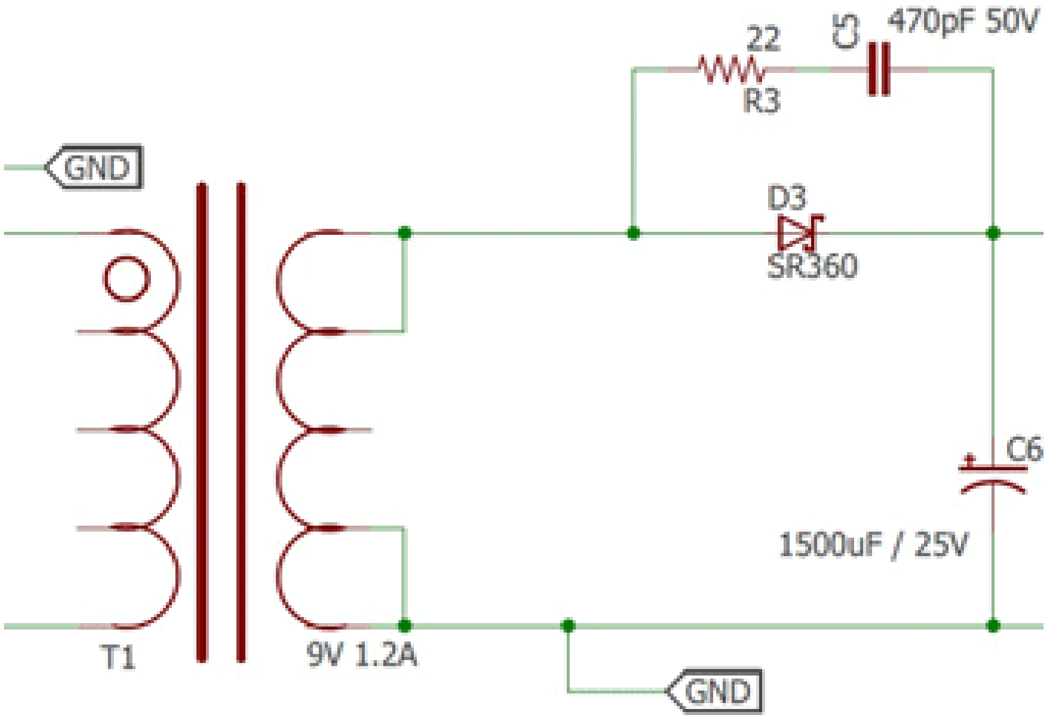
Case Study: 12V 15W SMPS Power Supply Desig

Secondary Rectifier and Snubber circuit

The output from the transformer is rectified and converted to DC using D3, a **Schottky rectifier diode**.

The snubber circuit across the D3 provides suppression of the voltage transient during switching operations.

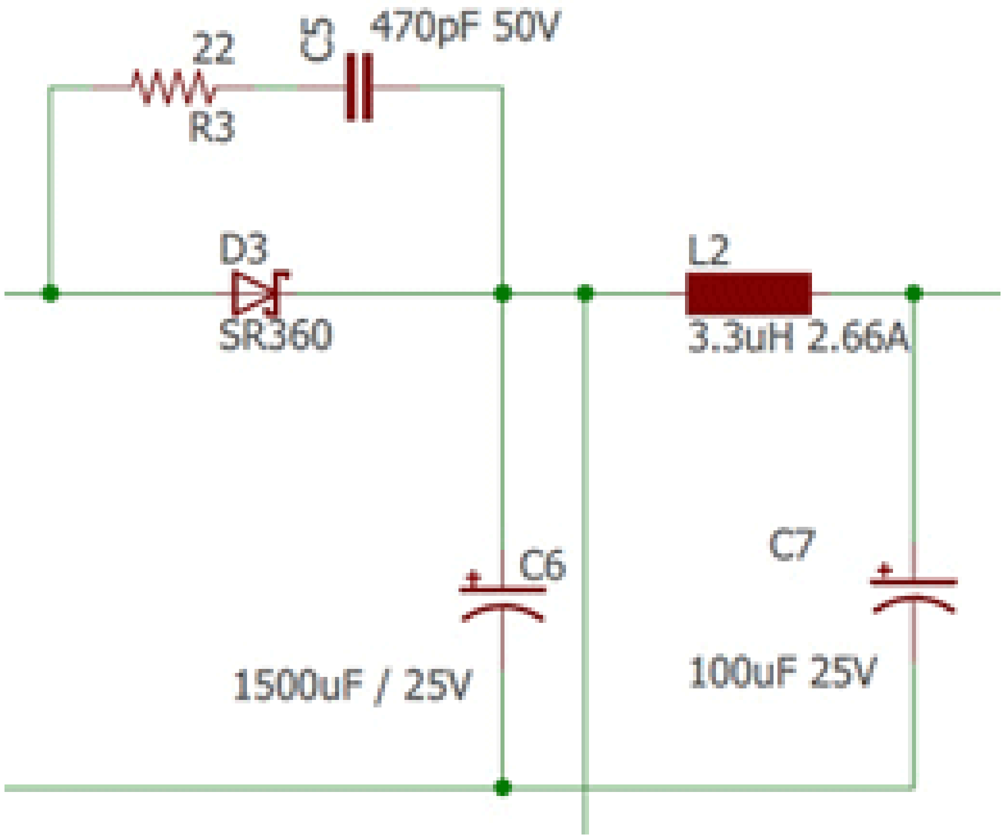
The snubber circuit consist one resistor and one capacitor, R3, and C5.



Case Study: 12V 15W SMPS Power Supply Desig

Filter Section

The filter section consists of a filter capacitor C6.
It is a Low ESR capacitor for better ripple rejection.
An LC filter using L2 and C7 provide better ripple rejection across the output.



Case Study: 12V 15W SMPS Power Supply Design

Feedback section

The output voltage is sensed by the U3 TL431 and R6 and R7.

After sensing the line, U2, the **optocoupler** is controlled and galvanically isolating the secondary feedback sensing portion with the primary side controller.

The Optocoupler has a transistor and a LED inside of it.

By controlling the LED, the transistor is controlled.

Since the communication is done by optically, it has no direct electrical connection

Case Study: 12V 15W SMPS Power Supply Desig

Now, as the LED directly controls the transistor, by providing sufficient bias across the optocoupler LED, one can control the **optocoupler transistor**, more specifically driver circuit. This control system is employed by the TL431.As the shunt regulator has a resistor divider across its reference pin, it can control the optocoupler led which is connected across it. The feedback pin has a **reference voltage of 2.5V**. Therefore, the TL431 can be active only if the voltage across the divider is sufficient. In our case, the **voltage divider set to a value of 12V**. Therefore, when the output reaches 12V the TL431 gets 2.5V across the reference pin and thus activate the optocoupler's LED which controls the transistor of the optocoupler and indirectly controls the TNY268PN. If the voltage is not sufficient across the output the switching cycle is immediately suspended.

First, the TNY268PN activates the first cycle of switching and then sense it's EN pin. If everything is alright, it will continue the switching, if not, it will try once again after sometimes. This loop gets continued until everything gets normal, thus preventing shortcircuit or overvoltage issues. This is why it is called flyback topology, as the output voltage is flown back to the driver for sensing related operations. Also, the trying loop is called a **hiccup mode** of operation on the failure condition.
The D3 is a **Schottky barrier diode**. This diode converts the high frequency AC output to a DC. 3A 60V Schottky Diode is selected for reliable operation. R4 and R5 is selected and calculated by the PI Expert. It creates a voltage dividerand passes the current to the Optocoupler LED from the TL431.
R6 and R7 is a simple voltage divider calculated by the formula TL431 **REF voltage = (Vout x R7) / R6 + R7**. The reference voltage is 2.5V and the Vout is 12V. By selecting the value of R6 23.7k, the R7 became 9.09k approximately.

Case Study: 12V 15W SMPS Power Supply Design

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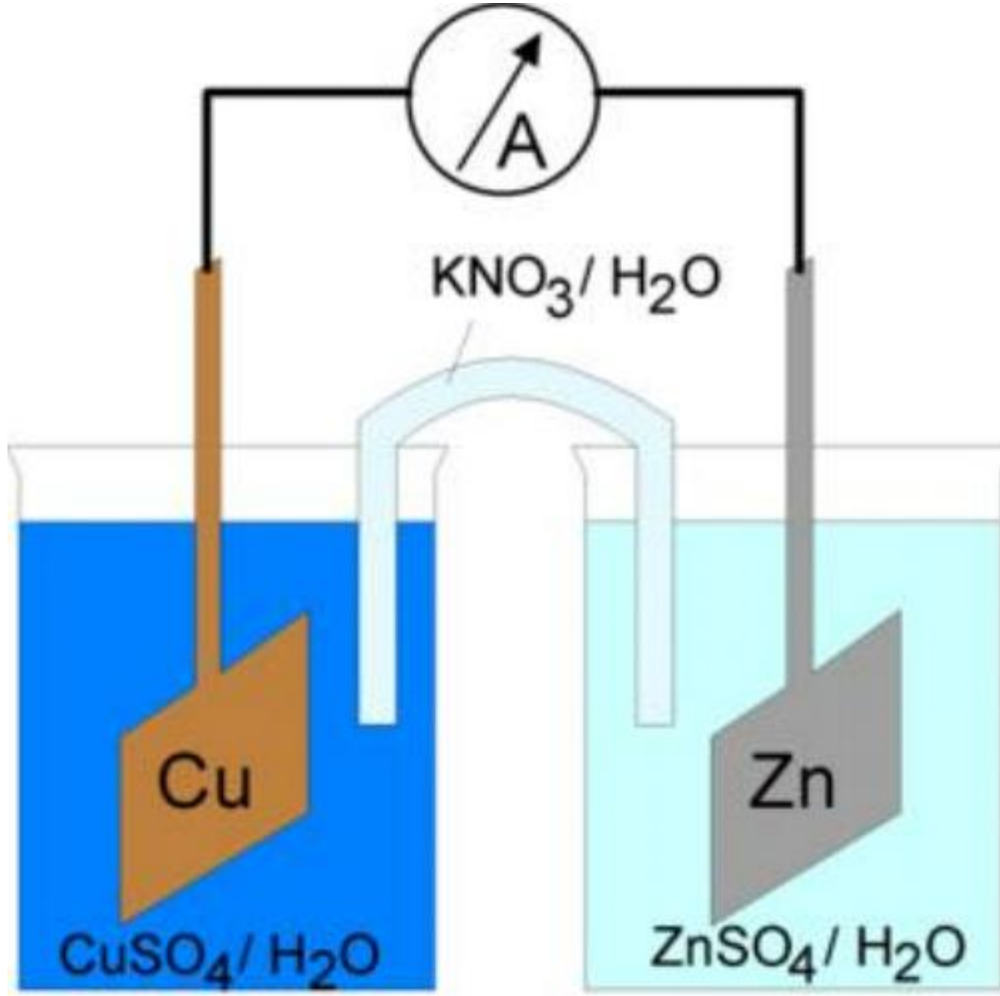
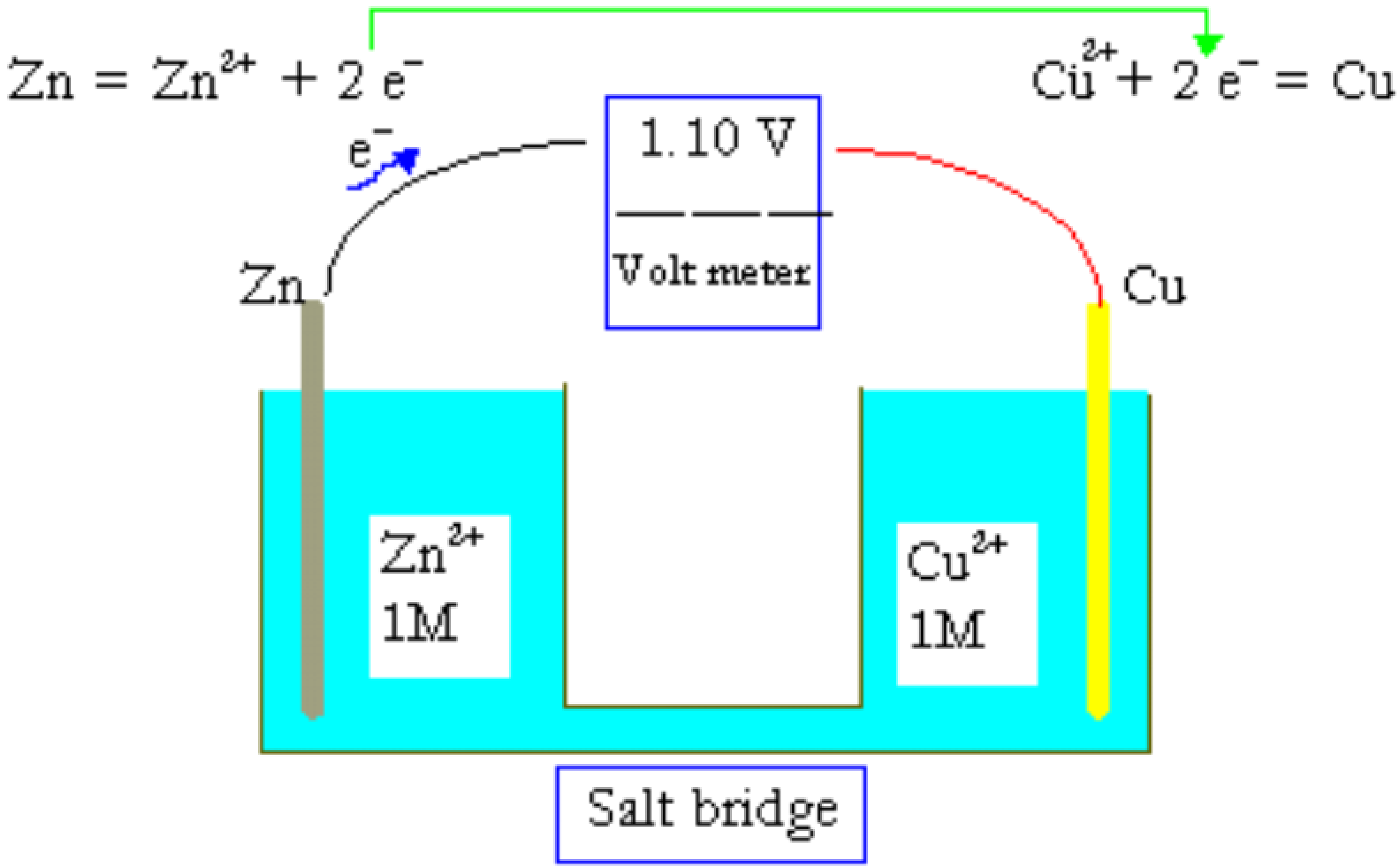
Battery Chemistry



Battery Chemistry




Types of Battery
395/399
0% Hg
Energizer
MADE IN USA
LG
Lithium Ion
Battery 3.7V
12V 100AH DEEP CYCLE
LITHIUM ION BATTERY
SMART BATTERY
WWW.SMARTBATTERY.COM
1-855-GO-LITHIUM
AA 1.5V
Thunderbolt Magnum
ALKALINE
Panasonic
Not for Retail Trade
Pas pour la vente au détail
LR14·C
Industrial ALKALINE
ALCALINE-Industrielle
Alkaline/Alcaline
Extra heavy duty
PKCELL
Green energy, easy life
9V
6F22
Ni-Cd Battery 1.2V
C 1200mAh
D 1.5V
ALKALINE

Battery Charging Methods

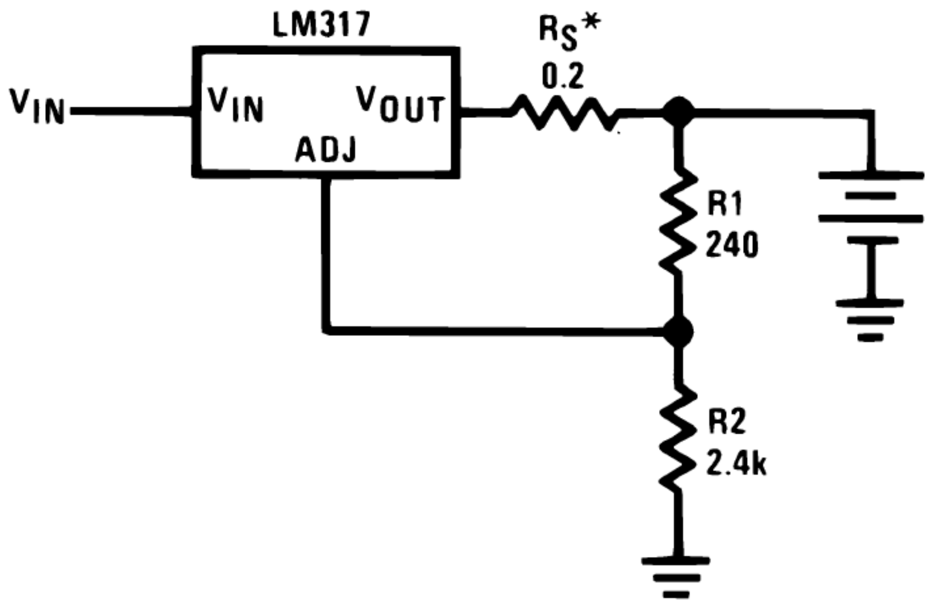
- **Constant Voltage**
  - A constant voltage charger is basically a DC power supply which in its simplest form may consist of a step down transformer from the mains with a rectifier to provide the DC voltage to charge the battery.
  - Such simple designs are often found in cheap car battery chargers, lithium-ion cells
- **Constant Current**
  - Constant current chargers vary the voltage they apply to the battery to maintain a constant current flow, switching off when the voltage reaches the level of a full charge.
  - This design is usually used for nickel-cadmium and nickel-metal hydride cells or batteries.
- **Taper Current**
  - This is charging from a crude unregulated constant voltage source.
  - It is not a controlled charge as in V Taper above.

Battery Charging Methods

- **Pulsed charge**
  - Pulsed chargers feed the charge current to the battery in pulses.
  - The charging rate (based on the average current) can be precisely controlled by varying the width of the pulses, typically about one second.
- **Trickle charge**
  - Trickle charging is designed to compensate for the self discharge of the battery.
  - Continuous charge.
  - Long term constant current charging for standby use.
  - The charge rate varies according to the frequency of discharge. Not suitable for some battery chemistries, e.g. NiMH and Lithium charging when the battery is fully charged.
- **Float charge.**
  - The battery and the load are permanently connected in parallel across the DC charging source and held at a constant voltage below the battery's upper voltage limit.
  - Used for emergency power back up systems. Mainly used with lead acid batteries.

Battery charger circuits

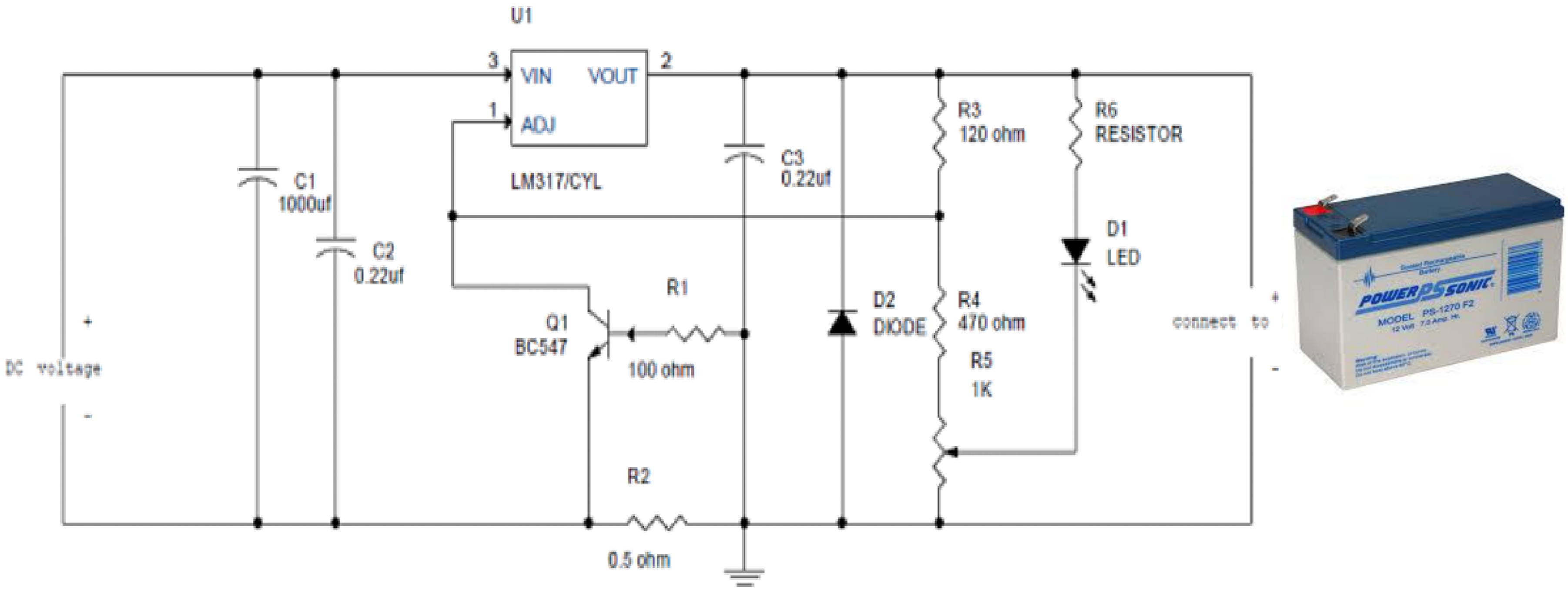
12V Battery Charger



- Rs is used to set the output impedance of the charger:

$$Z_{OUT} = R_S\left(1 + \frac{R2}{R1}\right)$$

Lead Acid Battery Charger Circuit



Lead Acid Battery Charger Circuit

- Here is a lead acid **battery charger circuit** using IC LM 317.
- The IC here provides the correct charging voltage for the battery.
- A battery must be charged with 1/10 its Ah value.
- This charging circuit is designed based on this fact.
- The charging current for the battery is controlled by Q1 ,R1,R4 and R5. Potentiometer R5 can be used to set the charging current.
- As the battery gets charged the the current through R1 increases .
- This changes the conduction of Q1.
- Since collector of Q1 is connected to adjust pin of IC LM 317 the voltage at the output of of LM 317 increases.
- When battery is fully charged charger circuit reduces the charging current and this mode is called trickle charging mode.

Lithium Ion Battery Charger Circuit