MODULE-1

Power Supplies – Block diagram, Rectifiers, Reservoir and smoothing circuits, Full-wave rectifiers, Bi-phase rectifier circuits, Bridge rectifier circuits, Voltage regulators, Output resistance and voltage regulation, Voltage multipliers.
Amplifiers – Types of amplifiers, Gain, Input and output resistance, Frequency response, Bandwidth, Phase shift, Negative feedback, Multi-stage amplifiers.

Power Supplies:

Block diagram:

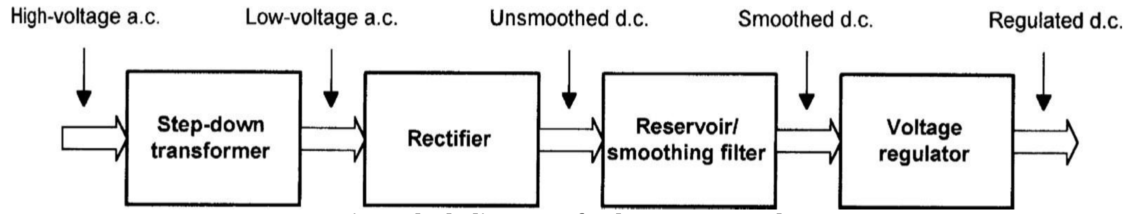


Fig 1:Block diagram of a d.c. power supply

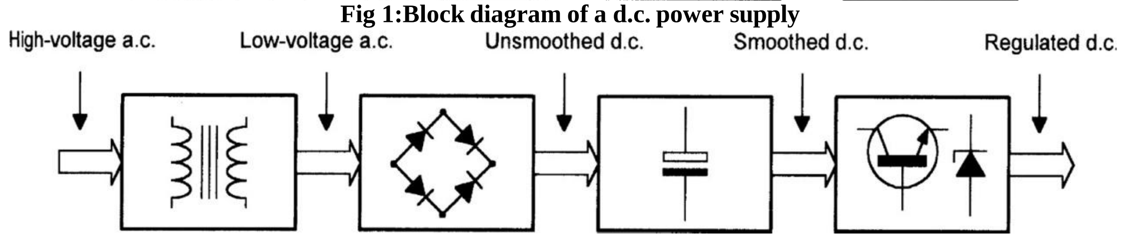


Fig 2: Block diagram of a d.c. power supply showing principal components

1. The block diagram of a d.c. power supply is shown in Fig. 1.
2. A step-down transformer of appropriate turns ratio is used to convert high voltage mains input to a low voltage.
3. The a.c. output from the transformer secondary is then rectified using conventional silicon rectifier diodes to produce an unsmoothed (sometimes referred to as **pulsating d.c.**) output.
4. Unsmoothed output is then smoothed and filtered before being applied to a circuit which will **regulate** (or **stabilize**) the output voltage so that it remains relatively constant in spite of variations in both load current and incoming mains voltage.

Fig.2. shows

1. The iron-cored step-down transformer feeds a rectifier arrangement (often based on a bridge circuit).
2. The output of the rectifier is then applied to a high-value **reservoir** capacitor.
3. This capacitor stores a considerable amount of charge and is being constantly topped-up by the rectifier arrangement. The capacitor also helps to smooth out the voltage pulses produced by the rectifier.
4. Finally, a stabilizing circuit (often based on a **series transistor regulator** and a zener diode **voltage reference**) provides a constant output voltage.

Rectifiers:

Rectifiers are electronic devices used to convert alternating current (a.c.) to direct current (d.c).

Half Wave Rectifiers:

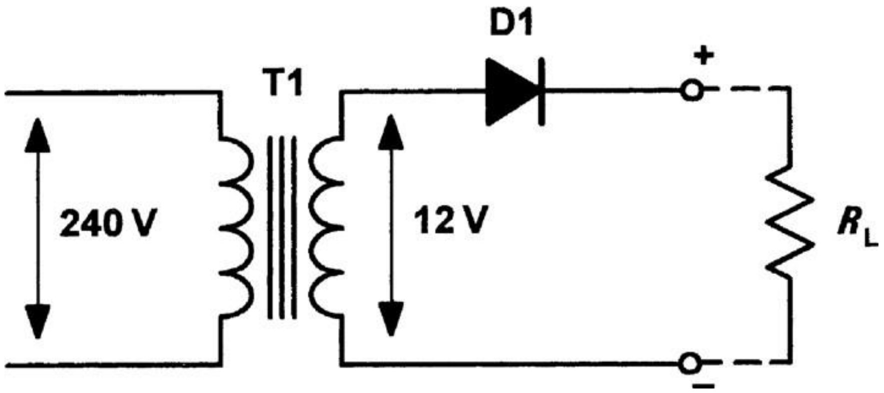


Fig: A simple half-wave rectifier circuit

The simplest form of rectifier circuit makes use of a single diode and, since it operates on only either positive or negative half-cycles of the supply, it is known as a **half-wave** rectifier.

Fig. shows a simple half-wave rectifier circuit. Mains voltage (220 to 240 V) is applied to the primary of a step-down transformer (T1).

The secondary of T1 steps down the 240Vr.m.s. to 12Vr.m.s. (the turns ratio of T1 will thus be 240/12 or 20:1).

Diode D1 will only allow the current to flow in the direction shown (i.e. from cathode to anode).

During positive half-cycle:

During the positive half cycle of the input, the ideal diode (D1) is forward biased and operates as a closed switch as shown in the figure.

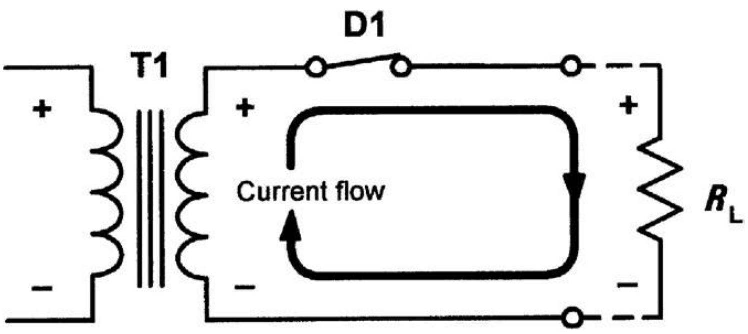


Fig:Half-wave rectifier circuit with D1 conducting (positive-going half-cycles of secondary voltage)

During negative half cycle:

During the negative half cycle, the diode is reverse biased and acts as an open switch as shown in the figure.

The source voltage is disconnected from the load. Hence no current flows through a circuit.

As no current flows through the load, the load voltage *vo* is zero.

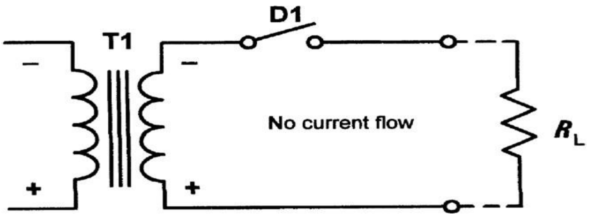
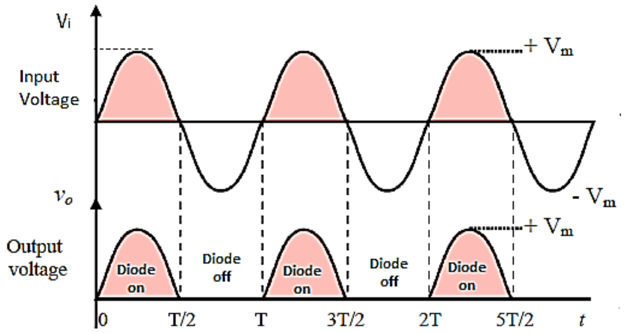


Fig: half-wave rectifier with D1 not conducting (negative-going half-cycles of secondary voltage)

The waveforms for input voltage *vi* and output voltage *vo* are shown in the figure.



Example 6.1

A mains transformer having a turns ratio of 44:1 is connected to a 220 V r.m.s. mains supply. If the secondary output is applied to a half-wave rectifier, determine the peak voltage that will appear across a load.

Solution

The r.m.s. secondary voltage will be given by:

$V_S = V_P / 44 = 220 / 44 = 5\ V$

The peak voltage developed after rectification will be given by:

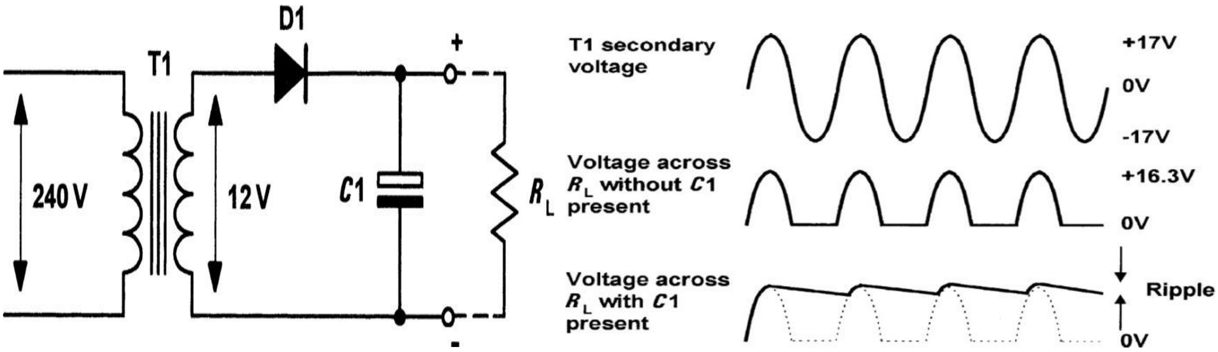
$V_{PK} = 1.414 \text{ x} 5\ V == 7.07\ V$

Assuming that the diode is a silicon device with a forward voltage drop of 0.6 V, the actual peak voltage dropped across the load will be:

$V_L = 7.07\ V - 0.6\ V = 6.47V$

HALF WAVE RECTIFIER WITH A RESERVOIR CAPACITOR:

Fig. shows half wave rectifier with a reservoir capacitor.



- The time required for C1 to charge to the maximum (peak) level is determined by the charging circuit time constant (the series resistance multiplied by the capacitance value).
- In this circuit, the series resistance comprises the secondary winding resistance together with the forward resistance of the diode and the (minimal) resistance of the wiring and connections.
- Hence C1 charges very rapidly as soon as D1 starts to conduct.
- The time required for *C*1 to discharge is determined by the capacitance value and the load resistance, *R*L. During this time, D1 will be reverse biased and will thus be held in its non-conducting state.
- As a consequence, the only discharge path for *C*1 is through *R*L.
- *C*1 is referred to as a **reservoir** capacitor. It stores charge during the positive halfcycles of secondary voltage and releases it during the negative half-cycles.

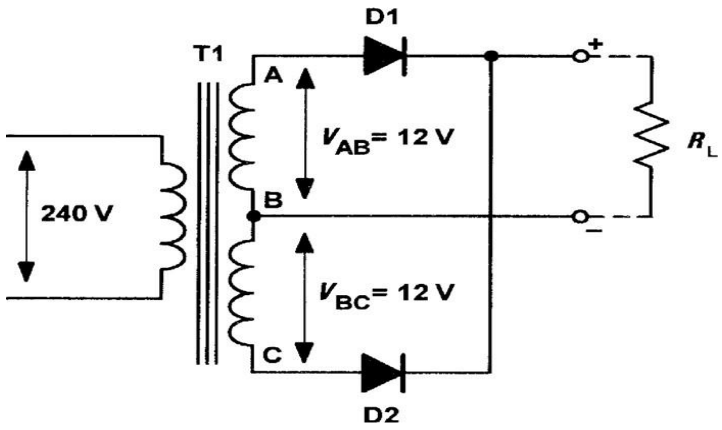
Full-wave rectifiers:

The half-wave rectifier circuit is relatively inefficient as conduction takes place only on alternate half-cycles. A better rectifier arrangement would make use of both positive *and* negative half-cycles. These **full-wave rectifier** circuits offer a considerable improvement over their half-wave rectifiers.

There are two basic forms of full-wave rectifier;
The bi-phase type and the bridge rectifier type.

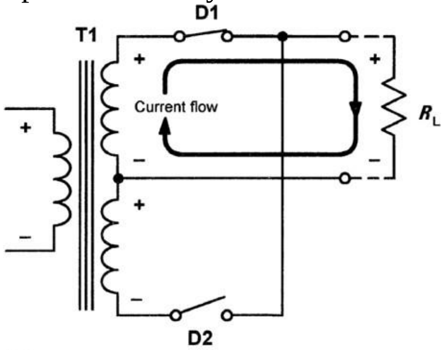
Bi-phase rectifier circuits:

Fig. shows a simple bi-phase rectifier circuit.
Mains voltage (240 V) is applied to the primary of the step-down transformer (T1) which has two identical secondary windings, each providing 12 V r.m.s. (the turns ratio of T1 will thus be 240/12 or 20:1 for *each* secondary winding).



During positive half-cycle:

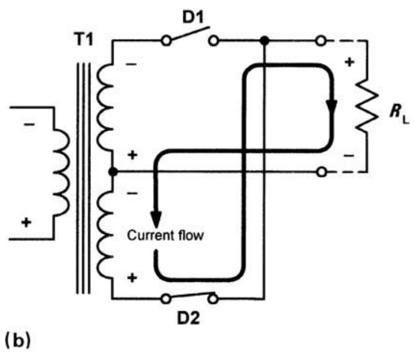
- On positive half-cycles, point A will be positive with respect to point B. Similarly, point B will be positive with respect to point C.
- In this condition D1 will allow conduction (its anode will be positive with respect to its cathode) while D2 will not allow conduction (its anode will be negative with respect to its cathode).
- Thus D1 alone conducts on positive half-cycles.
- Fig shows the bi-phase rectifier circuit with the diodes replaced by switches and D1 is shown conducting on a positive half-cycle.



(a)

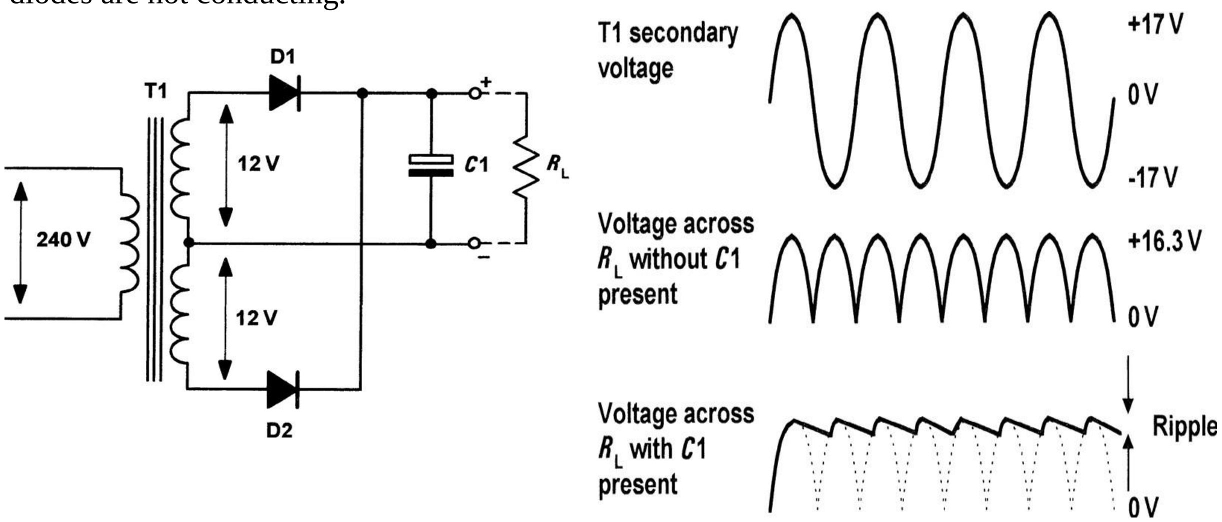
During negative half cycle:

- On negative half-cycles, point C will be positive with respect to point B. Similarly, point B will be positive with respect to point A.
- In this condition D2 will allow conduction (its anode will be positive with respect to its cathode) while D1 will not allow conduction (its anode will be negative with respect to its cathode).
- Thus D2 alone conducts on negative half-cycles.
- Fig. shows the bi-phase rectifier circuit with the diodes replaced by switches and D2 is shown conducting.



Bi-phase rectifier with reservoir capacitor:

Fig. shows Bi-phase rectifier with reservoir capacitor and how a reservoir capacitor (*C*1) can be added to ensure that the output voltage remains at, or near, the peak voltage even when the diodes are not conducting.



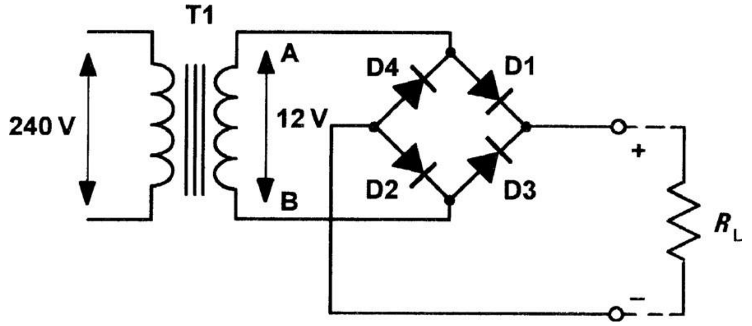
- In this circuit, *C*1 charges very rapidly as soon as either D1 or D2 starts to conduct.
- The time required for *C*1 to discharge is determined by the capacitance value and the load resistance, *R*L.
- In practice, *R*L is very much larger than the resistance of the secondary circuit and hence *C*1 takes an appreciable time to discharge.
- During this time, D1 and D2 will be reverse biased and held in a non-conducting state.
- As a consequence, the only discharge path for *C*1 is through *R*L.
- Fig. shows voltage waveforms for the bi-phase rectifier, with and without *C*1 present.

Bridge rectifier circuits:

A full-wave bridge rectifier arrangement is shown in Fig.

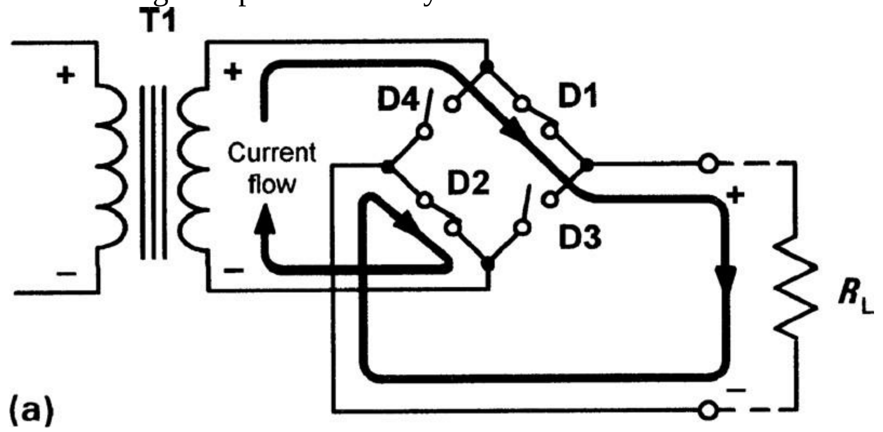
Mains voltage (240 V) is applied to the primary of a step-down transformer (T1).

The secondary winding provides 12 V r.m.s. (approximately 17 V peak) and has a turns ratio of 20:1, as before.



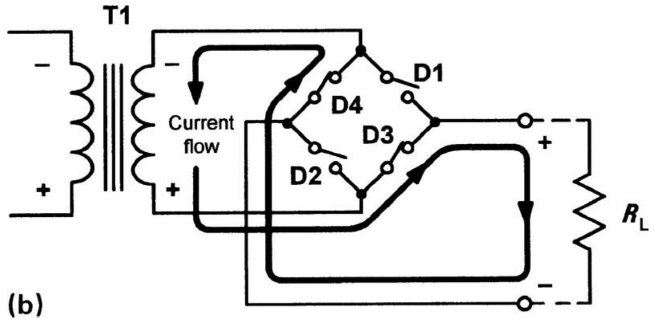
During positive half-cycle:

- On positive half-cycles, point A will be positive with respect to point B.
- In this condition D1 and D2 will allow conduction while D3 and D4 will not allow conduction.
- Fig. shows the bridge rectifier circuit with the diodes replaced by four switches, D1 and D2 are conducting on a positive half-cycle while D3 and D4 are not conducting.



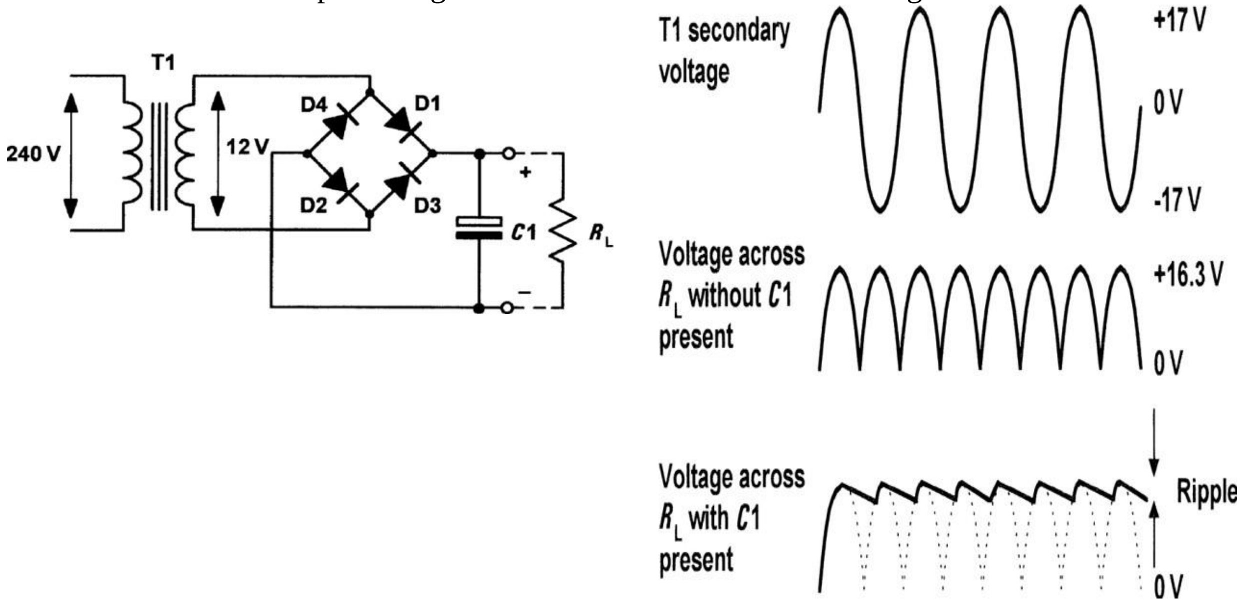
During negative half cycle:

- On negative half-cycles, point B will be positive with respect to point A.
- In this condition D3 and D4 will allow conduction while D1 and D2 will not allow conduction.
- Fig. shows the bridge rectifier circuit with the diodes replaced by four switches, D1 and D2 are not conducting on a positive half-cycle while D3 and D4 conducting.

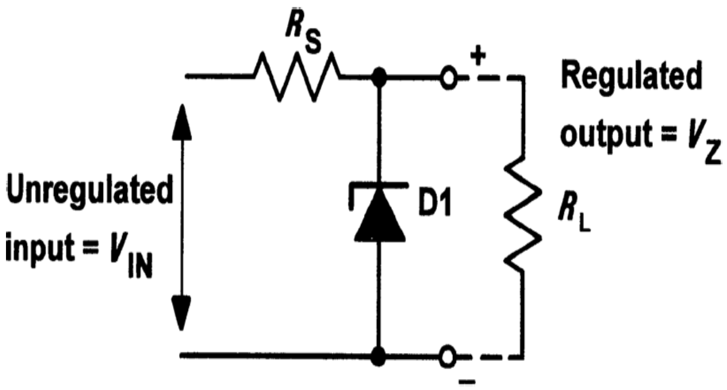


Bridge rectifier with reservoir capacitor:

Fig. shows Bridge rectifier with reservoir capacitor and how a reservoir capacitor ($C1$) can be added to maintain the output voltage when the diodes are not conducting.



Voltage regulators:



- A simple voltage regulator is shown in Fig.
- R_S is included to limit the zener current to a safe value when the load is disconnected.
- When a load (R_L) is connected, the zener current (I_Z) will fall as current is diverted into the load resistance.
- The output voltage (V_Z) will remain at the zener voltage until regulation fails at the point at which the potential divider formed by R_S and R_L produces a lower output voltage that is less than V_Z.

The ratio of *R*S to *R*L is thus important. At the point at which the circuit just begins to fail to regulate:

$$V_Z = V_{IN} \times \frac{R_L}{(R_L + R_S)}$$

where V_{IN} is the unregulated input voltage.

Thus the *maximum* value for R_S can be calculated from:

$$\boldsymbol{R_{S(MAX)} = R_L \times \left(\frac{V_{IN}}{V_Z} - 1\right)}$$

The power dissipated in the zener diode will be given by $P_Z = I_Z \times V_Z$, hence the minimum value for *R*S can be determined from the off-load condition when:

$$\boldsymbol{R_{S(MIN)} = \frac{V_{IN} - V_Z}{I_Z} = \frac{V_{IN} - V_Z}{\left(\frac{P_{Z(MAX)}}{V_Z}\right)} = \frac{(V_{IN} - V_Z) \times V_Z}{P_{Z(MAX)}}}$$

Thus:

$$\boldsymbol{R_{S(MIN)} = \frac{V_{IN}V_Z - V_Z{}^2}{P_{Z(MAX)}}}$$

where *P*Z max. is the maximum rated power dissipation for the zener diode.

OUTPUT RESISTANCE AND VOLTAGE REGULATION:

Output resistance is defined as the change in output voltage divided by the corresponding change in output current. Hence:

$$\boldsymbol{R_{OUT}} = \frac{\text{change in output voltage}}{\text{change in output current}} = \frac{\Delta \boldsymbol{V_{OUT}}}{\Delta \boldsymbol{I}_{\boldsymbol{OUT}}}$$

where $\Delta \boldsymbol{I_{OUT}}$ represents a small change in output (load) current and $\Delta \boldsymbol{V_{OUT}}$ represents a corresponding small change in output voltage.

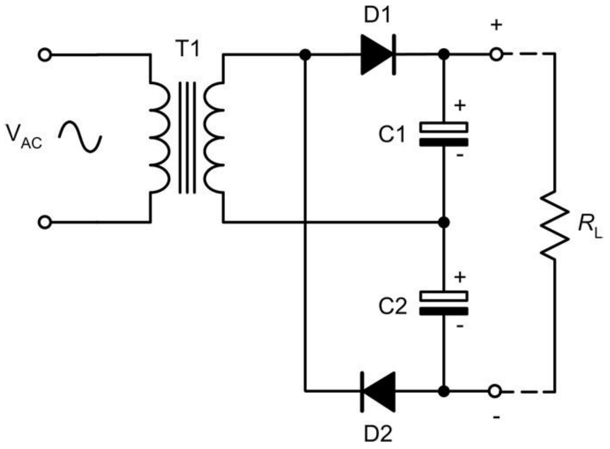
The **regulation** of a power supply is given by the relationship:

$$\boldsymbol{R_{OUT}} = \frac{\text{change in output voltage}}{\text{change in line (input) current}} \times \mathbf{100}\%$$

VOLTAGE MULTIPLIERS:

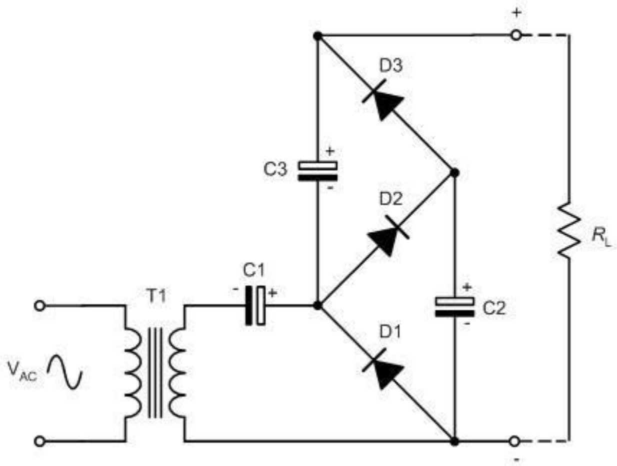
VOLTAGE DOUBLER:

- A voltage doubler using this technique is shown in Fig.
- In this arrangement C1 will charge to the positive peak secondary voltage while C2 will charge to the negative peak secondary voltage.
- Since the output is taken from C1 and C2 connected in series the resulting output voltage is twice that produced by one diode alone.



VOLTAGE TRIPLER:

Figure shows the circuit diagram of voltage tripler



- C1 charges to positive peak secondary voltage, while C2 and C3 charges to twice the positive peak secondary voltage.
- The result is that the output voltage is the sum of the voltages across C1 and C3 which is 3 times the voltage that would be produced by a single diode.
- The ladder arrangement can be easily extended to provide even higher voltages but the efficiency of the circuit becomes increasingly impaired and high order voltage multipliers of this type are only suitable for providing relatively small currents.

Amplifiers – Types of amplifiers, Gain, Input and output resistance, Frequency response, Bandwidth, Phase shift, Negative feedback, Multi-stage amplifiers.

Types of amplifiers:

1. **a.c. coupled amplifiers**: In a.c. coupled amplifiers, stages are coupled together in such a way that d.c. levels are isolated and only the a.c. components of a signal are transferred from stage to stage.
2. **d.c. coupled amplifiers**: In d.c. (or direct) coupled amplifiers, stages are coupled together in such a way that stages are not isolated to d.c. potentials. Both a.c. and d.c. signal components are transferred from stage to stage.
3. **Large-signal amplifiers**: Large-signal amplifiers are designed to cater for appreciable voltage and/or current levels (typically from 1 V to 100 V or more).
4. **Small-signal amplifiers**: Small-signal amplifiers are designed to cater for low-level signals (normally less than 1 V and often much smaller). Small-signal amplifiers have to be specially designed to combat the effects of noise.
5. **Audio frequency amplifiers**: Audio frequency amplifiers operate in the band of frequencies that is normally associated with audio signals (e.g. 20 Hz to 20 kHz).
6. **Wideband amplifiers**: Wideband amplifiers are capable of amplifying a very wide range of frequencies, typically from a few tens of hertz to several megahertz.
7. **Radiofrequency amplifiers**: Radiofrequency amplifiers operate in the band of frequencies that is normally associated with radio signals (e.g. from 100 kHz to over 1 GHz).
8. **Low-noise amplifiers**: Low-noise amplifiers are designed so that they contribute negligible noise (signal disturbance) to the signal being amplified. These amplifiers are usually designed for use with very small signal levels (usually less than 10 mV or so).

Gain:

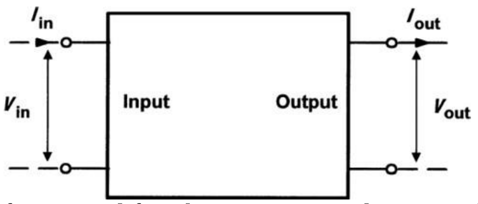


Fig: Block diagram for an amplifier showing input and output voltages and currents

Gain is simply the ratio of output voltage to the input voltage, output current to the input current, or output power to input power. These three ratios give, respectively, the voltage gain, current gain, and power gain.

Voltage gain, $A_v = \frac{V_{out}}{V_{in}}$

Current gain, $A_i = \frac{I_{out}}{I_{in}}$

Power gain, $A_p = \frac{P_{out}}{P_{in}}$

Problem 1:

An amplifier produces an output voltage of 2 V for an input of 50 mV. If the input and output currents in this condition are, respectively, 4 mA and 200 mA, determine:
(a)the voltage gain, (b)current gain, and (c)power gain.

Solution:
(a) The voltage gain is calculated from:
Voltage gain, $A_v = \frac{V_{out}}{V_{in}} = \frac{2}{50mv} = 40$

(b) The current gain is calculated from:
Current gain, $A_i = \frac{I_{out}}{I_{in}} = \frac{200mA}{4A} = 50$

(c) The power gain is calculated from:

Power gain, $A_p = \frac{P_{out}}{P_{in}} = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = A_i \times A_v = 50 \times 40 = 2000$

Input and output resistance:

Input resistance is the ratio of input voltage to input current and it is expressed in ohms.
Output resistance is the ratio of open-circuit output voltage to short-circuit output current and is measured in ohms.
Fig. shows how the input and output resistances are ‘seen’ looking into the input and output terminals, respectively.

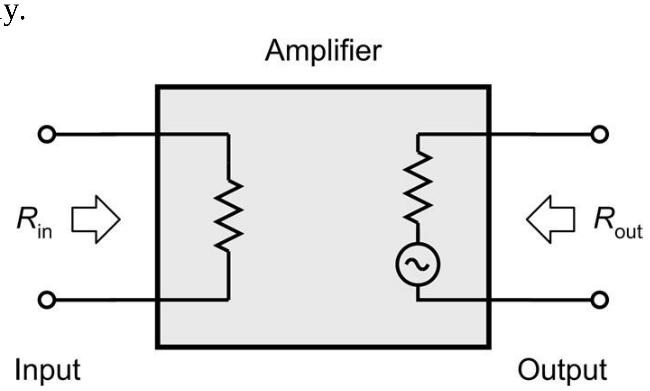


Fig: Input and output resistances ‘seen’ looking into the input and output terminals, respectively

Frequency response:

The frequency response characteristics for various types of amplifier are shown in Fig.

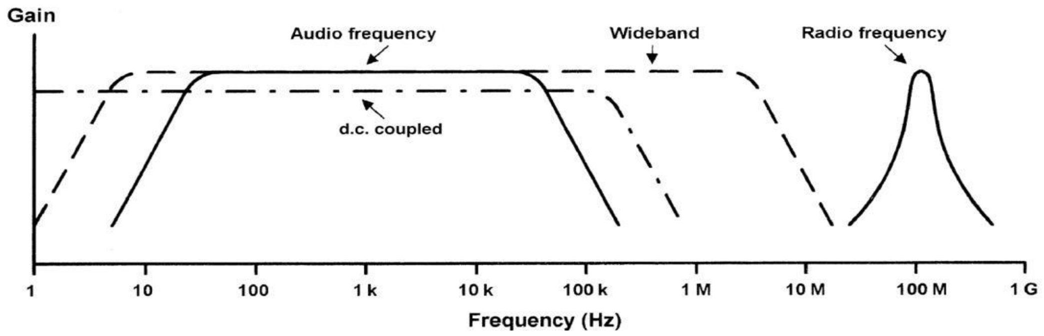
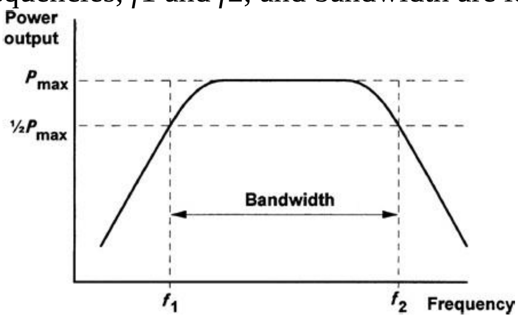


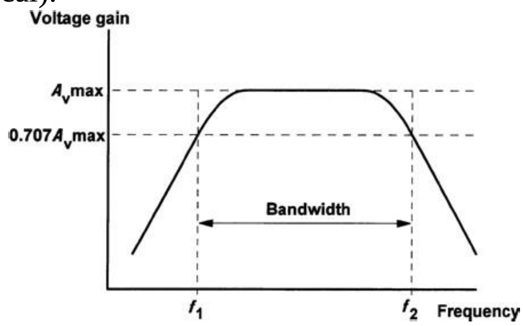
Fig: Frequency response and bandwidth (output power plotted against frequency)

The frequency response of an amplifier is usually specified in terms of the upper and lower **cut-off frequencies** of the amplifier. These frequencies are those at which the output power has dropped to 50% (otherwise known as the −**3 dB points**) or where the voltage gain has dropped to 70.7% of its mid-band value.

Figs show how the bandwidth can be expressed in terms of either power or voltage (the cut-off frequencies, *f*1 and *f*2, and bandwidth are identical).



Frequency response and bandwidth
(output power plotted against frequency)



Frequency response and bandwidth
(output voltage plotted against frequency)

Bandwidth:

The bandwidth of an amplifier is usually taken as the difference between the upper and lower cut-off frequencies (i.e. *f*2 - *f*1).
The bandwidth of an amplifier must be sufficient to accommodate the range of frequencies present within the signals that it is to be presented with.

Phase shift:

Phase shift is the phase angle between the input and output signal voltages measured in degrees. The measurement is usually carried out in the mid-band where, for most amplifiers, the phase shift remains relatively constant.
Note also that conventional single-stage transistor amplifiers provide phase shifts of either 180° or 360°.

Negative feedback:

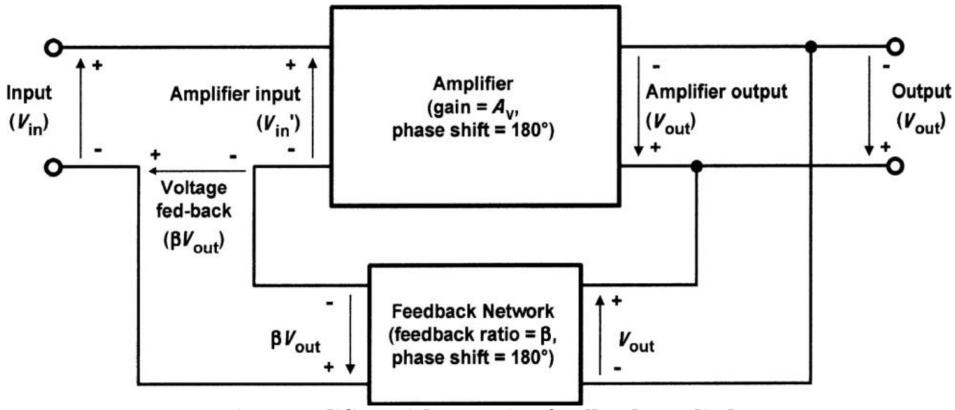


Fig: Amplifier with negative feedback applied

The above Fig. shows the block diagram of an amplifier stage with negative feedback applied. In this circuit, the proportion of the output voltage fed back to the input is given by β and the overall voltage gain will be given by:

Overall gain, $G = \frac{V_{out}}{V_{in}}$

Now $V_{in}^{`} = V_{in} - \beta V_{out}$ (by applying Kirchhoff's Voltage Law) (note that the amplifier's input voltage has been reduced by applying negative feedback) thus:

$$V_{in} = V_{in}^{`} + \beta V_{out}$$

And $V_{out} = A_V \times V_{in}^{`}$(note that Av is the internal gain of the amplifier)

Hence:

Overall gain, $G = \frac{V_{out}}{V_{in}} = \frac{A_V \times V_{in}}{V_{in}^{`} + \beta V_{out}} = \frac{A_V \times V_{in}^{`}}{V_{in}^{`} + \beta(A_V \times V_{in}^{`})} = \frac{A_V \times V_{in}^{`}}{V_{in}^{`}(1+\beta A_V)} = \frac{A_V}{(1+\beta A_V)}$

$$\therefore \text{Overall gain}, G = \frac{A_V}{(1 + \beta A_V)}$$

Hence, the overall gain with negative feedback applied will be less than the gain without feedback.

Problem:

An amplifier with negative feedback applied has an open-loop voltage gain of 50, and one-tenth of its output is fed back to the input (i.e. β = 0.1). Determine the overall voltage gain with negative feedback applied.

Solution:

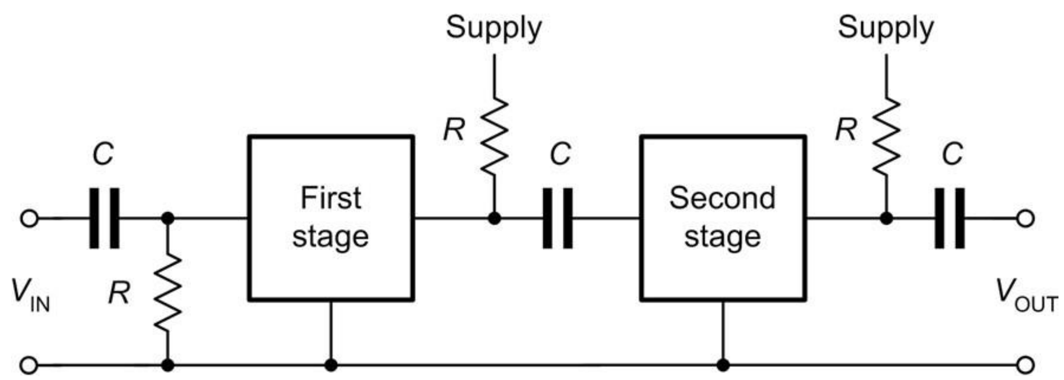
$$G = \frac{A_V}{(1 + \beta A_V)} = \frac{50}{1 + (0.1 \times 50)} = \frac{50}{6} = 8.33$$

Multi-stage amplifiers:
The overall gain of an amplifier with several stages (i.e. a multi-stage amplifier) is simply the product of the individual voltage gains.
Hence:
$AV = AV1 \times AV2 \times AV3$, etc.

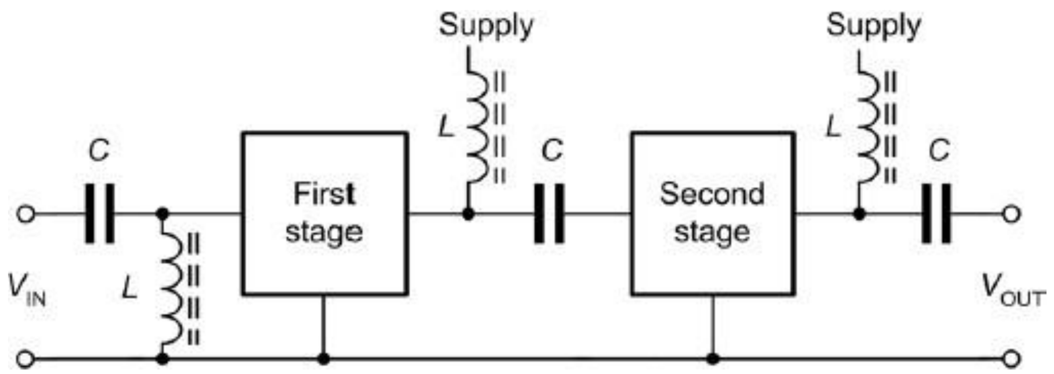
Signals can be coupled between the individual stages of a multi-stage amplifier using one of a number of different methods

1. ***R–C* Coupling**
2. ***L–C* Coupling**
3. **Transformer Coupling**
4. **Direct Coupling**

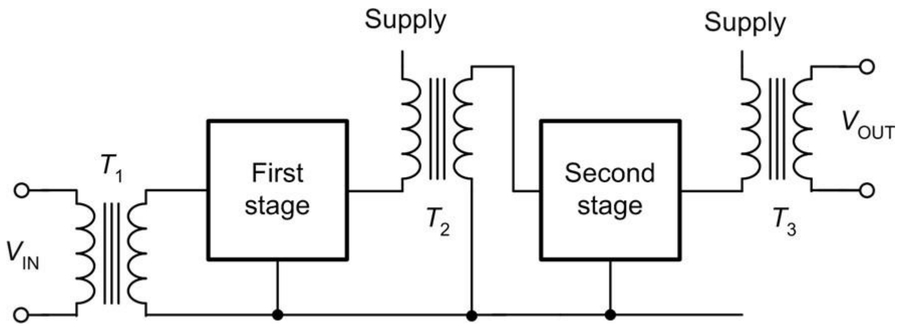
***1. R–C* Coupling Multi-stage amplifier:**
In this coupling method, the stages are coupled together using capacitors having a low reactance at the signal frequency and resistors (which also provide a means of connecting the supply).



2. *L–C* Coupling Multi-stage amplifier:
In this method, the inductors have a high reactance at the signal frequency. This type of coupling is generally only used in RF and high-frequency amplifiers.



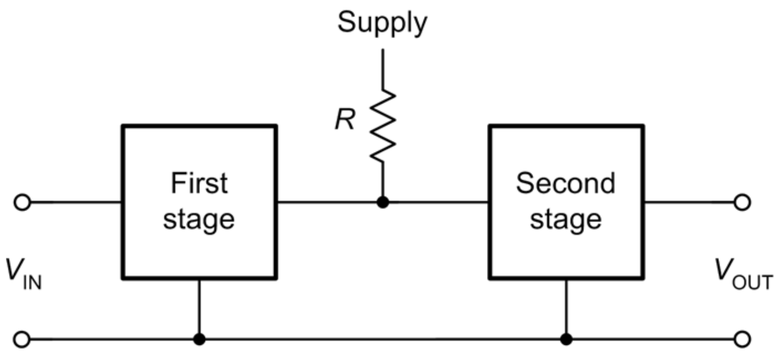
3. Transformer Coupling Multi-stage amplifier:
In this coupling method, the stages are coupled together using transformer.



- Gain achieved is higher.
- There will be no power loss in collector and base resistors.
- Efficient in operation.

4. Direct Coupling Multi-stage amplifier:

In this coupling method, the stages are coupled directly from one stage to another.



- The circuit cost is low because of the absence of expensive coupling components.
- Used where dc levels present on signals must be preserved.