YBN University, Ranchi

Feedback amplifier.

Feedback is a process/technique where a portion of the output signal of a system is **fed back** and **recombined** with the input.

- Feedback is used in all amplifier circuits.
- Some circuits virtually acts as a feedback in electronic systems and also can be introduced externally for some amplifiers.
- Invented in the year 1928 by Harold black, engineer, Western electric company.

Figure (1) shows the canonical form representation of a feedback system, block A_{OL} is the amplifier with gain A or A_{OL} and block β is the feedback network with gain β.

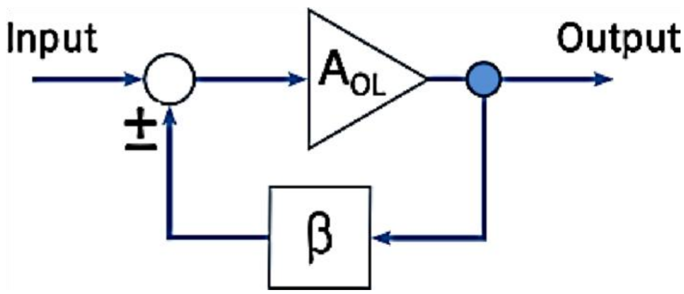


Figure 1: Canonical for representation of feedback system

Based on the way of combining the signals at input, feedback systems are classified into:

- Positive feedback
- Negative feedback

Positive Feedback:

- Positive feedback is a process of **adding** the portion of the output with the input and amplifying. This process is continuous and regenerative action takes place shown in figure (2).

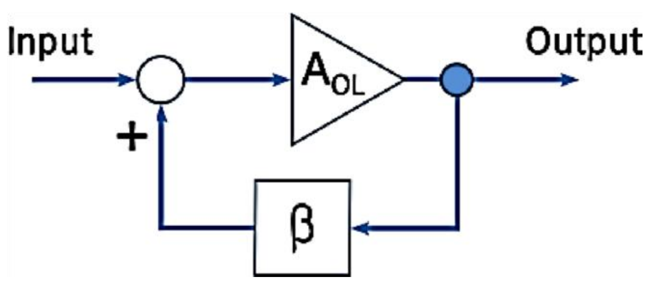


Figure 2: Canonical for representation of positive feedback system

Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as

- Increasing distortion
- Instability

NOTE: Positive feedback is mainly used in the design of oscillators.

Negative Feedback:

- Negative feedback is a process of **subtracting** the portion of the output with the input and amplifying. This process is continuous and degenerative action takes place shown in figure (3).

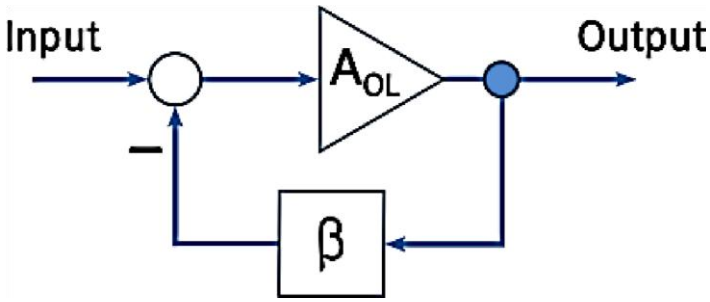


Figure 3: Canonical for representation of negative feedback system

NOTE: Negative feedback is used in the design of all types of amplifiers.

Advantages of Negative Feedback/Properties of negative feedback:

- Stabilizes the gain
- Increases the input impedance
- Decreases the output impedance
- Bandwidth increases
- Increases upper cut-off frequency
- Decreases the lower cut-off frequency
- Decreases the distortions
- Reduction in noise

Disadvantage:

- Decreases the gain

Basic structure of feedback amplifiers

Figure (4) shows the basic structure of a feedback system, which consisting of input unit, output unit, summing network, sampling network, basic amplifier and feedback network. The function each of these blocks are explained as follows.

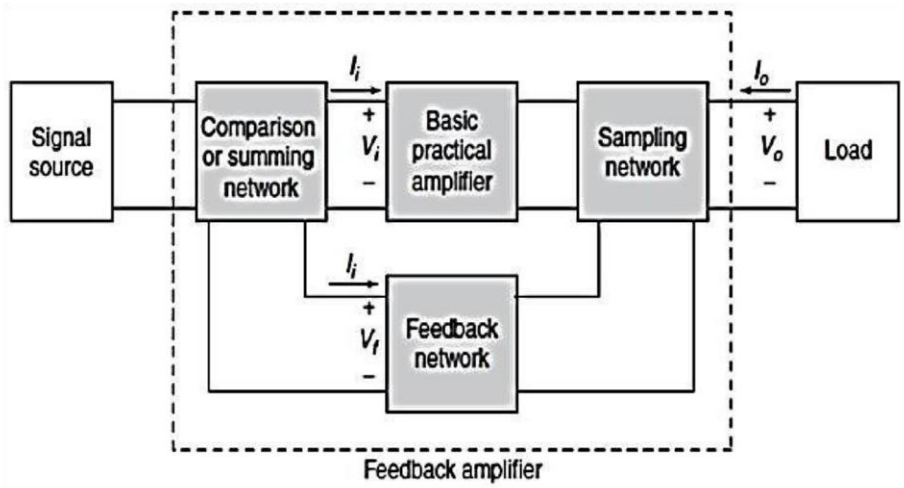
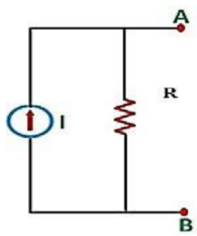


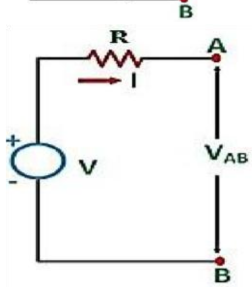
Figure 4: Basic block diagram of neagative feedback system

1. Input signal:

- It is a source wither modelled by a practical voltage source or practical current source.
- An ideal voltage source in series with a resistor is called practical voltage source
- An ideal current source in parallel with a resistor is called practical current source.

Practical voltage source   Practical Current source





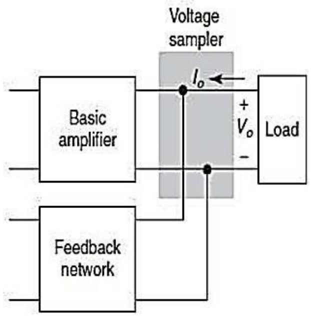
2. Output signal:

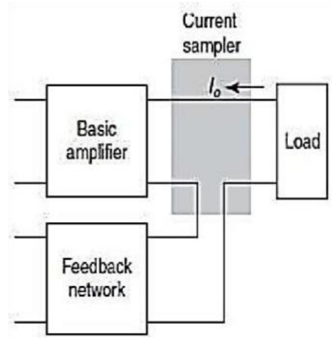
- The output of the system is either voltage across the load or current through the load.
- The output of the feedback amplifiers must be independent of the load variations and parameter variations in the amplifier.

3. Sampling Network :

- A network is used to mesure and sending the output signal to the feedback network is called sampling network.
- For measuring the voltage a parallel(shunt) connection is required
  - For measuring the current a series connection is required

Voltage measurement Current measuremen

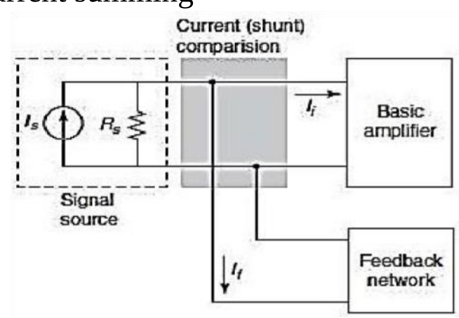


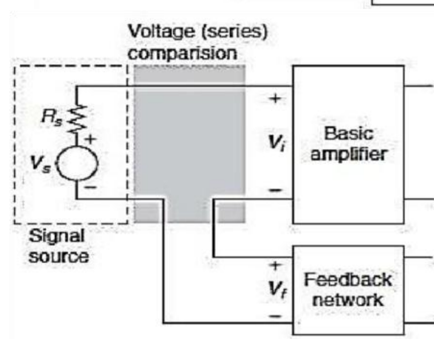


4. Comparison or summing network:

- Comparing the output signal with the input signal.
- Comparing voltage signals – series network
- Comparing the currents signals – parallel(Shunt) network

Voltage summing Current summing





5. Amplifier:

- Amplifies the compared or combined signal
- Electronic circuits

6. Feedback network:

- Combination of electronic/electrical/both elements
- Provides the feedback signal in proportional to the output signal.

Based on the type of summing network and sampling network, feedback systems are classified into four types, they are.

1. Voltage - Series negative feedback
2. Voltage - Shunt negative feedback

3. Current - Series negative feedback and
4. Current - Shunt negative feedback

1. Voltage Series negative feedback

Summing network is a series network and sampling network is a shunt network, output voltage is fed to the feedback network and feedback voltage and input voltage are combined at the summing netwrk. Actual inpt to the amplifier circuit is the difference of the feedback voltage and supply voltage. Figure (5) shows the block diagram of voltage series negative feedback system.

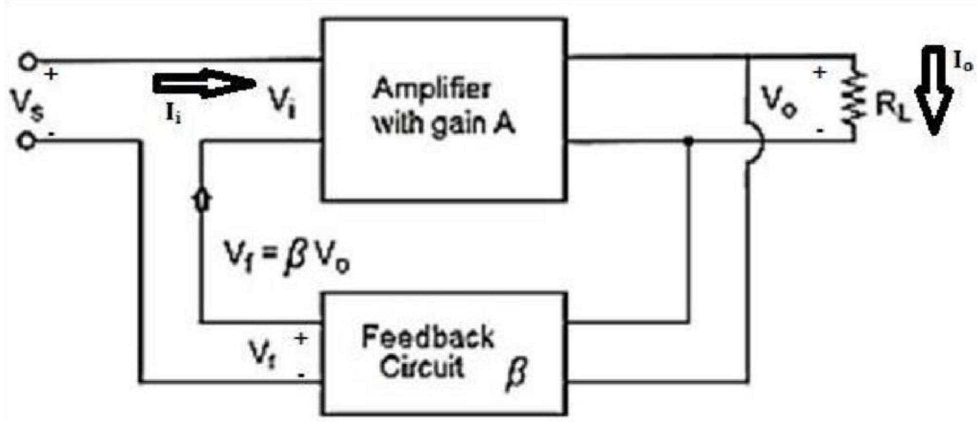


Figure 5: Block diagram of voltage series negative feedback system

Property-1: Reduces the overall gain and stabilizes the gain
Proof:

$$V_o = AV_i - - - (1)$$
$$V_i = V_s - V_f - - - (2)$$
$$V_f = \beta V_o - - - (3)$$
$$V_o = A[V_s - V_f]$$
$$V_o = A[V_s - \beta V_o]$$
$$V_o = A[V_s - \beta V_o]$$
$$V_o = AV_s - A\beta V_o$$
$$V_o[1 + A\beta] = AV_s$$
$$\frac{V_o}{V_s} = \frac{A}{1+A\beta} - - - (4)$$ **Closed loop gain**

Example:

P1: If gain of the amplifier is 10^5, what is the overall gain after introducing the feedback with feedback gain 0.01? Also compare the overall gain if the gain of the amplifier is changed by ±50% **Given data:**

$$A = 10^5 \; and \pm 50\%$$
$$\beta = 0.01$$

To find:

$$A_{CL}\ for\ A\ and\ A \pm 50\%$$

Solution:

$$A_{CL1} = \frac{A}{1+A\beta} \Rightarrow \frac{10^5}{1+10^5 * 0.01} \Rightarrow 99.9$$

$$A_{CL2} = \frac{A+50\%}{1+A\beta} \Rightarrow \frac{150000}{1+150000 * 0.01} \Rightarrow 99.93$$

$$A_{CL3} = \frac{A-50\%}{1+A\beta} \Rightarrow \frac{50000}{1+50000 * 0.01} \Rightarrow 99.8$$

Property-2: Increases the input impedance

Proof:

$$Z_{in} = input\ impedance\ without\ feedback \Rightarrow \frac{V_i}{I_i}$$

$$Z_{if} = input\ impedance\ with\ feedback \Rightarrow \frac{V_s}{I_i}$$

$$Z_{if} = \frac{V_s}{I_i} \Rightarrow \frac{V_s}{V_i} * \frac{V_i}{I_i} \Rightarrow \frac{\boldsymbol{V_s}}{\boldsymbol{V_i}} * \boldsymbol{Z_{in}} - - - (\mathbf{1})$$

$$V_i = V_s - V_f$$

$$V_i = V_s - \beta V_o$$

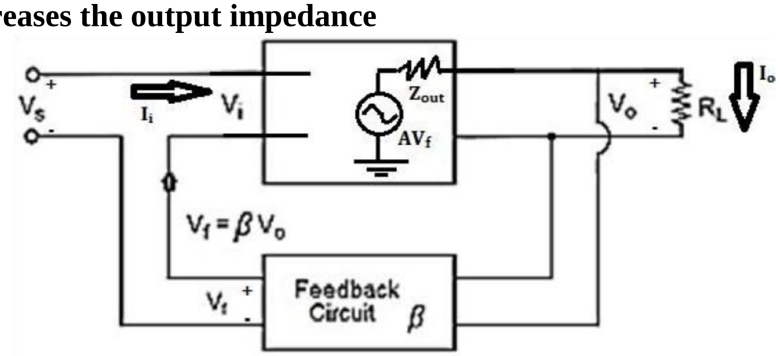
$$V_i = V_s - \beta A V_i$$

$$V_i[1 + A\beta] = Vs$$

$$\frac{V_s}{V_i} = 1 + A\beta - - - (2)$$

Substitute (2) in (1) we get $\boldsymbol{Z_{if} = (1 + A\beta) Z_{in} - - - (3)}$

Property-3: Decreases the output impedance



Proof:

$$Z_{out} = output\ impedance\ without\ feedback$$

$$Z_{of} = output\ impedance\ with\ feedback = \frac{V_o}{I_o}$$

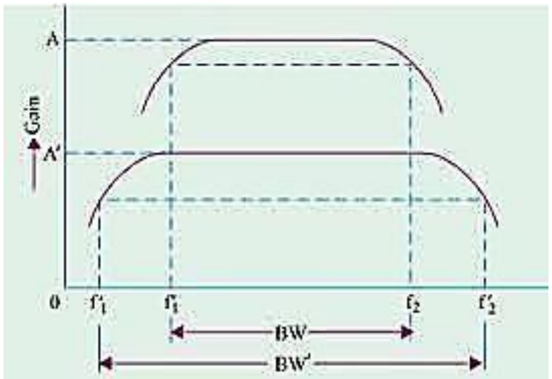
$$AV_f + V_o = I_o Z_{out}$$

$$A[\beta]V_o + V_o = Z_{out} I_o$$

$$V_o[1 + A\beta] = I_o Z_{out}$$

$$\boldsymbol{Z_{of}} = \frac{\boldsymbol{V_o}}{\boldsymbol{I_o}} \Rightarrow \frac{\boldsymbol{Z_{out}}}{[\boldsymbol{1} + \boldsymbol{A\beta}]} - - - (\boldsymbol{1})$$

Property-4: Bandwidth increases



$$\boldsymbol{BW = f2 - f1} - - - (\boldsymbol{1})$$

$$\boldsymbol{BW_f = BW}(\boldsymbol{1 + A\beta}) - - - (\boldsymbol{2})$$

$$\boldsymbol{f_{1f}} = \frac{\boldsymbol{f_1}}{(\boldsymbol{1 + A\beta})}$$

$$\boldsymbol{f_{2f} = f_2}(\boldsymbol{1 + A\beta})$$

Property-5: Reduction in distortion

$$\boldsymbol{Df} = \frac{\boldsymbol{D}}{(\boldsymbol{1 + A\beta})}$$

Property-6: Reduction in Noise

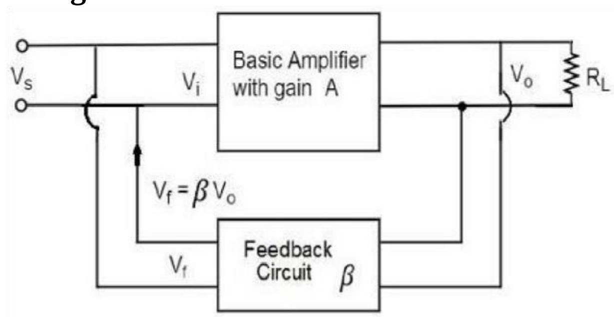
$$\boldsymbol{N_f} = \frac{\boldsymbol{N}}{(\boldsymbol{1 + A\beta})}$$

Summary:

Voltage Gain	Decreases and stabilizes
Bandwidth	Increases
Input resistance	Increases
Output resistance	Decreases
distortion	Decreases
Noise	Decreases

2. Voltage shunt negative feedback

Block diagram

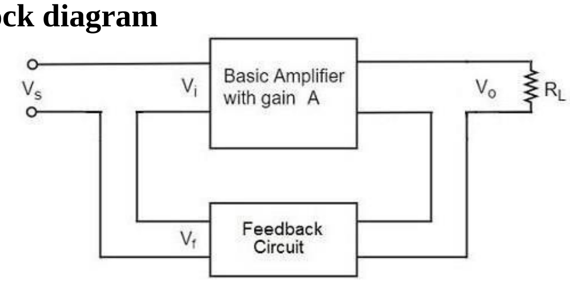


Properties

Voltage Gain	Decreases and stabilizes the gain
Bandwidth	Increases
Input resistance	Decreases
Output	Decreases
distortion	Decreases
Noise	Decreases

3. Current series negative feedback

Block diagram



Properties

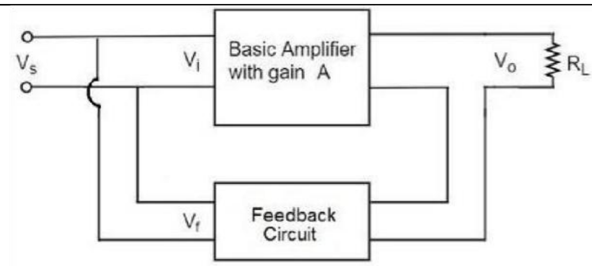
Voltage Gain	Decreases and stabilizes the gain
Bandwidth	Increases
Input resistance	Increases
Output	Increases
distortion	Decreases
Noise	Decreases

5. Current shunt negative feedback system

Block diagram

Properties

Voltage Gain	Decreases and stabilizes the gain
Bandwidth	Increases
Input resistance	Decreases
Output	Increases

	**distortion**	Decreases
	Noise	Decreases

By comparing the properties of all the four topologies of negative feedback systems, voltage series negative feedback has more advantages, and hence, voltage series negative feedback will be used for the design of amplifiers.

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Basic Electronics Notes

Subject Code: **18EC14/24**

UNIT-II

Chapter-3: Oscillators.

An Oscillator is an electronic circuit consisting of an amplifier with positive feedback, which generates the desired frequency of time-varying signals without an ac signal.

- Accepts DC and generates AC signals.

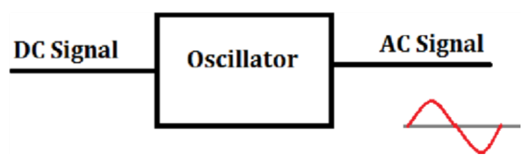


Figure 1: General operation of the oscillator

- Oscillators can generate the AC signal of frequency from few Hz to hundreds of GHz.
- An oscillator is an amplifier with positive feedback

Positive feedback and its closed-loop gain

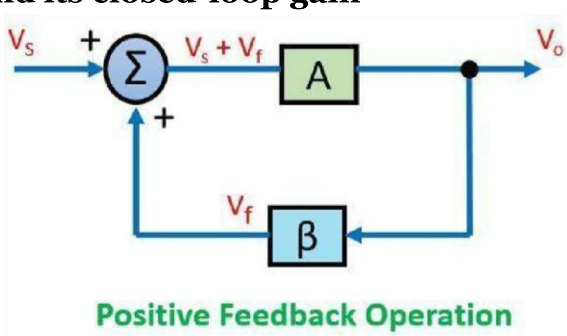


Figure 2: Canonical form representation of positive feedback system

Derivation of Closed Loop gain of the positive feedback system

$$V_o = A(V_i)$$
$$V_o = A(V_s + V_f)$$
$$V_o = A(V_s + \beta V_o$$
$$V_o = AV_s + A\beta V_o$$
$$\frac{\boldsymbol{V_o}}{\boldsymbol{V_s}} = \frac{\boldsymbol{A}}{\boldsymbol{1 - A\beta}}$$

NOTE: The feedback signal is in phase with the input and hence, the feedback signal gets added with the input – **positive feedback**.

Effect of loop gain $\boldsymbol{A\beta}$ in the positive feedback system

Case (i): $\boldsymbol{A\beta > 1}$

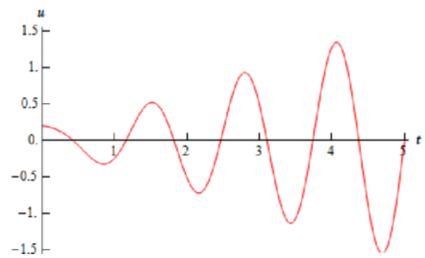


Figure 3: Output waveform of a positive feedback system, if Aβ > 1.

Case (ii): $\boldsymbol{A\beta < 1}$

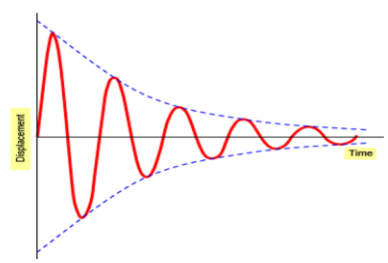


Figure 4: Output waveform a positive feedback system, if Aβ < 1.

Case (iii): $\boldsymbol{A\beta = 1}$

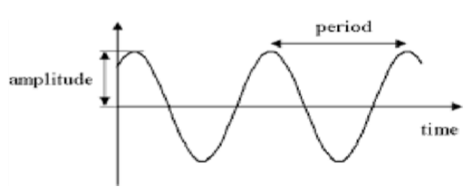


Figure 4: Output waveform a positive feedback system, if Aβ = 1.

Barkhausen's Criterion

Conditions to be satisfied for generation of sinusoidal Oscillations

Condition-1: The loop gain or Product of amplifier gain and feedback gain must be equal to one.

i.e., |Aβ|=1

Condition-2: Overall phase shift must be zero degree or 360 degrees i.e., $\angle A\beta = 0^{o}$ or 360^{o}

Classification

Based on the output waveform
1. Sinusoidal
2. Non-sinusoidal

Based on the feedback circuit
1. RC Oscillators
2. LC Oscillators
3. Crystal Oscillators

Based on frequency
1. Audio frequency(20Hz to 20KHz)
2. Radiofrequency(20KHz-30MHz)
3. Very high frequency(30MHz to 300MHz)
4. UHF Oscillators (300MHz to 3GHz)
5. Microwave Frequency Oscillators(3GHz to 30GHz)
6. Millimeter-wave frequency oscillators (30GHz to 300GHz)

Based on electronic device/amplifier
1. BJT Oscillators
2. FET Oscillators
3. UJT Oscillators
4. Op-Amp Oscillators

1. RC phase shift oscillator

An oscillator is an amplifier with positive feedback.
 Amplifier circuit-CE configured BJT
 Feedback circuit – multiple stages of RC networks. Audio frequency oscillators – hundreds of KHz.

Circuit diagram

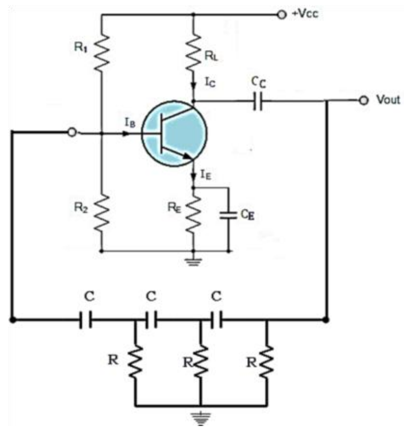


Figure 5: Circuit diagram of RC phase shift oscillator

Figure (5) shows the circuit diagram of the RC phase shift oscillator. BJT CE configuration is biased with voltage divider biasing technique using the resistors R_1 and R_2. R_C and R_E are collector and emitter resistors. C_C is a coupling capacitor that isolates the DC biasing settings and C_E is the bypass capacitor to avoid decreasing the output voltage by acting low resistance path across R_E under ac signal.

Further, three stages of the RC network are connected between the output terminal to the input terminal as a feedback circuit and this feedback circuit acts as a frequency selective network. Three stages of RC networks provide a constant attenuation factor of 1/29 (β) and an amplifier circuit should be designed to provide an amplification factor of 29(A), which satisfies the first condition of Barkhausen's criterion. Also, each RC stage is designed to provide a 60^o phase shift, so three stages of the RC network provide a 180^o phase shift and the BJT amplifier produces a 180^o phase shift. Hence, the total phase shift around a loop is 360^o or 0^o, which is the second condition of Barkhausen's criterion. Equation (1) is the expression of frequency of generated sinusoidal oscillations and figure (6) shows the waveform of generated oscillations.

The frequency of the generated sinusoidal signal is given by

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

Output waveform

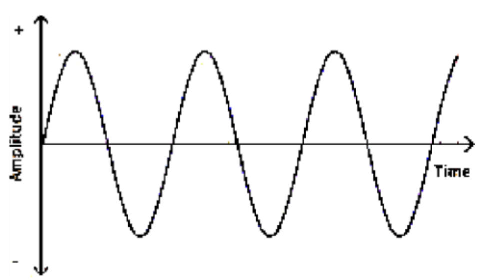


Figure 6: Output waveform of RC phase shift oscillator

LC oscillator basics.

- An oscillator is an amplifier with positive feedback.
- Amplifier circuit - CE configured BJT
- Feedback circuit – LC circuit (Tank circuit/resonant circuit/tuned circuit).
- Produces oscillations of up to 300KHz (Radio frequency)

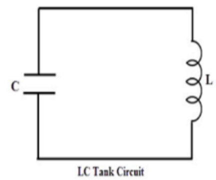
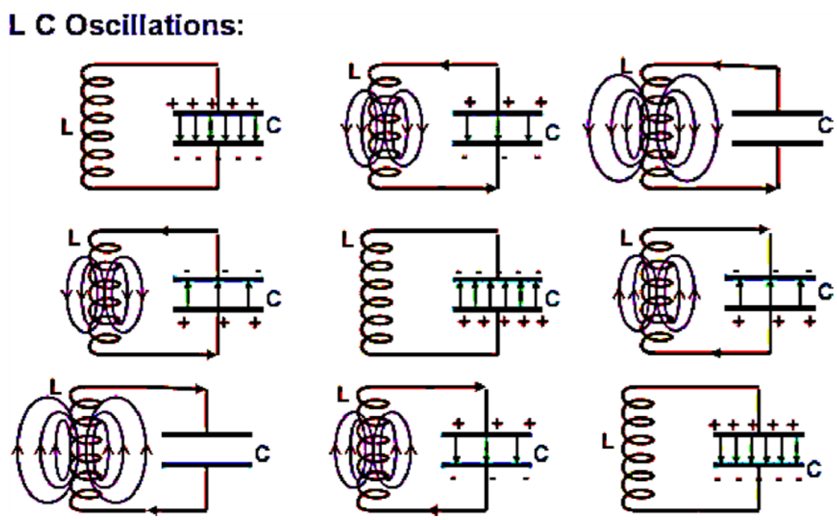


Figure 7: Tank circuit (LC circuit)

- The tank circuit is a Parallel connection of Capacitor and Inductor.
- Generates AC signal of frequency $f = \frac{1}{2\pi\sqrt{LC}}$
- Capacitor stores energy in the form of electrostatic field
- Inductor stores energy in the form of the electromagnetic field.
- Whenever a current flows through the inductor, a back e.m.f. will be established, which is the opposite polarity to the applied voltage.
- Energy stored across the elements is exchanged alternatively to produce an AC signal. The following section is explained the working of the LC circuit to generate an AC signal.



1. Initially capacitor is charged to maximum level with the polarity shown
2. Capacitor starts discharging through the inductor and inductor starts charging.
3. Capacitor discharged completely and inductor charged to the maximum level
4. L starts discharging and C starts charging, due to back emf across the inductor
5. L discharged completely and C charged to the maximum level
6. Capacitor starts discharging through the inductor and inductor starts charging.

7. This process continuously takes place

There are two types of LC oscillators, they are Colpitts and Hartley oscillators. These two oscillators are discussed as follows.

2. Colpitts Oscillator

The Colpitts oscillator is an electronic circuit, which consisting of an amplifier circuit and an LC circuit as a feedback circuit shown in figure (8). **Circuit diagram**

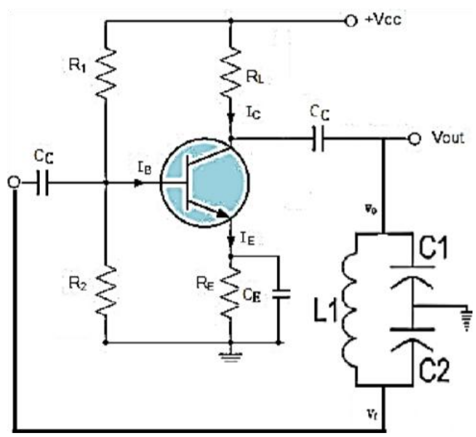


Figure 8: Circuit diagram of the Colpitts oscillator

Figure (8) shows the circuit diagram of the Colpitts oscillator. BJT CE configuration is biased with voltage divider biasing technique using the resistors R_1 and R_2. R_C and R_E are collector and emitter resistors. C_C is a coupling capacitor that isolates the DC biasing settings and C_E is the bypass capacitor to avoid decreasing the output voltage by acting low resistance path across R_E under ac signal. The feedback circuit is a series combination of two capacitors (C1, C2) across an inductor (L).

The amplifier gain is A and the feedback circuit gain β is $\frac{C1}{C2}$ by properly designing the circuits, Barkhausen's criterion condition number one can be achieved. i.e., $A\beta = 1$

The amplifier produces 180^o phase shift and the series connection of two capacitors provides phase inversion or 180^o phase shift, hence satisfies Barkhausen's criterion condition number two. i.e., $\angle A\beta = 0^o \; or \; 360^o$

Equation (1) is the expression of frequency of generated sinusoidal oscillations and figure (9) shows the waveform of generated oscillations.

The frequency of the generated sinusoidal signal is given by

$$\mathbf{f = \frac{1}{2\pi\sqrt{LC_{eq}}} - - - (1), where, C_{eq} = \frac{C_1 C_2}{C_1 + C_2}}$$

Output waveform

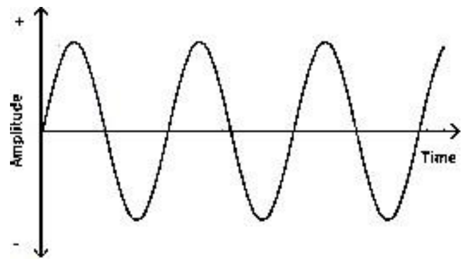


Figure 9: Output waveform of Colpitts oscillator

2. Hartley Oscillator

The Hartley oscillator is an electronic circuit, which consisting of an amplifier circuit and an LC circuit as a feedback circuit shown in figure (8). **Circuit diagram**

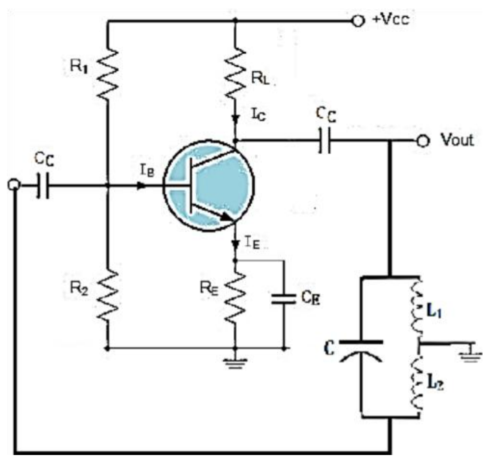


Figure 10: Circuit diagram of the Hartley oscillator

Figure (8) shows the circuit diagram of the Colpitts oscillator. BJT CE configuration is biased with voltage divider biasing technique using the resistors R_1 and R_2. R_C and R_E are collector and emitter resistors. C_C is a coupling capacitor that isolates the DC biasing settings and C_E is the bypass capacitor to avoid decreasing the output voltage by acting low resistance path across R_E under ac signal. The feedback circuit is a series combination of two Inductors (L1, L2) across a Capacitor(C).

The amplifier gain is A and the feedback circuit gain β is $\frac{L2}{L_1}$, By properly designing the circuits, Barkhausen's criterion condition number one can be achieved. i.e., $A\beta = 1$

The amplifier produces 180^o phase shift and the series connection of two inductors provides phase inversion or 180^o phase shift, hence satisfies Barkahusen's criterion condition number two. i.e., $\angle A\beta = 0^o \text{ or } 360^o$

Equation (1) is the expression of frequency of generated sinusoidal oscillations and figure (11) shows the waveform of generated oscillations.

The frequency of the generated sinusoidal signal is given by

$$\mathbf{f} = \frac{\mathbf{1}}{\mathbf{2\pi\sqrt{L_{eq}C}}} - - - (\mathbf{1}), \mathbf{where}, \mathbf{L_{eq}} = \boldsymbol{L_1} + \boldsymbol{L_2} + \mathbf{2}\boldsymbol{M},$$

where, M is the mutual inductance

Output waveform

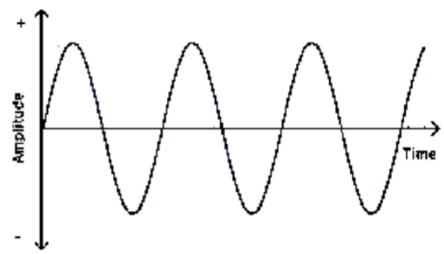


Figure 11: Output waveform of Hartley oscillator

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