NEPAL ENGINEERING COUNCIL

Concept of Basic Electrical and Electronics Engineering

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1.4 Semiconductor devices: Semiconductor diode and its characteristics, BJT Configuration and biasing, small and large signal model, working principle and application of MOSFET and CMOS. (AExE0104)

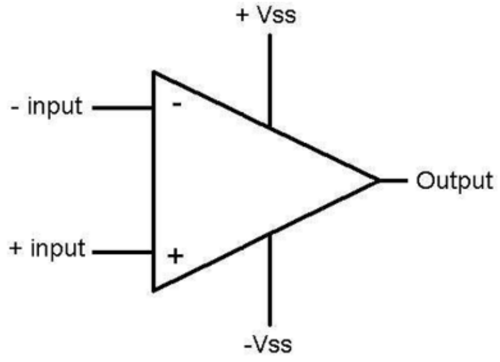
1.5 Signal generator: Basic Principles of Oscillator, RC, LC and Crystal Oscillators Circuits. Waveform generators. (AExE0105)

1.6 Amplifiers: Classification of Output Stages, Class A Output Stage, Class B Output Stage, Class AB Output Stage, Biasing the Class AB Stage, Power BJTs, Transformer-Coupled Push-Pull Stages, and Tuned Amplifiers, op-amps.

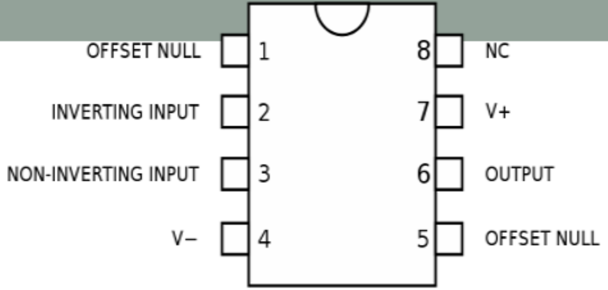
Operational Amplifier

- An ***operational amplifier*** (Op-Amp) is a differential amplifier that amplifies the difference of voltages applied to its two input terminals (differential input), and provides a single- ended output.
- Amplifiers are devices which take a relatively weak signal as an input and produce a much stronger signal as an output.

- V+: non-inverting input
- V−: inverting input
- Vout: output
- VS+: positive power supply
- VS−: negative power supply



LM741

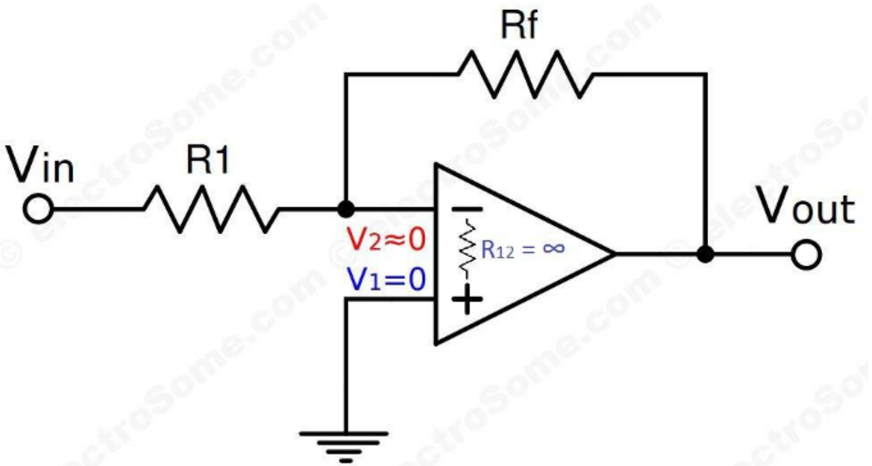


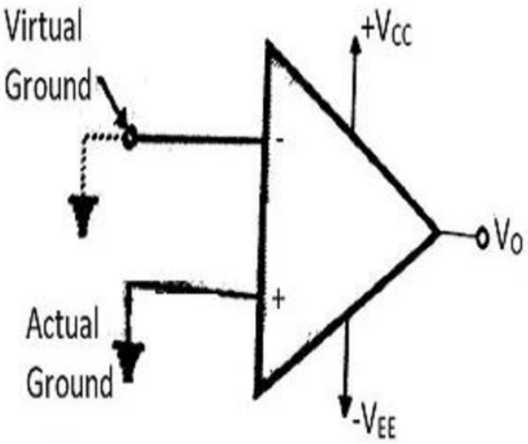
Pin Number	Pin Name	Pin Function
1	Offset Null	This pin is used to eliminate offset voltage and balance the input voltages
2	Inverting Input	Inverting Signal Input
3	Non-Inverting Input	Non-inverting Signal Input
4	Negative Supply Voltage	Negative Supply Voltage
5	Offset Null	This pin is used to eliminate offset voltage and balance the input voltages
6	Output	Amplified Signal Output
7	Positive Supply Voltage	Positive Supply Voltage
8	NC	Not Connected

IDEAL And PRACTICAL Characteristics Of Op-Amp

characteristics	Practical value	Ideal value
Voltage gain	2×10^5	∞
Input resistance	2MΩ	∞
Output resistance	75Ω	0
Bandwidth	1 MHz	∞
CMRR	90 dB	∞
Slew rates	0.5V/μs	∞
PSRR	150μV/V	0
Input offset voltage	2mV	0
Input bias current	50 nA	0
Input offset current	6 nA	0

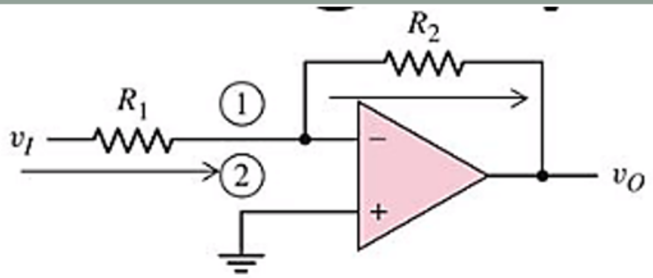
Virtual Short Circuit and Virtual Ground





Inverting Amplifier

- Inverting amplifier is one in which the output is exactly 180 degree out of phase with respect to input(i.e. if you apply a positive voltage, output will be negative).
- Output is an inverted(in terms of phase) amplified version of input.



KCL at node 1:

$(V_i - 0) / R_1 = (0 - V_o) / R_2$

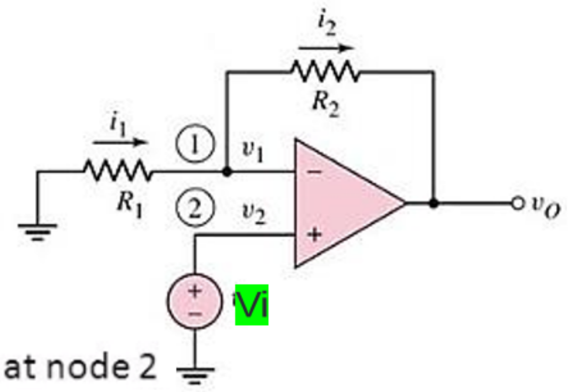
$V_i / R_1 = - V_o / R_2$

$$\frac{V_o}{V_i} = -\frac{R_2}{R_1}$$

$$\text{Voltage gain, } A_v = \frac{V_0}{V_i} = -\frac{R_2}{R_1}$$

Non Inverting Amplifier

- Non Inverting amplifier is one in which the output is in phase with respect to input(i.e. if you apply a positive voltage, output will be positive).
- Output is an Non inverted(in terms of phase) amplified version of input.



Voltage at node 1 = voltage at node 2

KCL at node 1:

$(0 - V_i) / R_1 = (V_i - V_o) / R_2$

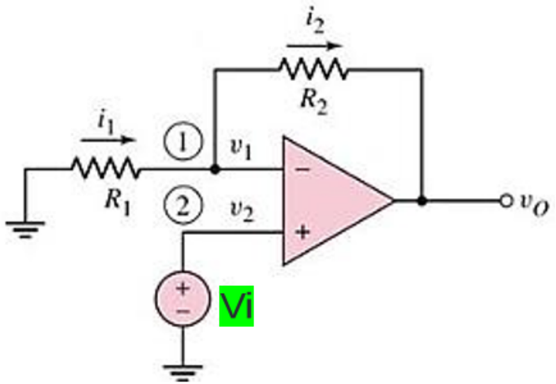
$-(V_i / R_1) = (V_i / R_2) - (V_o / R_2)$

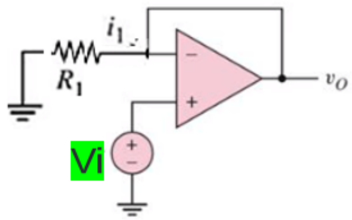
$V_o / R_2 = (V_i / R_2) + (V_i / R_1) = V_i \left(\frac{1}{R_2} + \frac{1}{R_1} \right)$

$V_o / V_i = R_2 \left(\frac{1}{R_2} + \frac{1}{R_1} \right)$

Voltage gain, $A_v = \frac{V_0}{V_i} = 1 + \frac{R_2}{R_1}$

Voltage Follower/ Buffer



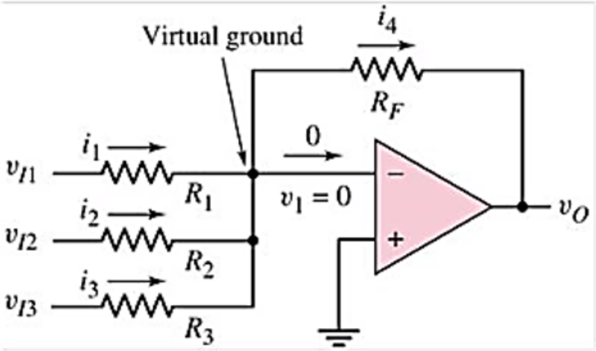


Voltage gain, $A_v = \frac{V_0}{V_i} = 1 + \frac{R_2}{R_1}$

Here if R_2=0, Av=1
i.e V_0=V_i

- **Used to isolate stages from each other.**
- **Used as an impedance transformer.**
- **Reduce power consumption of the source**
- **Reduce distortion from overloading, distortion and other electromagnetic interference.**

Summer/ Adder



Similarly,

Using KCL at the input node

$$i_1 + i_2 + i_3 - i_4 - 0 = 0$$

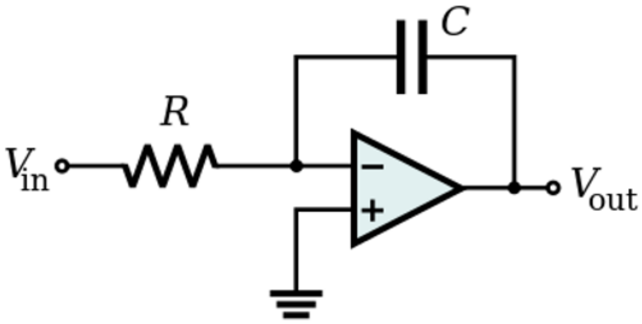
Output voltage

$$V_0 = -R_F\left(\frac{V_{i1}}{R_1} + \frac{V_{i2}}{R_2} + \frac{V_{i3}}{R_3}\right)$$

If R_f=R1=R2=R3
Then, $V_0 = -(V_{i1}+V_{i2}+V_{i3})$

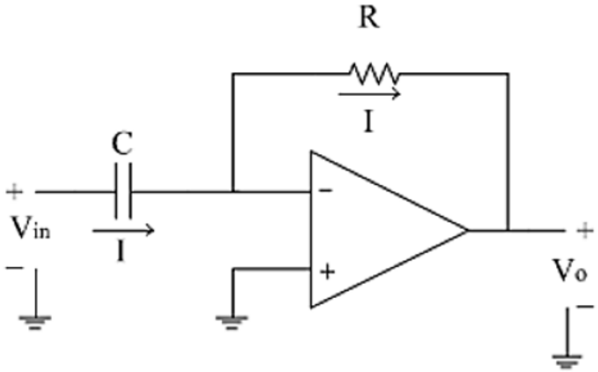
Thus,
Output signal is the sum of all input signals.

Integrator



$$V_o = -\frac{1}{RC}\int V_{in}\,dt$$

Differentiator



$$V_{out} = -RC\frac{dV_{in}}{dt}$$

Which of the following electrical characteristics is not exhibited by an ideal op-amp?

a) Infinite voltage gain

b) Infinite bandwidth

c) Infinite output resistance

d) Infinite slew rate

Answer: c

Explanation: An ideal op-amp exhibits zero output resistance so that output can drive an infinite number of other devices.

An ideal op-amp requires infinite bandwidth because

a) Signals can be amplified without attenuation

b) Output common-mode noise voltage is zero

c) Output voltage occurs simultaneously with input voltage changes

d) Output can drive infinite number of device

Answer: a

Explanation: An ideal op-amp has infinite bandwidth. Therefore, any frequency signal from 0 to ∞ Hz can be amplified without attenuation.

Find the output voltage of an ideal op-amp. If V1 and V2 are the two input voltages

a) VO= V1-V2

b) VO= A×(V1-V2)

c) VO= A×(V1+V2)

d) VO= V1×V2

Answer: b

Explanation: The output voltage of an ideal op-amp is the product of gain and algebraic difference between the two input voltages.

Which is not the ideal characteristic of an op-amp?

a) Input Resistance –> 0

b) Output impedance –> 0

c) Bandwidth –> ∞

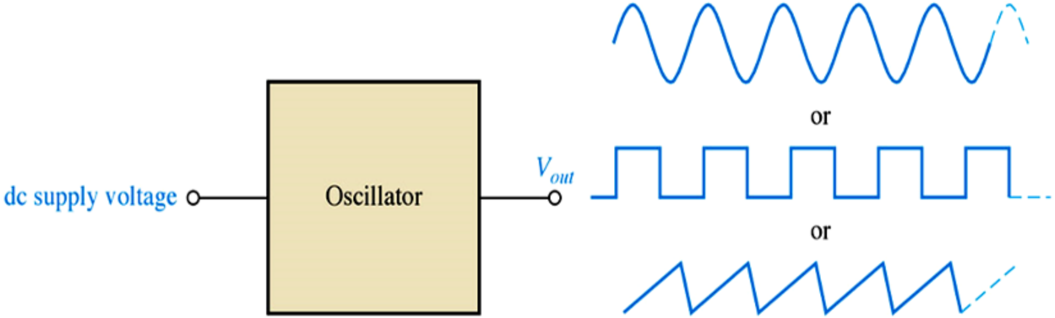
d) Open loop voltage gain –> ∞

Answer: a

Explanation: Input resistance is infinite so almost any signal source can drive it and there is no loading of the preceding stage.

Oscillator

- Oscillator is an electronic circuit that generates a periodic waveform on its output without an external signal source. It is used to **convert dc to ac**.
- Oscillators are circuits that produce a continuous signal of some type **without the need of an input**.
- These signals serve a variety of purposes.
- Communications systems, digital systems (including computers), and test equipment make use of oscillators



Basic Principle of Oscillator

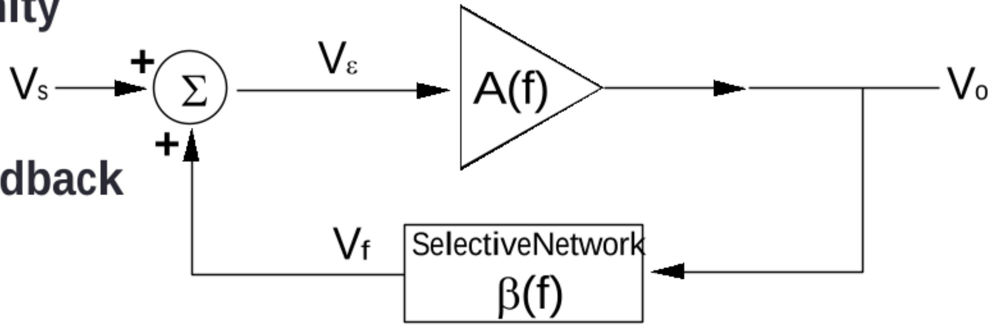
A Basic oscillator contains:

- a frequency selection feedback network
- an amplifier to maintain the loop gain at **unity**

Vs= input= 0

Vo= Output

A=Gain of amplifier and B gain of +ve feedback



$$V_o = AV_\varepsilon = A(V_s + V_f) \quad \text{and} \quad V_f = \beta V_o$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{A}{1 - A\beta}$$

If $V_s = 0$, the only way that V_o can be nonzero is that loop gain $A\beta=1$ which implies that

$$|A\beta| = 1 \quad \textbf{\textit{(Barkhausen Criterion)}}$$

$$\angle A\beta = 0$$

Fig: An amplifier with positive feedback acts as an oscillator".

Noise signals and the transients associated with the circuit turning on provide the initial source signal that initiate the oscillation

Oscillator Basics

Oscillators convert dc to ___________. ac

In order for an oscillator to work, the feedback must be ___________. positive

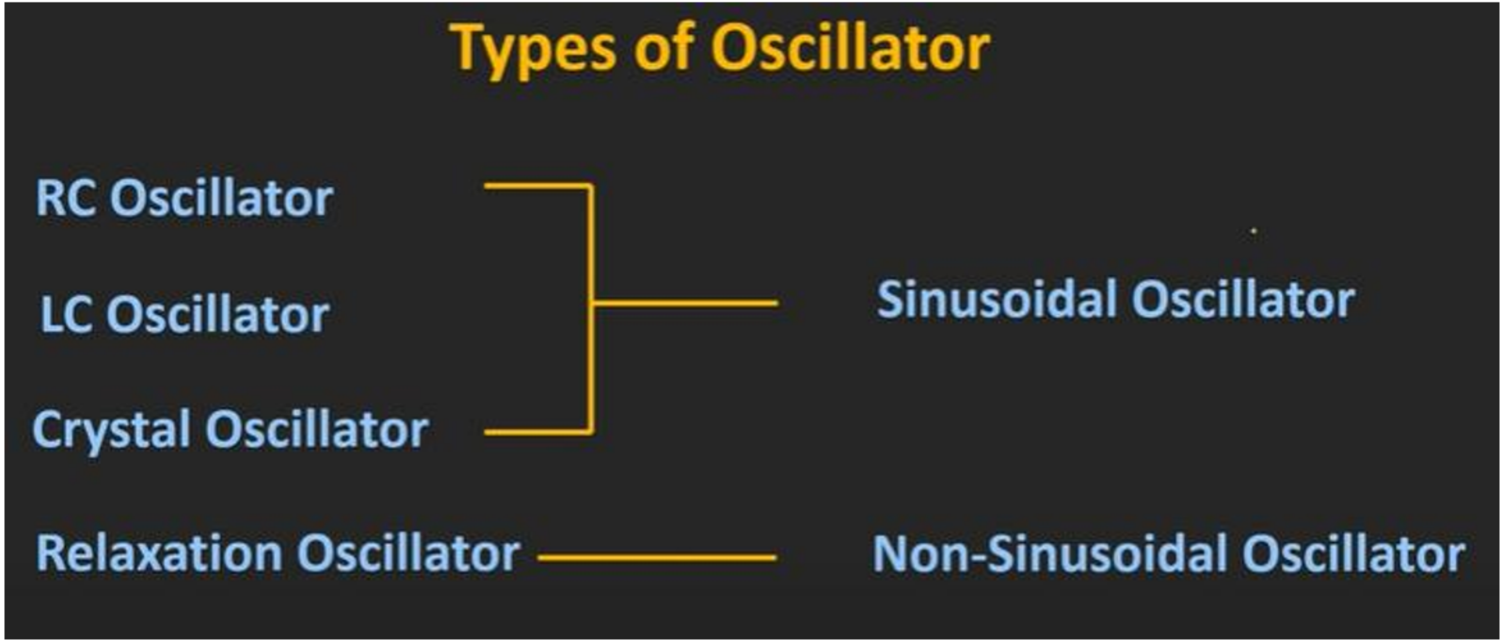
An oscillator can't start unless gain (A) is __________ than feedback fraction (B). greater

For sinusoidal signal the overall phase shift of the feedback loop should be 0/360/…n*360

Which among the following parameters acts as an initiator for the operation of an oscillator in the absence of input signal?

a. Noise voltage **b.** Noise power **c.** Noise temperature **d.** All

Types of Oscillator



RC Oscillator

RC feedback oscillators are generally limited to frequencies of 1 MHz or less.

Two Types

- Wien-bridge
- phase-shift

RC wein Bridge Oscillator

Components:

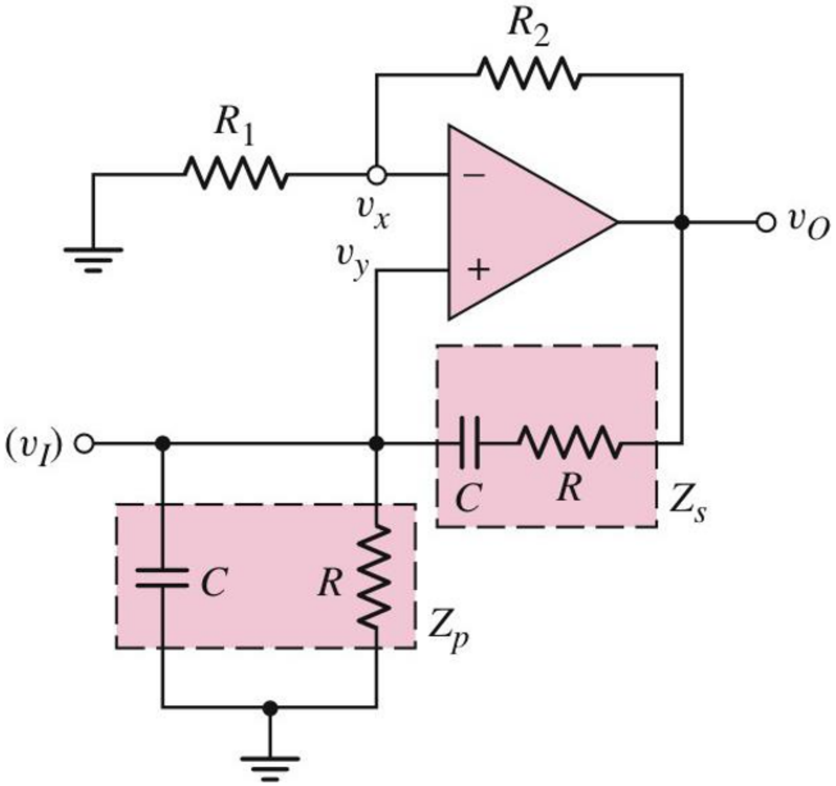
- Op amp operating at non- inverting mode
  No phase shift

$$A = 1 + \frac{R_2}{R_1}$$

- RC series branch (Zs): R-jXc

$$Z_s = \frac{1 + sRC}{sC} \qquad Z_p = \frac{R}{1 + sRC}$$

- RC parallel branch (Zp): -jXc*R/(R-jXc)
- No phase shift by feedback as well.



Wien-bridge Oscillator

Note: s=jw for frequency response

- The loop gain for the oscillator is;

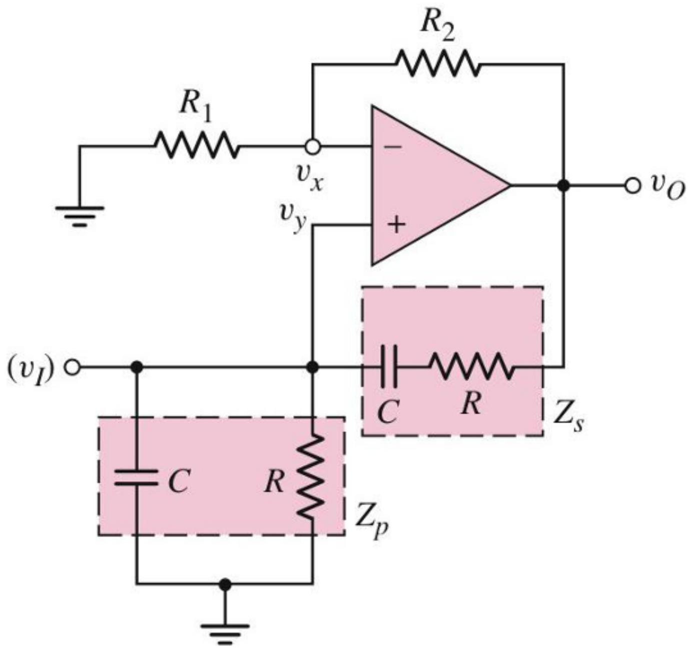
$$T(s) = A(s)\beta(s) = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{Z_p}{Z_p + Z_s}\right)$$

- where; $Z_p = \frac{R}{1 + sRC}$ $\quad Z_s = \frac{1 + sRC}{sC}$

$$T(s) = \left(1 + \frac{R_2}{R_1}\right)\left[\frac{1}{3 + sRC + (1/sRC)}\right]$$

- For Oscillation frequency, fo/wo

$$T(j\omega_0) = \left(1 + \frac{R_2}{R_1}\right)\left[\frac{1}{3 + j\omega_0 RC + (1/j\omega_0 RC)}\right]$$



Wien-bridge Oscillator

$$T(j\omega_0) = \left(1+\frac{R_2}{R_1}\right)\left[\frac{1}{3+j\omega_0 RC + (1/j\omega_0 RC)}\right]$$

Phase Shift Condition

Angle of $T(j\omega)$ be zero, i.e $T(j\omega)$ must be real (for zero phase condition), the imaginary component must be zero;

$$j\omega_0 RC + \frac{1}{j\omega_0 RC} = 0$$

$$==> j\omega_0 RC = -\frac{1}{j\omega_0 RC}$$

$$==> (j\omega_0 RC)^2 = -1$$

$$==> j^2(\omega_0 RC)^2 = -1$$

$$=> -1.(\omega_0 RC)^2 = -1$$

$$=> (\omega_0 RC)^2 = 1$$

$$=> \omega_0 RC = 1$$

$$=> \omega_0 = \frac{1}{RC}$$

Magnitude Condition

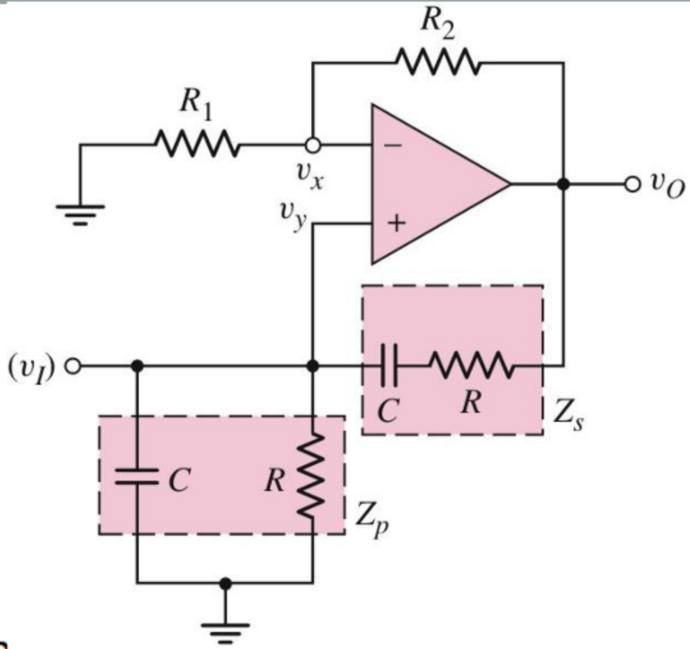
$T(j\omega)$ =1 in magnitude

$$1 = \left(1+\frac{R_2}{R_1}\right)\left(\frac{1}{3+0}\right) = \left(1+\frac{R_2}{R_1}\right)\left(\frac{1}{3}\right)$$

$$\Rightarrow \frac{R_2}{R_1} = 3-1 = 2$$

To ensure oscillation, the ratio R_2/R_1 must be slightly greater than 2.

RC wein Bridge Oscillator



Conclusion

$$\omega = \frac{1}{RC}$$

$$\frac{R_2}{R_1} = 2$$

$$\Rightarrow R_2 = 2R_1$$

$$non - inverting\ gain = A = 1 + \frac{R_2}{R_1} = 1 + 2 = 3$$

$$\beta = \frac{1}{3}$$

RC Oscillator

A properly designed Wien bridge oscillator provides a ___________ waveform. sine

The feedback fraction in a Wien bridge oscillator is ___________. 0.333

The feedback circuit in a wein bridge oscillator provides ___________ of phase shift. 0^o

The gain of amplifier in wein bridge oscillator should be at least 3

The ratio of feedback resistor and other resistor of amplifier in wein bridge oscillator is 2

RC Phase-Shift Oscillator

The phase shift oscillator utilizes three RC circuits to provide 180º phase shift that when coupled with the 180º of the op-amp itself provides the necessary feedback to sustain oscillations.

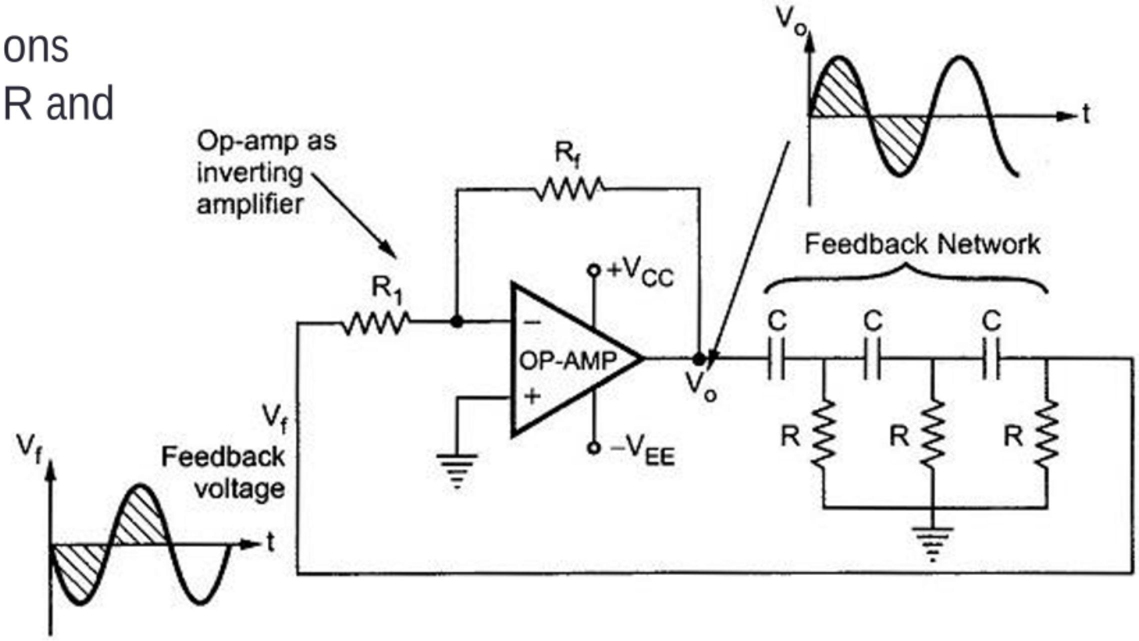
The frequency of sustained oscillations generated depends on the values of R and C and is given by, $f_r = \dfrac{1}{2\pi\sqrt{6}RC}$

At this frequency the gain of the op-amp must be at least 29 to satisfy $A\beta = 1$.

Now gain of the op-amp inverting amplifier is given by,

$$|A| \geq \frac{R_f}{R_1} \geq 29 \text{ for oscillations}$$

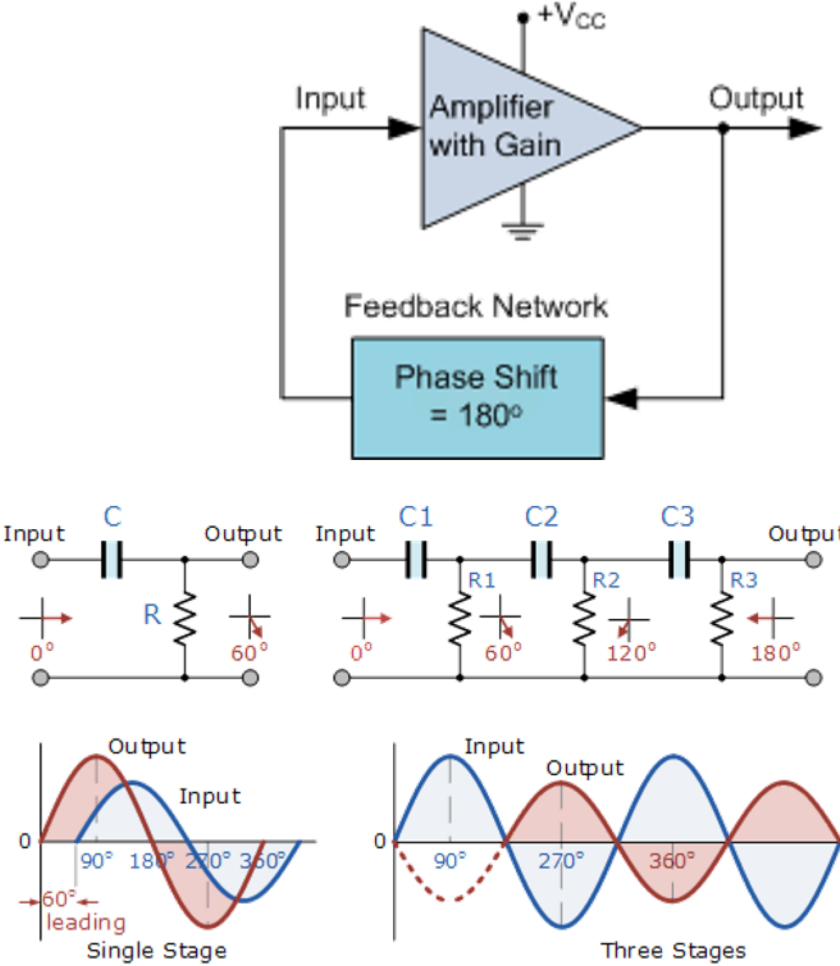
$$\therefore \quad R_f \geq 29\, R_1$$



Phase shift oscillator

- Total phase shift required= 360
- Amplifier phase shift= 180 (Non Inverting mode of Op Amp or CE configuration of BJT)
- One RC is selected to shift phase by 60 degree.
- For 3 same RC, total phase shift =3*60=180 degree.

- Total phase shift= 180+180=360



RC phase shift oscillators contain a minimum of __________ Phase shift network.

a) 1

b) 2

c) 3

d) 0

Answer: c

Explanation: RC phase shift oscillator contains a minimum of three phase shift networks. There can be also four (with 45 degree phase shift each) and it increases the stability of oscillation.

Amplifier gain for RC phase shift oscillation, to obey Barkhausen's criteria should be minimum of ____________

a) 43

b) 4

c) 10

d) 29

Answer d

One phase shift network of an RC phase contain __________ inductor.

a) 1

b) 2

c) 3

d) 0

Answer d

The phase shift network will produce a phase shift of 180 degrees at ____________

a) Three different frequencies

b) One frequency

c) Two different frequencies

d) Infinitely many frequencies

Answer: b

Explanation: The phase shift oscillator will produce a phase shift of 180 degrees only at a particular frequency by which it is meant to oscillate.

Frequency of oscillation for three section RC phase shift network is given by ____________

a) 1/(π√6 RC)

b) 2/(π√6 RC)

c) 1/(2π√6 RC)

d) 1/(2√6 RC)

Answer: c

Explanation: For an RC phase shift oscillator the frequency formula is 1/2πRC√2N where N is the total number of RC stages. For a 3 stage circuit, the frequency is 1/2πRC√6.

The feedback factor for RC phase shift oscillator is ____________

a) 1/18

b) 1/29

c) 1/11

d) 1/33

Answer d

What will be oscillator frequency, if phase shift network of 3stages of RC phase shift oscillator contains a capacitor of 7nF and a resistance of 10K in each stage?

a) 928 Hz

b) 1KHz

c) 1.2KHz

d) 895Hz

$$\frac{1}{2\pi\sqrt{6}RC} = \frac{0.065}{RC} = \frac{0.065}{10\times10^{3}\times7\times10^{-9}} = 928.57\text{Hz}$$

LC Oscillators

- Use transistors and LC tuned circuits or crystals in their feedback network.
- For generating high-frequency signals, LC Oscillator is preferred. At higher frequencies, better results are obtained with LC-tuned oscillators. The transistors (BJTs and FETs) used in the LC oscillators are used in the frequency range of 100 kHz to 100 GHz.
- Examine Colpitts, Hartley

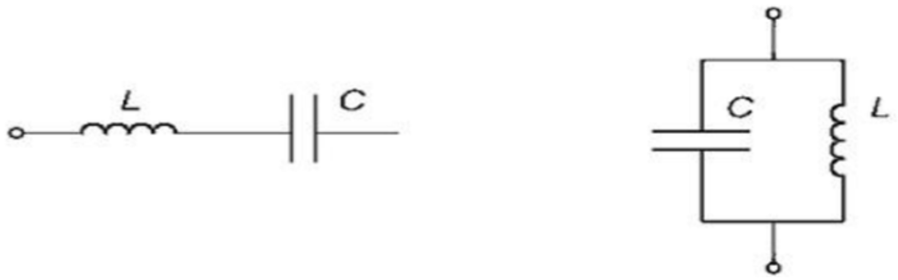
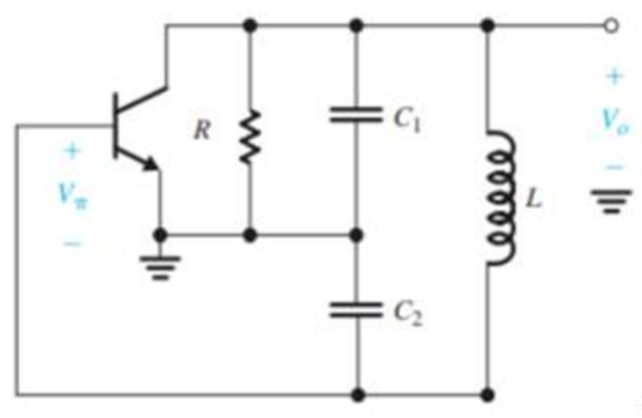


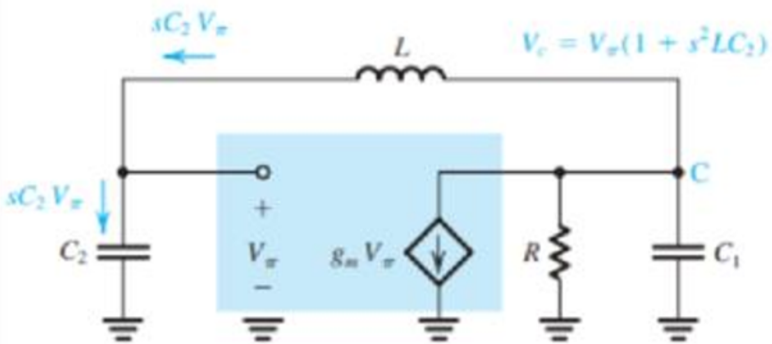
Fig: LC tank different configuration

Colpitts Oscillator

- The Colpitts oscillator is a type of oscillator that uses an LC circuit in the feed-back loop.
- The feedback network is made up of a pair of tapped capacitors (C_1 and C_2) and an inductor L to produce a feedback necessary for oscillations.
- The output voltage is developed across C_1.
- The feedback voltage is developed across C_2.



Colpitts Oscillator



- If we replace BJT by pi model we can get
- KCL at the output node:

$$\frac{V_o}{\frac{1}{sC_1}} + \frac{V_o}{R} + g_m V_{gs} + \frac{V_o}{sL + \frac{1}{sC_2}} = 0$$

- Eq (1)

- voltage divider produces:

$$V_{gs} = \left(\frac{\frac{1}{sC_2}}{\frac{1}{sC_2} + sL} \right) \bullet V_o$$

- Eq (2)

- substitute eq(2) into eq(1):

$$V_o \left[g_m + sC_2 + (1 + s^2 LC_2)\left(\frac{1}{R} + sC_1 \right) \right] = 0$$

Colpitts Oscillator

- Assume that oscillation has started, then $Vo \neq 0$

$$s^3LC_1C_2 + \frac{s^2LC_2}{R} + s(C_1 + C_2) + \left(g_m + \frac{1}{R}\right) = 0$$

- Let $s = j\omega$ $\left(g_m + \frac{1}{R} + \frac{\omega^2 LC_2}{R}\right) + j\omega\left[(C_1 + C_2) - \omega^2 LC_1C_2\right] = 0$

- both real & imaginary component must be zero
  - Imaginary component: $$\omega_o = \frac{1}{\sqrt{L\left(\frac{C_1C_2}{C_1 + C_2}\right)}}$$ - Eq (3)

Colpitts Oscillator

- both real & imaginary component must be zero
  - Imaginary component:

$$\frac{\omega^2 LC_2}{R} = g_m + \frac{1}{R}$$

- Eq (4)

- Combining Eq(3) and Eq(4):

$$\frac{C_2}{C_1} = g_m R$$

- to initiate oscillations spontaneously:

$$g_m R > \left(\frac{C_2}{C_1}\right)$$

Colpitts Oscillator

- Oscillation frequency

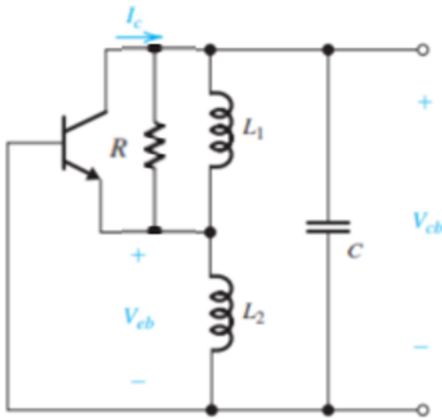
$$\omega_o = \frac{1}{\sqrt{L\left(\frac{C_1C_2}{C_1+C_2}\right)}} = \frac{1}{\sqrt{L * Ceq}}$$

- For ossicillator,

$$g_m R > \left(\frac{C_2}{C_1}\right)$$

Hartley Oscillator

- The Hartley oscillator is almost identical to the Colpitts oscillator.
- The primary difference is that the feedback network of the Hartley oscillator uses tapped inductors (L_1 and L_2) and a single capacitor C.



Feedback is achieved through the inductive divider circuit used in the Hartley oscillator. The ratio L_1/L_2 determines the feedback ratio and must be adjusted to ensure that oscillations will start.

Hartley Oscillator

The analysis of Hartley oscillator is identical to that Colpitts oscillator

The frequency of oscillation:

$$\omega_o = \frac{1}{\sqrt{(L_1 + L_2)C}} \qquad = \frac{1}{\sqrt{Leq * C}}$$

A ac circuit contains a capacitor of capacitance 10^{-6}F and an inductor of 10^{-4}H. The frequency of electrical oscillations will be

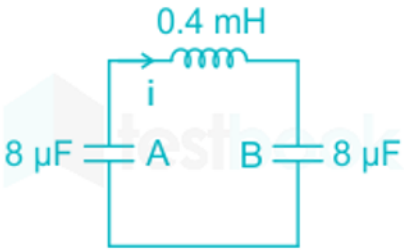
1. 10^5 Hz
2. 10 Hz
3. $\frac{10^5}{2\pi} Hz$
4. $\frac{10}{2\pi} Hz$

- The **resonance frequency** is given by

$$\Rightarrow f = \frac{1}{2\pi\sqrt{LC}}$$

$$\Rightarrow f = \frac{1}{2\pi\sqrt{10^{-6} \times 10^{-4}}} = \frac{10^5}{2\pi} Hz$$

Find the angular frequency of the oscillation for the circuit shown in the figure:



1. 5×10^3 rad/sec
2. 20×10^3 rad/sec
3. 25×10^3 rad/sec
4. None of the above

$$\Rightarrow \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\Rightarrow \frac{1}{C} = \frac{1}{8\times10^{-6}} + \frac{1}{8\times10^{-6}}$$

$\Rightarrow C = 4 \times 10^{-6}$ C

$$\Rightarrow \omega_o = \frac{1}{\sqrt{LC}}$$

$$\Rightarrow \omega_o = \frac{1}{\sqrt{0.4\times10^{-3}\times4\times10^{-6}}}$$

$\Rightarrow \omega_o = 25 \times 10^3$ rad/sec

Find the true statement.

a) When a resistor is connected to an inductor, the electric current in the circuit undergoes LC oscillations

b) When a resistor is connected to a capacitor, the electric current in the circuit undergoes LC oscillations

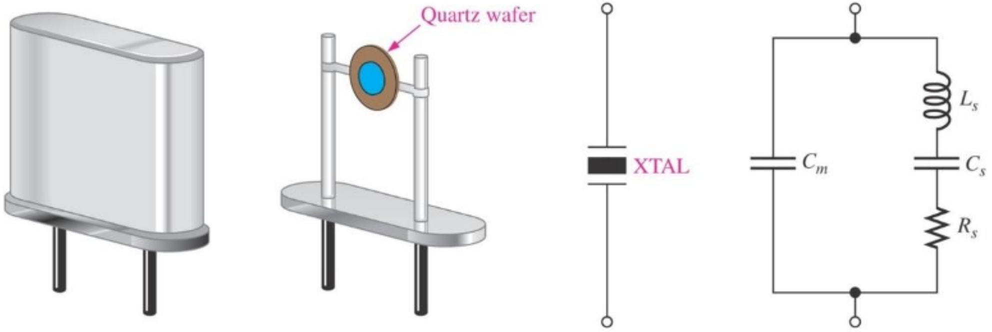
c) When a charged capacitor is connected to an inductor, the electric current in the circuit and charge on the capacitor undergoes LC oscillations

d) All

- Answer C

Crystal Oscillator

- Most communications and digital applications require the use of oscillators with extremely stable output. Crystal oscillators are invented to overcome the output fluctuation experienced by conventional oscillators.
- Crystals used in electronic applications consist of a quartz wafer held between two metal plates and housed in a a package as shown in Fig. 9 (a) and (b).



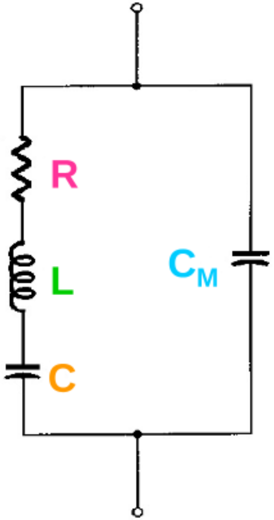
(a) Typical packaged crystal (b) Basic construction (without case) (c) Symbol (d) Electrical equivalent

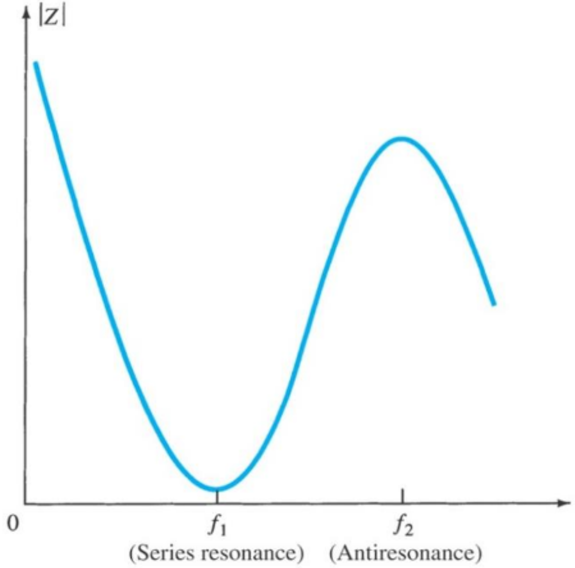
Crystal Oscillator

- Piezoelectric Effect
  - The quartz crystal is made of silicon oxide (SiO_2) and exhibits a property called the piezoelectric
  - When a changing an alternating voltage is applied across the crystal, it vibrates at the frequency of the applied voltage. In the other word, the frequency of the applied ac voltage is equal to the natural resonant frequency of the crystal.
  - The thinner the crystal, higher its frequency of vibration. This phenomenon is called piezoelectric effect.

Crystal Oscillator

- Characteristic of Quartz Crystal
  - The crystal can have two resonant frequencies;
  - One is the series resonance frequency f_1 which occurs when $X_L = X_C$. At this frequency, crystal offers a very low impedance to the external circuit where Z = R.
  - The other is the parallel resonance (or antiresonance) frequency f_2 which occurs when reactance of the series leg equals the reactance of C_M. At this frequency, crystal offers a very high impedance to the external circuit

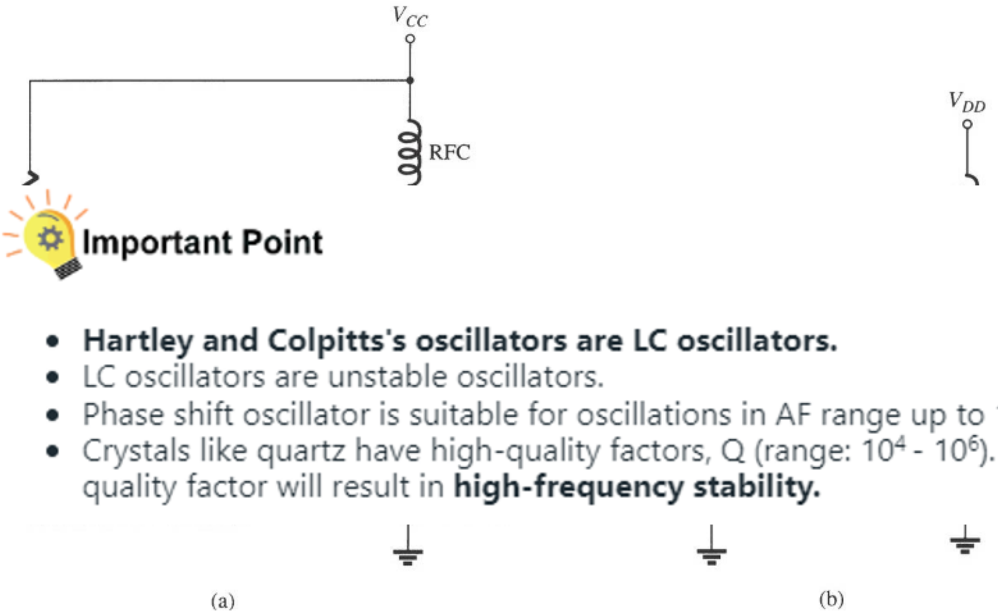




$$f_S = \frac{1}{2\pi\sqrt{L_S C_S}} \qquad f_P = \frac{1}{2\pi\sqrt{L_S\left(\frac{C_P C_S}{C_P + C_S}\right)}}$$

Crystal Oscillator

- The crystal is connected as a series element in the feedback path from collector to the base so that it is excited in the series-resonance mode



Important Point

- **Hartley and Colpitts's oscillators are LC oscillators.**
- LC oscillators are unstable oscillators.
- Phase shift oscillator is suitable for oscillations in AF range up to 1 kHz
- Crystals like quartz have high-quality factors, Q (range: 10^4 - 10^6). The high-quality factor will result in **high-frequency stability.**

Crystal Oscillator

- Since, in series resonance, crystal impedance is the smallest that causes the crystal provides the largest positive feedback.
- Resistors R_1, R_2, and R_E provide a voltage-divider stabilized dc bias circuit. Capacitor C_E provides ac bypass of the emitter resistor, R_E to avoid degeneration.
- The RFC coil provides dc collector load and also prevents any ac signal from entering the dc supply.
- The coupling capacitor C_C has negligible reactance at circuit operating frequency but blocks any dc flow between collector and base.
- The oscillation frequency equals the series-resonance frequency of the crystal and is given by:

$$f_o = \frac{1}{2\pi\sqrt{LC_C}}$$

A quartz crystal has the following values: Rs = 6.4Ω, Cs = 0.09972pF and Ls = 2.546mH. Calculate the fundamental oscillating frequency of the crystal.

$$f_S = \frac{1}{2\pi\sqrt{L_S C_S}} = \frac{1}{2\pi\sqrt{2.546mH \times 0.09972pF}}$$

$$f_S = \frac{1}{2\pi\sqrt{0.002546 \times 99.72 \times 10^{-15}}} = 9.987MHz$$

Like which of the following circuit does a quartz oscillator behaves like at stable resonant based frequency?

a) RC
b) RLC
c) LC
d) RL

Ans: b

A quartz crystal has ____ value of Q factor?

a) Greater
b) Lesser
c) Infinite
d) Zero

Answer a

A crystal oscillator generates electrical oscillation of constant frequency based on the ________ effect.

1. ultrasonic
2. magnetic
3. piezoelectric
4. photoelectric

In a crystal oscillator, a crystal has thickness of t, If you reduce t by 1%, what happens to the frequency 'f'?

1. f will increase by 2%
2. f will decrease by 2%
3. f will increase by 1%
4. f will decrease by 1%

The oscillator that gives good frequency stability is _____

1. Harley Oscillator
2. Colpitts Oscillator
3. Crystal oscillator
4. RC phase shift oscillator

In a crystal oscillator, the frequency(f) of the oscillator is inversely the thickness(t) of the crystal,

$$f \propto \frac{1}{t}$$

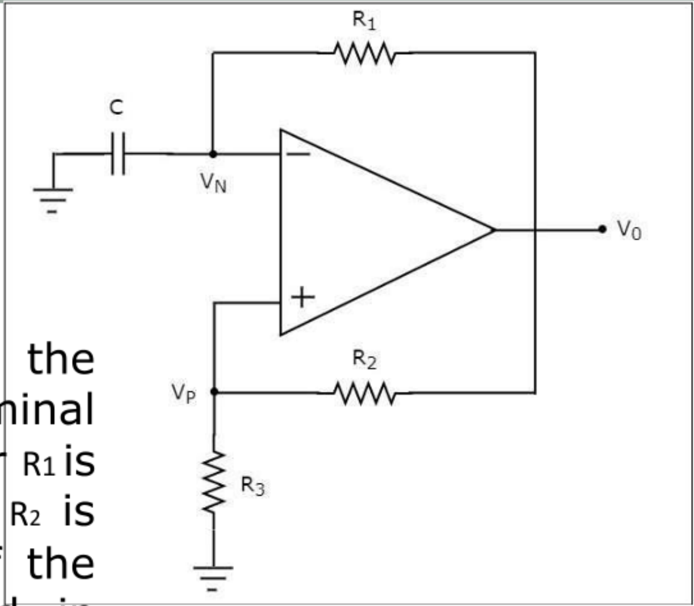
Wave Generator

A waveform generator is an electronic circuit, which generates a standard wave. There are two types of op-amp based waveform generators −

- Square wave generator
- Triangular wave generator

Square wave generator Construction

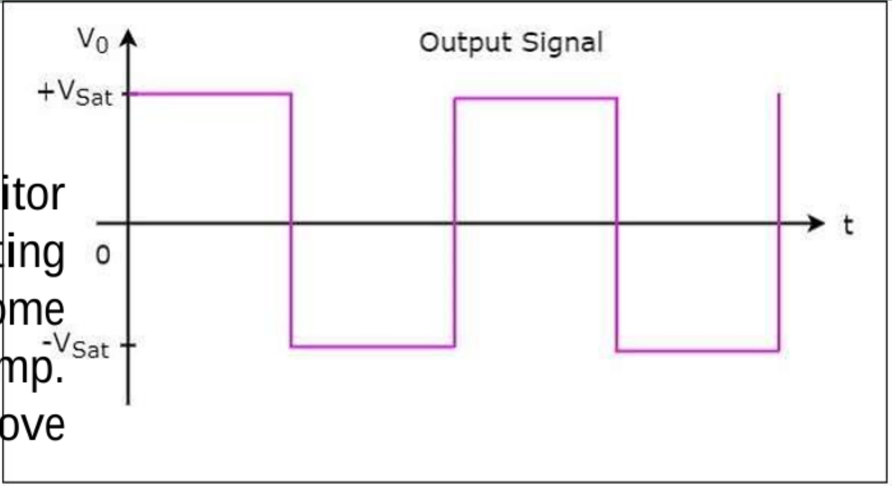
A square wave generator is an electronic circuit which generates square wave.



Observe that in the circuit diagram shown above, the resistor R_1 is connected between the inverting input terminal of the op-amp and its output of op-amp. So, the resistor R_1 is used in the **negative feedback.** Similarly, the resistor R_2 is connected between the noninverting input terminal of the op-amp and its output. So, the resistor R_2 is used in the **positive feedback** path.

A capacitor C is connected between the inverting input terminal of the op-amp and ground. So, the **voltage across capacitor C** will be the input voltage at this inverting terminal of op-amp. Similarly, a resistor R_3 is connected between the non-inverting input terminal of the op-amp and ground. So, the **voltage across resistor** R_3 will be the input voltage at this non-inverting terminal of the op-amp.

Working



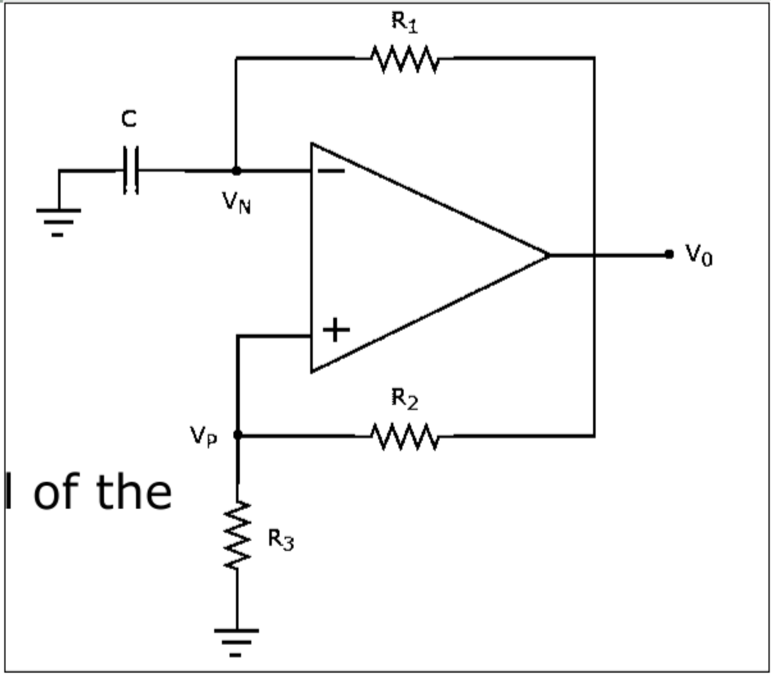
•Assume, there is **no charge** stored in the capacitor initially. Then, the voltage present at the inverting terminal of the op-amp is zero volts. But, there is some offset voltage at non-inverting terminal of op-amp. Due to this, the value present at the output of above circuit will be +Vsat.

•Now, the capacitor C starts **charging** through a resistor R1.The value present at the output of the above circuit will change to −Vsat, when the voltage across the capacitor C reaches just greater than the voltage (positive value) across resistor R3.

•The capacitor C starts **discharging** through a resistor R1, when the output of above circuit is −Vsat. The value present at the output of above circuit will change to +Vsat, when the voltage across capacitor C reaches just less than (more negative) the voltage (negative value) across resistor R3.

The output of the op-amp is forced to swing repetitively between positive saturation, +Vsat and negative saturation, -Vsat.

Important Conclusion



1 Op amp

1 Capacitor

3 Resistors:

R1 is for negative feedback

R2 is for positive feedback

R3 between the non-inverting input terminal of the op-amp and ground. So, the voltage across resistor R_3 will be the input voltage

Expression for period is

$$T = 2RC\ln\frac{1+\beta}{1-\beta} \qquad \text{where } \beta = \frac{R_2}{R_1+R_2}$$

If $R_1 = R_2$, the equation for period reduces to $T = 2RC\ln 3$

The frequency of oscillation, $f = \dfrac{1}{2RC\ln 3}$

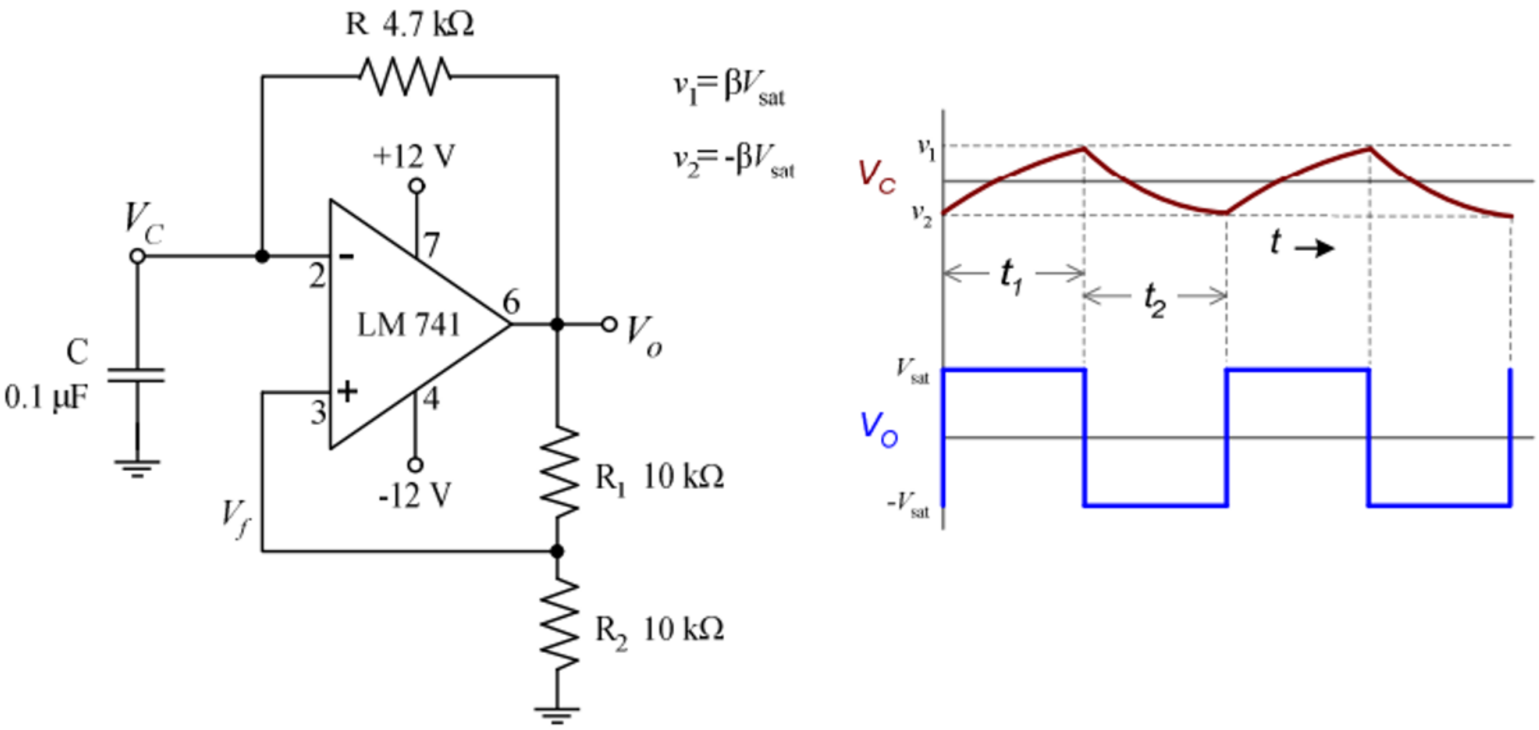
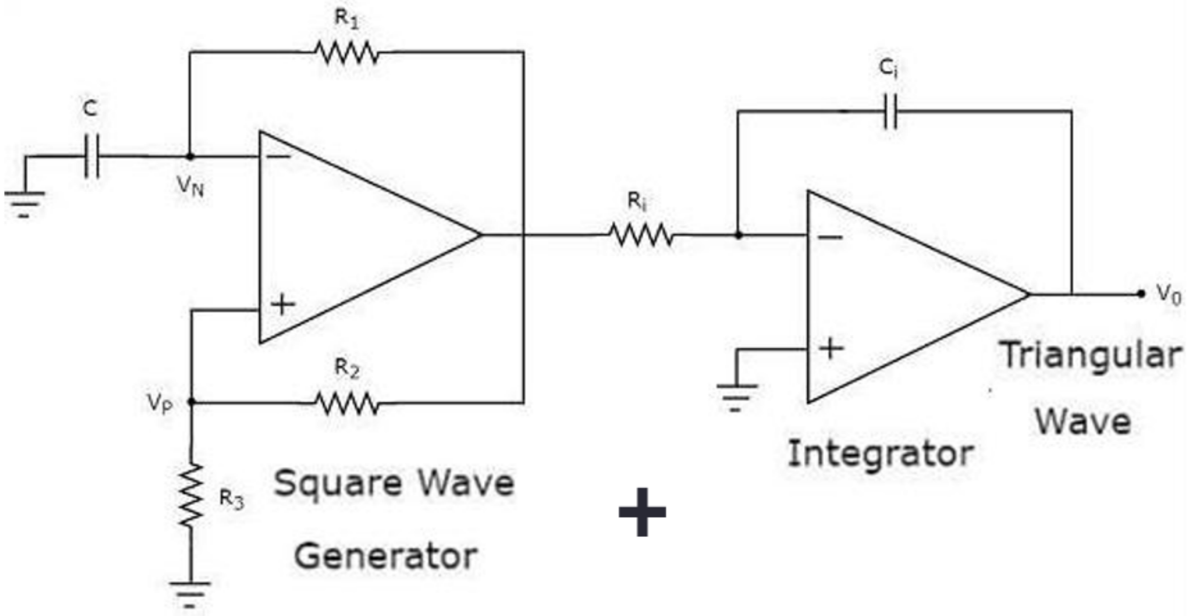


Fig 1. Square wave generator and waveforms

Triangular Wave Generator

- A triangular wave generator is an electronic circuit, which generates a triangular wave.



MCQs

How are the square wave output generated in op-amp?

a) Op-amp is forced to operate in the positive saturation region

b) Op-amp is forced to operate in the negative saturation region

c) Op-amp is forced to operate between positive and negative saturation region

d) None of the mentioned

Answer: c

Explanation: Square wave outputs are generated where the op-amp is forced to operate in saturated region, that is, the output of the op-amp is forced to swing repetitively between positive saturation, +Vsat and negative saturation, -Vsat.

Determine the expression for time period of a square wave generator

a) $T= 2RC \ln\times[(R1+ R2) / (R2)]$.

b) $T= 2RC \ln\times[(2R1+ R2) / (R2)]$.

c) $T= 2RC \ln\times[(R1+ 2R2) / (R2)]$.

d) $T= 2RC \ln\times[(R1+ R2) / (2 R2)]$.

Answer: b

Explanation: The time period of the output waveform for a square wave generator is $1/f = T= 2RC \ln\times[(2R1+ R2)/(R2)]$.

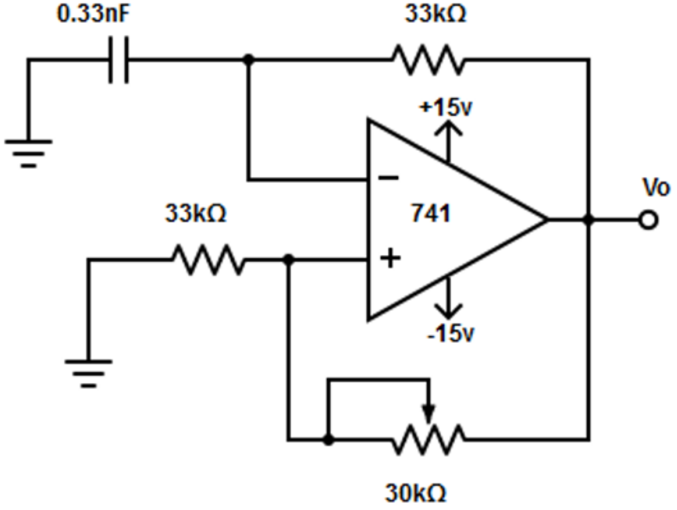
Determine the output frequency for the circuit given below

a) 28.77 Hz

b) 31.97 Hz

c) 35.52 Hz

d) 39.47 Hz



Answer: d

Explanation: The output frequency

$f_o = 1/2RC \times \ln [(2R_1 + R_2)/ R_2]$

$= 1 / \{(2\times 33k\Omega \times 0.33\mu F)\times \ln[(2\times 33k\Omega + 30k\Omega)/30k\Omega]\}$

$= 1/ (0.02175\times \ln 32) = 39.47$ Hz.