MODULE - 1

ELECTRONIC CIRCUITS:

POWER SUPPLIES: Block diagram, Rectifiers, Reservoir, and Smoothing circuits, Full-Wave rectifiers, Bi-phase 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 amplifier.

OPERATIONAL AMPLIFIER: Operational Amplifier parameter Characteristics, Configurations, Operational amplifier circuits.

OSCILLATORS: positive feedback, Conditions for Oscillation, Ladder network Oscillator, wein bridge Oscillator, Multivibrator, Single-stage astable Oscillator, Crystal Controlled Oscillator.

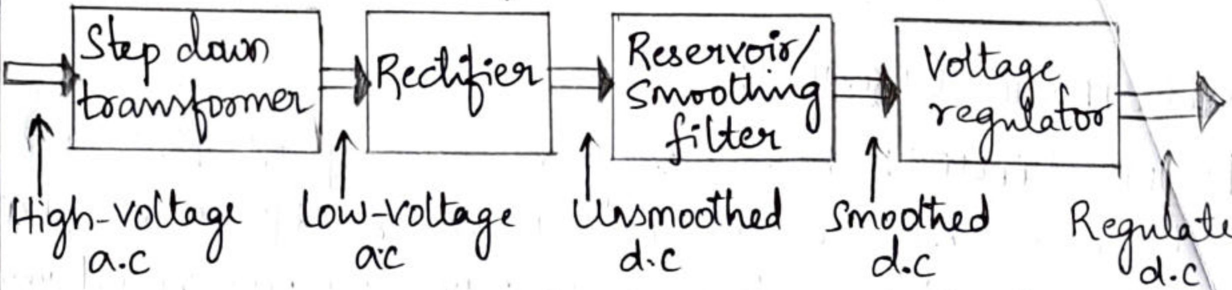
POWER SUPPLIES:

Most of the electronic circuits require a source of well regulated d.c at voltages of typically between 5V and 30V. In some cases, this supply can be derived directly from batteries (Eg: 6V, 9V and 12V).

The basic block diagram of a d.c power supply is shown in figure below.

The main components of a power supply consists of step-down transformer, Rectifier, Reservoir, and a voltage regulator.

fig: Block diagram of d.c



* Since the input mains is at a relatively high voltage, a step-down transformer of appropriate turns ratio is used to convert this to a low voltage.
* 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 ~~to~~ both load current and incoming mains voltage.

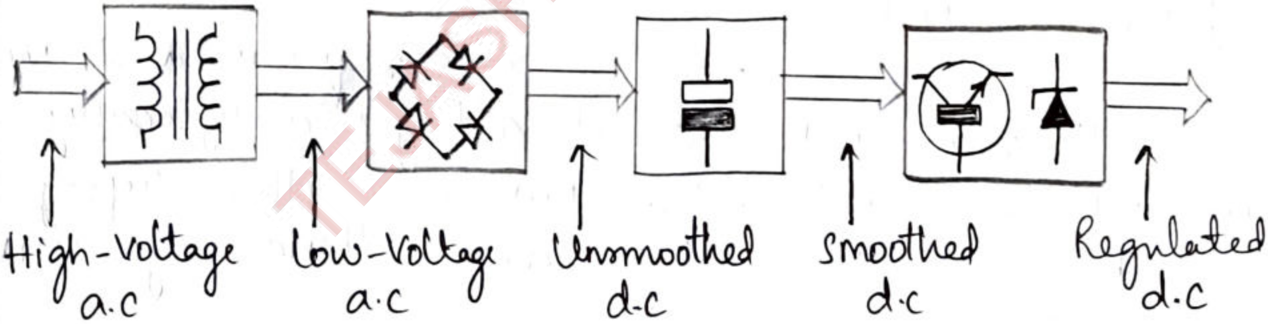


fig: Block diagram of a d.c power supply showing principal components.

* The above figure shows how the electronic components can be used in the realization of the block diagram.

* The iron-cored step-down transformer feeds a rectifier arrangement.
* The output of the rectifier is then applied to a high-value reservoir capacitor. 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.
* Finally, a stabilizing circuit provides a constant output voltage.

RECTIFIERS:

* Semiconductor diodes are commonly used to convert alternating current (a.c) to direct current (d.c) 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.

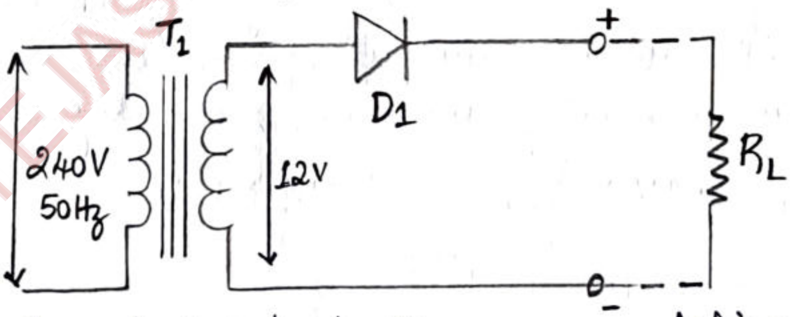


Fig: A simple half-wave rectifier output

* Mains voltage (220V to 240V) is applied to the primary of a step-down transformer (T_1). The secondary of the transformer (T_1) steps down the 240 V_{rms} to 12 V rms.

* During positive half-cycle of the input, the diode D_1 will be forward biased and the current will flow from cathode to anode as shown in figure below and hence the diode D_1 acts as a closed-switch.
* During Negative half-cycle of the input, the diode D_1 will be reverse biased and acts as a open-switch. Hence there is no flow of electric current.
* The Switching action of D_1 results in a pulsating output voltage which is developed across the load resistor R_L.

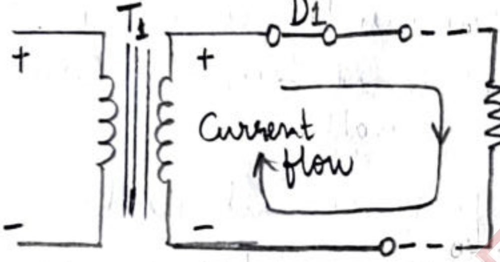


fig (a) D_1 Conducting

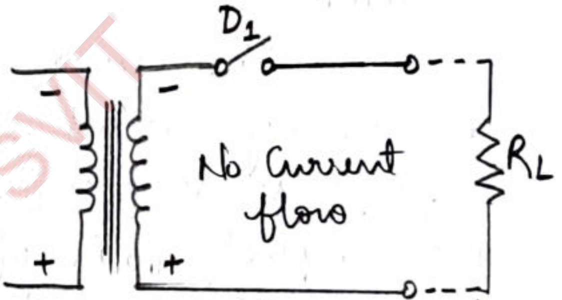


fig (b) D_1 Non-conducting

* When selecting a diode for a particular application. Assuming that the secondary of T_1 provides 12V r.m.s, the peak voltage output from the transformer's secondary winding will be given by:

$$V_{pk} = 1.414 \times V_{r.m.s} = 1.414 \times 12V$$

$$\boxed{V_{pk} = 16.97V}$$

* The peak voltage applied to D_1 will thus be approximately 17V. The negative half cycles are blocked by D_1 and thus only the positive half-cycles appear across R_L.

Peak amplitude $= 17V - 0.7V = \underline{16.3V}$

0.7V - forward threshold voltage

Problem:

* A mains transformer having a turns ratio of 44:1 is connected to a 220V 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.

Soln: The r.m.s secondary voltage is given by.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = V_p \times \frac{N_s}{N_p} = 220 \times \frac{1}{44}$$

$$\boxed{V_s = 5V}$$

The peak voltage developed after rectification will be given by:

$$V_{PK} = 1.414 \times 5V = 7.07V.$$

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

$$V_L = 7.07V - 0.6V$$

$$\boxed{V_L = 6.47V}$$

RESERVOIR AND SMOOTHING CIRCUITS:

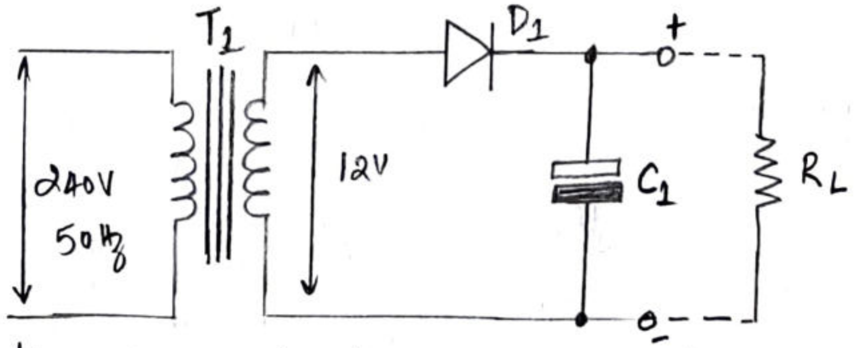


fig: A simple half-wave rectifier circuit with reservoir capacitor.

* The figure above shows a simple half-wave rectifier circuit with reservoir capacitor.
* The Capacitor C_1 has been added to ensure that the output voltage remains at, or near, the peak voltage even when the diode is not conducting.
* When the primary voltage is first applied to T_1, the first positive half-cycle output from the secondary will charge C_1 to the peak value seen across R_L.
* Hence C_1 charges to 16.3V at the peak of the positive half cycle. Because C_1 and R_L are in parallel, the voltage across R_L will be the same as that of C_1
* The time required for C_1 to charge to the maximum (peak) level is determined by the charging circuit time constant.
* The time required for C_1 to discharge is, determined by the Capacitance value and the load resistance R_L.
* Hence C_1 is referred to as a reservoir capacitor. It stores charge during the positive half-cycles of Secondary voltage and releases it during the negative half-cycles.

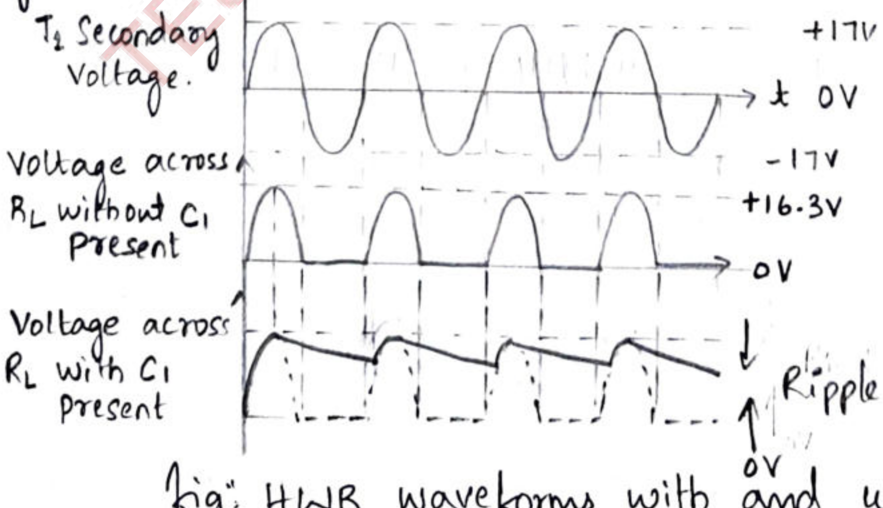


fig: HWR waveforms with and without reservoir Capacitor.

Problem:

* The R-C smoothing filter in a 50Hz mains operated half-wave rectifier circuit consists of $R_1 = 100\Omega$ and $C_2 = 1000\mu F$. If 1V of ripple appears at the input of the circuit, determine the amount of ripple appearing at the output.

Soln:

For HWR, $f = 50Hz$

$$X_C = \frac{1}{2\pi f c} = \frac{1}{2\pi \times 50 \times 1000 \times 10^{-6}}$$

$$\boxed{X_C = 3.18\Omega}$$

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

$$V = 0.032V$$

$$\boxed{V = 32mV}$$

b)

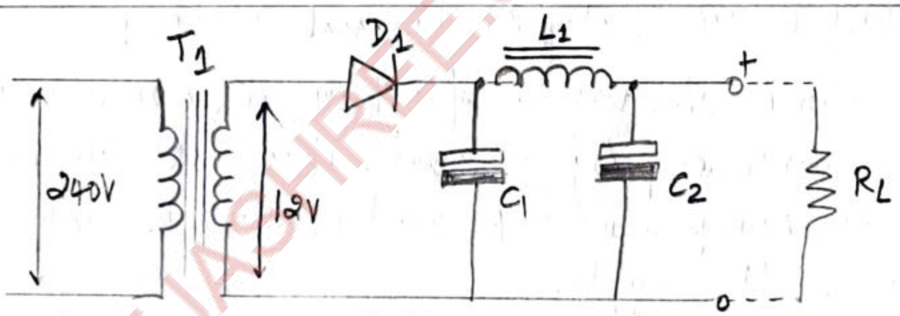


fig: Half wave rectifier circuit with L-C Smoothing Filter.

* A further improvement can be achieved by using an inductor L_1 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.
* The above figure shows the circuit of a half-wave power supply with an L-C smoothing circuit.

* Figure below shows secondary voltage waveforms together with the voltage developed across R_L with and without C_1 present.
* This gives rise to a small variation in d.c output voltage known as ripple. Since ripple is undesirable we must take additional precautions to reduce it.
* One obvious method is by simply reducing the discharge time constant. This can be achieved by increasing the value of C_1 or by increasing the resistance value of R_L.

SMOOTHING FILTERS:

a)

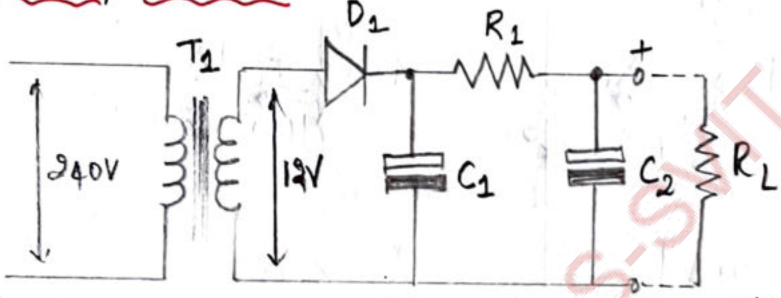


fig: Half wave rectifier circuit with R-C Smoothing filter

* Figure above shows a further refinement of the simple power supply circuit. This circuit employs two additional components R_1 and C_1, which act as a filter to remove the ripple.
* The value of C_1 is chosen so that the component exhibits a negligible reactance at the ripple frequency.
* In effect, R_1 and C_1 act like a potential divider. The amount of ripple is reduced by an approximate factor equal to:

$$\frac{X_C}{\sqrt{R^2 + X_C^2}}$$

* At the ripple frequency, L_1 exhibits a high value of inductive reactance while C_1 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 direct voltage.

Problem.

* The L-C smoothing filter in a 50 Hz mains operated half-wave rectifier circuit consists of $L_1 = 10H$ and $C_2 = 1000\mu F$. If 1V of ripple appears at input of the circuit, determine the amount of ripple appearing at the output.

Soln: $f = 50\text{ Hz (HWR)}$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 1000 \times 10^{-6}}$$

$$\boxed{X_C = 3.18\,\Omega}$$

$$X_L = 2\pi f L$$
$$= 2\pi \times 50 \times 10$$

$$\boxed{X_L = 3140\,\Omega}$$

The amount of ripple at the output of the circuit will be approximately.

$$V = 1 \times \frac{X_C}{X_C + X_L} = \frac{3.18}{3140 + 3.18}$$

$$\boxed{V \simeq 0.001V}$$

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 counterparts.

* There are two basic forms of full-wave rectifier.
  1) The bi-phase rectifier
  2) The Bridge rectifier.

BI-PHASE RECTIFIER CIRCUITS:

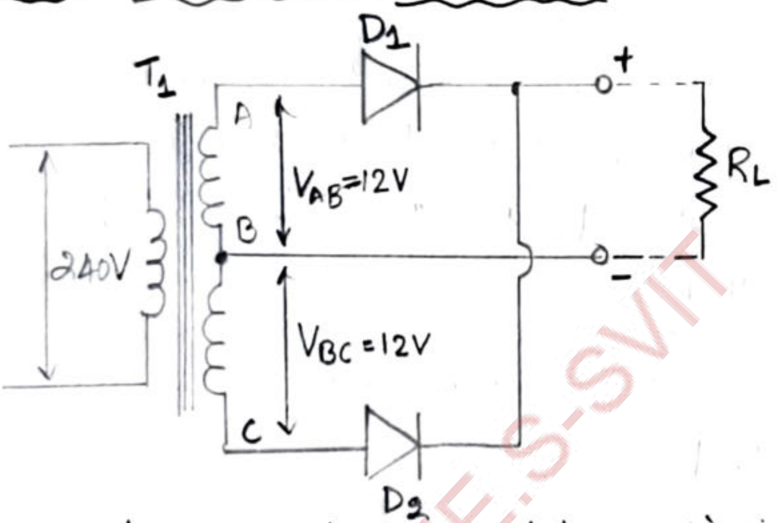


fig: Bi-phase rectifier circuit.

* The figure above shows a simple bi-phase rectifier circuit.
* Mains voltage (240V) is applied to the primary of step-down transformer (T_1) which has two identical secondary windings, each providing 12 V r.m.s.
* 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 D_1 will allow conduction while D_2 will not allow conduction. Thus D_1 alone conducts on positive half-cycles.

* On negative half-cycles, point C will be positive w.r.t B. Similarly, point B will be positive w.r.t point A.
* In this condition, D_2 will allow conduction while D_1 will not allow conduction. Thus D_2 alone conducts on negative half-cycles.

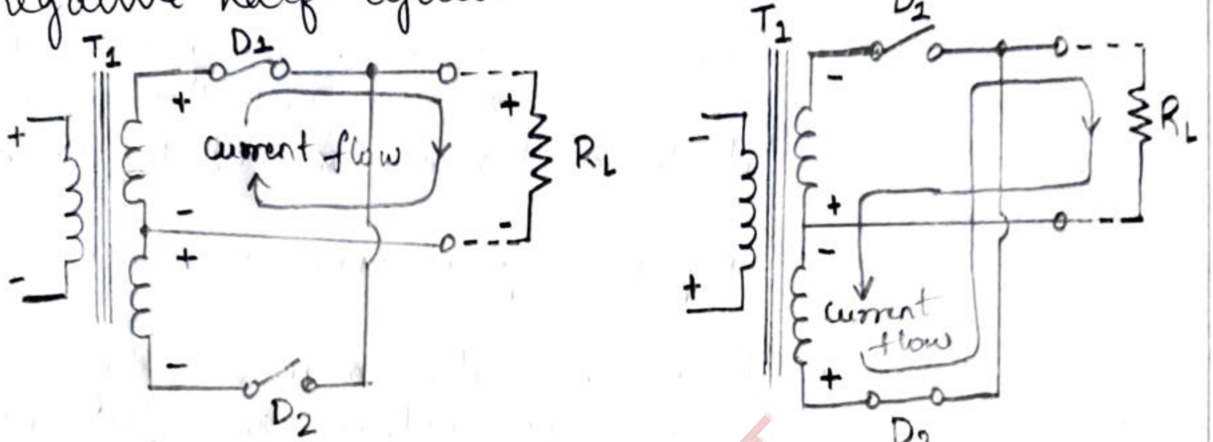
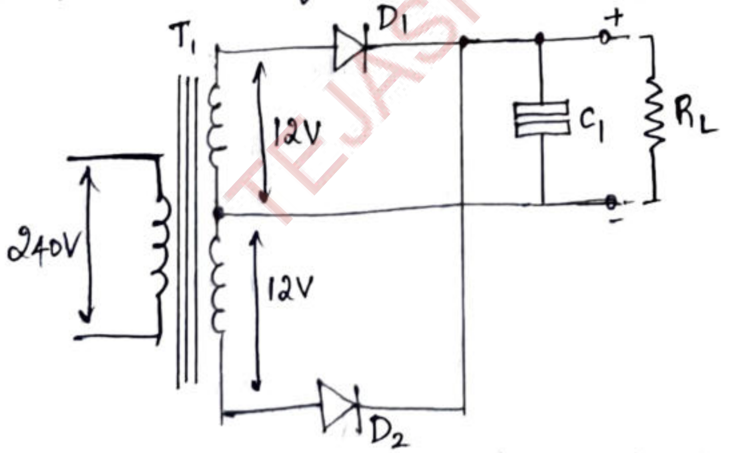


fig (a) fig (b)

* The figure shows the bi-phase rectifier circuit with diodes replaced by switches. fig (a) shows D_1 conducting on a positive half-cycle while fig (b) shows D_2 conducting on a Negative half cycle.

Bi-phase rectifier with reservoir Capacitor.



* fig above shows 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.

* This component operates in exactly the same way as for the half-wave circuit. i.e it charges to approximately 16.3V at the peak of the positive half-cycle.
* The time required for C_1 to charge to the maximum (peak) level is determined by the charging circuit time constant.
* In this circuit, the series resistance comprises the secondary winding resistance together with the forward resistance of the diode and resistance of the wiring and connections.
* Hence C_1 charges very rapidly as soon as either D_1 or D_2 starts to conduct.
* The time required for C_1 to discharge is very much greater and discharge time contrast 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, D_1 and D_2 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.

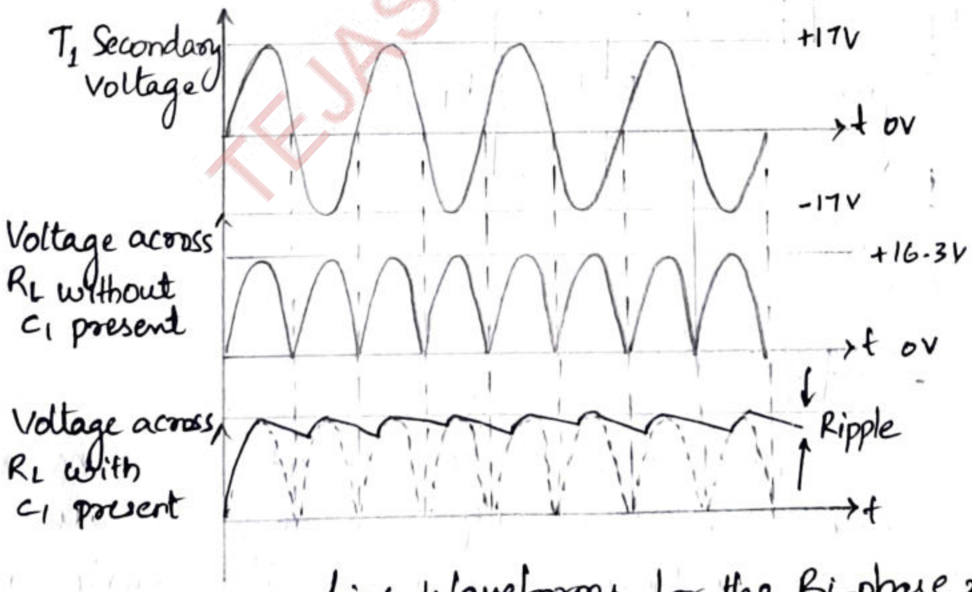


fig: Waveforms for the Bi-phase rectifier.

Bridge Rectifier circuits:

* An alternative to the use of the bi-phase circuit is that of using a four-diode bridge rectifier. in which opposite pairs of diode conduct on alternate half-cycles.
* This arrangement avoids the need to have two separate secondary windings.

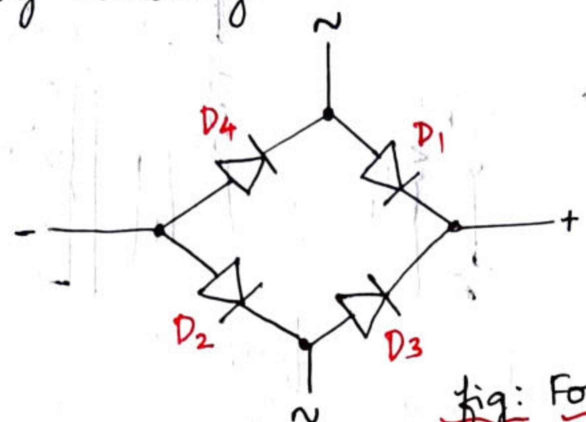


fig: Four diodes connected as a bridge.

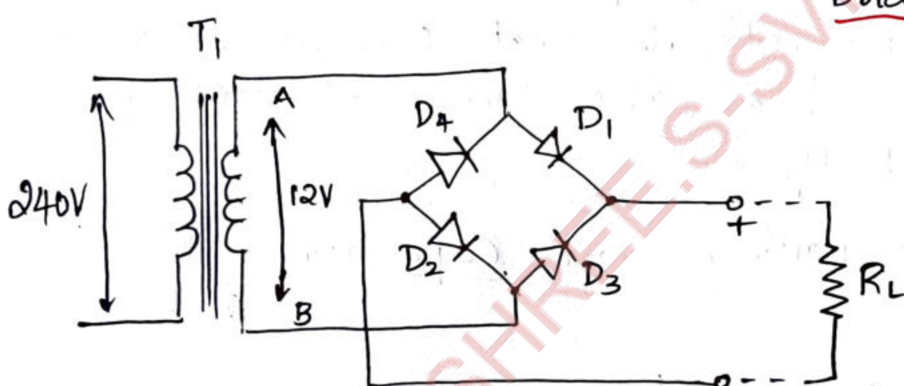


fig: Full wave bridge rectifier circuit.

* A Full-wave bridge rectifier arrangement is shown in figure above.
* Mains voltage (240V) is applied to the primary of a Step-down transformer (T_1)
* The Secondary winding provides 12V r.m.s 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 D_1 and D_2 will allow conduction while D_3 and D_4 will not allow conduction

* Conversely, on negative half-cycles, point B will be positive with respect to point A. In this condition, D_3 and D_4 will allow conduction while D_1 and D_2 will not allow conduction.

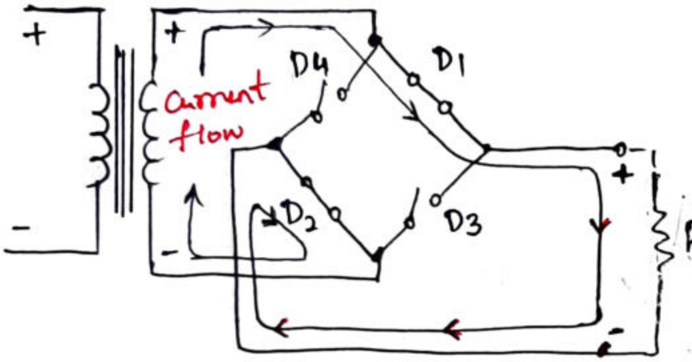


fig (a) D_1 & D_2 Conducting
D_3 & D_4 Non-Conducting

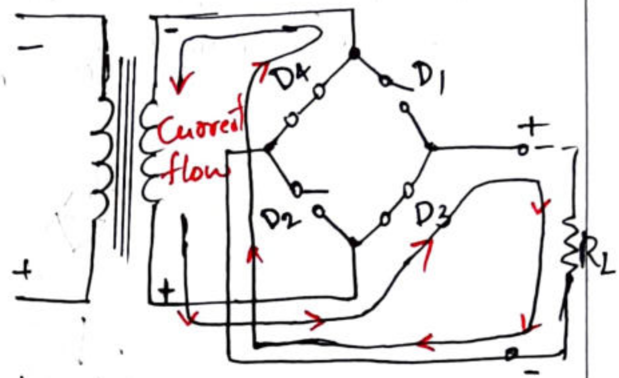


fig (b) D_3 & D_4 Conducting
D_1 & D_2 Non-Conducting

* Once again, the result is that current is routed through the load in the same direction on successive half cycles.

Bridge rectifier with reservoir Capacitor.

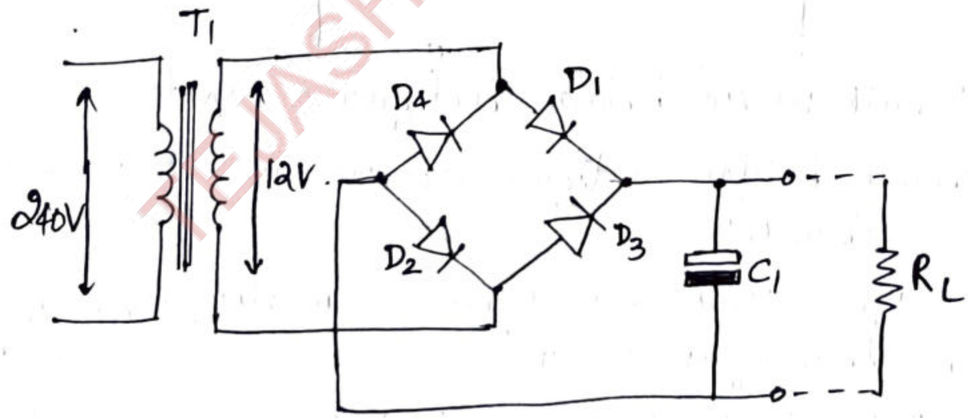


fig: Bridge rectifier with reservoir Capacitor

* The figure above shows how a reservoir Capacitor (C_1) can be added to maintain the output voltage when diodes are not conducting.

* This component operates in exactly the same way as for the bi-phase circuit, i.e. it charges to approximately 16.3V at the peak of the positive half-cycle and holds the voltage at this level when the diodes are in their non-conducting states.

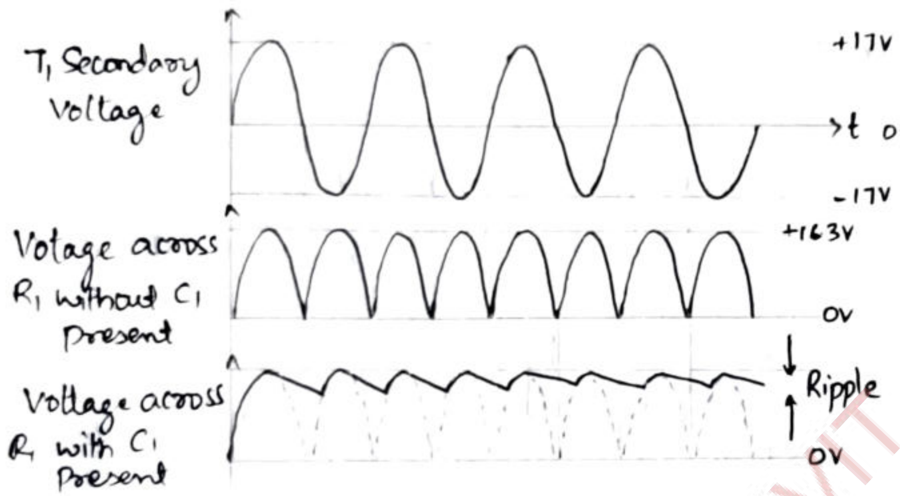


fig: waveforms for the bridge rectifier

VOLTAGE REGULATORS

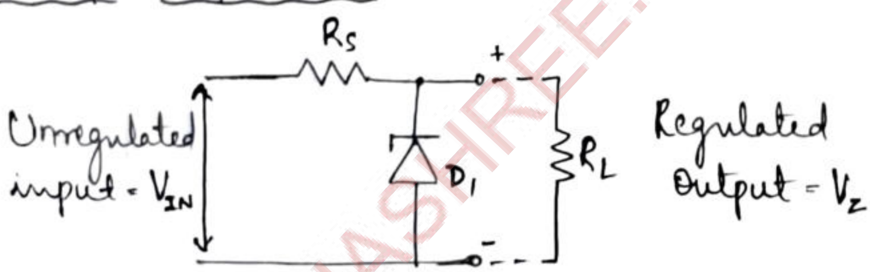


fig: Voltage regulator

* A simple voltage regulator is shown in figure above.
* 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 (allow minimum current 2mA to 5mA in order to ensure that the diode regulates)
* 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:

$$\boxed{V_Z = V_I \times \frac{R_L}{R_L + R_S}}$$

Where V_{IN} is the Unregulated input voltage. Thus the maximum value of R_S can be calculated from:

$$\boxed{R_{S(max)} = R_L \times \left[\frac{V_{IN}}{V_Z} - 1\right]}$$

* The power dissipated in the Zener diode, will be given by $\boxed{P_Z = I_Z \times V_Z}$ Hence the minimum value for R_S can be determined from the off-load condition when:

$$R_{S(min)} = \frac{V_{IN} - V_Z}{I_Z} = \frac{V_{IN} - V_Z}{\left(\frac{P_{Z\,max}}{V_Z}\right)} = \frac{(V_{IN} - V_Z) \times V_Z}{P_{Z\,max}}$$

Thus,

$$\boxed{R_{S(min)} = \frac{V_{IN} V_Z - V_Z^2}{P_{Z\,max}}}$$

where $P_{Z\,max}$ is the maximum power dissipation for the Zener diode.

Problem:

* A 5V Zener diode has a maximum rated power dissipation of 500mW. If the diode is to be used in a simple regulator circuit to supply a regulated 5V to a load having a resistance of 400Ω, determine a

suitable value of series resistor for operation in conjunction with a supply of 9V.

Soln: Given

$V_Z = 5V$

$V_{IN} = 9V$

$R_L = 400\Omega$

$P_{Z\,max} = 500mW = 0.5W$

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

$$= 400 \times \left(\frac{9}{5} - 1\right)$$

$$\boxed{R_{S\,max} = 320\,\Omega}$$

$$R_{S\,min} = \frac{V_{IN}V_Z - V_Z^2}{P_{Z\,max}}$$

$$= \frac{(9\times5) - 5^2}{0.5}$$

$$\boxed{R_{S\,min} = 40\,\Omega}$$

Hence a suitable value for R_S would be 150Ω (roughly mid-way between the two extreames)

OUTPUT RESISTANCE AND VOLTAGE REGULATION:

* In a perfect power supply, the output voltage would remain constant regardless of the current taken by the load.
* In practice, however, the output voltage falls as the load current increases. To account for this fact, we say that the power supply has internal resistance (ideally this should be zero). 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,

$$\boxed{R_{out} = \frac{\text{Change in output voltage}}{\text{Change in output current}} = \frac{\Delta V_{out}}{\Delta I_{out}}}$$

Where ΔI_{out} represents a small change in output (load) current and ΔV_{out} represents a corresponding small change in output voltage.

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

$$\boxed{\text{Regulation} = \frac{\text{Change in output Voltage}}{\text{Change in line input Voltage}} \times 100\%}$$

* Ideally, the value of regulation should be very small.
* Simple shunt zener diode regulators of the type shown are capable of producing values of regulation of 5% to 10%. More sophisticated circuits based on discrete components produce values between 1% and 5% and integrated circuit regulators often provide values of 1% or less.

Problem.

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

i) Load test

Output Voltage (no-load) = 12V

Output Voltage (2A load current) = 11.5V

ii) Regulation test

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

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

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

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

$$R_{out} = \frac{\text{Change in output Voltage}}{\text{Change in output current}} = \frac{12 - 11.5}{2 - 0}$$

$$\boxed{R_{out} = 0.25\Omega}$$

The regulation can be determined from the regulation test data:

$$\text{Regulation} = \frac{\text{Change in output Voltage}}{\text{Change in line input Voltage}} \times 100\%$$

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

$$\boxed{\text{Regulation} = 0.5\%}$$

VOLTAGE MULTIPLIERS

* By adding a second diode and Capacitor, we can increase the output of the simple-half wave rectifier that we seen before.
* A voltage doubler is shown in figure below

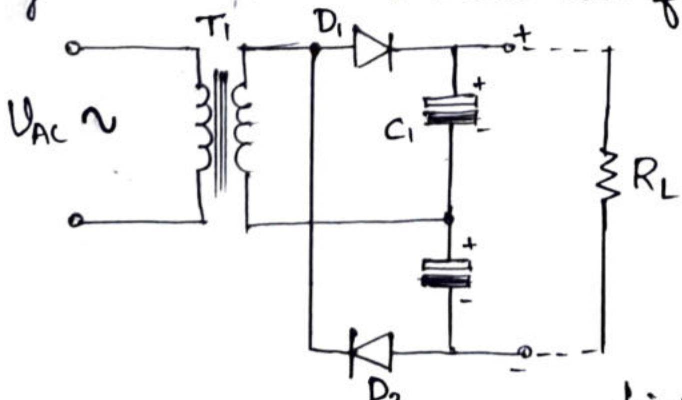


fig: Voltage doubler.

* In this arrangement C_1 will charge to the positive peak secondary voltage while C_2 will charge to the negative peak secondary voltage.
* Since the output is taken from C_1 and C_2 connected in series the resulting output voltage is twice that produced by one diode alone.
* The voltage doubler can be extended to produce higher voltages using the cascade arrangement shown in figure below.

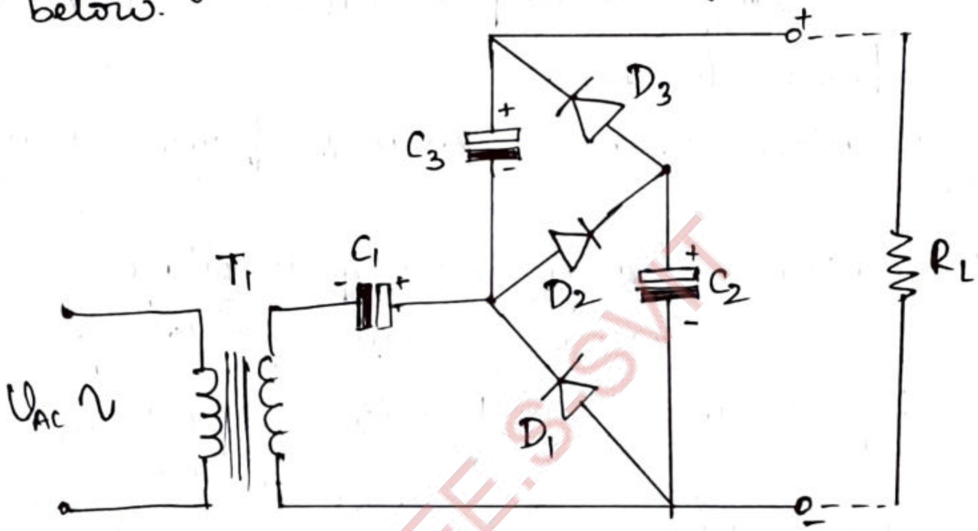


fig: A Voltage tripler.

* Here C_1 charges to the positive peak secondary voltage, while C_2 and C_3 charge to twice the positive peak secondary voltage. The result is that the output voltage is the sum of voltage across C_1 and C_3 which is three times the voltage that would be produced by a single diode.

TYPES OF AMPLIFIER

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 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 1V to 100V or more)

4) **Small-Signal amplifiers:**

Small-signal amplifiers are designed to cater for low-level signals (less than 1V). 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. 20Hz to 20kHz)

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) **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)

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 10mV)

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.

Thus,

$$\boxed{\begin{aligned} \text{Voltage gain } A_V &= \frac{V_{out}}{V_{in}} \\ \text{Current gain } A_I &= \frac{I_{out}}{I_{in}} \\ \text{Power gain } A_P &= \frac{P_{out}}{P_{in}} \end{aligned}}$$

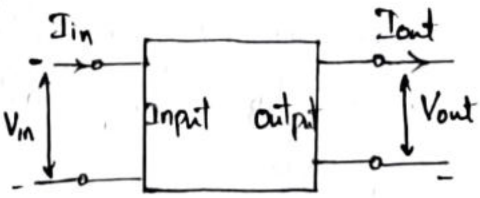


fig: Block diagram of amplifier showing input and output voltages and current.

Since power is the product of current and voltage ($P = V.I$) we can infer that,

$$\boxed{A_P = \frac{P_{out}}{P_{in}} = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{I_{out}}{I_{in}} \times \frac{V_{out}}{V_{in}} = A_I \times A_V}$$

Problem:

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

Soln: Given

$V_{out} = 2V$, $V_{in} = 50mV$, $I_{out} = 200mA$, $I_{in} = 4mA$

a) $A_V = \frac{V_{out}}{V_{in}} = \frac{2V}{50mV} = 40$

b) $A_I = \frac{I_{out}}{I_{in}} = \frac{200mA}{4mA} = 50$

c) $A_P = \frac{I_{out} \times V_{out}}{I_{in} \times V_{in}} = \frac{200mA \times 2V}{4mA \times 50mV} = \frac{0.4W}{200\mu W}$

$\boxed{A_P = 2000}$

(or) $A_P = A_V \times A_I$

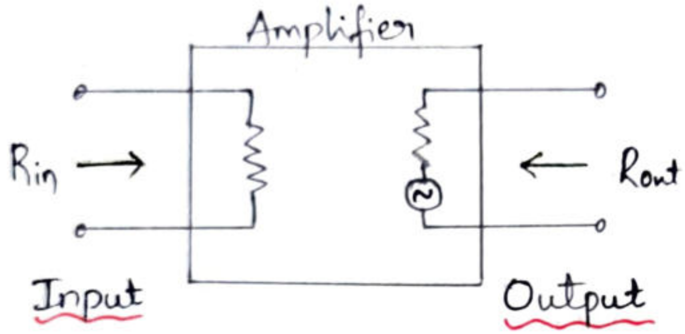
$= 40 \times 50$

$\boxed{A_P = 2000}$

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.
* In some cases, the reactance of the input may become appreciable. In such cases we would refer to input impedance rather than input resistance.
* Output resistance is the ratio of open-circuit output voltage to short-circuit output current and is measured in ohms.

* As with input resistance, the output of an amplifier is normally purely resistive and we can safely ignore any reactive component. If this is not the case, we would once again need to refer to output impedance rather than output resistance.



* The figure above shows 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 figure below

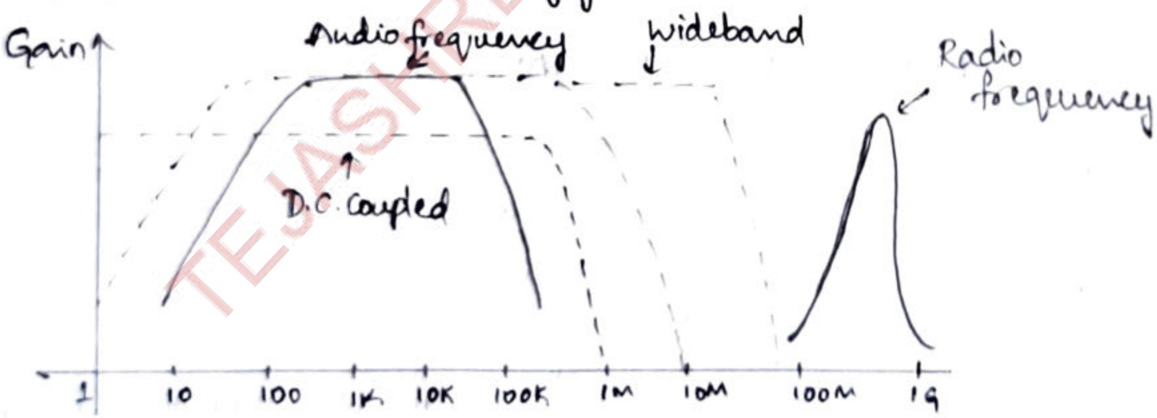
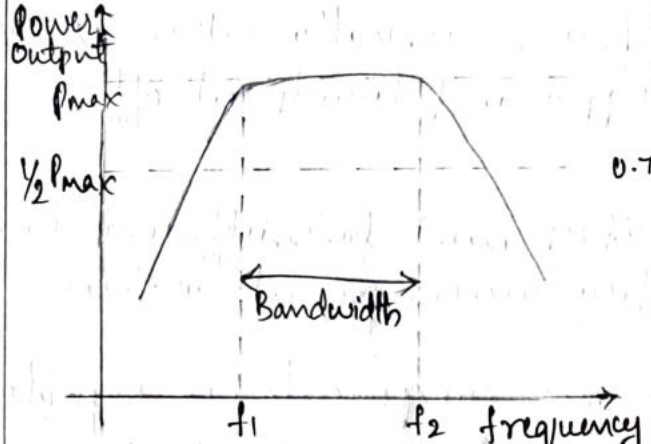


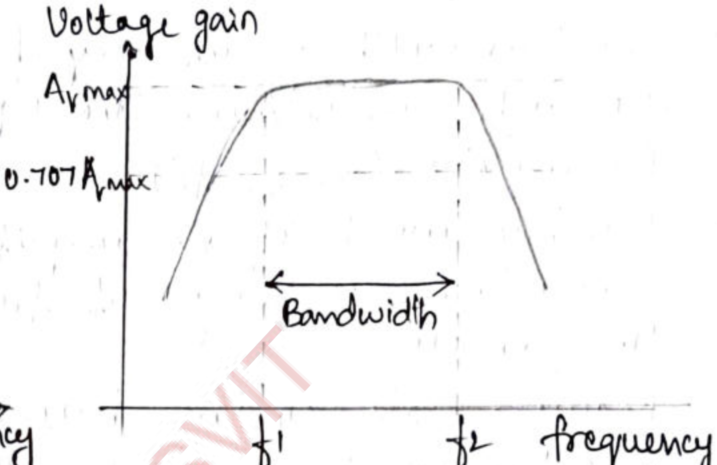
fig: Frequency response and Bandwidth

* The frequency response of an amplifier is usually specified in terms of upper and lower cut-off frequency of the amplifier.

* These frequencies are those at which the output power has dropped to 50% (otherwise known as -3dB points) or where the voltage gain has dropped to 70.7% of its mid-band value.
* The figures below show how the bandwidth can be expressed in terms of either power or voltage.



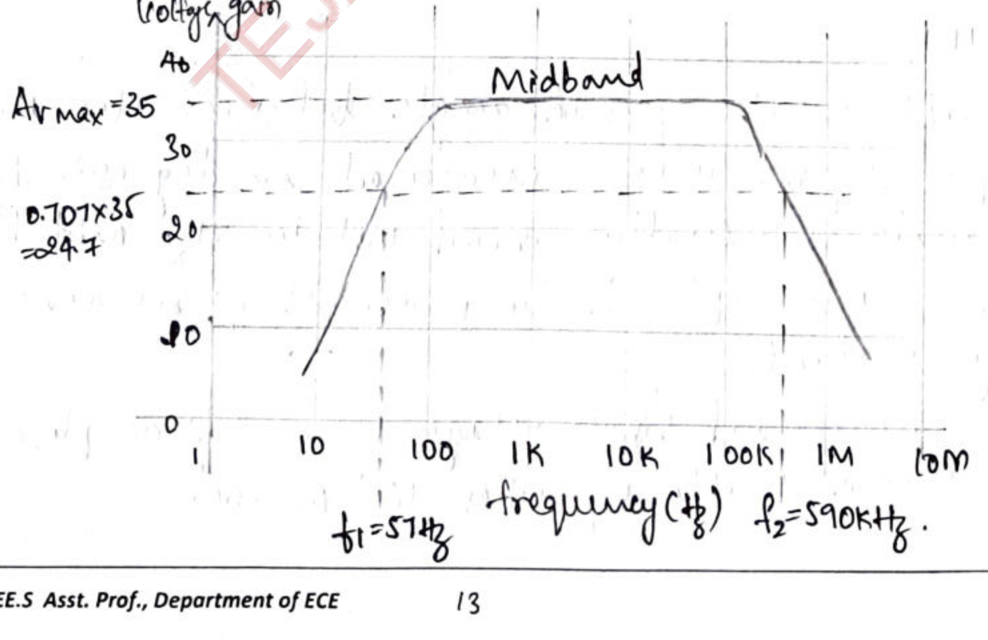
fig(a) Output power plotted again frequency



fig(b) output voltage plotted against frequency.

Problem:

* Determine the mid-band voltage gain and Upper and lower cut-off frequencies for the amplifier whose frequency response is shown below.



Soln: The voltage gain at the two cut-off frequencies can be calculated from:

$$A_{V\,cut\text{-}off} = 0.707 \times A_{Vmax} = 0.707 \times 35$$

$$A_{Vcut\text{-}off} = 24.7$$

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 accomodate the range of frequencies present within the signals.
* Many signals contain harmonic components (i.e signals at 2f, 3f, 4f etc, where f is the frequency of the fundamental signal).
* To reproduce a square wave, for example, requires an amplifier with a very wide bandwidth, but it is not possible to perfectly reproduce such a wave because a square wave comprises of an infinite series of harmonics.

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.
* Also the 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 of 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".
* An alternative form of feedback, where the output is fed back in such a way as to reinforce (strengthen) the input signal is known as "positive feedback".

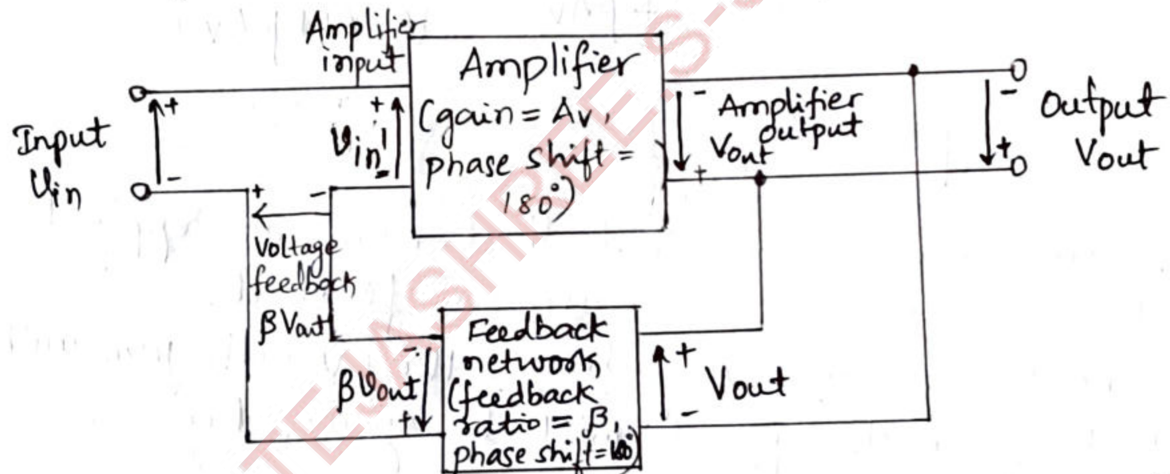


fig: Amplifier with negative feedback applied.

* 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,

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

Now, $V_{in}' = V_{in} - \beta V_{out}$ (Apply KVL)

$$V_{in} = V_{in}' + \beta V_{out} \rightarrow (1)$$

and

$$V_{out} = A_V \times V_{in}' \rightarrow (2)$$ {A_V - internal gain}

Hence, overall gain is given by

$$G = \frac{V_{out}}{V_{in}} = \frac{A_V \cdot V_{in}'}{V_{in}' + \beta V_{out}}$$

{Sub V_{out}}

$$G = \frac{A_V \cdot V_{in}'}{V_{in}' + \beta(V_{in}' A_V)}$$

$$G = \frac{A_V \cdot V_{in}'}{V_{in}' + \beta V_{in}'} = \frac{A_V \cdot \cancel{V_{in}'}}{\cancel{V_{in}'}(1+\beta A_V)}$$

$$\boxed{G = \frac{A_V}{1+\beta A_V}}$$

* Hence, the overall gain with feedback negative 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

$$\boxed{G = \frac{1}{\beta}}$$

* Also, loop gain of a feedback amplifier is defined as the product of β and A_V.

Problem:

(1) An amplifier with negative feedback applied has an open-loop voltage gain of 50 and one-tenth of its output is fedback to the input (i.e $\beta = 0.1$). Determine the overall voltage gain with negative feedback applied.

Soln: Given

$A_V = 50, \ \beta = 0.1$

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

$$\boxed{G = 8.33}$$

(2) If, in problem (1), the amplifier's open-loop voltage gain increases by 20%. determine the percentage increase in overall voltage gain.

Soln: The new value of voltage gain will be given by

$$A_V = A_V + 0.2A_V$$

$$= 50 + (0.2\times 50)$$

$$\boxed{A_V = 60}$$

Overall gain $G = \frac{A_V}{1+\beta A_V} = \frac{60}{1+(0.1\times 60)} = \frac{60}{7}$

$$\boxed{G = 7.14}$$

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

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

(3) 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.

Soln: $G = \frac{A_v}{1+\beta A_v}$

Re-arranging the formula for β

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

$$\beta = \frac{1}{20} - \frac{1}{100}$$

$$\beta = 0.05 - 0.01$$

$$\boxed{\beta = 0.04}$$

MULTISTAGE 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 (i.e. a multi-stage amplifier) is simply the product of the individual voltage gains. Hence,

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

* However, Bandwidth of multi-stage amplifier will be less than the bandwidth of each individual stage.
* In otherwords, an increase in gain results in decrease of a bandwidth.
* Signals can be coupled between the individual stages of a multi-stage amplifier by using different methods.

a) R-C Coupling method.

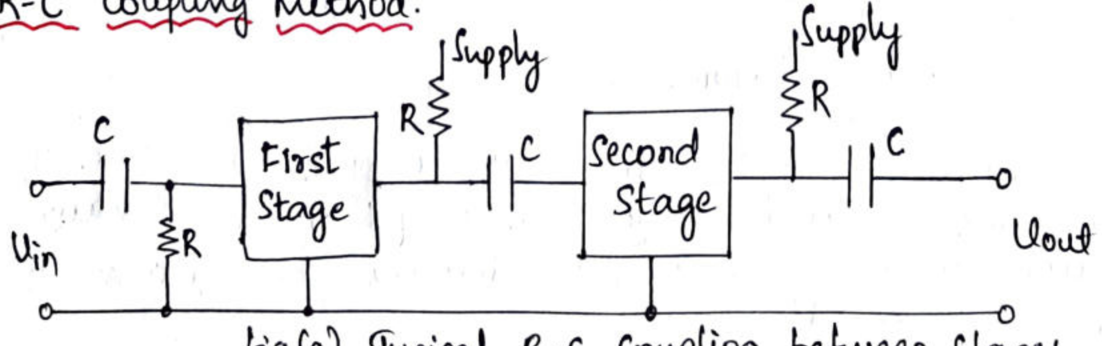


fig (a) Typical R-C Coupling between stages.

* In this coupling method, the stages are coupled together using capacitors having a low reactance at the signal frequency and resistors.

(b) L-C Coupling Method:

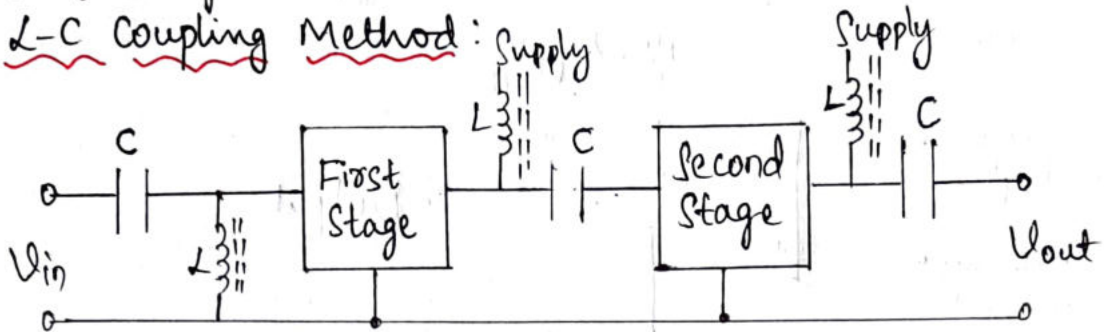


fig: Typical L-C coupling between stages.

* 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.

(c) Transformer Coupling Method.

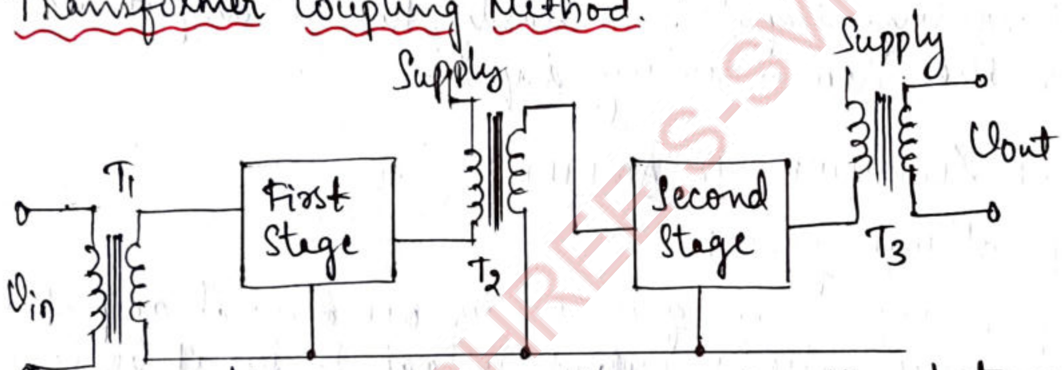


fig: Typical transformer coupling between stages

(4) Direct-Coupling Method:

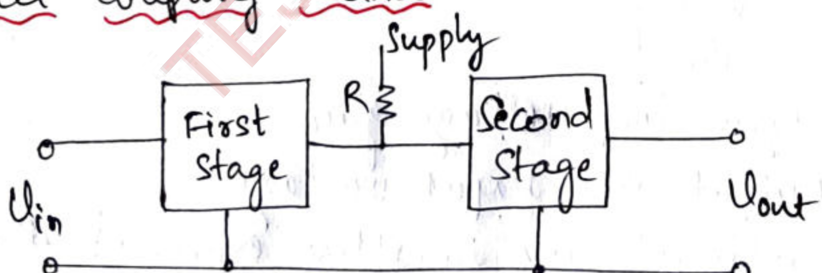
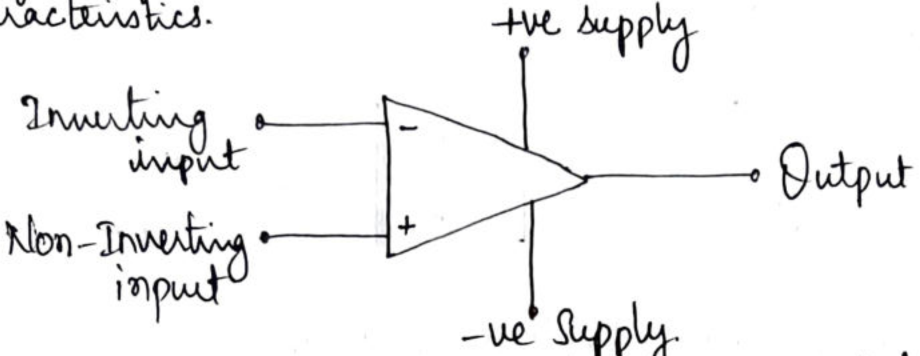


fig: Typical direct-coupling between stages.

OPERATIONAL AMPLIFIERS:

* Operational amplifiers are analogue integrated circuits designed for linear amplification that offer near-ideal characteristics.



* The '+' sign indicates zero phase-shift while '−' sign indicates 180° phase shift. Since 180° phase shift produces an inverted waveform, the '−' input is often referred to as the 'inverting input'. Similarly, the '+' input is known as the 'non-inverting input'.

OPERATIONAL AMPLIFIER PARAMETER:

(i) Open-loop voltage gain:

The open-loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage measured with no feedback applied.

$$\boxed{A_{V(OL)} = \frac{V_{OUT}}{V_{IN}}}$$

where $A_{V(OL)}$ = open-loop voltage gain

V_{OUT} & V_{IN} = Output and input voltages.

* The open-loop voltage gain is often expressed in decibels (dB) rather than as a ratio.

$$\boxed{A_{V(OL)} = 20 \log_{10} \frac{V_{OUT}}{V_{IN}}}$$

* Most operational amplifiers have open-loop voltage gain of 90 dB.

(2) Closed-loop voltage gain:

The closed-loop voltage gain of an operational amplifier is defined as the ratio of output voltage to input voltage measured with a small proportion of the output fed back to the input.

* closed loop voltage gain is once again the ratio of output voltage to input voltage but with negative feedback applied.

Hence, $\boxed{A_{V(CL)} = \frac{V_{OUT}}{V_{IN}}}$

where, $A_{V(CL)}$ - open-loop voltage gain

V_{OUT} & V_{IN} - output and input voltages.

Problem:

* An operational amplifier operating with negative feedback produces an output voltage of 2V when supplied with an input of 400 μV. Determine the value of closed-loop voltage gain.

Soln

$$A_{V(CL)} = \frac{V_{OUT}}{V_{IN}} = \frac{2}{400 \times 10^{-6}} = \frac{2 \times 10^{6}}{400}$$

$$\boxed{A_{V(CL)} = 5000}$$

$$A_{V(CL)} = 20 \log_{10}(5000) = 20 \times 3.7$$

$$\boxed{A_{V(CL)} = 74\,dB}$$

(3) Input Resistance:

The input resistance of an operational amplifier is defined as the ratio of input voltage to input current expressed in ohms.

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

where R_{IN} - input resistance in ohms.
V_{IN} - input voltage, I_{IN} - input current.

Problem:

* An operational amplifier has an input resistance of $2M\Omega$. Determine the input current when an input voltage of 5mV is present.

Sol:

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

Given: $R_{in} = 2M\Omega$
$V_{IN} = 5mV$

$$I_{IN} = \frac{V_{IN}}{R_{in}} = \frac{5\times10^{-3}}{2\times10^{6}} = 2.5\times10^{-9}A$$

$$\boxed{I_{in} = 2.5nA}$$

(4) Output Resistance:

The output resistance of an operational amplifier is defined as the ratio of open-circuit output voltage to short-circuit output current expressed in ohms.

* Typical values of output resistance range from less than 10Ω to around 100Ω, depending on configuration and amount of feedback employed.

$$\boxed{R_{OUT} = \frac{V_{OUT(OC)}}{I_{OUT(SC)}}}$$

where, R_{OUT} - output resistance in ohms
$V_{OUT(OC)}$ - open circuit output voltage.
$I_{OUT(SC)}$ - Short circuit output current.

(5) Input-offset voltage:

The voltage that must be applied differentially to the operational amplifier input in order to make the output voltage exactly zero is known as input-offset voltage.

* Input offset voltage may be minimized by applying relatively large amounts of negative feedback.

(6) Full-power Bandwidth:

The full-power bandwidth for an operational amplifier is equivalent to the frequency at which the maximum undistorted peak output voltage swing falls to 0.707 of its low-frequency value.

* Typical full-power bandwidths range from 10KHz - 1MHz for some high-speed devices.

(7) Slew Rate:

Slew rate is the rate of change of output voltage with time, when a rectangular step input voltage is applied.

$$\boxed{\text{Slew rate} = \frac{\Delta V_{out}}{\Delta t}}$$

where ΔV_{OUT} - change in output voltage

Δt – corresponding interval of time.

* slew rate is measured in V/s and typical values range from 0.2 V/μs to over 20V/μs.

OPERATIONAL AMPLIFIER CHARACTERISTICS:

The characteristics for an Ideal-operational Amplifiers are

1. The open-loop voltage gain should be very high (ideally infinite)
2. The input resistance should be very high (ideally infinite)
3. The output resistance should be very low (ideally zero)
4. Full-power Bandwidth should be as wide as possible.
5. Slew-rate should be as large as possible.
6. Input offset should be as small as possible.

Problem (Slew-rate)

1. A perfect rectangular pulse is applied to the input of an operational amplifier. If it takes 4μs for the output voltage to change from −5V to +5V. determine the slew rate of the device.

Soln

$$\text{Slew rate} = \frac{\Delta V_{OUT}}{\Delta t} = \frac{10\,V}{4\mu s}$$

$$\text{Slew rate} = 2.5\,V/\mu s$$

2. A wideband operational amplifier has a slew-rate of 15V/μs. If the amplifier is used in a circuit with a voltage gain of 20 and a perfect step input of 100mV is applied to its input, determine the time taken for the output to change level.

Soln

The output voltage change will be 20×100 = 2000mV

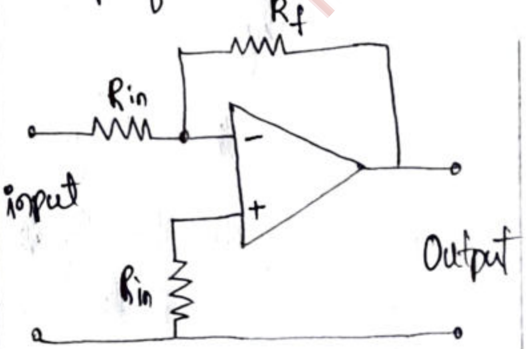
Re-arranging formula for slew-rate,

$$\Delta t = \frac{\Delta V_{OUT}}{\text{slew rate}} = \frac{2\,V}{15\,V/\mu s}$$

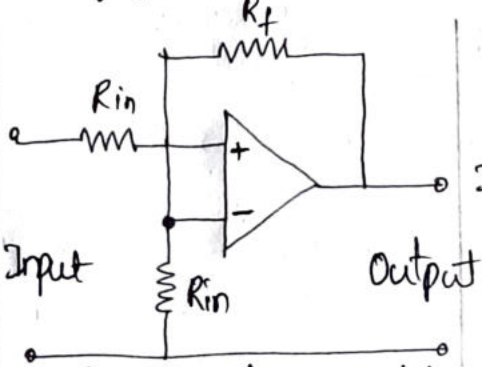
$$\Delta t = 0.133\mu s.$$

OPERATIONAL AMPLIFIER CONFIGURATION:

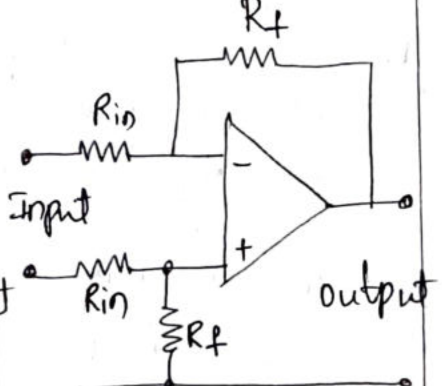
The three basic configurations for operational voltage amplifiers is shown in figure below.



a) Inverting Amplifier



b) Non-Inverting Amplifier



c) Differential Amplifier

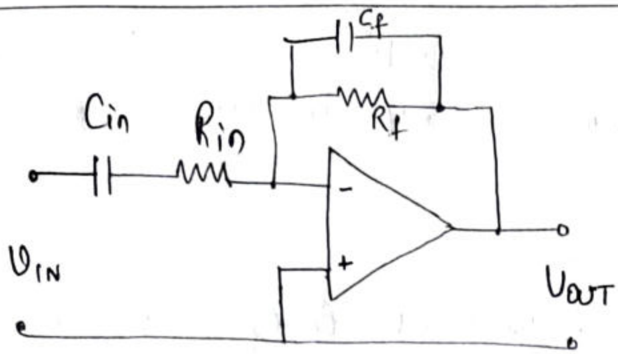


fig: Adding Capacitors to modify the frequency response of an inverting operational Amplifier.

$R_2 = A_V \times R_1$

$$f_1 = \frac{1}{2\pi C_{in} R_{in}} = \frac{0.159}{C_{in} R_{in}}$$

$$f_2 = \frac{1}{2\pi C_f R_f} = \frac{0.159}{C_f R_f}$$

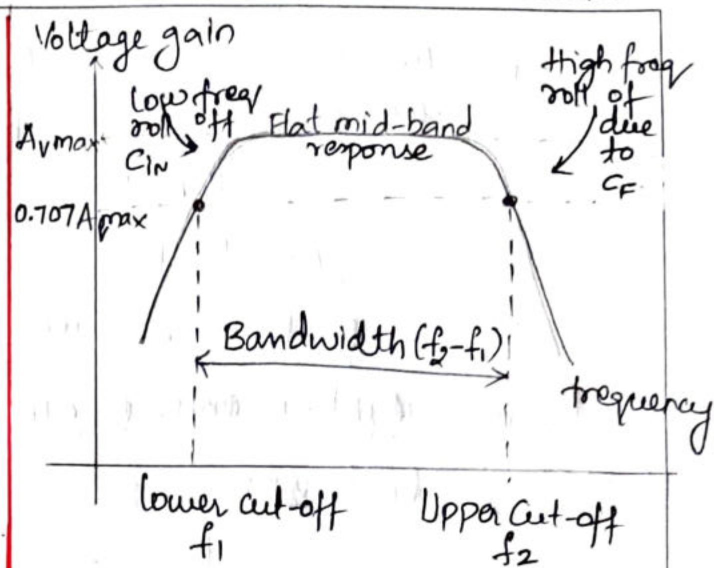


fig: Effect of adding capacitors Cin and Cf to modify the frequency response of an operational amplifier.

Problem:

(1) An inverting opamp is to operate according to the following specification.
voltage gain - 100
Input resistance (at mid-band - 10 KHz)
Lower-cut-off frequency = 250 Hz
Upper-cut-off frequency = 15 KHz
Devise a circuit to satisfy the above specification using an operational amplifier.

Sol: $R_{in} = 10\,k\Omega$ The nominal input resistance is the same as the value of R_{in}

$$A_V = \frac{R_2}{R_1}$$

$$f_1 = \frac{0.159}{C_{in} R_{in}}$$

$R_2 = 100 \times 10\,k\Omega$, $C_{in} = \frac{0.159}{f_1 R_{in}} = \frac{0.159}{250 \times 10 \times 10^3}$

$R_2 = 1000\,k\Omega$

$C_{in} = 63 \times 10^{-9} \Rightarrow \boxed{C_{in} = 63\,nF}$

$$f_2 = \frac{0.159}{C_f R_f} \Rightarrow C_f = \frac{0.159}{f_2 R_{in}} = \frac{0.159}{15\times10^3 \times 100\times10^3}$$

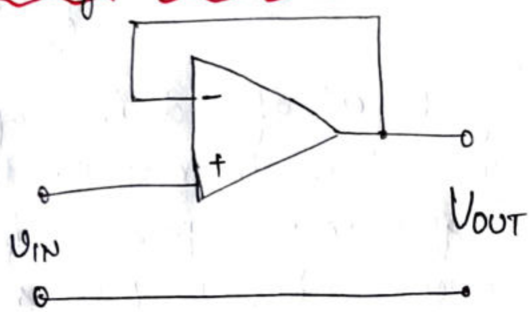
$$C_f = 0.106 \times 10^{-9}$$

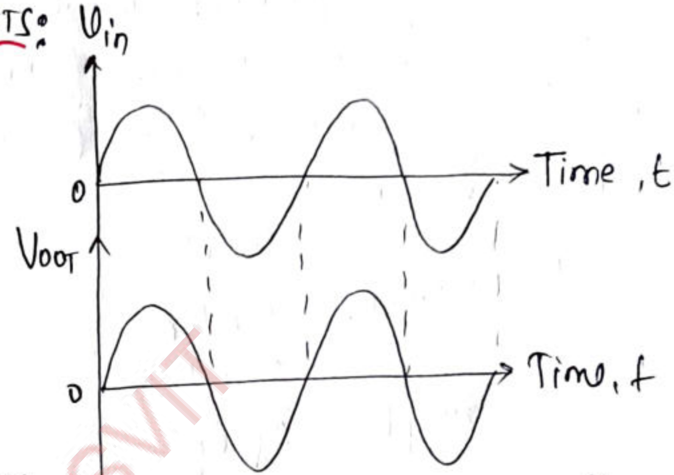
$$\boxed{C_f = 106\,pF}$$

choose preffered values C_{IN} as 68nF & $C_f = 100pF$.

OPERATIONAL AMPLIFIER CIRCUITS:

① Voltage Follower:





* This circuit is essentially an inverting amplifier in which 100% of the output is fedback to the input.
* The amplifier has an unity voltage gain, a very high input and output resistance.

② Differentiators:

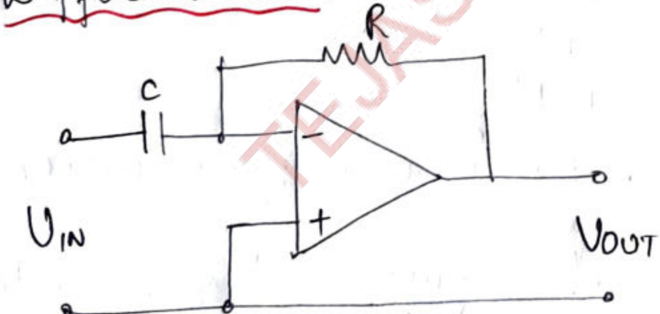
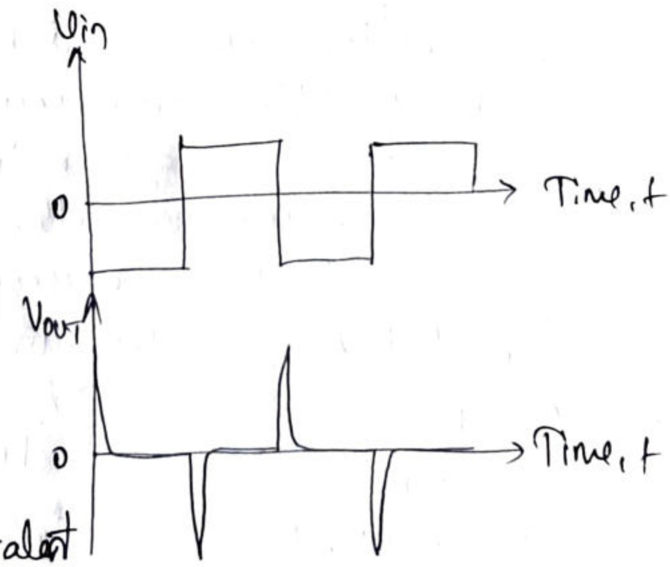


fig: Differentiator



* A differentiator produces an output voltage that is equivalent to the rate of change of its input.
* The square wave input is converted to a train of short duration pulses at the output.

(3) INTEGRATORS:

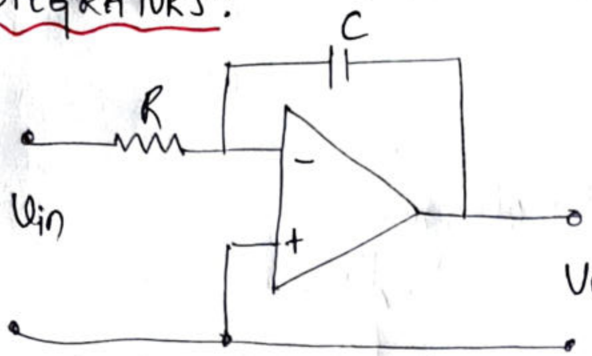
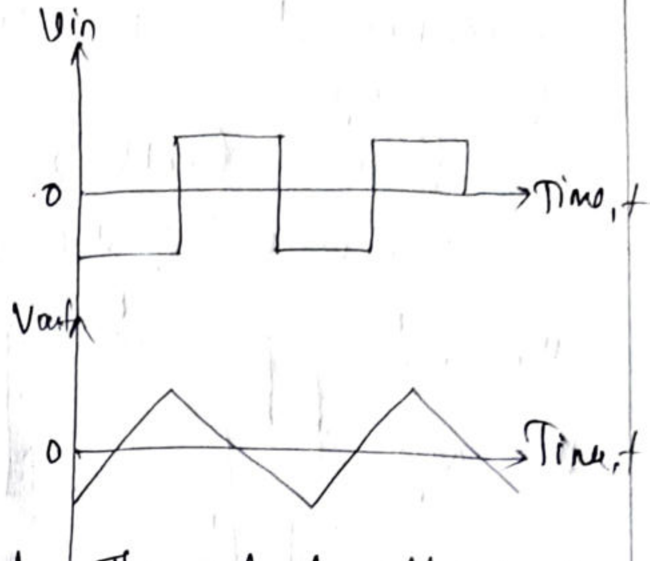


fig: An Integrator



* This circuit provides the opposite function to that of a differentiator. The output voltage ramp up or down according to the polarity of the input.

(4) COMPARATORS:

*

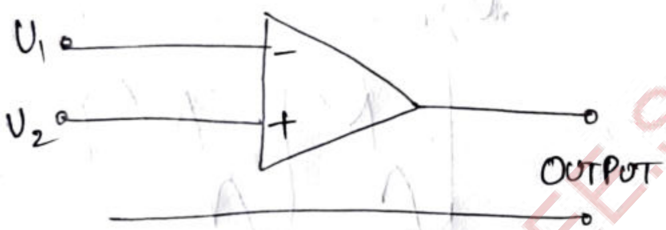
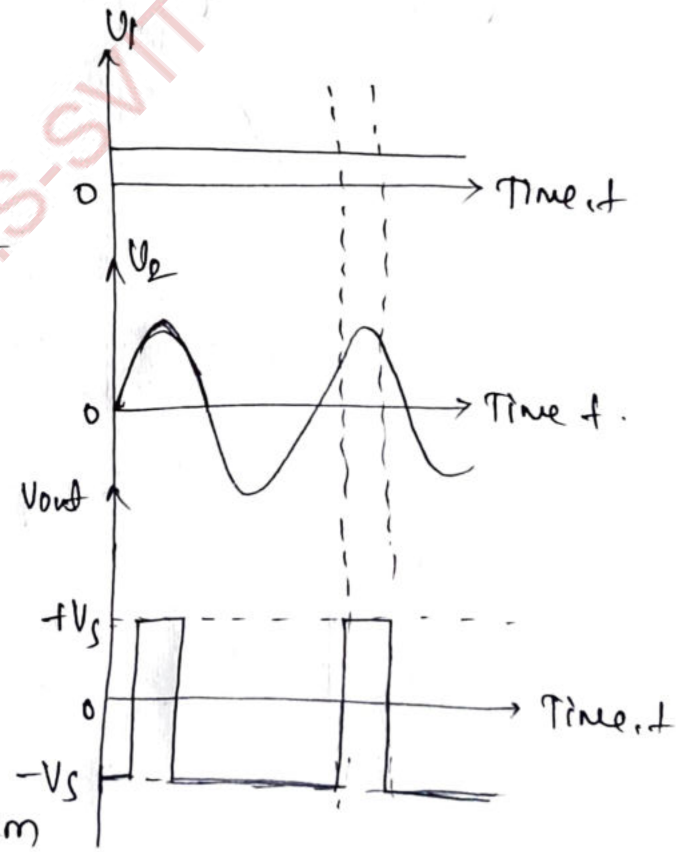


fig: Comparator



* Since no-negative feedback has been applied, this circuit uses the maximum gain of the operational amplifier.
* The output voltage produced by the operational amplifier will thus rise to the maximum possible value.

(5) SUMMING AMPLIFIERS:

* This circuit produces an output that is the sum of its two input voltages. However, since the operational amplifier

is connected in inverting mode, the output voltage is given by,

$$\boxed{V_{OUT} = -(V_1+V_2)}$$

where v_1 and v_2 are input voltages.

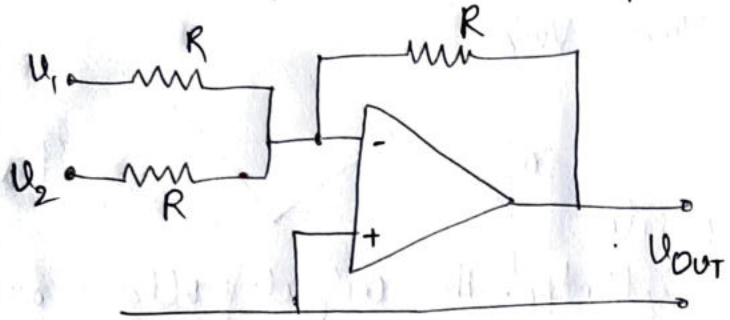
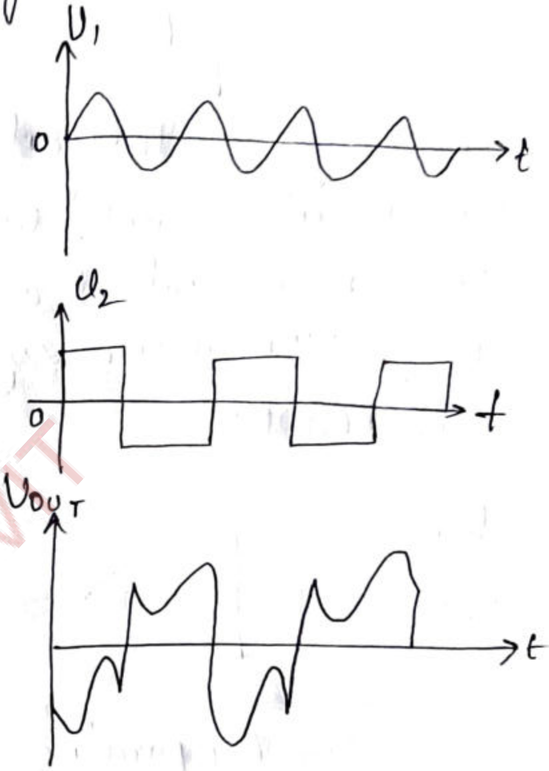


fig: A Summing Amplifier



OSCILLATORS:

POSITIVE FEEDBACK:

An alternative form of feedback, where the output is fed back in such a way as to reinforce the input is known as positive feedback.

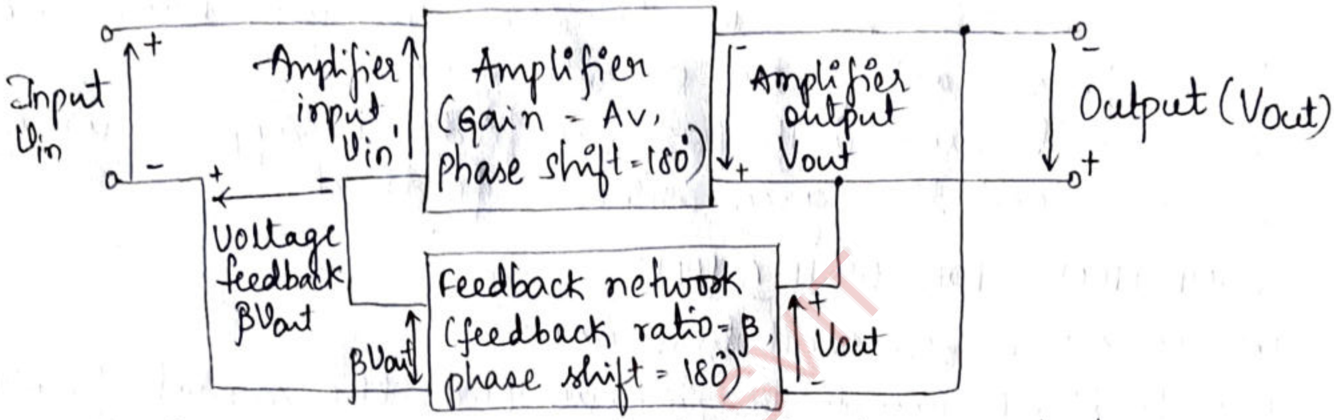


fig: Amplifier with positive feedback applied

* The figure above shows the block diagram of an amplifier stage with positive feedback applied.
* Note that the amplifier provides a phase shift of 180° and the feedback network provides a further 180°. Thus the overall phase shift is 0°. The overall voltage gain G is given by,

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

By applying Kirchoff's voltage law

$$\boxed{V_{in}' = V_{in} + \beta V_{out}}$$

Thus, $\boxed{V_{in} = V_{in}' - \beta V_{out}}$

and $\boxed{V_{out} = A_v \cdot V_{in}}$

where Av – internal gain of the amplifier.

Overall gain, $G = \frac{A_v \cdot V_{in}'}{V_{in}' - \beta V_{out}} = \frac{A_v \cdot V_{in}'}{V_{in}' - \beta(A_v \times V_{in}')}$

Thus, $\boxed{G = \frac{A_v}{(1-\beta A_v)}}$

* when loop gain βA_v approaches Unity, The denominator $(1-\beta A_v)$ will become close to Zero. This will have the effect of increasing the overall gain.

* The overall gain with positive feedback applied will be greater than the gain without feedback.

CONDITIONS FOR OSCILLATION:

The condition for oscillation are:

1) the feedback must be positive (i.e, the signal fedback must arrive back in-phase with the signal at the input).

2) the overall loop voltage gain must be greater than 1. (i.e, the amplifier's gain must be sufficient to overcome the losses associated with any frequency selective feedback network).

* A number of circuits can be used to provide 180° phase shift, one of the simplest being a three stage C-R ladder network that we shall meet next.

LADDER NETWORK OSCILLATOR:

* A simple phase-shift oscillator based on a three stage C-R ladder network is shown below.

* TR1 operates as a conventional common-emitter amplifier stage with R_1 and R_2 providing base bias potential and R_3 and C_1 providing emitter stabilization.

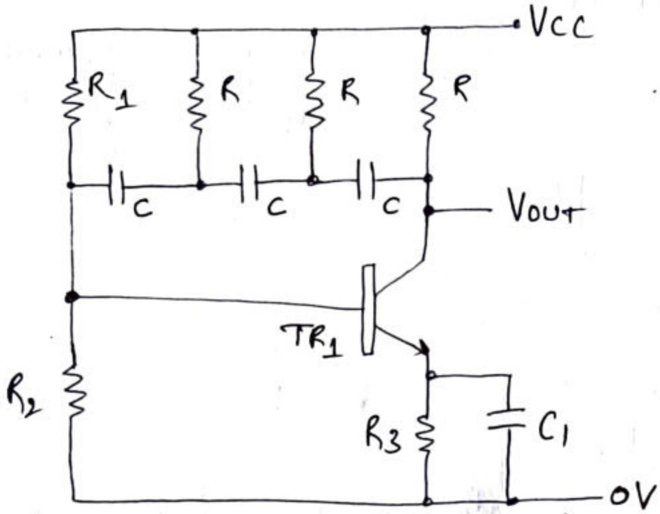


fig: Sine wave Oscillator based on three stage C-R ladder network.

* The total phase shift provided by the C-R ladder network (connected between collector and base) is 180° at the frequency of oscillation.
* The transistor provides the other 180° phase shift in order to realize an overall phase shift of 360° or 0°.
* The frequency of oscillation of the circuit is

$$\boxed{f = \frac{1}{2\pi\sqrt{6}CR}}$$

* The loss associated with the ladder network is 29, thus the amplifier must provide a gain of at least 29 in order for the circuit to oscillate.

Problem

* Determine the frequency of oscillation of a three-stage ladder network oscillator in which C=10nF and R=10KΩ

Soln: Given C=10nF, R=10KΩ

$$f = \frac{1}{2\pi\sqrt{6}CR} = \frac{1}{2\pi\sqrt{6}\times 10\times 10^{-9}\times 10\times 10^{3}} = \frac{10^{4}}{15.386}$$

$$\boxed{f = 647Hz}$$

WEIN BRIDGE OSCILLATOR:

* An alternative approach to providing the phase shift required is the use of a wein bridge oscillator network.

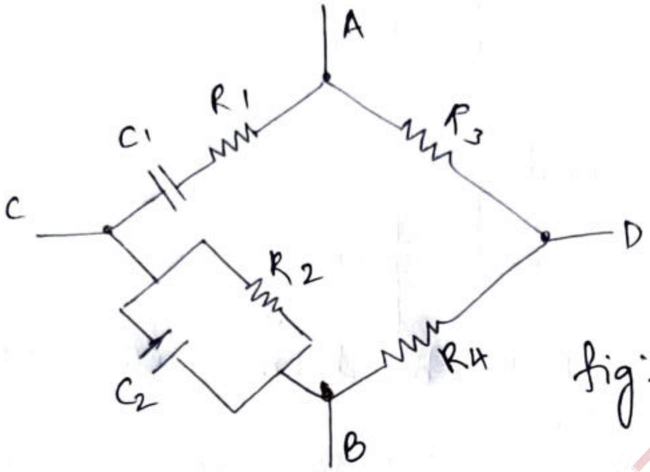


fig: A wein Bridge network.

* Like the C-R ladder, this network provides a phase-shift which varies with frequency.
* The input signal is applied to A and B while the output is taken from C and D.
* At one particular frequency, the phase shift produced by the network will be exactly zero. (input and output signals will be in-phase).
* If we connect the network to an amplifier producing 0° phase shift which has sufficient gain to overcome the losses of the wein bridge, oscillation will result.
* The minimum amplifier gain required to sustain oscillation is given by.

$$\boxed{A_V = 1 + \frac{C_1}{C_2} + \frac{R_2}{R_1}}$$

In most cases, $C_1 = C_2$ and $R_1 = R_2$. Hence the amplifier gain will be $\boxed{A_V = 3}$

* The frequency at which the phase-shift will be zero

is given by

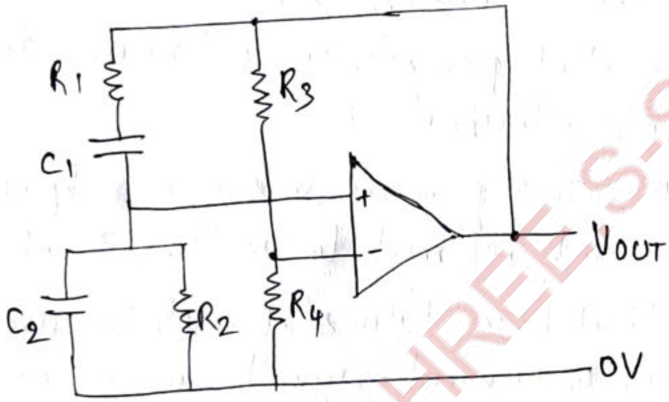
$$\boxed{f = \frac{1}{2\pi\sqrt{C_1C_2R_1R_2}}}$$ if $R_1 = R_2$ and $C_1 = C_2$

Then, $f = \frac{1}{2\pi\sqrt{C^2R^2}}$, $\boxed{f = \frac{1}{2\pi RC}}$

where $R = R_1 = R_2$ and $C = C_1 = C_2$

Problem.

* Figure below shows a wein bridge oscillator based on an operational amplifier. If $C_1 = C_2 = 100nF$. Determine the Output frequencies produced by this arrangement (a) when $R_1 = R_2 = 1K\Omega$ and b) when $R_1 = R_2 = 6K\Omega$.



Soln: a) when $R_1 = R_2 = 1K\Omega$ where $R = R_1 = R_2$ and $C = C_1 = C_2$

$$f = \frac{1}{2\pi RC} = \frac{1}{6.28 \times 100 \times 10^{-9} \times 1 \times 10^{3}}$$

$$\boxed{f = 1.59KHz}$$

b) when $R_1 = R_2 = 6K\Omega$ where $R = R_1 = R_2$ and $C = C_1 = C_2$

$$f = \frac{1}{2\pi RC} = \frac{1}{6.28 \times 100 \times 10^{-9} \times 6 \times 10^{3}}$$

$$\boxed{f = 265 Hz}$$

MULTIVIBRATORS:

* There are many occasions when we require a square wave output from an oscillator rather than a sine wave output.
* Multivibrators are a family of oscillator circuits that produce output waveforms consisting of one or more rectangular pulses.
* The term 'Multivibrator' simply originates from the fact that this type of waveform is rich in harmonics (i.e 'multiple vibrations').
* Multivibrators use regenerative (i.e. positive) feedback.
* The principal types of multivibrators are

1) Astable multivibrators: that provide a continuous train of pulses. (free-running multivibrators)
2) Monostable multivibrators: that produce a single output pulse (have one stable state and referred to as 'one-shot')
3) Bistable multivibrators: that have two stable states and require a trigger pulse or control signal to change from one state to another.

SINGLE-STAGE ASTABLE OSCILLATOR:

* A simple form of astable oscillator that produces a square wave output can be built using just one operational amplifier as shown below.

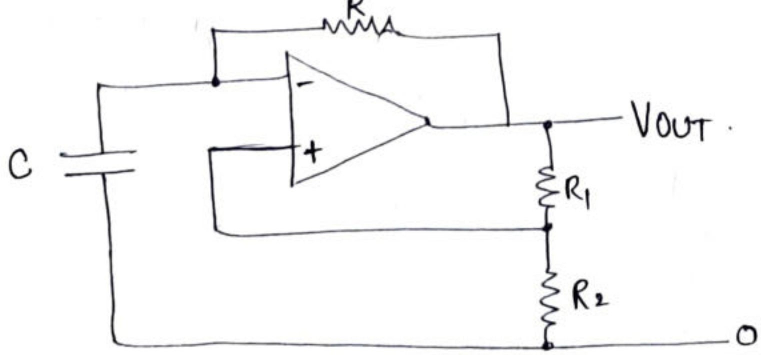


fig: Single-stage astable oscillator using op-Amps.

- The circuit employs positive feedback with the output fedback to the non-inverting input via the potential divider formed by R_1 and R_2.
- This circuit can make a very simple square wave source with a frequency that can be made adjustable by replacing R with a variable or preset resistor.
- Assume that C is initially uncharged and the voltage at the inverting input is slightly less than the voltage at the non-inverting input. The output voltage will rise rapidly to $+V_{CC}$ and voltage at the inverting input will begin to rise exponentially as Capacitor C charges through R.
- Eventually, the voltage at inverting input will have reached a value that causes the voltage at the inverting input to exceed at non-inverting input. At this point, the output voltage will rapidly fall to $-V_{CC}$. Capacitor C will then start to charge in the other direction and the voltage at the inverting input will begin to fall exponentially and process continues.
- The Upper threshold voltage is given by

$$\boxed{V_{UT} = V_{CC} \times \frac{R_2}{R_1 + R_2}}$$

- The lower threshold voltage is given by

$$\boxed{V_{LT} = -V_{CC} \times \frac{R_2}{R_1 + R_2}}$$

- Finally, the time for one complete cycle of the output waveform produced by the astable oscillator is given by $\boxed{T = 2CR \ln\left[1 + 2\left(\frac{R_2}{R_1}\right)\right]}$

CRYSTAL CONTROLLED OSCILLATORS:

* A requirement of some oscillators is that they accurately maintain an exact frequency of oscillation.
* In such cases, a quartz crystal can be used as the frequency determining element. The Quartz crystal vibrates whenever a potential difference is applied across its faces. The frequency of oscillation is determined by the crystal's 'cut' and physical size.
* Most Quartz Crystals can be expected to stabilize the frequency of oscillation of a circuit to within a few parts in a million.
* Crystals can be manufactured for operation in fundamental mode over a frequency range extending from 100KHz to around 20MHz and for overtone operation from 20MHz to well over 100MHz.
* Figure below shows a simple crystal Oscillator circuit in which the crystal provides feedback from the drain to the source of a junction gate FET

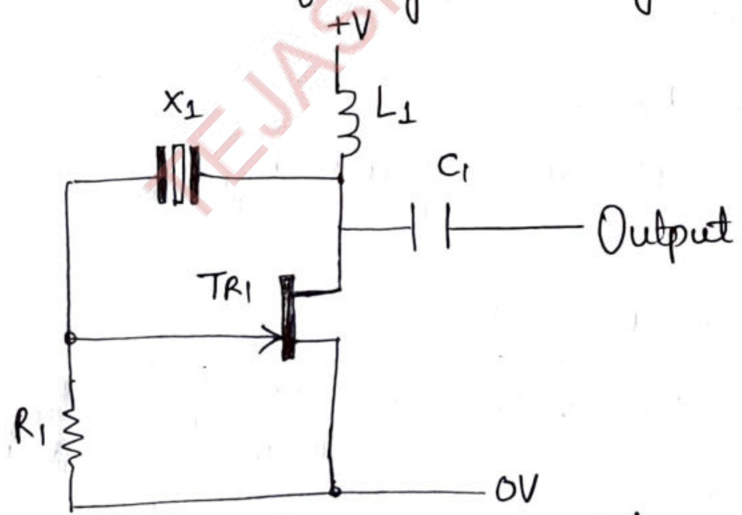


fig: A Simple JFET Oscillator.