Jaipur Engineering College & Research Centre, Jaipur

Lecture Notes

3EE4-06: Analog Electronics

ACADEMIC SESSION 2020-21

Prepared By:
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VISION OF ELECTRICAL ENGINEERING DEPARTMENT

Electrical Engineering Department strives to be recognized globally for outcome based knowledge and to develop human potential to practice advance technology which contribute to society.

MISSION OF ELECTRICAL ENGINEERING DEPARTMENT

M1. To impart quality technical knowledge to the learners to make them globally competitive Electrical Engineers.

M2. To provide the learners ethical guidelines along with excellent academic environment for a long productive career.

M3. To promote industry-institute relationship.

PROGRAM OUTCOMES

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems in Electrical Engineering.
2. **Problem analysis:** Identify, formulate, research literature, and analyze complex engineering problems reaching substantial conclusions using first principles of mathematics, natural sciences, and engineering sciences in Electrical Engineering.
3. **Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations using Electrical Engineering.
4. **Conduct investigations of complex problems:** Use research based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of the information to provide valid conclusions using Electrical Engineering.
5. **Modern tool usage:** Create, select and apply appropriate techniques, resources, and modern engineering and EE tools including prediction and modeling to complex engineering activities with an understanding of the limitations in EE.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice using EE.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of EE and need for sustainable development in EE.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice using EE.
9. **Individual and team work:** Function effectively as an individual and as a member or leader in diverse teams, and multi-disciplinary settings in EE.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage EE projects and in multi-disciplinary environments.
12. **Life-long learning:** Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological changes needed in EE.

COURSE OUTCOMES:

On successful completion of the course, the students will be able to: -

CO 1	Understand the characteristics of Diodes, concepts behind the Clippers, and Clampers. Design and analysis of various rectifier and amplifier circuits
CO 2	Analyze the characteristics of current flow in a bipolar junction transistor and MOSFET & different electronic devices such as Amplifiers
CO 3	Understand the dynamics of Linear & Non Linear Devices

Syllabus

RAJASTHAN TECHNICAL UNIVERSITY, KOTA

SYLLABUS

2nd Year - III Semester: B.Tech. (Electrical Engineering)

3EE4-06: Analog Electronics

Credit: 3 | **Max. Marks: 150 (IA:30, ETE:120)**
3L+0T+0P | **End Term Exam: 3 Hours**

SN		Hours
1.	**Diode circuits** P-N junction diode, I-V characteristics of a diode; review of half-wave and full-wave rectifiers, Zener diodes, clamping and clipping circuits.	4
2.	**BJT circuits** Structure and I-V characteristics of a BJT; BJT as a switch. BJT as an amplifier: small-signal model, biasing circuits, current mirror; common-emitter, common-base and common collector amplifiers; Small signal equivalent circuits, high-frequency equivalent circuits.	8
3.	**MOSFET circuits** MOSFET structure and I-V characteristics. MOSFET as a switch. MOSFET as an amplifier: small-signal model and biasing circuits, common-source, common-gate and common-drain amplifiers; small signal equivalent circuits - gain, input and output impedances, transconductance, high frequency equivalent circuit.	8
4.	**Differential, multi-stage and operational amplifiers** Differential amplifier; power amplifier; direct coupled multi-stage amplifier; internal structure of an operational amplifier, ideal op-amp, non-idealities in an op-amp (Output offset voltage, input bias current, input offset current, slew rate, gain bandwidth product)	8
5.	**Linear applications of op-amp** Idealized analysis of op-amp circuits. Inverting and non-inverting amplifier, differential amplifier, instrumentation amplifier, integrator, active filter, P, PI and PID controllers and lead/lag compensator using an op-amp, voltage regulator, oscillators (Wein bridge and phase shift). Analog to Digital Conversion.	8
6.	**Nonlinear applications of op-amp** Hysteretic Comparator, Zero Crossing Detector, Square-wave and triangular-wave generators, Precision rectifier, peak detector. Monoshot	6
	TOTAL	**42**

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Unit: 5

Chapter: Linear applications of op-amp

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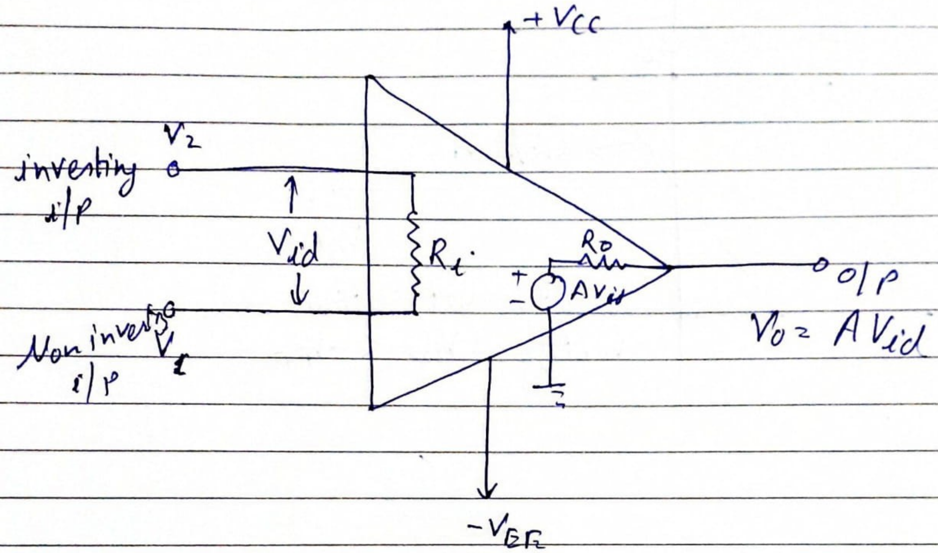
OP-Amp

Equivalent Circuit of an OP-Amp.



Where AV_{id} = equivalent Thevenin voltage source.
R_o = Thevenin equivalent resistance.

For the above circuit

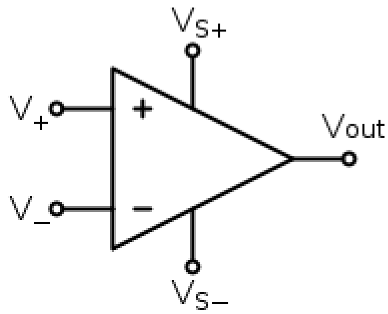
$$V_o = AV_{id} = A(V_1 - V_2)$$

where A = large signal voltage gain
V_{id} = diff. i/p voltage.

V_1 = Voltage at non inverting i/p terminal w.r.t to ground.

V_2 = Voltage at inverting i/p terminal w.r.t to ground.

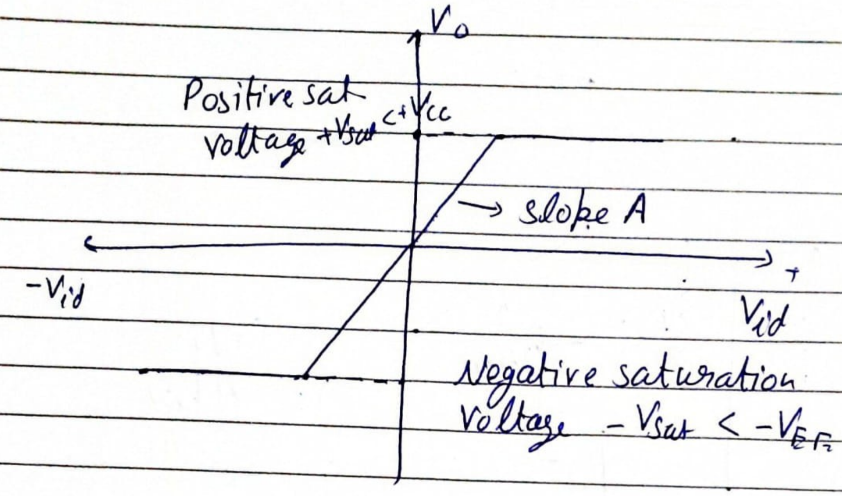
Ideal Op-Amp: Representation



Symbol Description:

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

Ideal voltage transfer curve :-



Open Loop OP-Amp Configuration :-

Term open loop means no connection, either direct or through another network, existing between the o/p and i/p terminal.

This means that the o/p s/g is not fed back in any form as part of the i/p s/g. and the loop which was formed with feedback is now open.

We use op amp as high gain Amplifier when connected in open loop configuration.

Ideal Op-Amp: Properties:

These properties apply to ideal op-amps and can be used to analyze and design many circuits:

• **Infinite open loop gain :** Assume the op-amp has no positive or negative feedback. The open loop gain, denoted by A_{vol} ranges from 0 to infinity. In practical amplifiers this is not true.

• **Infinite input impedance :** The input impedance is given by Zin = Vin/Iin For ideal op-amps Zin is infinite. This means that Iin is 0 (No current flows into the inputs of the op-amp). Real amplifiers don't have infinite impedance.

• **Zero output impedance:** Ideal op-amp acts as perfect internal voltage source with no output impedance This means the internal resistance is in series with the load. This results in a decrease in the output voltage of the load. However, Real Op-Amps have an output impedance.

• **Zero noise contribution:** The same noise present at the input is present at the output. Real op-amps have noise contributions that differ at the input and the output.

• **Zero DC output offset:** Output offset: output voltage when both inputs are grounded. This offset has a value of 0 for the ideal op-amp. Real op-amps however don't have a zero offset.

• **Infinite bandwidth:** For ideal op-amps, the input signal can be amplified with even infinitely large frequencies. For real op-amps, there is a frequency limit for signal amplification.

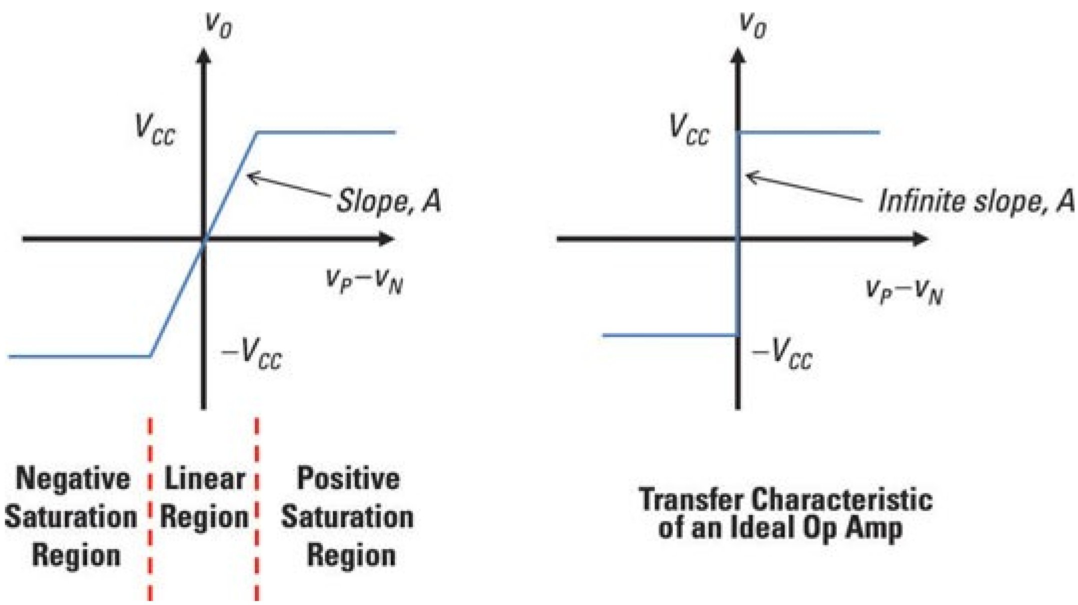
• **Same voltage is observed at both inputs:** The voltage on observed on the positive input is similar to the voltage observed on the negative input.. For the figure on the right, this means that: V+ = V- True only for ideal op-amps

Transfer characteristics:

The op amp amplifies the difference between the two inputs, v_P and v_N, by a gain A

$$v_O = A(v_P - v_N)$$

The voltage gain *A* for an op amp is very large — greater than 10^5. When the output voltage exceeds the supplied power, the op amp *saturates*. This means that the output is clipped or maxed out at the supplied voltages and can increase no further. When this happens, the op amp behavior is no longer linear but operates in the nonlinear region. The left diagram shows the transfer characteristic, whereas the right diagram shows the ideal transfer characteristic of an op amp with an infinite gain. The graph shows three modes of operation for the op amp.



Common Op-Amp Circuits:

Most commonly used Op-Amp Circuit are:

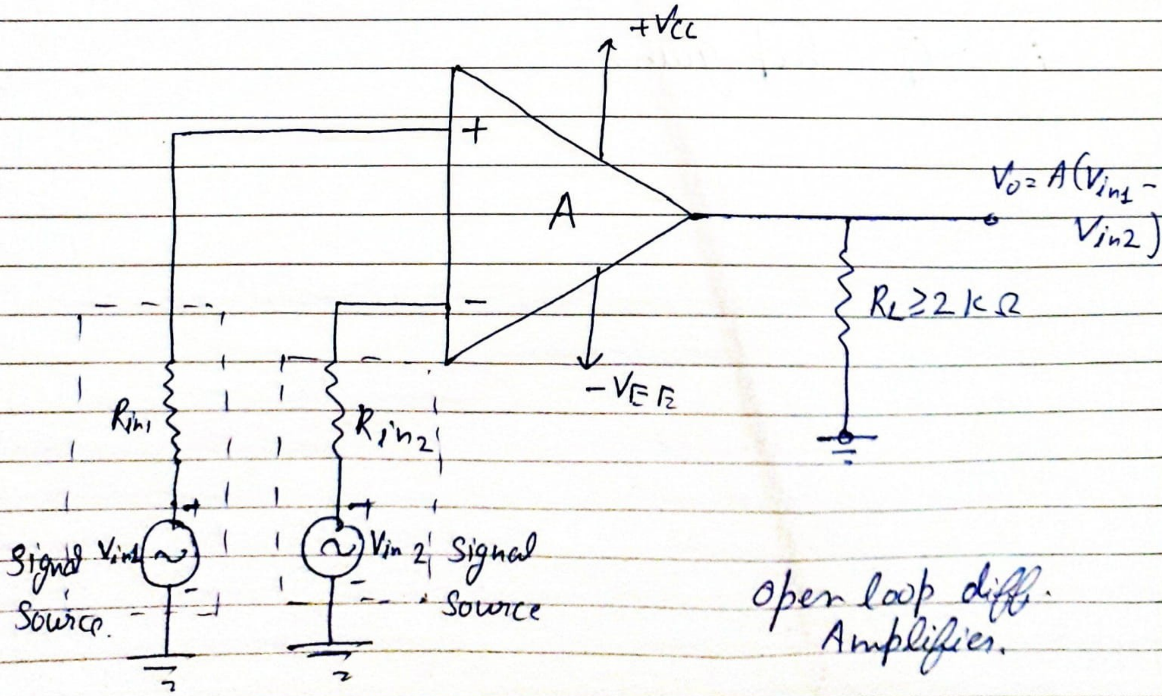
- Inverting Amplifier
- Non-Inverting Amplifier
- Comparator
- Differentiator
- Summing Amplifier
- Voltage Follower (buffer)

3 open loop op-amp configurations are :-

1. Differential Amplifiers
2. Inverting Amplifiers
3. Non inverting Amplifiers.

The above 3 configurations are classed according to the number of i/p used and the terminal to which the i/p is applied when a single i/p is used.

1. Differential Amplifiers :-



Open loop diff. Amplifier.

Let V_{in1} and V_{in2} are the i/p s/g which are applied to the +ve and -ve terminals.

From the figure we can see, that the op amp amplifies the difference obtained between the two i/p s/g, this configuration is called differential amplifier.

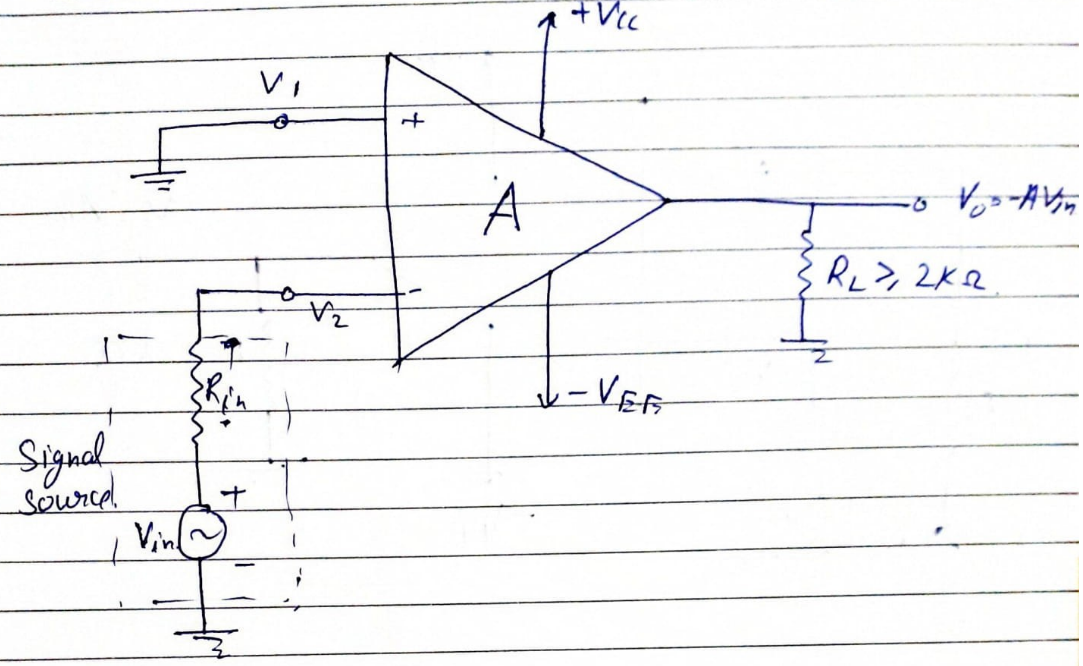
* Op-amp amplifies both ac and dc i/p s/g. ie V_{in1} & V_{in2} can be either ac or dc voltage.

Source resistance R_{in1} & R_{in2} are negligible compared to i/p resistance R_i hence the drop assumed is zero.

$$\therefore V_O = A(V_{in1} - V_{in2})$$

A → Open loop gain.

Inverting Amplifier



Only one i/p is applied and that is to the inverting i/p terminal. The non inverting i/p terminal is grounded.

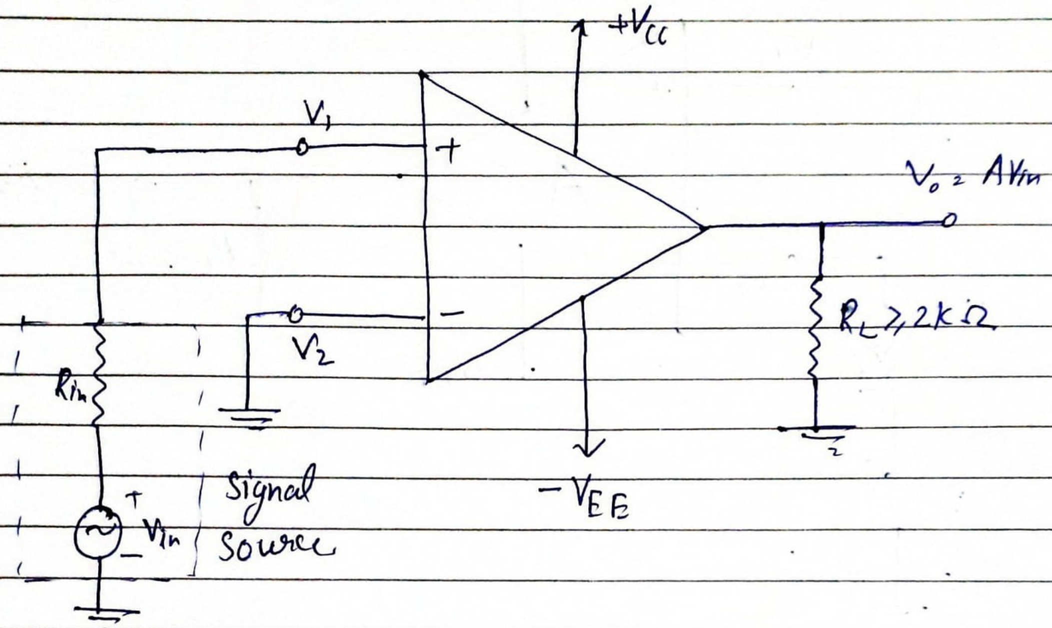
Since $V_1 = 0V$ & $V_2 = V_{in}$.

$$V_0 = -AV_{in}.$$

-ve sign indicates that the o/p voltage is out of phase w.r.t to i/p by 180° or is of opposite polarity.

Thus ~~at~~ in the inverting amplifier the i/p s/g is amplified by gain A and is also inverted at the o/p.

Non Inverting Amplifier :-



i/p is applied to the noninverting i/p terminal, and inverting terminal is connected to ground.

$V_1 = V_{in}$ $V_2 = 0 V$.

$$V_0 = A V_{in}$$

o/p voltage is larger than the i/p voltage by gain A and is in phase with i/p s/g.

PAGE NO.
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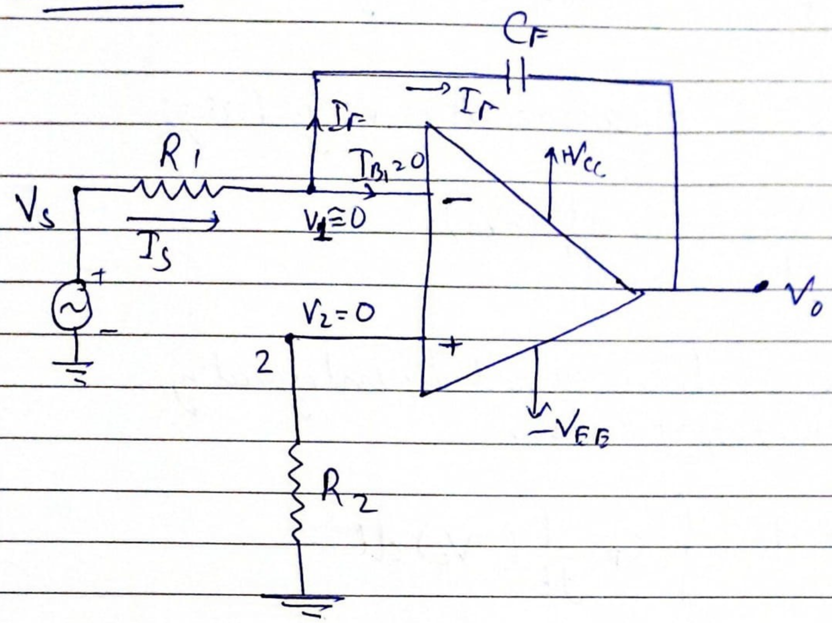
Integrator:- / Square Wave to Triangular Wave generator



A circuit in which the o/p voltage waveform is the integral of the i/p voltage waveform

C_F is the capacitor connected in the feedback path.

$$I_S = I_F + I_{B_1}$$

Since I_B is negligibly small ($I_{B_1} = 0$)

$$\therefore I_S \cong I_F$$

Let us now consider the relation between current through and voltage across the capacitor.

$$i_c = C\frac{dV_c}{dt}$$

PAGE NO.:
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$$\therefore \frac{V_S - V_1}{R_1} = C_F \frac{d}{dt}\left(V_1 - V_0\right)$$

$\because$ $V_1 = V_2 \approx 0$ because A is very large

$$\therefore \frac{V_S}{R_1} = C_F \frac{d}{dt}(-V_0)$$

The o/p voltage can be obtained by integrating both side w.r.t respect to time.

$$\int_0^t \frac{V_S}{R_1}\,dt = \int_0^t C_F \frac{d}{dt}(-V_0)\,dt$$

$$= C_F(-V_0) + V_0\big|_{t=0}$$

$$\therefore \boxed{V_0 = -\frac{1}{R_1 C_1}\int_0^t V_S\,dt + C}$$

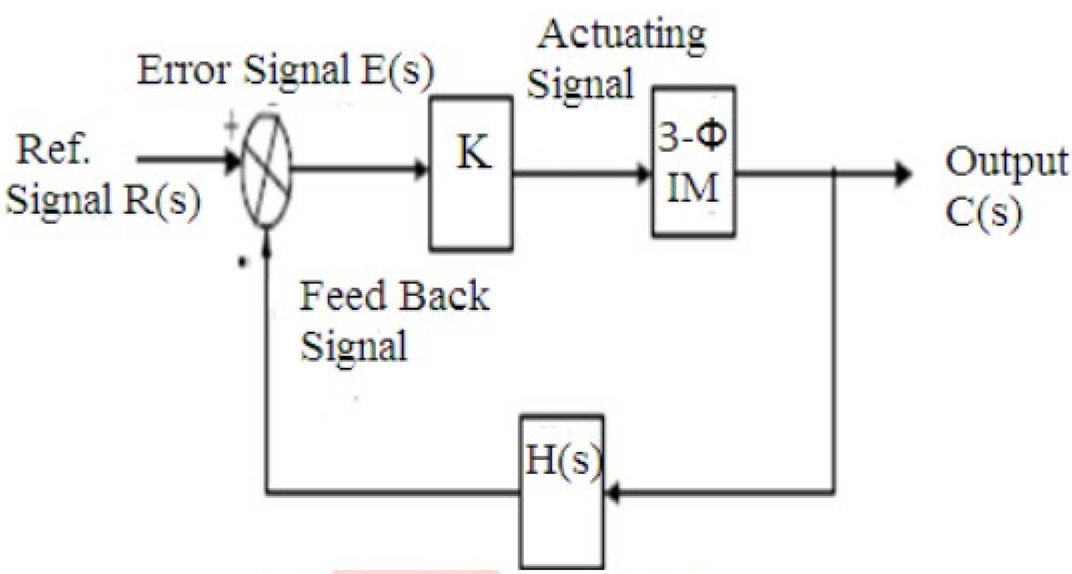
C → integration constant

$\therefore$ if i/p is a sine wave, o/p will be cosine wave
if i/p is square wave, o/p will be triangular wave

P, PI and PID controllers:

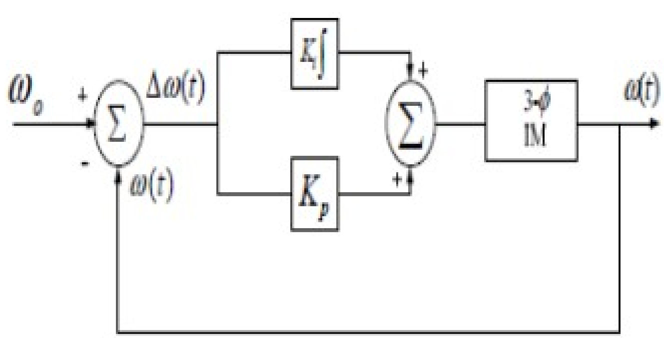
FUNDAMENTALS OF CONVENTIONALCOTROLLERS SUCH AS P, PI AND PID CONTROLLER PID controllers use a 3 basic behavior types of modes: P-proportional, I-integral and D- derivative. While Proportional and integrative modes are also used as single control modes a derivative mode is rarely used on it's own in control systems. Such combinations such as PI and PID controller are very often in practical systems (A) Proportional (P) Controller A P controller system is a type of linear feedback control system. The P controller system is more complex than on-off control systems like a bi-metallic domestic thermostat, but simpler than a PID control system used in something like an automobile cruise controlIn general it can be said that P controller cannot stabilize higher order processes. For the 1st order processes, meaning the p

Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics. A large controller gain will result in control system with: a) Smaller steady state error, i.e. better reference following b) Faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise c) Smaller amplitude and phase margin Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics. A large controller gain will result in control system with: a) Smaller steady state error, i.e. better reference following b) Faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise c) Smaller amplitude and phase margin



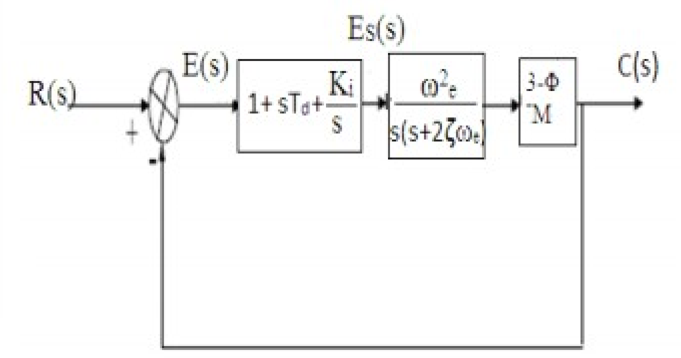
In the P controller algorithm, the controller output is proportional to the error signal, which is the difference between the set point and the process variable. In P controller the actuating signal for the control action in a control system is proportional to the error signal. The error signal being the difference between the reference input signal and feedback signal obtained from the output. For the system considered as shown in the Fig. 5. The actuating signal is proportional to the error signal therefore; the system is called P controller system. The error of signal given as follows: e(t) = k[r(t) - h(t)] It is desirable that the control system be under damped for the point of view of quick response. An under damped control system exhibits exponentially decaying in the output time response during the transient period.

(B) Proportional Integral (PI) Controller At present, the PI controller is most widely adopted in industrial application due to its simple structure, easy to design and low cost. Despite these advantages, the PI controller fails when the controlled object is highly nonlinear and uncertain. PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when 1. Fast response of the system is not required 2. Large disturbances and noise are present during operation of the process 3. There is only one energy storage in process (capacitive or inductive) 4. There are large transport delays in the system. Therefore, we would like to keep the advantages of the PI controller. This leads to propose a PI controller shown in Fig. 6. This controller uses of the proportional term while the integral term is kept, unchanged



The controller output in this case is $u(t) = K_p \cdot e(t) + K_i \int e(t)\,dt$ Fig. 6.block diagram PI controller an integral error compensation scheme, the output response depends in some manner upon the integral of the actuating signal. This type of compensation is introduced by a using a controller which produces an output signal consisting of two terms, one proportional to the actuating signal and the other proportional to its integral. Such a controller is called proportional plus integral controller or PI controller.

(c) Proportional Integral Derivative (PID) Controller. Many industrial controllers employ a proportional, integral plus differential PID regulator arrangement that can be tailored to optimize a particular control system. PID controller is most commonly used algorithm for controller design and it is most widely used controller in industry. The controllers used in industry are either PID controller or its improved version. The basic types of PID controller are parallel controller, serial controller, and mixed controller. The PID controller algorithm utilized for is design velocity algorithm, it is also called incremental algorithm. In the industry, PID controllers are the most common control methodology to use in real applications. PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response.PID controllers are the most often used controllers in the process industry. The majority of control systems in the world are operated PID controllers. It has been reported that 98% of the control loops in the pulp and paper industries are controlled by single-input single output PI controllers and that in process control applications, more than 95% of the controllers are of the PID type controller. PID controller combines the advantage of proportional, derivative and integral control action.



Introduction to Oscillators:

- **"An oscillator is just an electronic circuit which converts dc energy into ac energy of required frequency".**

Or

- **"An oscillator is an electronic circuit which produces an ac output without any input".**

An oscillator is a circuit which produces a continuous, repeated, alternating waveform without any input. Oscillators basically convert unidirectional current flow from a DC source into an alternating waveform which is of the desired frequency, as decided by its circuit components. An amplifier with positive feedback acts as an oscillator

Positive Feedback:

An oscillator always employs a sensitive amplifier whose output is fed back to the input in phase. Thus, the signal regenerates and sustains itself. This is known as positive feedback

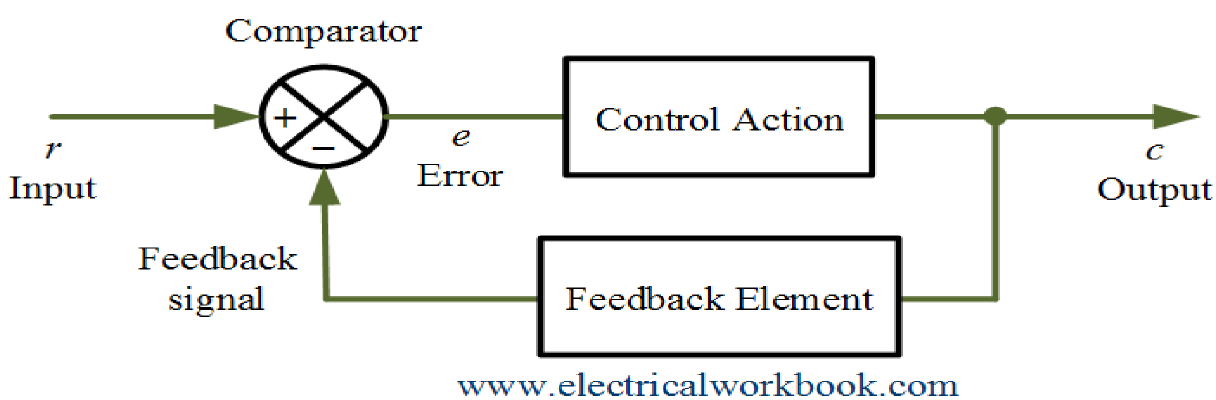


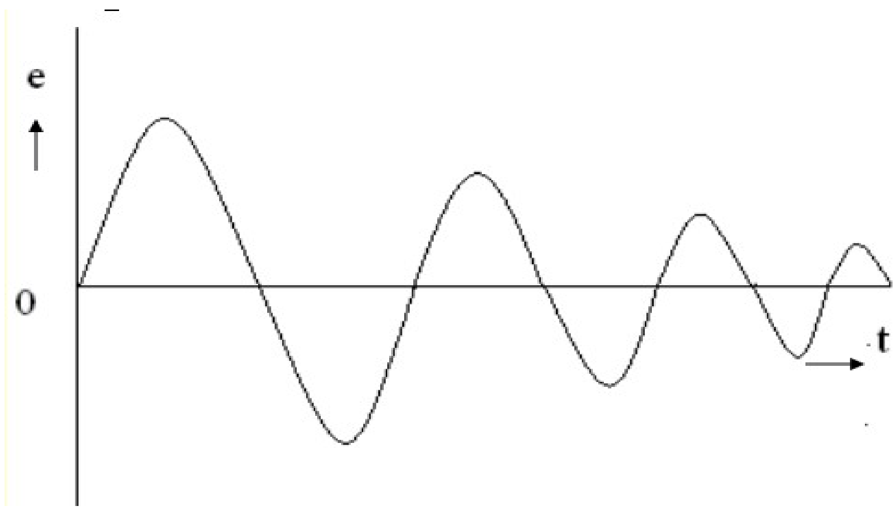
Figure 1 Closed loop control system.

Principle for Oscillations:

Sinusoidal electrical oscillations are of two types:

- Damped oscillations

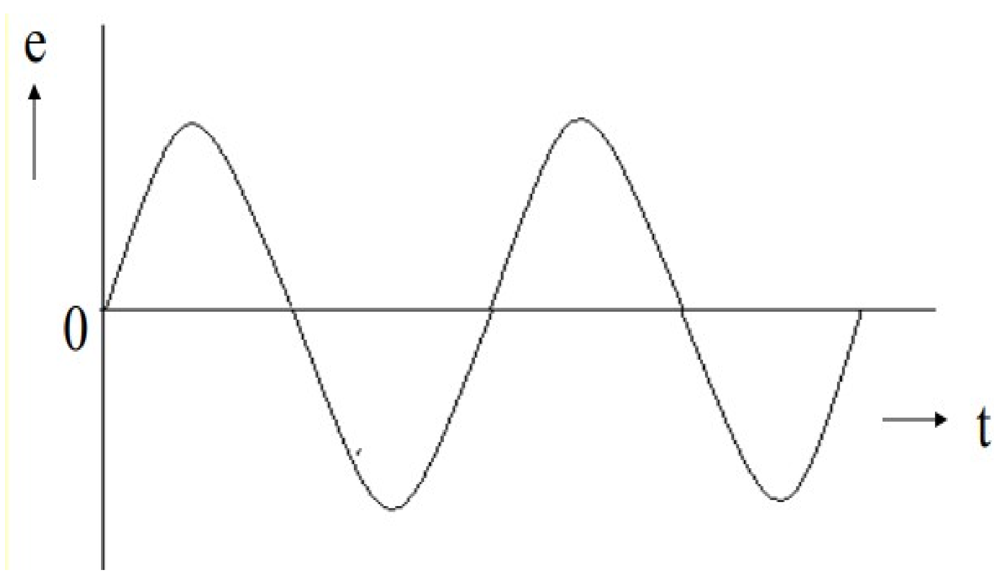
- Un-damped oscillations
- Damped oscillations : The electrical Oscillations in which amplitude decreases with time are known as damped oscillations.



It can be observed that the amplitude of oscillations decrease with time, though the frequency remains same. It is due to the loss of energy in the system producing oscillations.

Un-damped oscillations:

The electrical oscillations in which amplitude does not change with time are known as un-damped oscillations

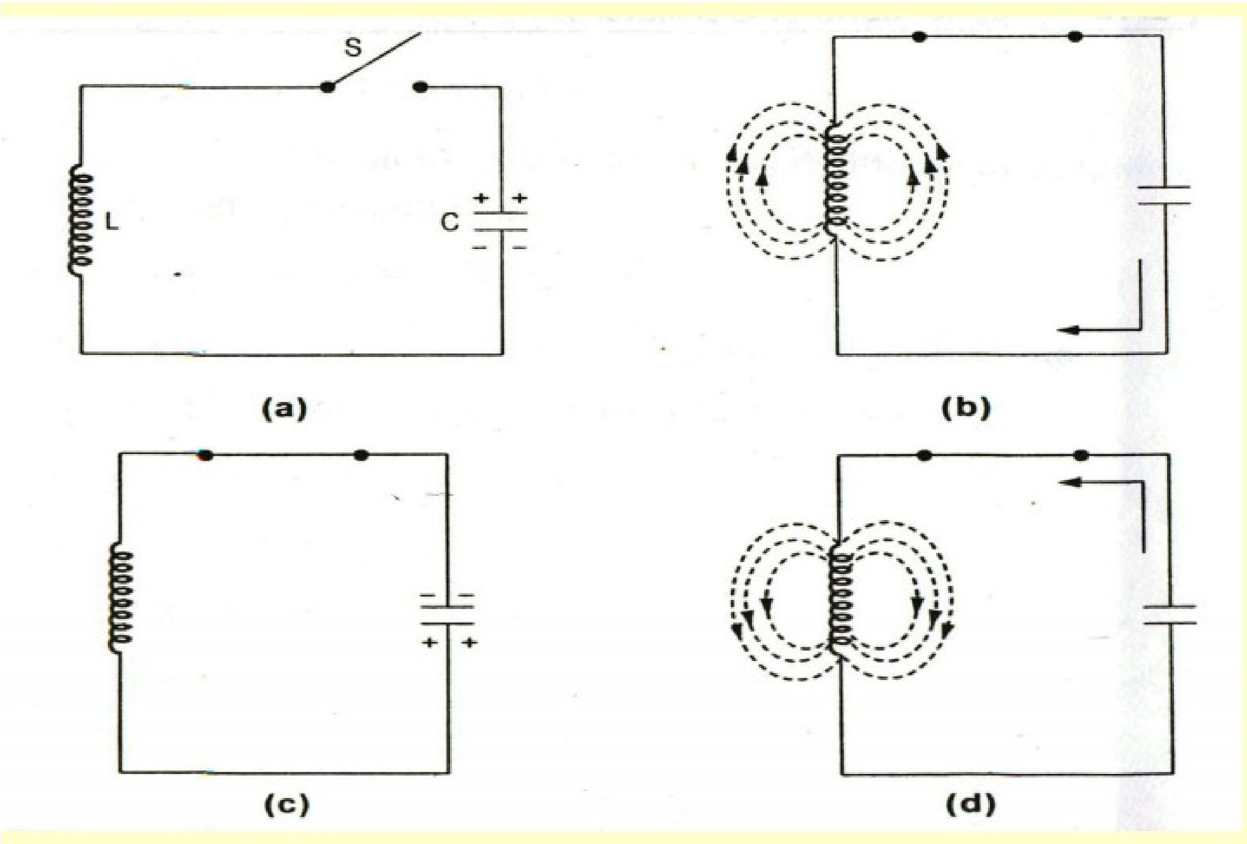


Here the amplitude of oscillations are constant with time and there is no change in frequency. These are the oscillations which are used in various electronic equipment. These un damped oscillations are produced by providing an energy compensation circuit

Tank Circuit:

The circuit that produces these oscillations is known as TANK CIRCUIT. The frequency of oscillations depend upon the parameters used in this tank circuit i.e., L & C. The frequency of oscillations is given by the following formula

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$



Definition of a tank circuit:

"A circuit that produces electrical oscillations of desired frequency is known as an oscillatory circuit or tank circuit."

The circuit arrangement to charge the capacitor of an oscillatory circuit is shown in above diagram. When switch ‘S’ is closed, the capacitor ‘C’ is charged to the external battery potential in the direction shown. The capacitor discharges through the inductor ‘L’ thereby producing a magnetic field around the coil.

Basic types of oscillators:

Based on the waveform produced at the output:

- Sinusoidal oscillators.
- Non sinusoidal oscillators
- Sweep circuits
- Relaxation oscillators.

Classification of oscillators:

- Based on the frequency generated

Oscillator type	Frequency range
AF Oscillators	Few Hz - 20 kHz.
RF Oscillators	20 kHz – 30 MHz.
VHF Oscillators	30 MHz – 300 MHz.
UHF Oscillators	300 MHz – 3 GHz.
Microwave Oscillators	Above 3 GHz.

- Based on the Auxiliary Oscillatory circuit used :

a) Non-Resonant Oscillators

• RC oscillators e.g. Phase-shift and Wein-bridge oscillators

b) Resonant Oscillators

• LC Oscillators e.g. Tuned collector, Hartley & Colpitts oscillators, crystal Oscillator.

RC OSCILLATORS

RC oscillators are a type of feedback oscillator; they consist of an amplifying device, a transistor, vacuum tube, or op-amp, with some of its output energy fed back into its input through a network of resistors and capacitors, an RC network, to achieve positive feedback, causing it to generate an oscillating sinusoidal voltage.[1][2][3] They are used to produce lower frequencies, mostly audio frequencies, in such applications as audio signal generators and electronic musical instruments.[4][5] At radio frequencies, another type of feedback oscillator, the LC oscillator is used, but at frequencies below 100 kHz the size of the inductors and capacitors needed for the LC oscillator become cumbersome, and RC oscillators are used instead.[6] Their lack of bulky inductors also makes them easier to integrate into microelectronic devices. Since the oscillator's frequency is determined by the value of resistors and capacitors, which vary with temperature, RC oscillators do not have as good frequency stability as crystal oscillators.

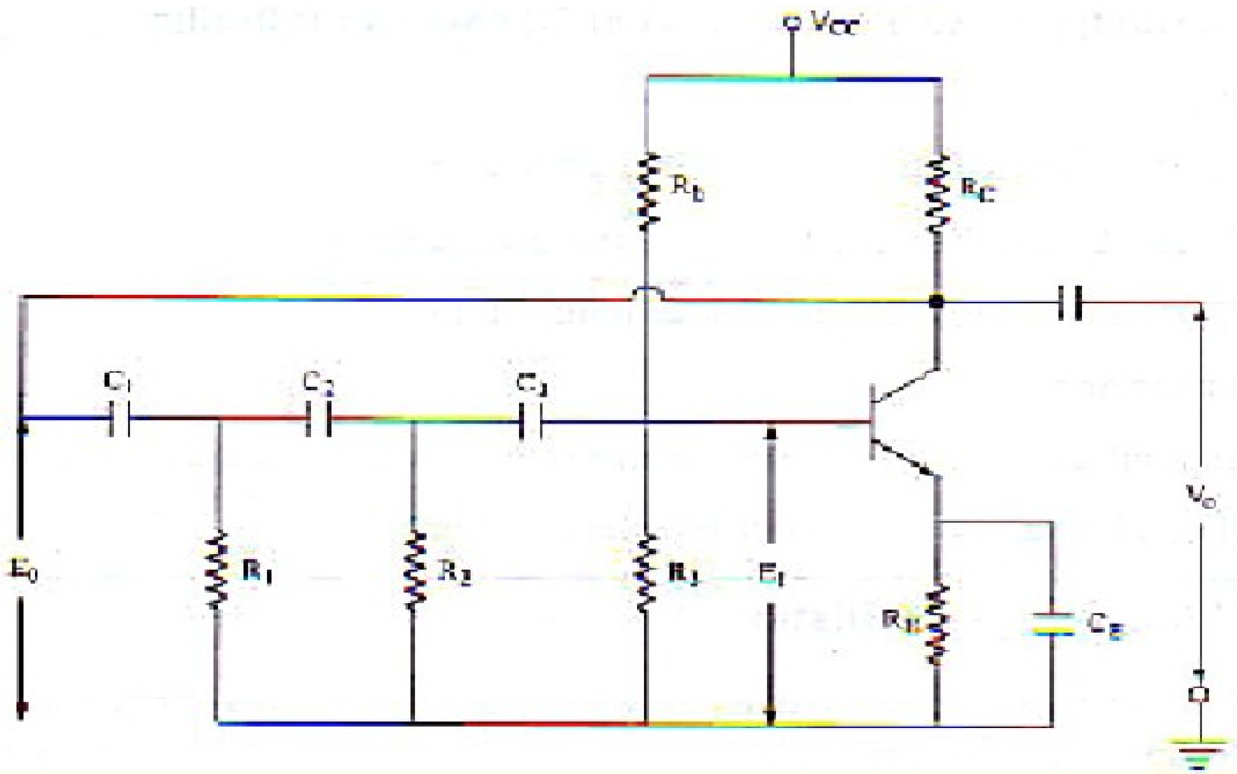
The frequency of oscillation is determined by the Barkhausen criterion, which says that the circuit will only oscillate at frequencies for which the phase shift around the feedback loop is equal to 360° (2π radians) or a multiple of 360°, and the loop gain (the amplification around the feedback loop) is equal to one.[7][1] The purpose of the feedback RC network is to provide the correct phase shift at the desired oscillating frequency so the loop has 360° phase shift, so the sine wave, after passing through the loop will be in phase with the sine wave at the beginning and reinforce it, resulting in positive feedback.[6] The amplifier provides gain to compensate for the energy lost as the signal passes through the feedback network, to create sustained oscillations. As long as the gain of the amplifier is high enough that the total gain around the loop is unity or higher, the circuit will generally oscillate.

In RC oscillator circuits which use a single inverting amplifying device, such as a transistor, tube, or an op amp with the feedback applied to the inverting input, the amplifier provides 180° of the phase shift, so the RC network must provide the other 180°.[6] Since each capacitor can provide a maximum of 90° of phase shift, RC oscillators require at least two frequency-determining capacitors in the circuit (two poles), and most have three or more,[1] with a comparable number of resistors.

In the phase-shift oscillator the feedback network is three identical cascaded RC sections.[10] In the simplest design the capacitors and resistors in each section have the same value and

. Then at the oscillation frequency each RC section contributes 60° phase shift for a total of 180°. The oscillation frequency is

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



Wein bridge oscillator:

The **Wien Bridge Oscillator** is so called because the circuit is based on a frequency-selective form of the Wheatstone bridge circuit. The Wien Bridge oscillator is a two-stage RC coupled amplifier circuit that has good stability at its resonant frequency, low distortion and is very easy to tune making it a popular circuit as an audio frequency oscillator but the phase shift of the output signal is considerably different from the previous phase shift **RC Oscillator**.

The **Wien Bridge Oscillator** uses a feedback circuit consisting of a series RC circuit connected with a parallel RC of the same component values producing a phase delay or phase advance circuit depending upon the frequency. At the resonant frequency fr the phase shift is 0°. Consider the circuit below.

Wien Bridge Oscillator Frequency

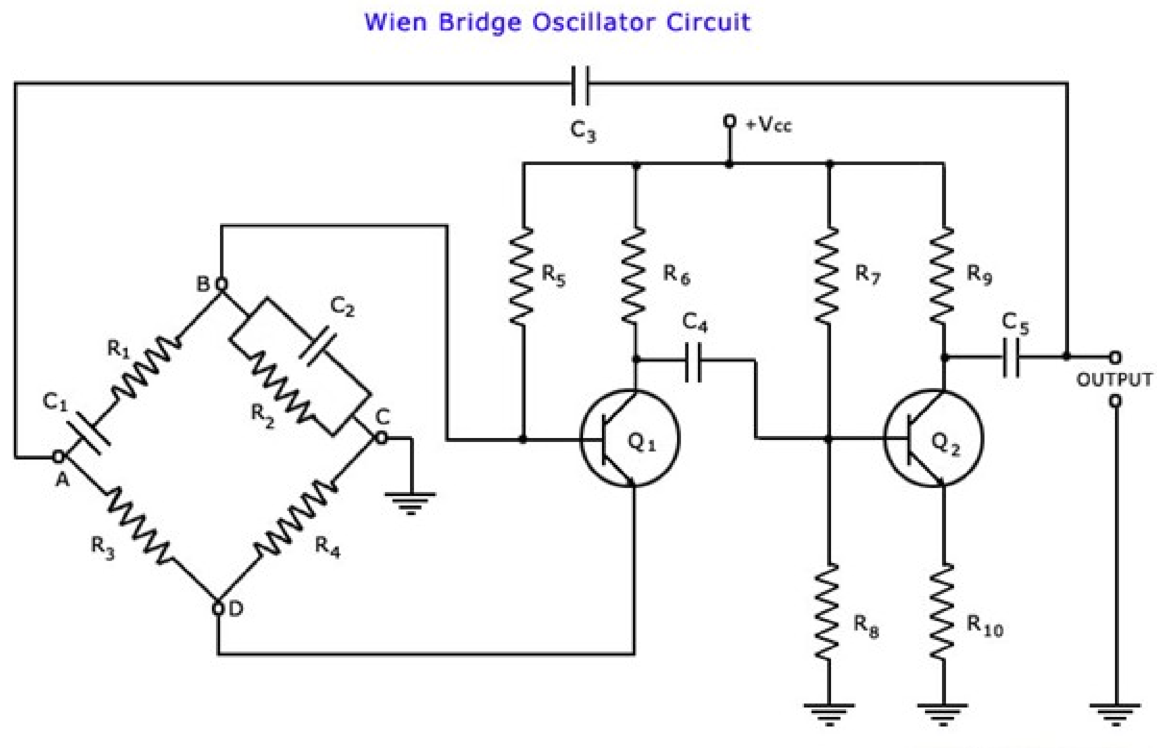
$$f_r = \frac{1}{2\pi RC}$$

Where:

- fr is the Resonant Frequency in Hertz
- R is the Resistance in Ohms
- C is the Capacitance in Farads

We said previously that the magnitude of the output voltage, Vout from the RC network is at its maximum value and equal to one third (1/3) of the input voltage, Vin to allow for oscillations to occur. But why one third and not some other value. In order to understand why the output from the RC circuit above needs to be one-third, that is 0.333xVin, we have to consider the complex impedance (Z = R ± jX) of the two connected RC circuits.

We know from our AC Theory tutorials that the real part of the complex impedance is the resistance, R while the imaginary part is the reactance, X. As we are dealing with capacitors here, the reactance part will be capacitive reactance, Xc.



Analogue to Digital Converter: