Department of Electrical & Electronic Engineering
Electronic Engineering Section

ANALOG ELECTRONIC EG 306

Year: THIRD

Theoretical : 2 hrs/Week
Tutorial : 1 hrs/Week

Operational Amplifier Circuits and Applications 10 Hrs.

Integrated Differential Amplifier, Common Mode Parameters, Bias Methods in Integrated Circuits, Introduction to op-amp, Circuit Analysis of an op– amp Ideal op-amp , Inverting Amplifier, Noninverting Amplifier , Feedback Theory Frequency Response, Stability, Gain-Bandwidth Product, Slew Rate, Offset Currents and Voltages.Voltage Summer,Subtraction, Controlled Voltage and Current Sources, Integration, Differentiation and Wave Shaping, Instrumentation Amplifiers, voltage Comparators , Clipping , Clamping and Rectifying Circuits .

Large-Signal Amplifier 10 Hrs.

Amplifier Classes and Efficiency, Class- (A),Class- (B),Class- (AB),Class- (C), Power BJTs, Junction Temperature ,Thermal Resistance, Power Dissipation Versus Temperature , Transistor Case and Heatsink , Power Field-Effect Transistors (VMOS), Integrated Circuit Power Amplifier.

Oscillators 10 Hrs.

Basic Principles of Sinusoidal Oscillators , Positive Feedback and Oscillation, The Oscillation Criterion (Barkhausen Criterion). RC Oscillator: RC Phase-Shift Oscillator and Wien-Bridge Oscillator. LC and Crystal Oscillator.

Non-Sinusoidal Oscillators and Tim Circuits 10 Hrs.

Schmitt Trigger Oscillator, The 555 Circuit and applications (Monostable Multivibrator , Astable Multivibrator, Other Applications).

Filters 6 Hrs.

Types of Filters (Passive and Active, LPF,HPF,BPF,BRF),Chebysheve , Butterworth and Bessel Filters, Design of n-order Filters.

Tuned Amplifiers 8 Hrs.

Single Tuned Capacitively – Coupled Amplifiers , Time Response of Tuned Amplifiers , Inductively – Coupled Tuned Amplifiers , Tapped – Tuned Circuits , Double – Tuned Circuits , Tuned – Amplifiers Stability .

Power Supplies and Voltage Regulators 6 Hrs.

Voltage Regulators , Basic Regulator Description, Output Resistance and Load Regulation, Line Regulation , Series and shunt Voltage Regulators , Switching Regulators , Integrated - Circuit Regulators , Practical Power Supplies .

References :-

1 - Electronic Devices and Circuits Bogart.
2 – Microelectronic Circuits Sedra / Smith.
3 – Electronic Devices and Circuit theory
Robert L. Boylestad.
4 - Microelectronics / Jacob Millman
5 – Electronic Devices / Floyd.

Osillators

An oscillator is a circuit that is capable of sustaining an ac output signal by converting dc power to ac power (power converter in the sense that its only input is the dc supply potential and its output is a time varying wave form).

- **Sinusoidal Oscillators.**

  If the generated wave forms, is sine wave.

- Feedback Oscillators:

  R-C Oscillators, Audio frequency Oscillator.

  L-C Oscillators, Radio Frequency Oscillator.

  - Negative – Resistance Oscillators.

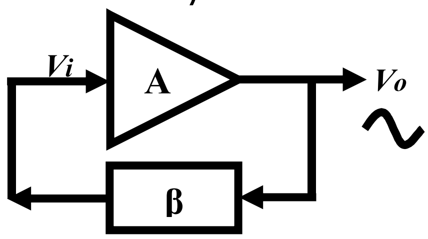
- **Non Sinusoidal Oscillators. (Relaxation Oscillators)**

  If the Generated wave form is saw tooth, square… etc.

  e.g. Astable Multivibreators.

Sinusoidal Oscillators: Feedback oscillator.

1. Positive feedback. $A_f = \dfrac{A}{1 + A\beta}$



Frequency-selective network

Where A: the gain without feedback.

β: the Fraction of the o/p feedback to the input.

2. (1-AB)=0 $\Rightarrow$ $|A\beta| = 1$ so that $A_f = \infty$ at specified frequency f_o

This is known as the ***Barkhausen criteria*** for oscillator.

This means that $A\beta = 1+j0$

Where $A = |A|\angle\theta 1$, $\beta = |\beta|\angle\theta 2$, $\therefore A\beta = |A||\beta|\angle(\theta 1+\theta 2)$

Therefore, to sustain oscillation:

1- $\theta 1+\theta 2$ = 0, 2π, 4π,…

2- $|A||\beta|$ = 1

The RC Oscillator

a) <u>The phase shift oscillator.</u>

Op-amp phase shift oscillator.

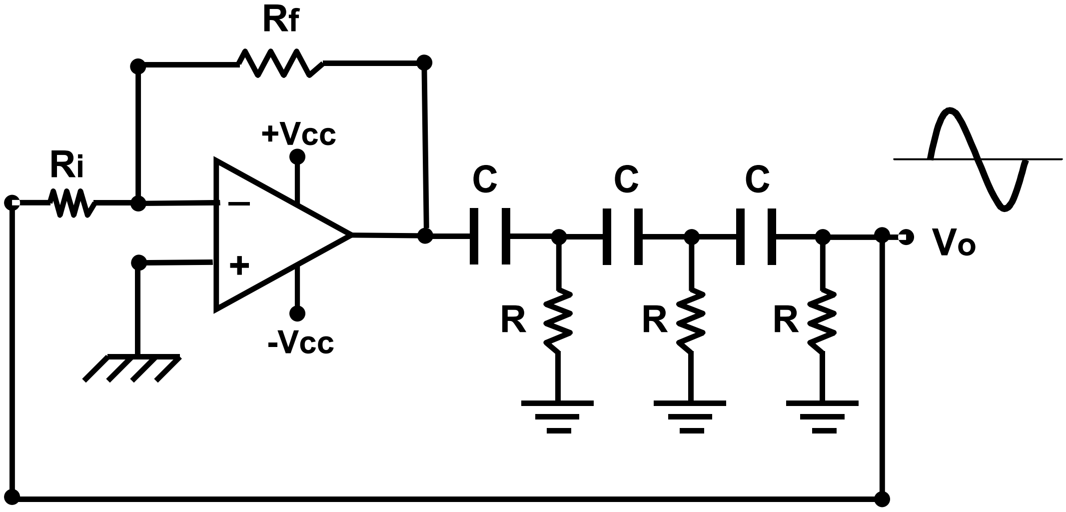


Fig .1

Each of the three RC networks in the F.B. loop can provide a maximum phase shift of 60° , Oscillation occurs at the frequency where the total phase shift through the three RC networks is 180° . The inversion of the op-amp, itself, provides the additional 180° to meet the requirement for oscillation.

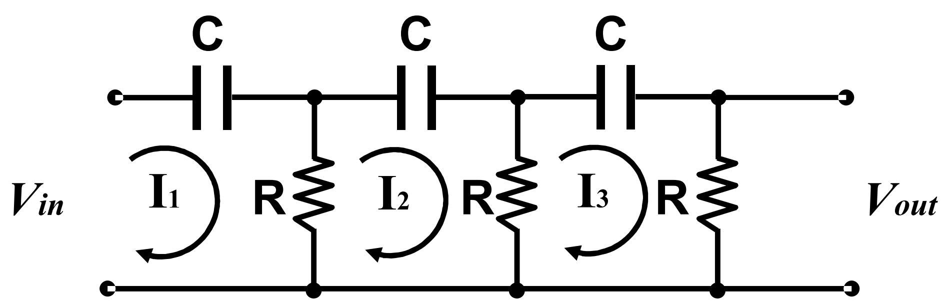


Fig.2

$$(R - \frac{j}{2\pi f C})I_1 - RI_2 + 0 I_3 = V_{in} \quad \text{...(1)}$$

$$- RI_1 + (2R - \frac{j}{2\pi f C})I_2 - RI_3 = 0 \quad \text{...(2)}$$

$$0 I_1 - RI_2 + (2R - \frac{j}{2\pi f C})I_3 = 0 \quad \text{....(3)}$$

In order to get V_{out}, we must solve for I_3 using ***determinates***.

$$\beta = \frac{V_{out}}{V_{in}} = \frac{RI_3}{V_{in}} = \frac{1}{(1-\frac{j}{2\pi fRC})(2-\frac{j}{2\pi fRC})^2 - (3-\frac{2j}{2\pi fRC})} \quad \text{...(4)}$$

Combining the real terms and the imaginary terms separately.

$$\beta = \frac{V_{out}}{V_{in}} = \frac{1}{(1-\frac{5}{(2\pi f)^2 R^2 C^2}) - j(\frac{6}{2\pi fRC} - \frac{1}{(2\pi f)^3 R^3 C^3})} \quad \text{........(5)}$$

In order to have a 180° phase shift through the network, the first term must be a negative number and the value of imaginary term must be equal ***zero*** at the frequency of oscillation f_o.

$$\therefore \frac{6}{2\pi f_o RC} - \frac{1}{(2\pi f_o)^3 R^3 C^3} = 0 \quad \text{.....(6)}$$

Solving for f_o.

$$\boxed{f_o = \frac{1}{2\pi \sqrt{6} RC}} \quad \text{..........(7)}$$

Since the imaginary terms is zero.

$$\frac{V_{out}}{V_{in}} = \frac{1}{(1 - \frac{5}{\left(2\pi f_o\right)^2 R^2 C^2})} = \frac{-1}{29} = \beta \quad \text{........(8)}$$

Thus the gain for the feedback network, β = $\frac{-1}{29}$

∴The closed-loop gain of op.amp must be (≥ -29)

i.e. A≥-29 and Aβ=1.

Example (1):-

For the circuit as shown in Fig.3:

a) Determine the value of Rf necessary for this circuit to operate as an oscillator.

b) Determine the frequency of oscillation.

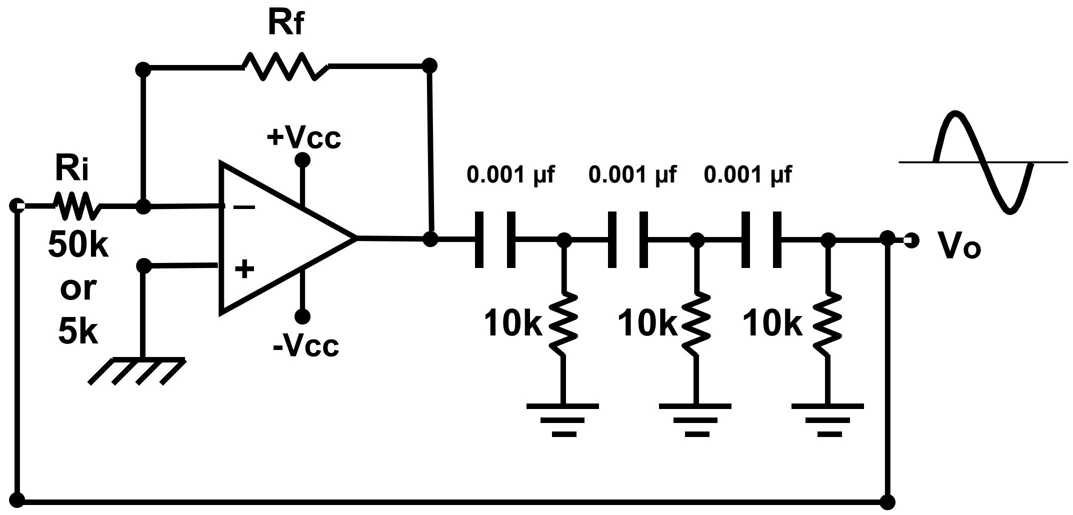


Fig.3

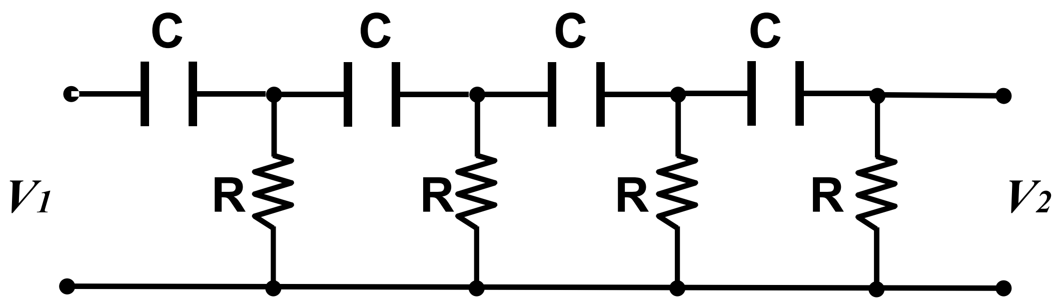
Ans.

a) $\beta = \frac{-1}{29}$ & $(1\text{-}A\beta) = 0$ ➡ A= -29

$A = -\frac{R_f}{R_i} = -29$ ➡ R_f = 145 kΩ for R_i = 5KΩ, to prevent R_i from loading the value of R, we choose R_i=50 KΩ and find R_f.

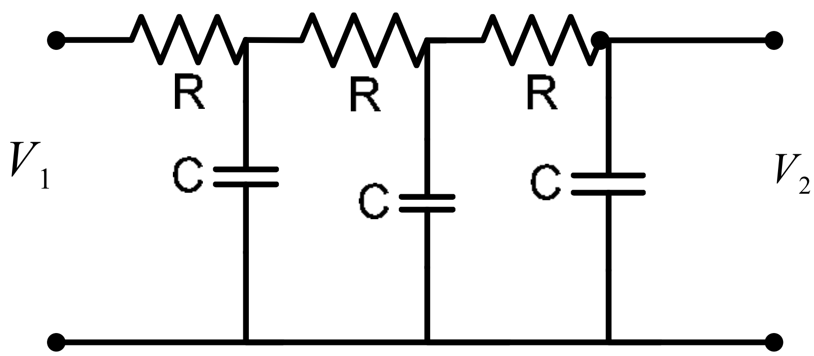
b) $f_o = \dfrac{1}{2\pi\sqrt{6}RC} \approx 6.5$ kHz

Other typical network using R and C that produce a phase shift of 180° are shown:



$$f_{\circ} = \frac{1}{2\pi\sqrt{\frac{10}{7}}RC} \quad , \quad \frac{V_2}{V_1} = \frac{-1}{18.4}$$

Fig.4



$$f_{\circ} = \frac{\sqrt{6}}{2\pi RC} \quad , \quad \frac{V_2}{V_1} = \frac{-1}{29}$$

Fig.5

Exercise (1):

Derive the expression for resonant frequency and the expression for minimum gain for the (Fig.4 and Fig.5), also evaluate this frequency when R=2kΩ and C=0.01μF?

Exercise (2):

For the circuit shown in Fig.6 (RC phase-shift oscillator using transistor) RL=3kΩ, Vcc=6V, ICQ=1mA, hfe=hFE=200 and R=10kΩ.

a) Calculate RE, assuming the feedback network does not Load RL.

b) Calculate RB.

c) Find C for $W_{\circ} = 10 rad/\sec$.

d) Evaluate R2.

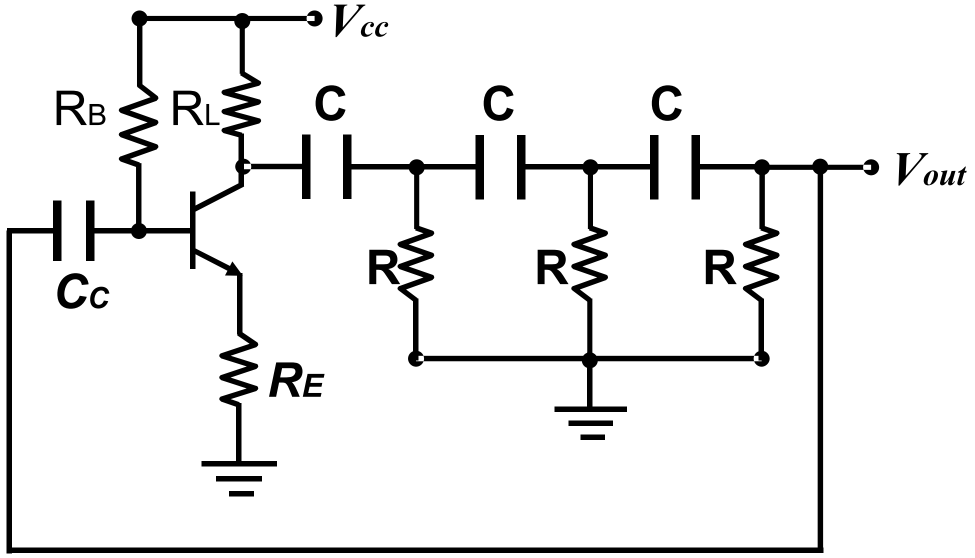


Fig.6

RC Phase Shift Oscillator Using FET Transistor

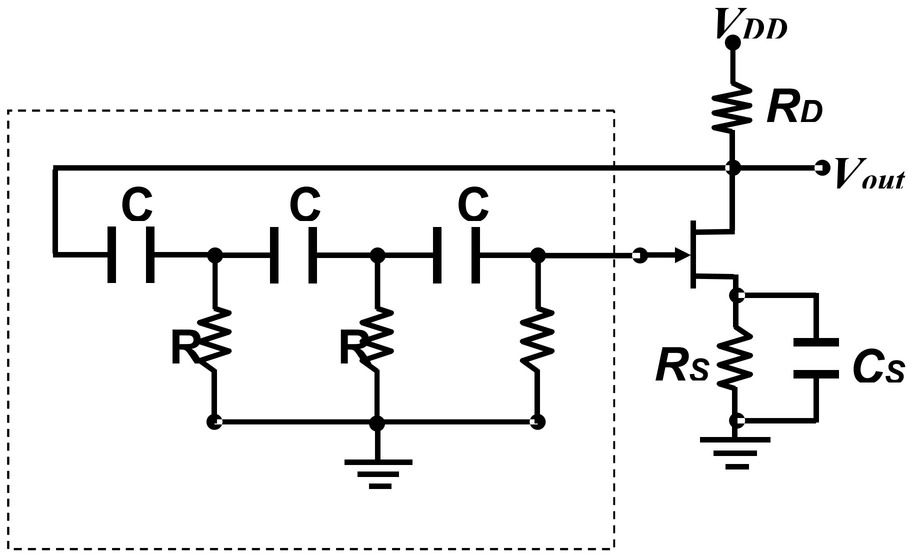


Fig.7

The FET amplifier is biased by RS & RD the voltage

Gain = $-g_m R_D$, the amplifier output to input voltages phase shift $=180^{\circ}$, β network provides an additional 180° phase shift at f_o

$$f_o = \frac{1}{2\pi\sqrt{6}RC}, \quad \beta = -\frac{1}{29}$$

The gain of the amplifier must be ≥ -29

<u>b)Wien- bridge oscillator</u> (using op-amp)

Fig.8 shows a widely used type of oscillator called a ***Wien-bridge***. The operational amplifier is used in a noninverting configuration, and the impedance blocks labeled Z_1 and Z_2 form a voltage divider that determines the feedback ratio. Resistors R_i and R_F determine the amplifier gain and are selected to make the magnitude of the loop gain equal to 1. If the feedback impedances (Z1 and Z2) are chosen properly, there will be some frequency at which there is zero phase shift in the signal feedback to the amplifier input V+. Since the amplifier noninverting, it also contributes zero phase shift so the total around the loops is zero at the frequency, as required for oscillation.

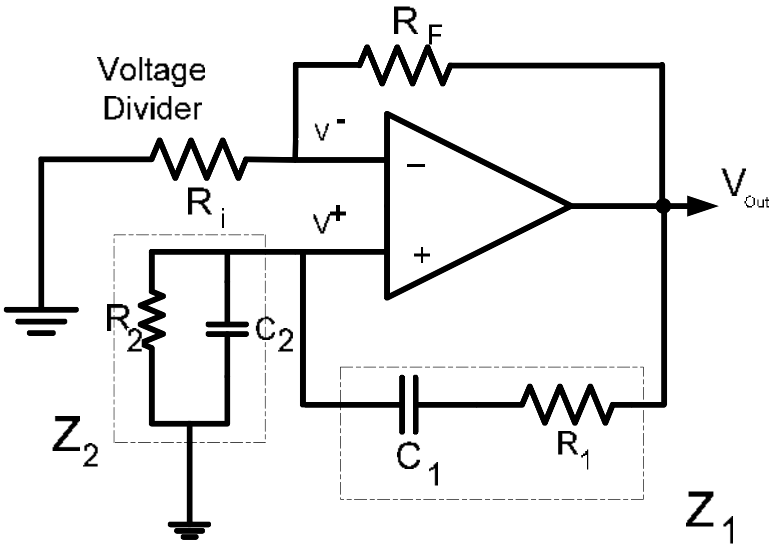


Fig.8

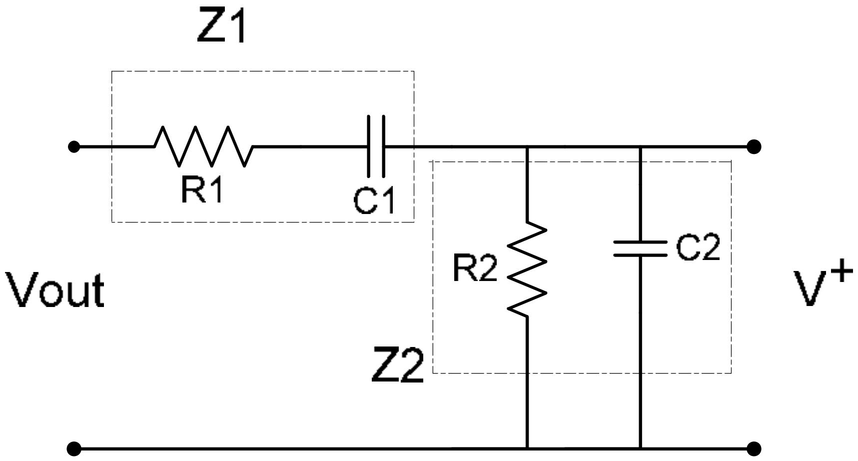


Fig.9 lead-lag circuit.

$$Z_1 = R_1 - \frac{j}{\omega c_1} \qquad \text{……………………………………(1)}$$

$$Z_2 = R_2 \backslash\backslash - \frac{j}{\omega c_2} = \frac{R_2 \times \frac{-j}{\omega c_2}}{R_2 - \frac{j}{\omega c_2}} \qquad \text{…………………...(2)} \qquad \div\left(\frac{-j}{\omega c_2}\right)$$

$$\therefore Z_2 = \frac{R_2}{j\omega R_2 C_2 + 1} \qquad \text{………………………………(3)}$$

$$\beta = \frac{V^+}{V_{Out}} = \frac{Z_2}{Z_1 + Z_2} = \frac{(\frac{R_2}{j\omega R_2 C_2 + 1})}{(R_1 - \frac{j}{\omega C_1}) + (\frac{R_2}{j\omega R_2 C_2 + 1})} \qquad \text{……………(4)}$$

$$\beta = \frac{V^+}{V_{Out}} = \frac{(\frac{R_2}{j\omega R_2 C_2 + 1})}{(\frac{R_1 + j\omega R_1 R_2 C_2 + \frac{R_2 C_2}{C_1} - \frac{j}{\omega C_1} + R_2}{j\omega R_2 C_2 + 1})} \qquad \text{………………(5)}$$

$$\beta = \frac{V^+}{V_{Out}} = \frac{R_2}{(R_1 + R_2 + R_2 \times \frac{C_2}{C_1}) + j(\omega R_1 R_2 C_2 - \frac{1}{\omega C_1})} \qquad \text{………………(6)}$$

In order for V^+ to have the same phase as V_{Out}, this ratio must be a purely real number. Therefore, the imaginary part in Equation (6) must be zero. Setting the imaginary part equal to zero and solving for ω`gives us the oscillation frequency:

$$\omega_o R_1 R_2 C_2 - \frac{1}{\omega_o C_1} = 0 \Rightarrow \omega_o R_1 R_2 C_2 = \frac{1}{\omega_o C_1} \Rightarrow \omega_o{}^2 = \frac{1}{R_1 R_2 C_1 C_2} \quad \ldots(7)$$

$$\omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$f = f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

In most applications, the resistors are made equal and so are the capacitors:
$R_1 = R_2 = R$ and $C_1 = C_2 = C$. In this case , the oscillation frequency becomes:-

$$f = f_o = \frac{1}{2\pi RC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

When $R_1 = R_2 = R$ and $C_1 = C_2 = C$, the feedback ratio at the oscillation frequency is:

$$\beta = \frac{R}{R + R + R \times \dfrac{C}{C} + j0} = \frac{R}{3R} = \frac{1}{3} \quad \ldots\ldots\ldots\ldots\ldots(11)$$

Therefore, the amplifier must provide a gain of 3 to make the magnitude of the loop gain unity and sustain oscillation.

$$A = \frac{1}{\beta} = 3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

For non-inverting amplifier:

$$A = 1 + \frac{R_F}{R_i} = 3 \Rightarrow \frac{R_F}{R_i} = 2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

Exercise (3): Design a wein-bridge oscillator that oscillates at 25 kHz.

2. LC Oscillator circuit.

The Colpitts oscillator

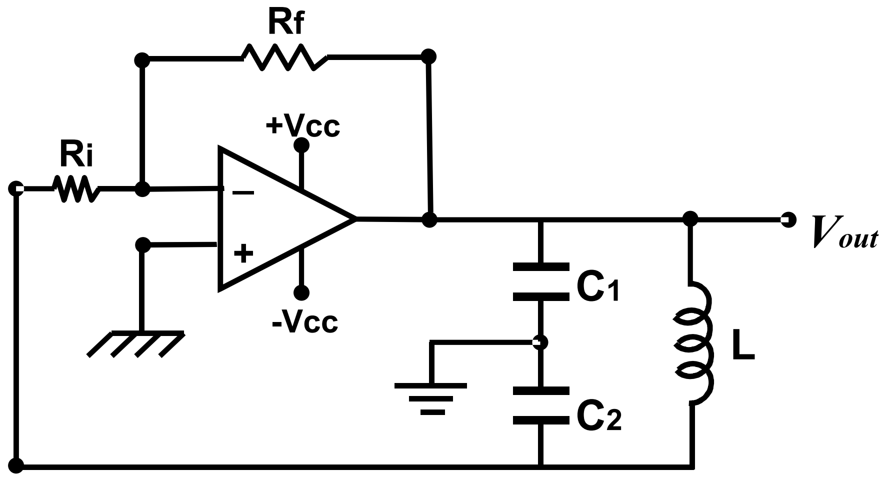


Fig.10

The combination of C1, C2 and L acts as a parallel resonant circuit in the F.B. loop and the frequency of oscillator is:

$$f_{\circ} = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

Where $C_{eq} = \dfrac{C_1 C_2}{C_1 + C_2}$ (C1 in series with C2)

The Hartley oscillator

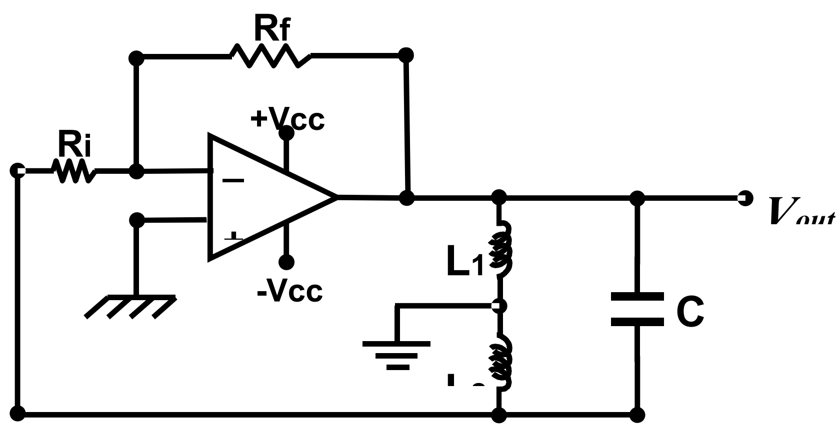


Fig.11

L1, L2 and C act as a resonant Circuit in the F.B. loop. The frequency of oscillator is.

$$f_{\circ} = \frac{1}{2\pi\sqrt{L_{eq}C}}$$

Where $L_{eq} = L_1 + L_2$ (L1, L2 are in series)

Example (2):-

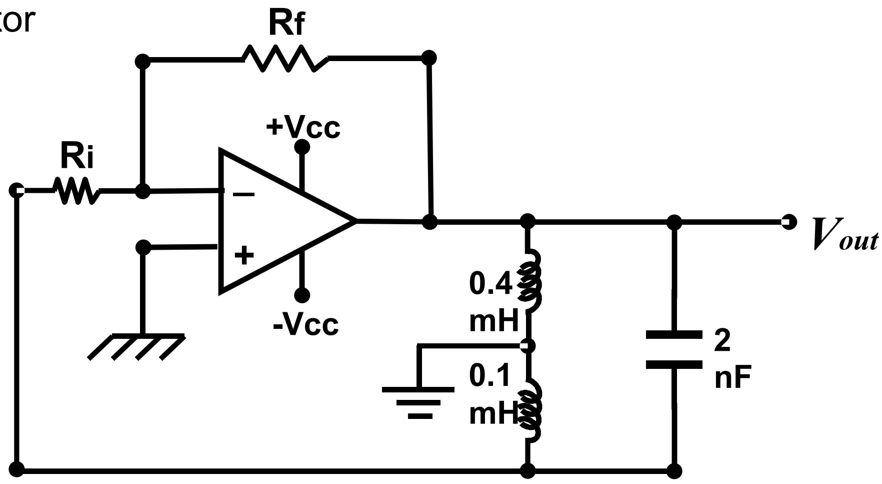
Identity each oscillator in figures below and determine its frequency of oscillation.

a. Hartly oscillator

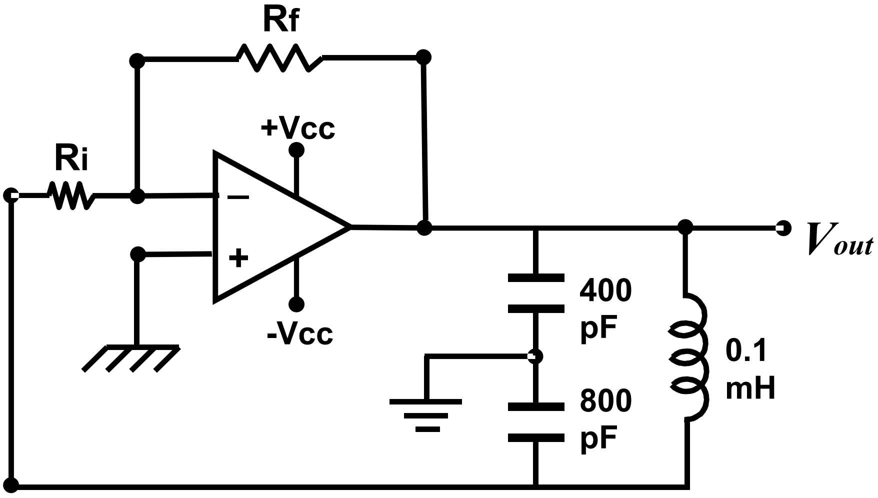
Leq = L1 + L2

$$f_{\circ} = \frac{1}{2\pi\sqrt{L_{eq}C}}$$

$f_{\circ}$ = 160 kHz



(a)



(b)

Fig.12

b. Colpitts oscillator

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

C_{eq} = 270 pF

$$f_\circ = \frac{1}{2\pi\sqrt{LC_{eq}}} = 0.97\,MHz$$

<u>The Crystal Oscillator</u>

Crystal oscillators offer greater frequency stability than other types. The crystal oscillator uses a quartz crystal as the resonant circuit.

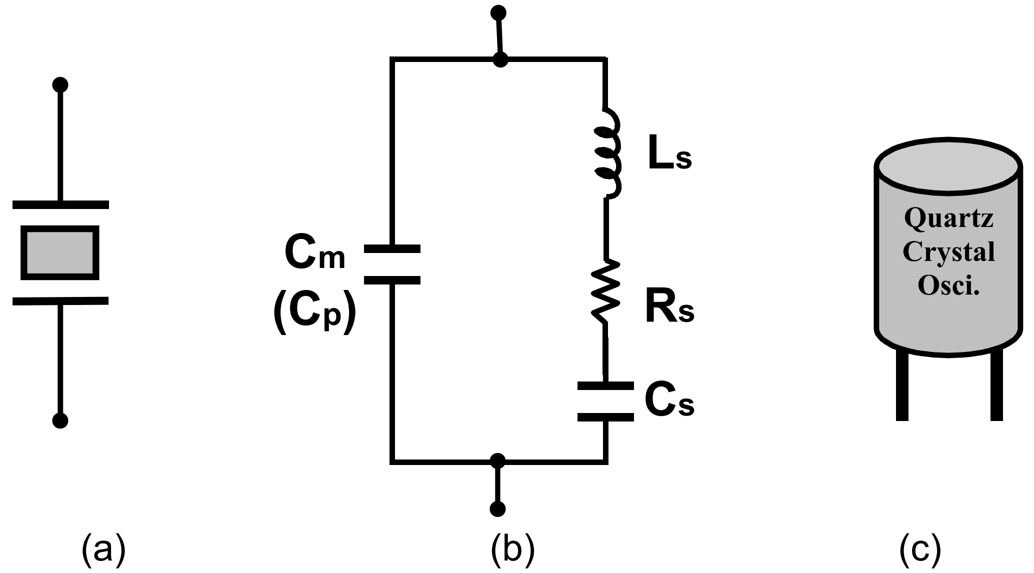


Fig.13: (a) Quartz crystal symbol,(b) Electrical equivalent circuit of a crystal, (c) Quartz crystal real symbol.

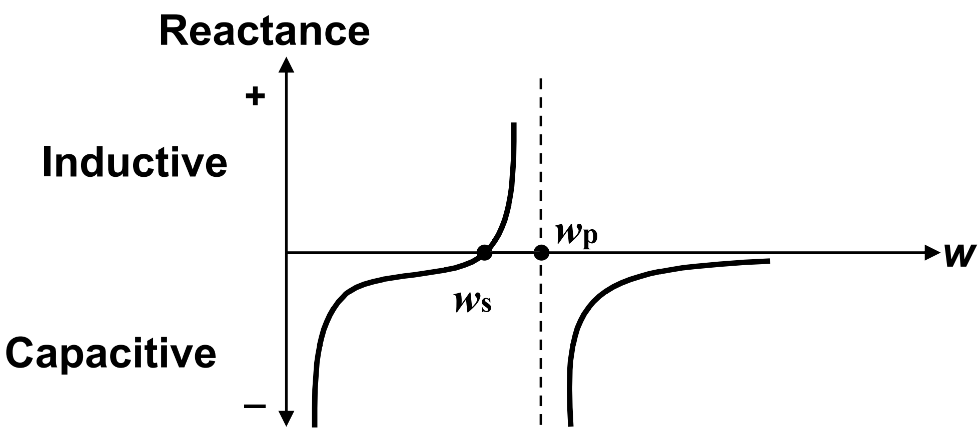
The crystal will deform if a voltage is placed across their parallel faces. Similarly, if the crystal is mechanically deform, a voltage will appear across its opposite faces.

This property of crystal is called ***piezoelectric*** effect.

The piezoelectric crystal has a mechanical resonant frequency; its Q factor is very high.

Series resonance occurs in the crystal when the reactances in the series branch are equal.

Parallel resonance occurs, at a higher frequency, when the reactance of Ls equals the reactance of Cm.



Sketch of reactance as a function of frequency

Fig.14

w_s : Series resonant frequency. $$w_s = \frac{1}{\sqrt{L_s C_s}}$$

w_p : Parallel resonant frequency. $$w_p = \sqrt{\frac{1}{L_s}\left(\frac{1}{C_m} + \frac{1}{C_s}\right)}$$

$$C_m >> C_s$$

The oscillator frequency is essentially determined by the crystal and not by the rest of the circuit.

Example (3):-

A crystal oscillator, (as shown in fig.15), using the crystal as a series resonant circuit. The impedance of the crystal is minimum at the series resonance, providing maximum feedback. Cc is a coupling capacitor to prevent dc voltage from being fed back.

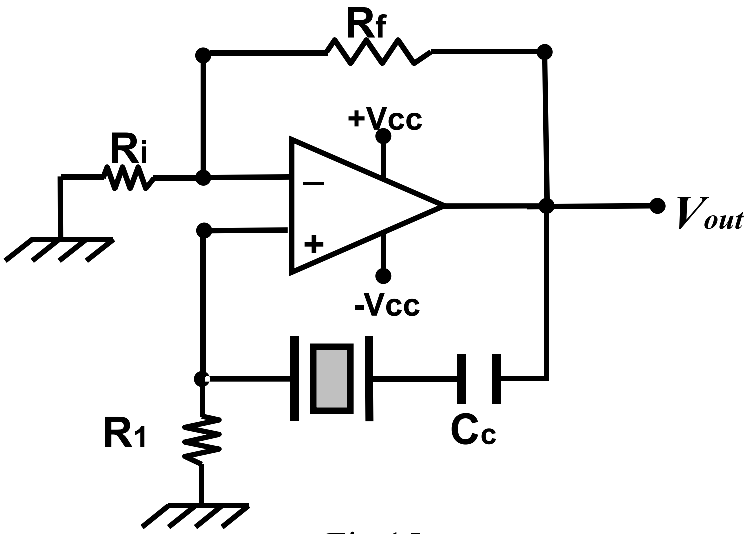


Fig.15

Example (4) :-

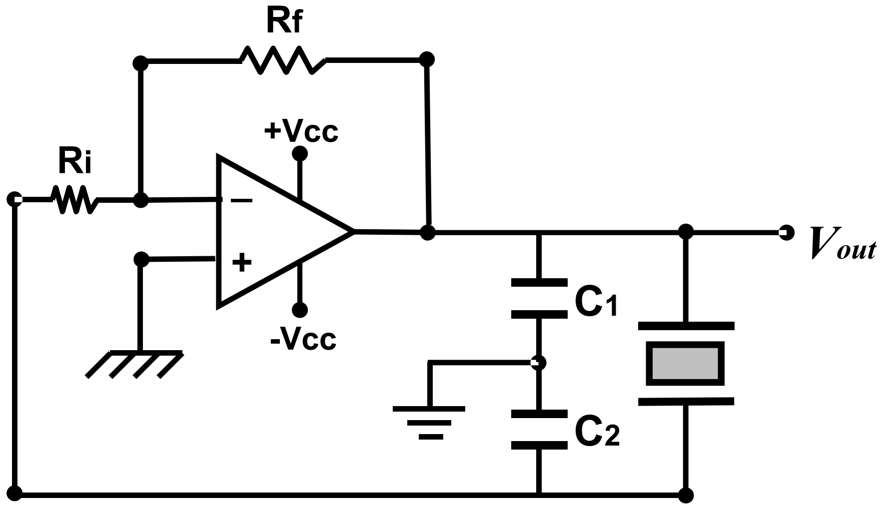


Fig.16

A modified Colpitts oscillator, (as shown in fig.16), uses the crystal in its parallel resonant mode. The impedance of the crystal is maximum at parallel resonance thus developing the maximum voltage across both C1 and C2. The voltage across C2 is fed back to the input.

Exercise (4): Sketch a circuit diagram of a phase shift RC oscillator using BJT & FET. Derive the expression for the frequency of oscillator and the minimum amplifier gain.

Exercise (5): For a Wien bridge oscillator circuit if the lead-lag network has the following R=12kΩ and C=0.015μF. Calculate the resonant frequency and the minimum amplifier gain.

Exercise (6):

Derive the equation of frequency of oscillator for the Colpitts and Hartly oscillators.

Negative Resistance Concepts

Negative resistance occurs in electronics when an increase in voltage results in a decrease in current (a Voltage – Controlled Negative Resistance) or where an increase in current results in a decrease in voltage (a Current Controlled Negative Resistance).

$$r = -\frac{dv}{di}$$

- Voltage – controlled negative - resistance is the property of tunnel diode.

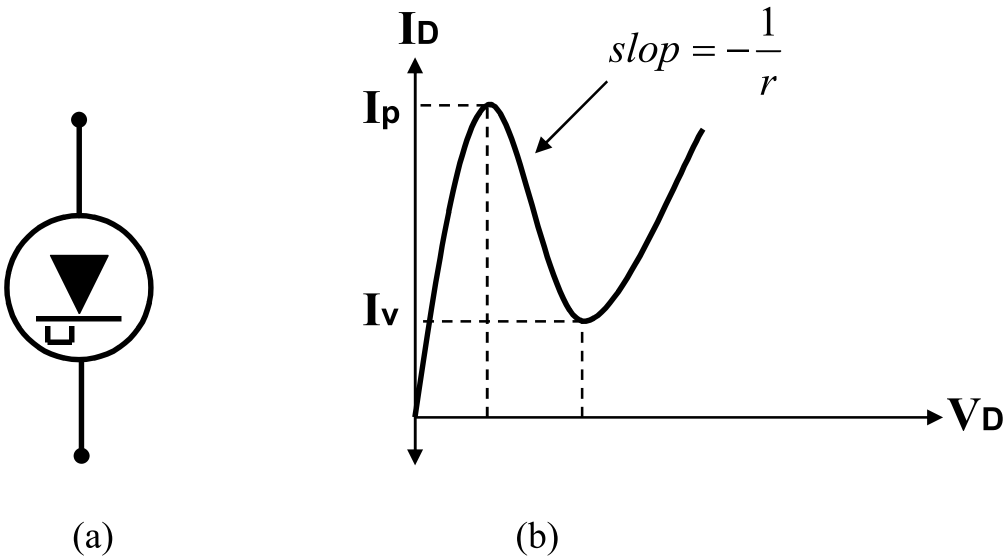


Fig.17: (a) Tunnel diode symbol, (b) tunnel diode characteristic.

Tunnel diode sinusoidal oscillator.

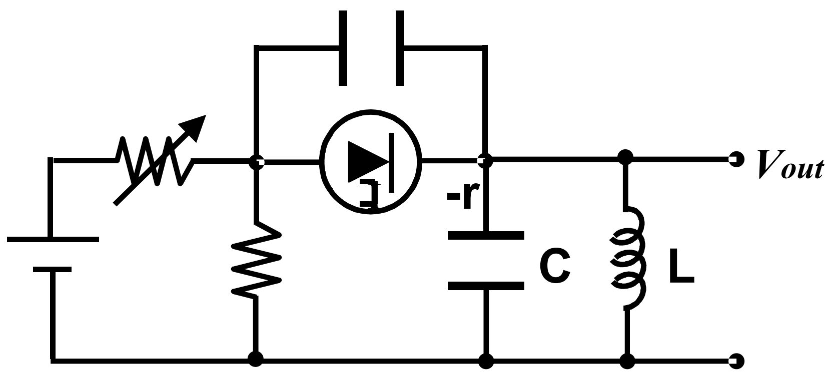


Fig.18

It is suitable for use in microwave oscillators.