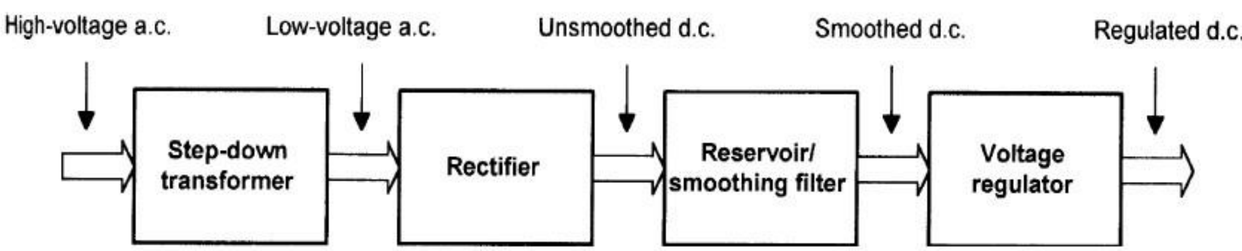
MODULE-1

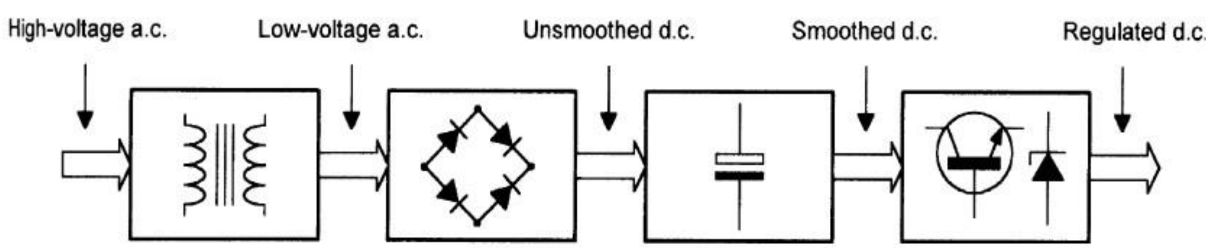
Power supplies

- As we concentrating on electronic circuits, the power supply required to run this circuit is very low and constant DC supply.

The block diagram of a d.c. power supply is shown in Fig. The mains input are at a relatively high voltage, a step-down transformer of appropriate turn's ratio is used to convert this to a low voltage.



Block diagram of a d.c. power supply

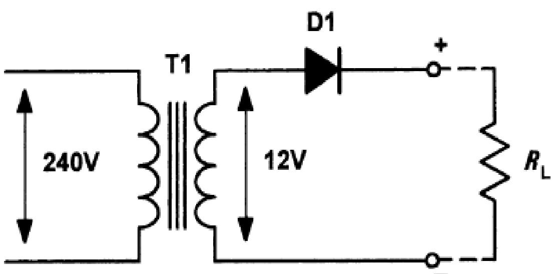


Block diagram of a d.c. power supply showing principal components used in each stage

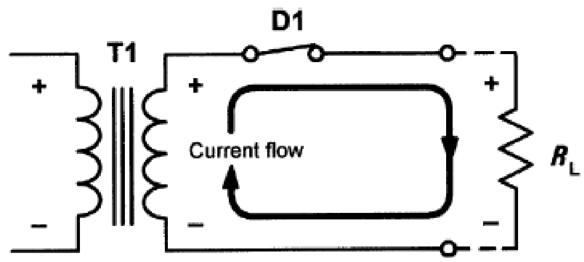
- The a.c. output from the transformer secondary is then rectified using conventional silicon rectifier diodes to produce an unsmoothed output.
- This is then smoothed and filtered before being applied to a circuit which will regulate (or stabilize) the output voltage so that it remains relatively constant in spite of variations in both load current and incoming mains voltage.

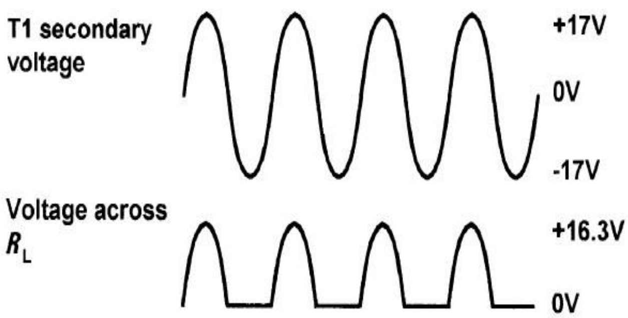
RECTIFIERS

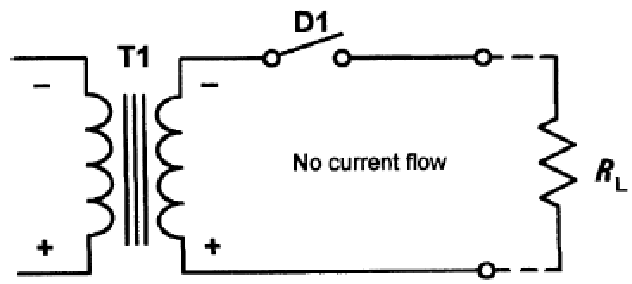
- Semiconductor diodes are commonly used to convert alternating current (a.c.) to direct current (d.c.), in which case they are referred to as rectifiers.
- The simplest form of rectifier circuit makes use of a single diode and, since it operates on only either positive or negative half-cycles of the supply, it is known as a half-wave rectifier.



Simple half-wave rectifier circuit







- Figure shows a simple half-wave rectifier circuit.
- Mains voltage (240 V) is applied to the primary of a stepdown transformer (T1).
- The secondary of T1 steps down the 240 V r.m.s. to 12 V r.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). D1 will be forward biased during each positive half-cycle (relative to common) and will effectively behave like a closed switch.
- During the positive half-cycle, the diode will drop the 0.6 V to 0.7 V forward threshold voltage normally associated with silicon diodes.

- When the circuit current tries to flow in the opposite direction, the voltage bias across the diode will be reversed, causing the diode to act like an open switch as shown in fig.
- The negative half-cycles are blocked by D1 and thus only the positive half-cycles appear across R_L.
- Assuming that the secondary of T1 provides 12 Vr.m.s, the peak voltage output from the transformer's secondary winding wil be given by:

  V_{pk} = 1.414 × Vr.m.s. = 1.414 × 12 V = 16.97 V

- the actual peak voltage across RL will be the 17 V positive peak being supplied from the secondary on T1, minus the 0.7 V forward threshold voltage dropped by D1. In other words, positive half-cycle pulses having a peak amplitude of 16.3 V will appear across R_L

A mains transformer having a turns ratio of 44:1 is connected to a 220 Vr.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 $\frac{V_{pk}}{V_s} = \frac{N_p}{N_s} \rightarrow V_{pk} = V_s \times \frac{N_p}{N_s}$

- $V_s = V_{pk} \times \frac{N_s}{N_p} = 220 \times \frac{1}{44} = 5\ V$
- The peak voltage developed after rectification will be given by:

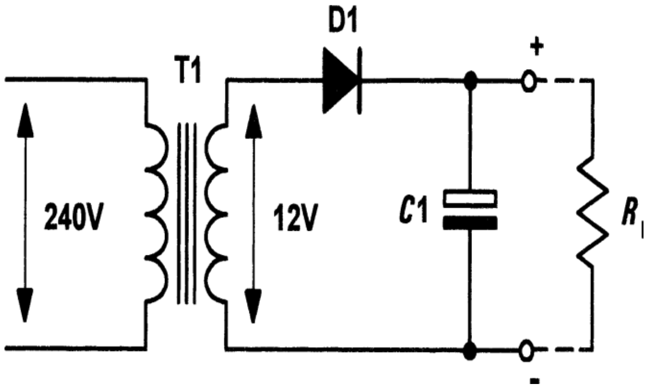
  V_{pk} = 1.414 × 5 V = 7.07 V

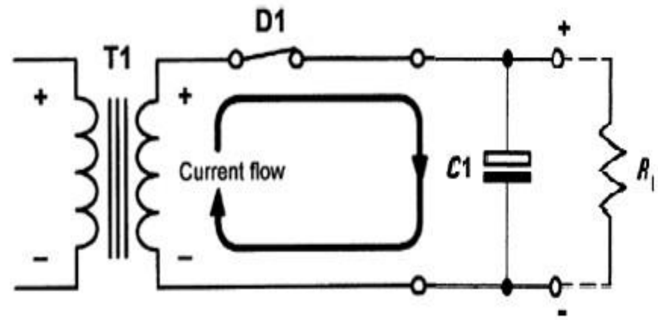
- Assuming that the diode is a silicon device with a forward voltage drop of 0.7 V, the actual peak voltage dropped across the load will be: V_L = 7.07 V - 0.7 V = 6.47 V

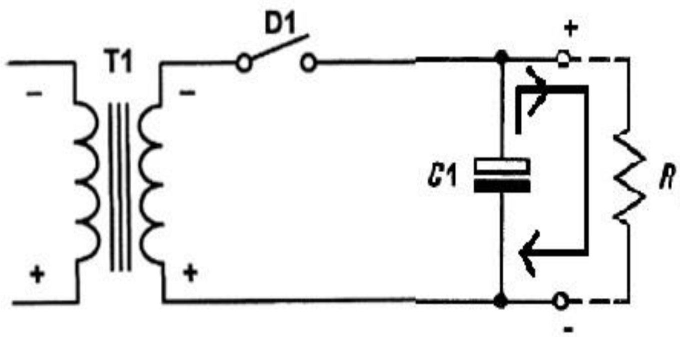
Half-wave rectifier with reservoir capacitor

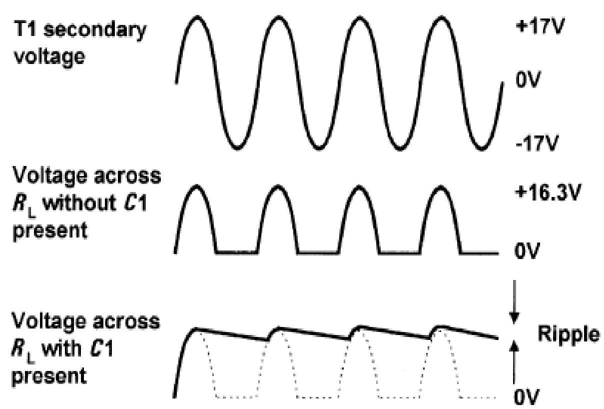
- The capacitor, C1, has been added to ensure that the output voltage remains at, or near, the peak voltage even when the diode is not conducting.
- The first positive half-cycle output from the secondary will charge C1 to the peak value seen across R_L.

- The time required for C1 to charge to the maximum (peak) level is determined by the charging circuit time constant.



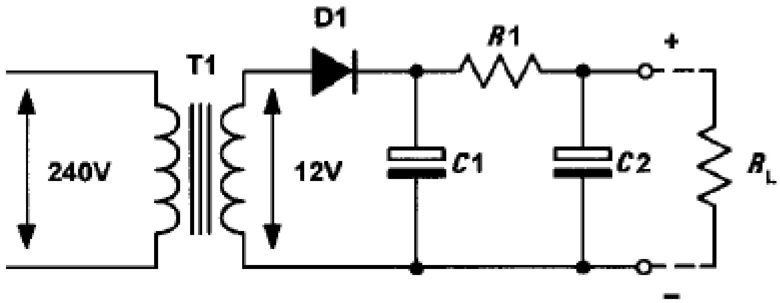






- Because C1 and R_L are in parallel, the voltage across R_L will be the same as that across C1.
- During negative half cycle, D1 will be reverse biased and will thus be held in its non-conducting state. As a consequence, the only discharge path for C1 is through R_L.
- C1 will discharge by a small amount during the negative half-cycle periods from the transformer secondary.

Half-wave rectifier circuit with R–C smoothing filter



- Figure shows a further refinement of the simple power supply circuit. This circuit employs two additional components, R1 and C1, which act as a filter to remove the ripple. The value of C1 is chosen so that the component exhibits a negligible reactance at the ripple frequency. In effect, R1 and C1 act like a potential divider.
- The amount of ripple is reduced by an approximate factor equal to: $\frac{X_C}{\sqrt{(R_1)^2+(X_C)^2}}$

Example The R–C smoothing filter in a 50 Hz mains operated half-wave rectifier circuit consists of R1 =100 G and C2 = 1,000 µF. If 1 V of ripple appears at the input of the circuit, determine the amount of ripple appearing at the output.

Solution

First we must determine the reactance of the capacitor, C1, at the ripple frequency (50 Hz):

$$X_C = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 50 \times 1{,}000 \times 10^{-6}} = \frac{1{,}000}{314} = 3.18\ \Omega$$

The amount of ripple at the output of the circuit (i.e. appearing across C1) will be given by:

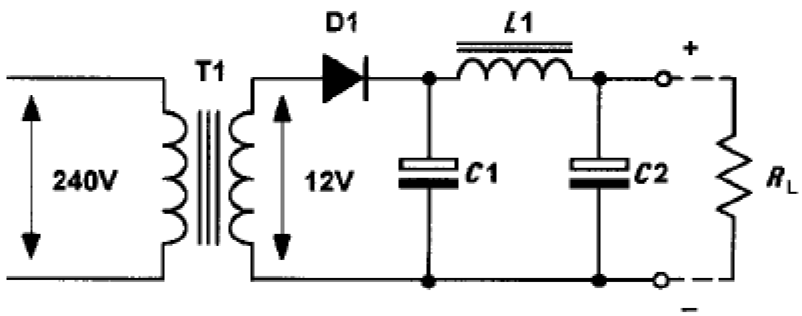
$$V_{\text{ripple}} = 1 \times \frac{X_C}{\sqrt{R^2 + X_C{}^2}} = 1 \times \frac{3.18}{\sqrt{100^2 + 3.18^2}}$$

From which: $V_{\text{ripple}} = 0.032\ \text{V} = 32\ \text{mV}$

Improved ripple filters

- A further improvement can be achieved by using an inductor, L1, instead of a resistor in the smoothing circuit. This circuit also offers the advantage that the minimum d.c. voltage is dropped across the inductor

- Half-wave rectifier circuit with L–C smoothing filter



- Figure shows the circuit of a half-wave power supply with an L–C smoothing circuit. At the ripple frequency, L1 exhibits a high value of inductive reactance while C1 exhibits a low value of capacitive reactance. The combined effect is that of an attenuator which greatly reduces the amplitude of the ripple while having a negligible effect on the direct voltage.

- The amount of ripple is reduced by an approximate factor equal to: $\frac{X_C}{X_C + X_L}$

Example

The L–C smoothing filter in a 50 Hz mains operated half-wave rectifier circuit consists of L1 = 10 H and C2 = 1,000 µF. If 1 V of ripple appears at the input of the circuit, determine the amount of ripple appearing at the output.

Solution

The reactance of the capacitor, C1, $X_C = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 50 \times 1{,}000 \times 10^{-6}} = \frac{1{,}000}{314} = 3.18\ \Omega$

The reactance of L1 at 50 Hz can be calculated from:

$$X_L = 2\pi f L = 2 \times 3.14 \times 50 \times 10 = 3{,}140\ \Omega$$

The amount of ripple at the output of the circuit (i.e. appearing across C1) will be approximately given by:

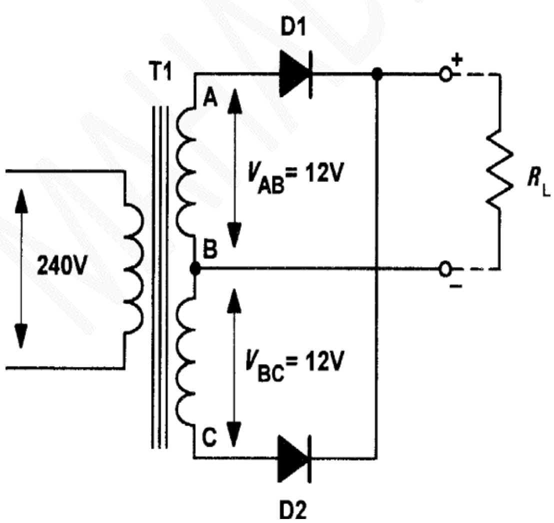
$$V_{\text{ripple}} = 1 \times \frac{X_C}{X_C + X_L} = 1 \times \frac{3.18}{3140 + 3.18} \approx 0.001 \text{ V}$$

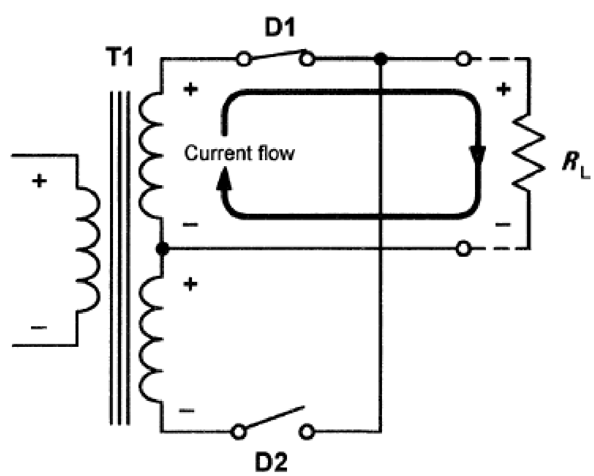
Full-Wave Rectifier

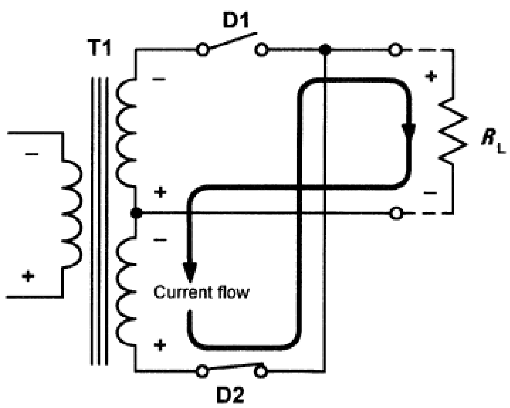
- The half-wave rectifier circuit is relatively inefficient as conduction takes place only on alternate half-cycles.
- A better rectifier arrangement would make use of both positive and negative half-cycles.
- They are not only more efficient but are significantly less demanding in terms of the reservoir and smoothing components.
- There are two basic forms of full-wave rectifier; the bi-phase type and the bridge rectifier type.

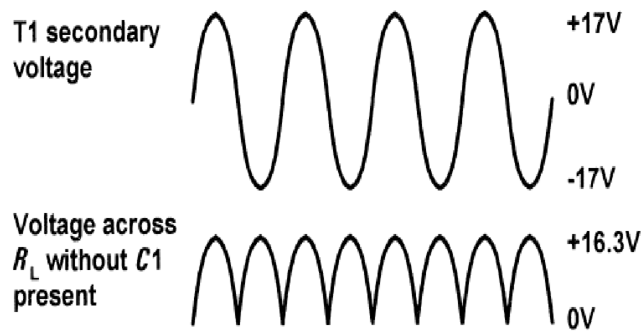
Bi-phase rectifier circuits

- Figure shows a simple bi-phase rectifier circuit. Mains voltage (240 V) is applied to the primary of a stepdown transformer (T1) which has two identical secondary windings, each providing 12 V r.m.s.
- During positive half-cycles, D1 alone conducts while D2 will be off.



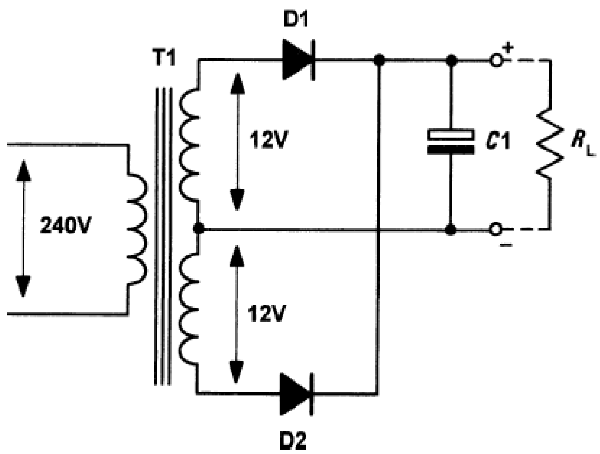


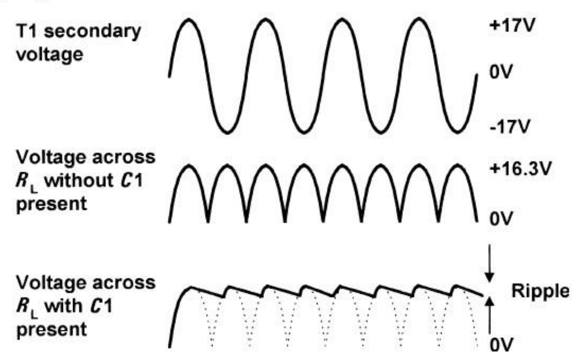




- And during negative half-cycles, D2 alone conducts while D1 will be off.
- Figure shows voltage waveforms for the bi-phase rectifier, with and without C1 present.

Bi-phase rectifier circuits with reservoir capacitor

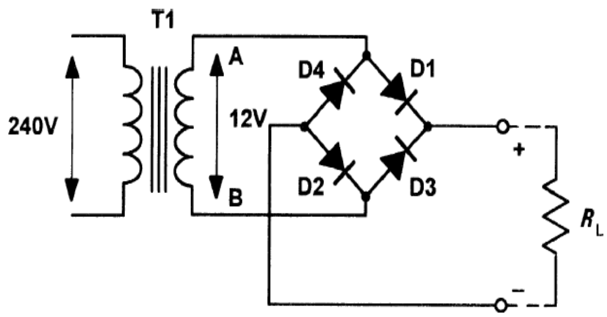


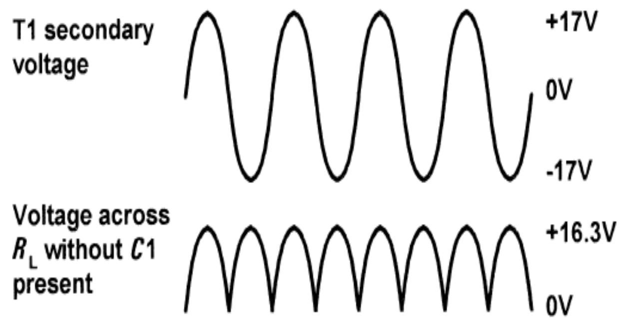


Waveforms for the bi-phase rectifier

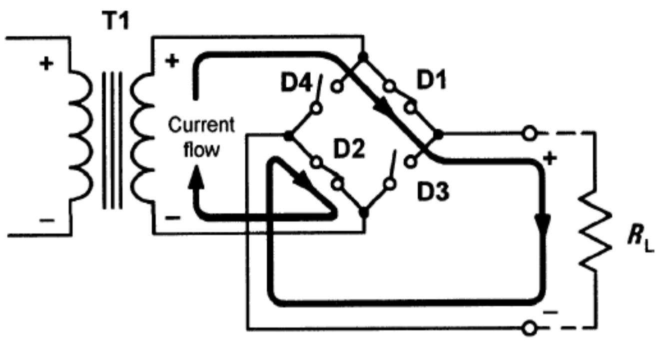
- Figure shows how a reservoir capacitor (C1) can be added to ensure that the output voltage remains at, or near, the peak voltage even when the diodes are not conducting.
- The time required for C1 to charge to the maximum (peak) level is determined by the charging circuit time constant.
- Hence C1 charges very rapidly as soon as either D1 or D2 starts to conduct
- The time required for C1 to discharge is, in contrast, very much greater. The discharge time contrast is determined by the capacitance value and the load resistance, RL.

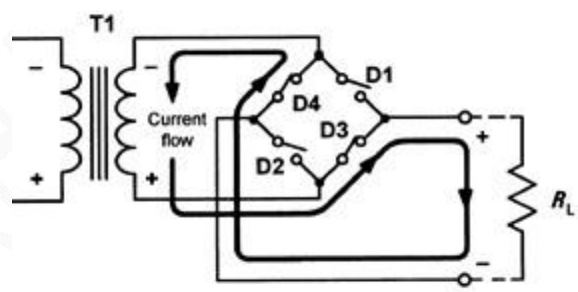
Full Wave Bridge Rectifier





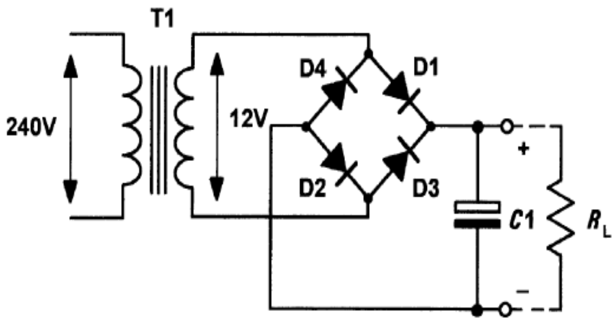
- A full-wave bridge rectifier arrangement is shown in Fig. Mains voltage (240 V) is applied to the primary of a stepdown transformer (T1).



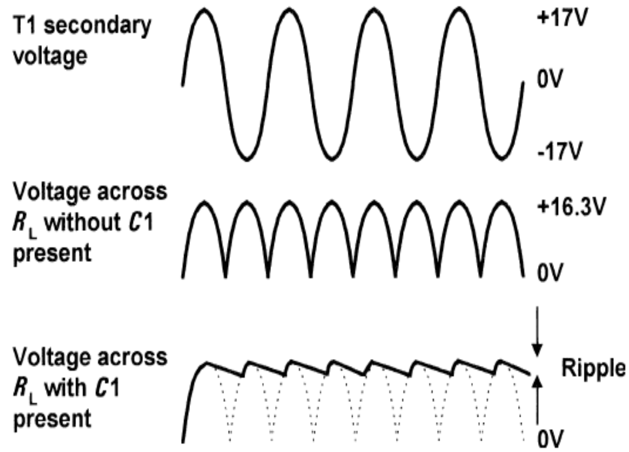


- The secondary winding provides 12 V r.m.s. (approximately 17 V peak) and has a turns ratio of 20:1.
- On positive half-cycles, point A will be positive with respect to point B. In this condition D1 and D2 will conduct while D3 and D4 will be off.
- Conversely, on negative half-cycles, point B will be positive with respect to point A. In this condition D3 and D4 will conduct while D1 and D2 will be off.

Full Wave Bridge Rectifier with reservoir capacitor

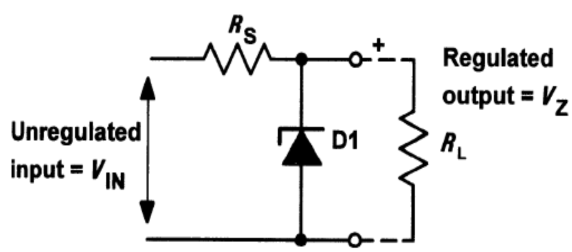


Bridge rectifier with reservoir capacitor



- A simple voltage regulator is shown in Figure. 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_O) 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.

Voltage regulator



Zener diode shunt voltage regulator

- A simple voltage regulator is shown in Figure. 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_O) 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.
- 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:

$$R_S \text{ max.} = R_L \times \left(\frac{V_{IN}}{V_{IN}} - 1 \right)$$

- the minimum value for RS can be determined from the off-load condition when:

$$R_S \text{ min.} = \frac{V_{IN} - V_Z}{I_Z} = \frac{V_{IN} - V_Z}{\left(\frac{P_Z \text{ max.}}{V_Z} \right)} = \frac{(V_{IN} - V_Z) \times V_Z}{P_Z \text{ max.}}$$

- The power dissipated in the zener diode, wil be given by $P_Z = I_Z \times V_Z$

  where P_{Zmax}. is the maximum rated power dissipation for the zener diode.

Example

A 5V zener diode has a maximum rated power dissipation of 500 mW. If the diode is to be used in a simple regulator circuit to supply a regulated 5 V to a load having a resistance of 400 G, determine a suitable value of series resistor for operation in conjunction with a supply of 9 V.

Solution

We shall use an arrangement similar to that shown in Fig. First we should determine the maximum value for the series resistor, R_s

$$R_S \text{ max.} = R_L \times \left(\frac{V_{IN}}{V_{IN}} - 1 \right)$$

$$R_S \text{ max.} = 400 \times \left(\frac{9}{5} - 1 \right) = 400 \times (1.8 - 1) = 320 \ \Omega$$

$$R_S \text{ min.} = \frac{V_{IN} V_Z - V_Z^2}{P_Z \text{ max.}}$$

$$R_S \text{ min} = \frac{(9 \times 5) - 5^2}{0.5} = \frac{45 - 25}{0.5} = 40 \ \Omega$$

Output resistance and voltage regulation

- This internal resistance appears at the output of the supply and is defined as the change in output voltage divided by the corresponding change in output current. Hence:

$$R_O = \frac{\text{change in output voltage}}{\text{change in output current}} = \frac{dV_O}{dI_L}$$

Where dV_O represents a small change in output voltage and dI_L represents a corresponding small change in output current

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

$$\text{regulation} = \frac{\text{change in output voltage}}{\text{change in line (input) voltage}} \times 100\%$$

Ideally, the value of regulation should be very small.

Example : The following data was obtained during a test carried out on a d.c. power supply:

(i) Load test

Output voltage (no-load) = 12 V

Output voltage (2 A load current) = 11.5 V

(ii) Regulation test

Output voltage (mains input, 220 V) = 12 V

Output voltage (mains input, 200 V) = 11.9 V

Determine (a) the equivalent output resistance of the power supply and (b) the regulation of the power supply

Solution

The output resistance can be determined from the load test data:

$$R_{out} = \frac{\text{change in output voltage}}{\text{change in output current}} = \frac{12-11.5}{2-0} = 0.25\ \Omega$$

$$\text{Regulation} = \frac{\text{change in output voltage}}{\text{change in line (input) voltage}} \times 100\%$$

$$\text{Regulation} = \frac{12-1.9}{220-200}\times 100\% = \frac{0.1}{20}\times 100\% = 0.5\%$$

Voltage multipliers

- By adding a second diode and capacitor, we can increase the output of the simple half-wave rectifier that we met earlier.
- A voltage doubler using this technique is shown in Fig. In this arrangement C1 will charge to the positive peak secondary voltage whilst 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.

Figure: A voltage doubler

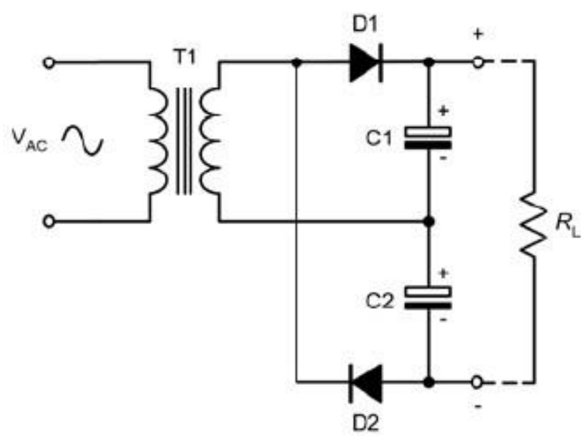
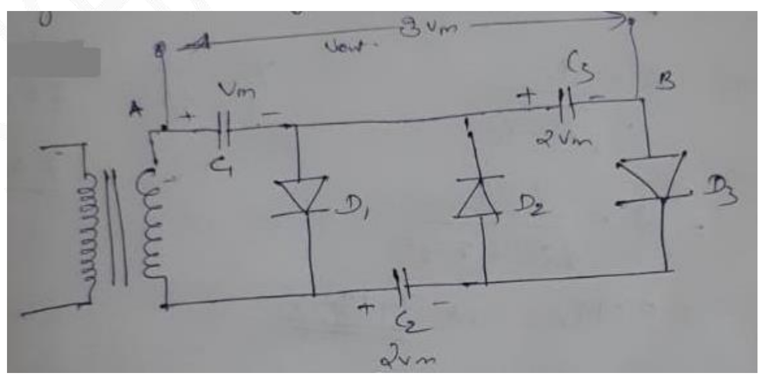


Figure: A voltage Tripler



- The voltage doubler can be extended to produce higher voltages using the cascade arrangement shown in Fig by adding C3 and Diode D3.

AMPLIFIER

Types of amplifier

Many different types of amplifier are found in electronic circuits. The main types of amplifier.

a.c. coupled amplifiers

In a.c. coupled amplifiers, stages d.c. levels are isolated and only the a.c. components of a signal are transferred from stage to stage.

d.c. coupled amplifiers

In d.c. (or direct) coupled amplifiers. Both a.c. and d.c. signal components are transferred from stage to stage.

Large-signal amplifiers

Large-signal amplifiers are designed to cater for appreciable voltage and/or current levels (typically from 1V to 100 V or more).

Small-signal amplifiers

Small-signal amplifiers are designed to cater for low-level signals (normally less than 1V and often much smaller). Small-signal amplifiers have to be specially designed to combat the effects of noise.

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).

Wideband amplifiers

Wideband amplifiers are capable of amplifying a very wide range of frequencies, typically from a few tens of hertz to several megahertz.

Radio frequency amplifiers

Radio frequency amplifiers operate in the band of frequencies that is normally associated with radio signals (e.g. from 100 kHz to over 1 GHz).

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

One of the most important parameters of an amplifier is the amount of amplification or gain that it provides. Gain is simply the ratio of output voltage to input voltage, output current to input current, or output power to input power. These three ratios give, respectively, the voltage gain, current gain and power gain.

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

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

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

$$A_p = \frac{P_{out}}{P_{in}} = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{I_{out}}{I_{in}} \times \frac{V_{out}}{V_{in}} = A_i \times A_v$$

Example

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) the current gain;

(c) the power gain.

Solution

The voltage gain is calculated from:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{2\ \text{V}}{50\ \text{mV}} = 40$$

(b) The current gain is calculated from:

$$A_i = \frac{I_{out}}{I_{in}} = \frac{200\ \text{mA}}{4\ \text{mA}} = 50$$

(c) The power gain is calculated from:

$$A_p = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{200\ \text{mA} \times 2\ \text{V}}{4\ \text{mA} \times 50\ \text{mV}} = \frac{0.4\ \text{W}}{200\ \mu\text{W}} = 2,000$$

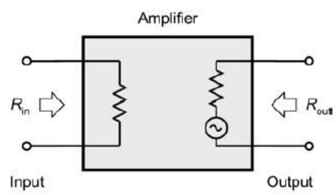
or

$$A_p = A_i \times A_v = 50 \times 40 = 2,000$$

Input and output resistance

Input resistance is the ratio of input voltage to input current and it is expressed in ohms. The input of an amplifier is normally purely resistive in the middle of its working frequency range (i.e. the mid-band). In some cases, the reactance of the input may become appreciable (e.g. if a large value of stray capacitance appears in parallel with the input resistance). In such cases we would refer to input impedance rather than input resistance.

$$R_{IN} = \frac{V_{OUT}}{I_{IN}}$$



Output resistance is the ratio of open-circuit output voltage to short-circuit output current and is measured in ohms. Note that this resistance is internal to the amplifier and should not be confused with the resistance of a load connected externally. Figure shows how the input and output resistances are 'seen' looking into the input and output terminals, respectively.

Frequency response

The frequency response characteristics for various types of amplifier are shown in Fig.-1 below. Note that, for response curves of this type, frequency is almost invariably plotted on a logarithmic scale.

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 *3dB points) or where the voltage gain has dropped to 70.7% of its mid-band value. Figures-1 and Figure-2, respectively, show how the bandwidth can be expressed in terms of either power or voltage (the cut-off frequencies, f1 and f2, and bandwidth are identical).

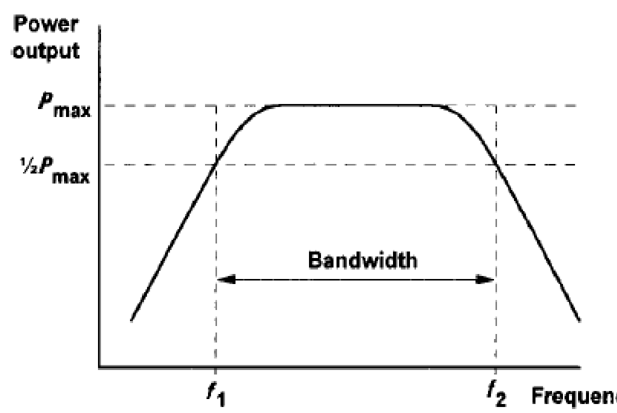


Figure -1 Frequency response and bandwidth (output power plotted against frequency)

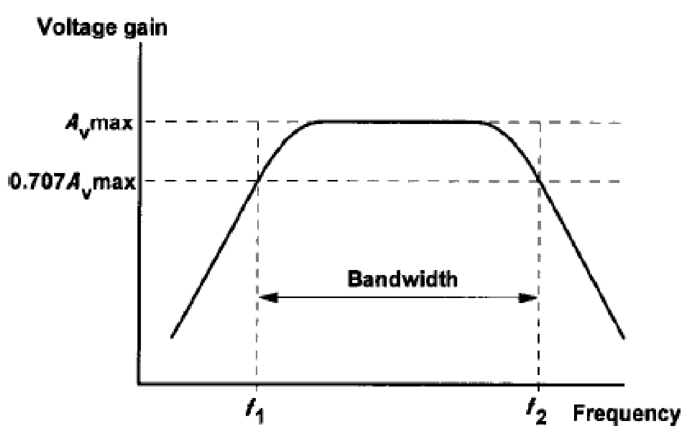


Figure -2 Frequency response and bandwidth (output voltage plotted against frequency)

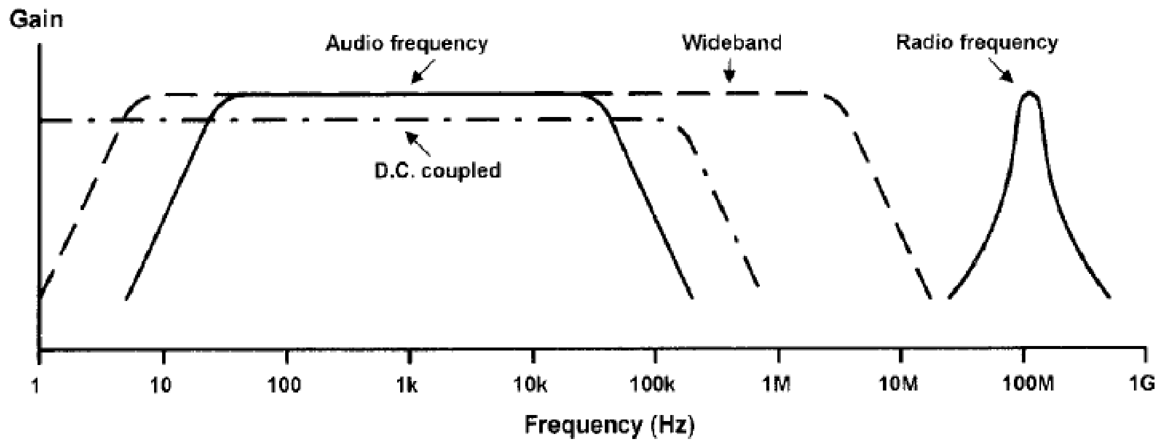
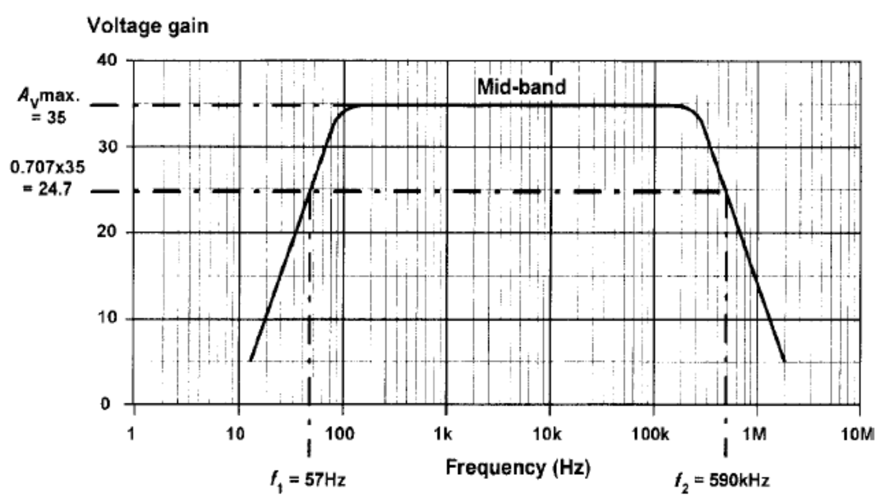


Figure-3 Frequency response and bandwidth (output power plotted against frequency)

Example Determine the mid-band voltage gain and upper and lower cut-off frequencies for the amplifier whose frequency response is shown in Fig

.



Solution

The mid-band voltage gain corresponds with the flat part of the frequency response characteristic. At the point the voltage gain reaches a maximum of 35 (see Fig.). The voltage gain at the two cut-off frequencies can be calculated from:

A_v cut-off = 0.707 × A_v max = 0.707 × 35 = 24.7 This value of gain intercepts the frequency response graph at f1 = 57 Hz and f2 = 590 kHz (see Fig.).

Bandwidth

The bandwidth of an amplifier is usually taken as the difference between the upper and lower cut-off frequencies (i.e. f2 I f1 in Figs 1 and 2).

$$Bandwidth = f_2 - f_1$$

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.

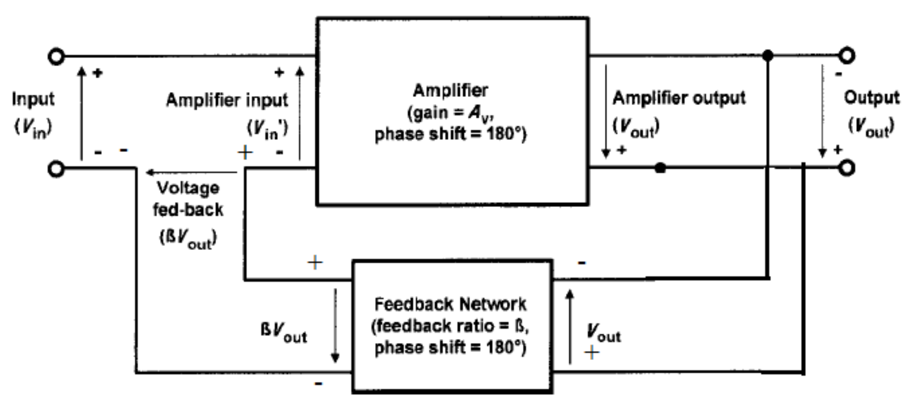
Phase shift

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

Many practical amplifiers use negative feedback in order to precisely control the gain, reduce distortion and improve bandwidth. The gain can be reduced to a manageable value by feeding back a small proportion of the output. The amount of feedback determines the overall (or **closed-loop**) gain. Because this form of feedback has the effect of reducing the overall gain of the circuit, this form of feedback is known as **negative feedback**.
Figure 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:

Figure Amplifier with negative feedback applied



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

Now, by applying Kirchhoff's Voltage Law, $V_{\text{in}}' = V_{\text{in}} - \beta V_{\text{out}}$

$$\Rightarrow \quad V_{\text{in}} = V_{\text{in}}' + \beta V_{\text{out}}$$

and $V_{\text{out}} = A_{\text{v}} \times V_{\text{in}}$

$$\text{Overall gain, } G = \frac{A_{\text{v}} \times V'_{\text{in}}}{V'_{\text{in}} + \beta V_{\text{out}}} = \frac{A_{\text{v}} \times V'_{\text{in}}}{V'_{\text{in}} + \beta\left(A_{\text{v}} \times V'_{\text{in}}\right)}$$

$$\Rightarrow \quad G = \frac{A_{\text{v}}}{1 + \beta A_{\text{v}}}$$

Thus overall gain with negative feedback applied will be less than the gain without feedback. Furthermore, if *A*v is very large the overall gain with negative feedback applied will be given by:

$$G = 1/\beta \quad (\text{when } A_{\text{v}} \text{ is very large})$$

Example (A) 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. J = 0.1). Determine the overall voltage gain with negative feedback applied.

Solution

With negative feedback applied the overall voltage gain will be given by:

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

Example If, in Example (A), the amplifier's open-loop voltage gain increases by 20%, determine the percentage increase in overall voltage gain.

Solution

The new value of voltage gain will be given by:

$$A_v = A_v + 0.2A_v = 1.2 \times 50 = 60$$

The overall voltage gain with negative feedback will then be:

$$G = \frac{A_v}{1+\beta A_v} = \frac{60}{1+(0.1\times 60)} = \frac{60}{7} = 7.14$$

The increase in overall voltage gain, expressed as a percentage, will thus be:

$$\frac{8.57-8.33}{8.33}\times 100\% = 2.88\%$$

Example An integrated circuit that produces an open-loop gain of 100 is to be used as the basis of an amplifier stage having a precise voltage gain of 20. Determine the amount of feedback required.

Solution

Re-arranging the formula, $G = \frac{A_v}{1+\beta A_v}$

To make β the subject gives:

$$\beta = \frac{1}{G} - \frac{1}{A_v}$$

thus

$$\beta = \frac{1}{20} - \frac{1}{100} = 0.05 - 0.01 = 0.04$$

Multi-stage amplifiers

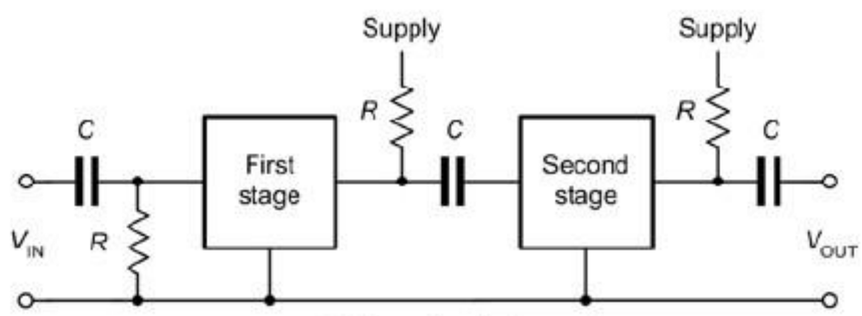
In order to provide sufficiently large values of gain, it is frequently necessary to use a number of interconnected stages within an amplifier. The overall gain of an amplifier with several stages is simply the product of the individual voltage gains. Hence:

$$A_V = A_{V1} \times A_{V2} \times A_{V3} \quad \text{etc.}$$

Note, however, that the bandwidth of a multi-stage amplifier will be less than the bandwidth of each individual stage. In other words, an increase in gain can only be achieved at the expense of a reduction in bandwidth. Signals can be coupled between the individual stages of a multi-stage amplifier using one of a number of different methods shown in Fig.

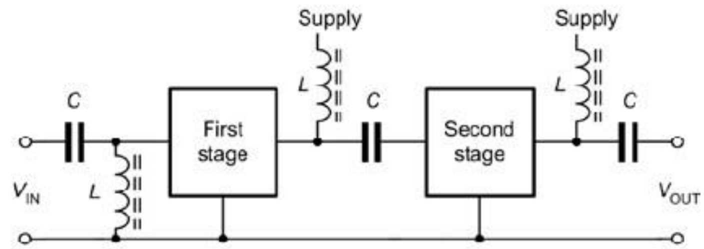
The types of multistage amplifier are

- ❖ ***R–C* coupling,** In this coupling method, the stages are coupled together using capacitors having a low reactance at the signal frequency and resistors



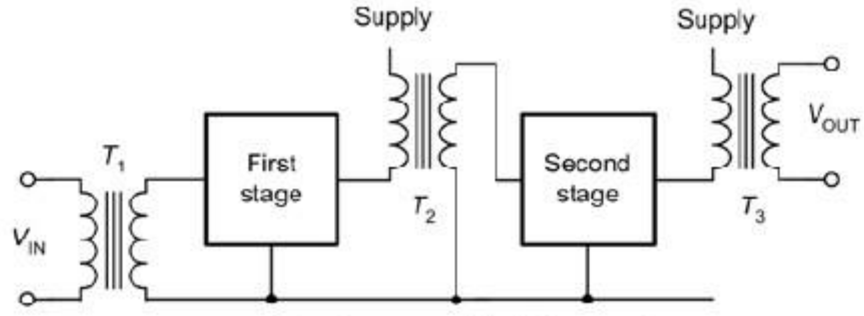
R-C coupling between stages

- ❖ ***L–C* coupling** In this method, the inductors have a high reactance at the signal frequency. This type of coupling is enerally only used in RF and high-frequency amplifiers.



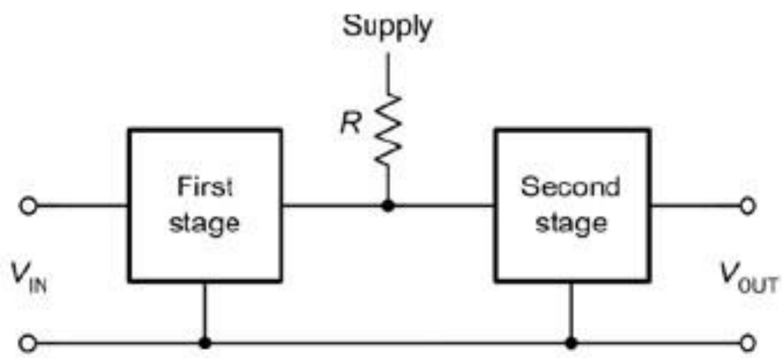
L-C coupling between stages

❖ **Transformer coupling** and



transformer coupling between stages

❖ **Direct coupling**



direct coupling between stages