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Electronics and Communication Engineering

II YEAR / IV SEMESTER

EC8452-Electronic Circuits II

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"Electronics is clearly the winner of the day."

—John Ford.

UNIT II

OSCILLATORS

Topics to be Covered

1. Barkhausen criterion for oscillation
2. phase shift Oscillator
3. Wien Bridge Oscillator
4. Hartley Oscillator
5. Colpitt's Oscillator
6. Clapp Oscillator
7. Crystal Oscillator
8. Ring Oscillator
9. Stabilization

Oscillator Definition

"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".

Introduction to Oscillators:

The transfer function of a feed back amplifier is as follows

$$A_f = \frac{A}{1 - A\beta}$$

Where A is amplifier gain

β is feed back factor, if $(A\beta) = 1$

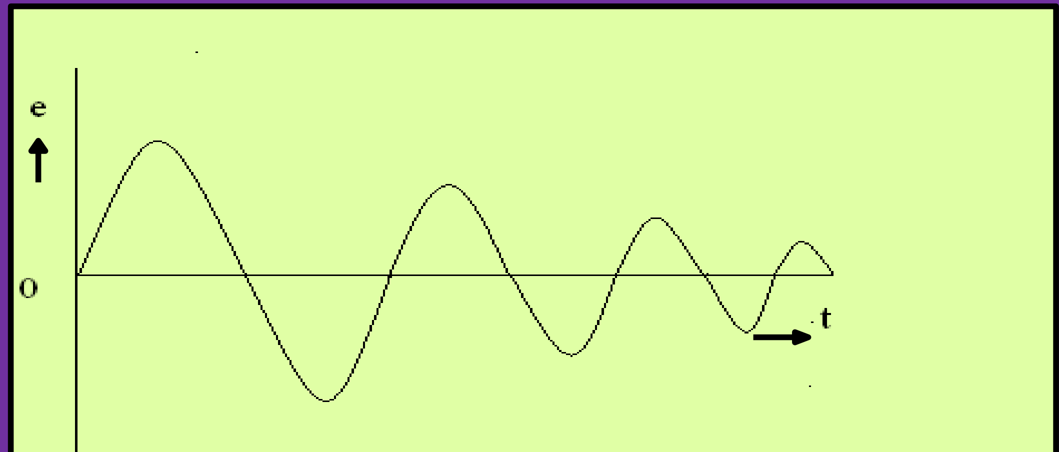
Then $A_f = \infty$, which is condition for oscillations.

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.



2.1.(a) Damped oscillations

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Un-damped oscillations :

- The electrical oscillations in which amplitude does not change with time are known as un-damped oscillations.
- These are shown in the figure .

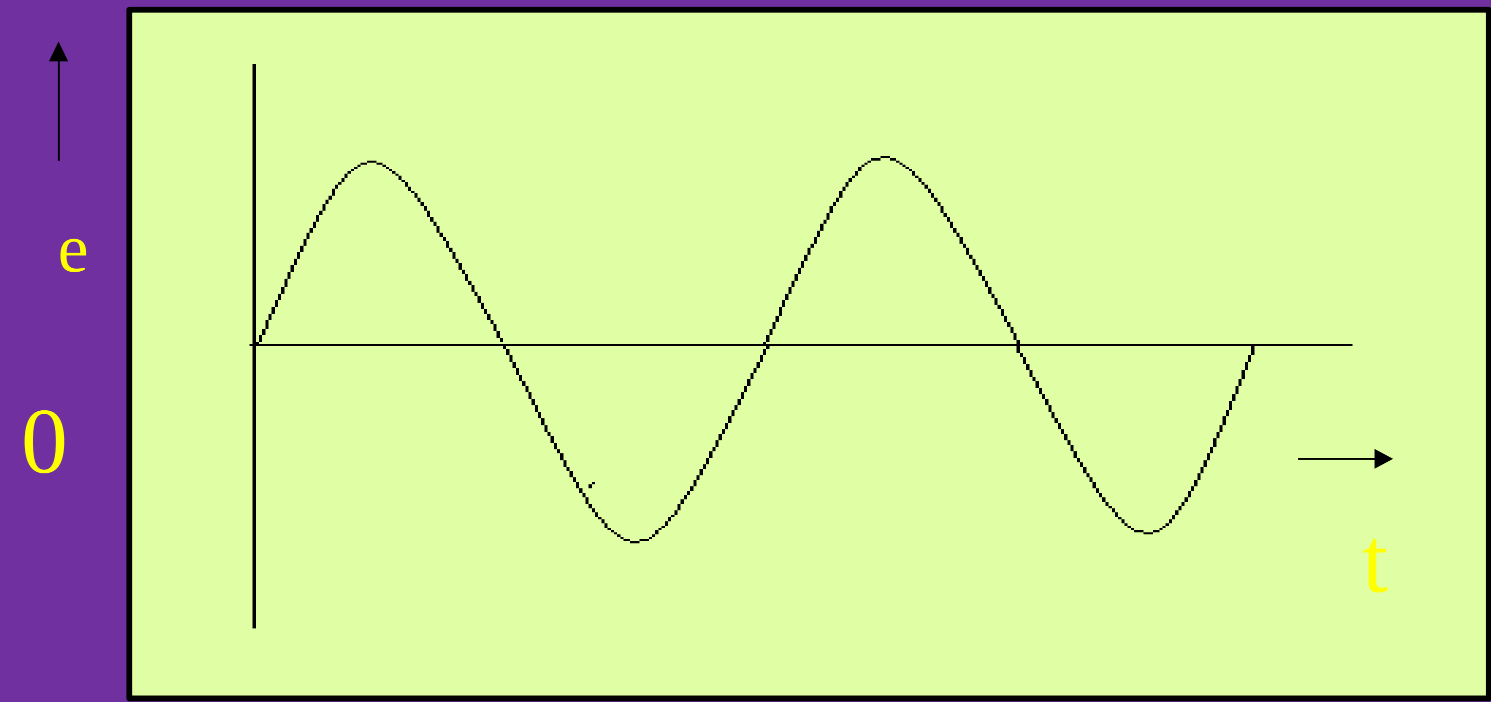


Fig. Un-damped Oscillations

Basic types of oscillators

Based on the waveform produced at the output:

- Sinusoidal oscillators.
- Non sinusoidal oscillators

    i)Sweep circuits

    ii) Relaxation oscillators.

Sinusoidal oscillators :

- A static electronic device that produces sinusoidal oscillations of desired frequency is called sinusoidal oscillator.

Eg. LC oscillators, RC phase shift oscillator etc.,

Amplifier as an oscillator:

- The Block diagram i.e. Fig. shown below is the amplifier with positive feedback which works as an oscillator.

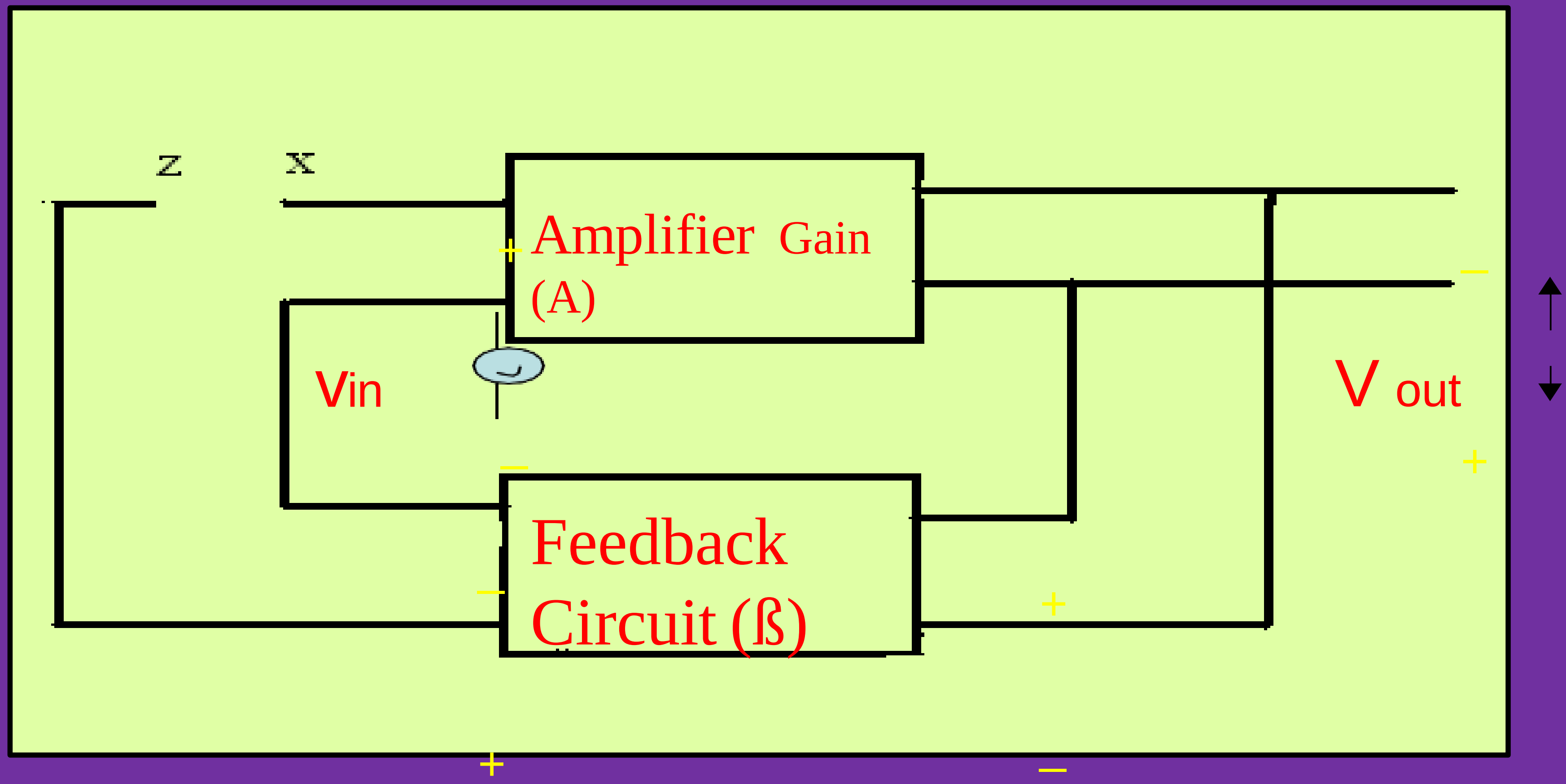


Fig.Amplifier with Positive feedback

The Essentials of an Oscillator

- An oscillatory circuit.
- Transistor Amplifier.
- Feedback circuit.

Requisites of an Oscillator

- The following block diagram, fig.2.2(a), shows the essential parts of an oscillator.

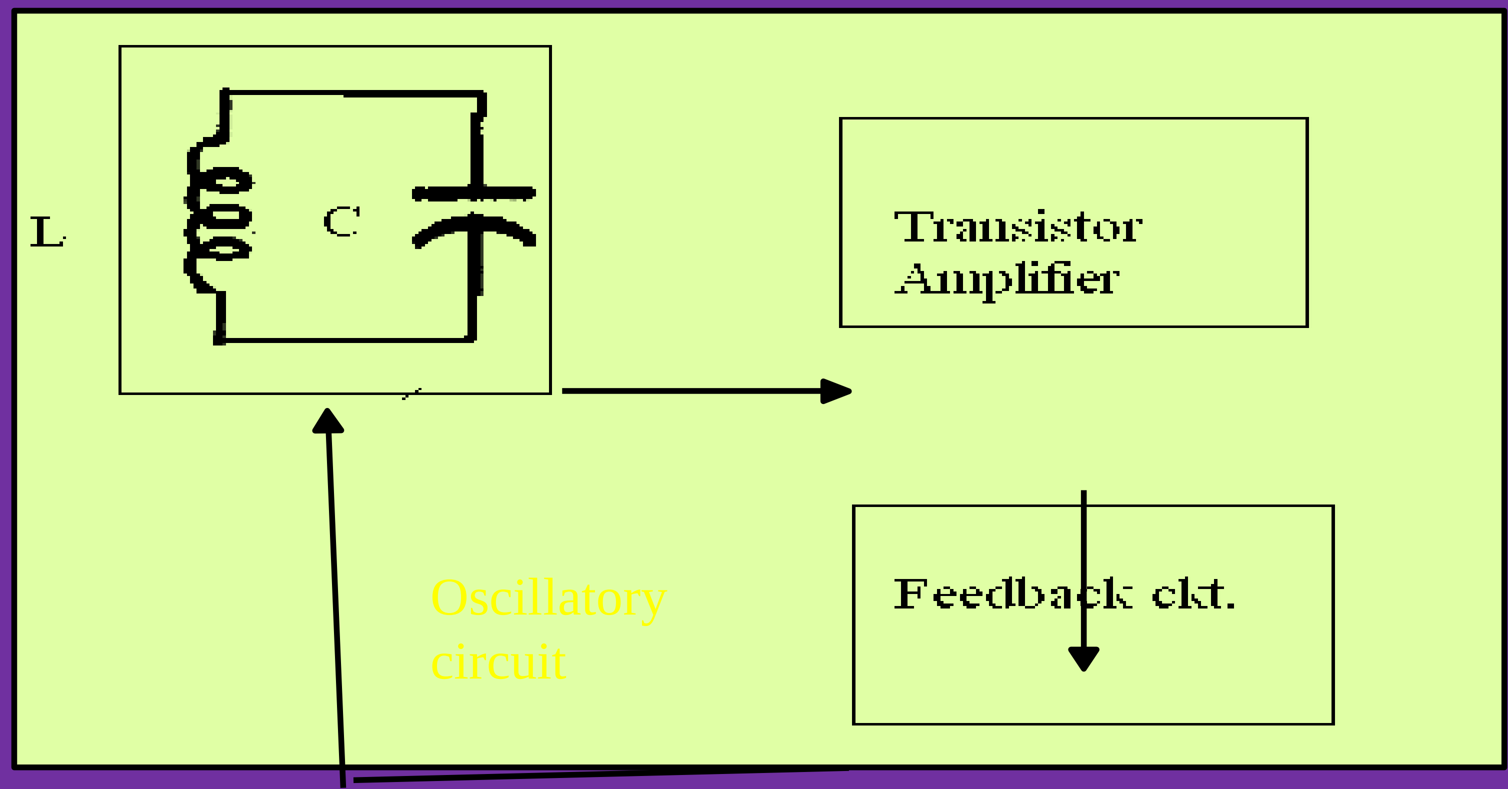


Fig 2.2 (a)

Classification of oscillators

1. **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.

Classification of Oscillators

2. **Based on the Auxiliary Oscillatory circuit used :**

i) Non-Resonant Oscillators

- RC oscillators

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

ii) Resonant Oscillators

- LC Oscillators

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

Applications of Oscillators

- Phase-shift and Wein-bridge oscillators are used to generate audio frequencies.
- Tuned collector, Hartley and Colpitts oscillators are used to produce radio frequencies.
- Crystal oscillators are used where high frequency stability is required.

RC Oscillators

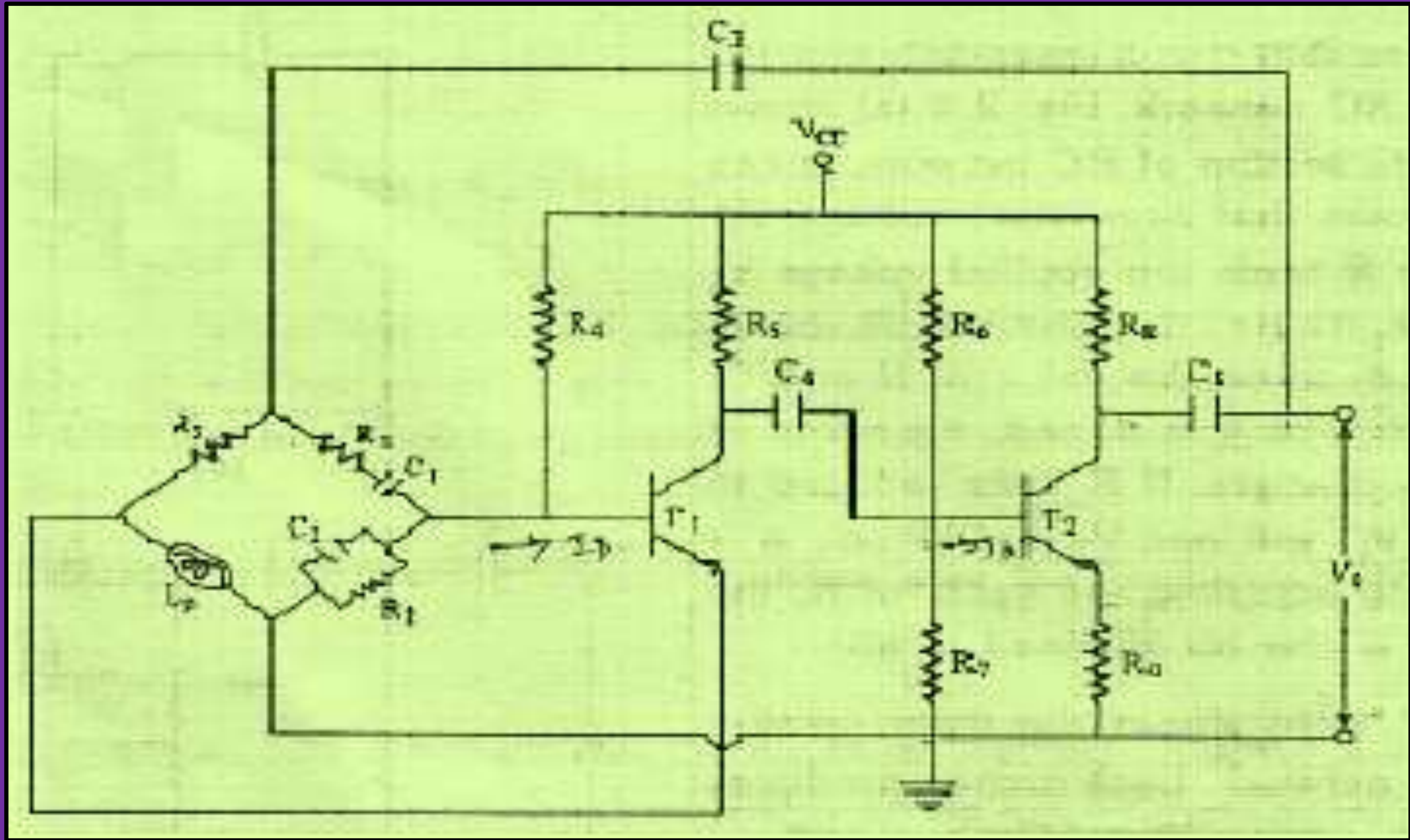
- These oscillators employ resistors and capacitors.
- These are more suitable for generating low frequency signals.
- They are also known as AF oscillators.
- These have good frequency stability.

TYPES OF RC OSCILLATORS

- Wein bridge oscillator
- RC phase shift oscillator

Basic Principle of Wein Bridge Oscillator

- It employs two stages of amplifiers.
- Each amplifier gives phase shift of 180^0.
- Combination of two amplifiers gives 360^0 phase shift, which is equal to 0^0
- A fraction of the output from the second stage is fed back to the input of the first stage without producing any further phase shift.
- This oscillator can be used from 10Hz to 10MHz.
- It is extensively used as audio oscillator since its output is free from circuit fluctuations and ambient temperature, whose circuit is shown in fig.2.4(a).



2.4 (a). Wein bridge oscillator

Circuit Analysis

- The circuit arrangement of a wein bridge oscillator is shown in fig 2.4 (a).
- It is extensively a two stage amplifier with RC bridge circuit.
- The bridge circuit has four arms each containing components R_1C_1 in series, R_2C_2 in parellel, R_3 and R_4.
- The transistor T_1 with its biasing network serves as an oscillator and amplifier while the other transistor T_2 with its biasing network serves as an inverter (it is used for phase reversal).
- The frequency of oscillations is provided by the series elements R_1C_1 and parallel elements R_2C_2 of the bridge network.

Operation of Oscillator

- When the power is ON the bridge circuit produces the oscillations of frequency determined by the expression,

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$R_1 = R_2 = R$; $C_1 = C_2 = C$;

Therefore $$f = \frac{1}{2\pi RC}$$

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Working of Wein bridge oscillator

- The desired frequency of oscillations can be produced by varying the two capacitors C_1 and C_2 simultaneously.
- These oscillations are fed to first transistor T_1.
- After amplification these oscillations are fed to the second transistor T_2.
- First transistor T1 serves as an amplifier and second transistor T2 serves as an inverter.

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Working of Wein bridge oscillator

- A total phase shift of 360º is obtained at the output of the second transistor.
- A fraction of this output energy is fed back to the oscillatory circuit (bridge) at the upper terminal.
- This positive feedback is to meet with the losses in the oscillator and hence undammed oscillations are produced.
- A negative feedback ensures stability and constant output.

Working of Wein bridge oscillator

- This negative feedback is provided through the voltage divider (R_3 and R_4) to the input of transistor T_2.
- Usually a temperature sensitive tungsten lamp is used in place of R_4.
- Its resistance increases with current.
- As soon as the amplitude of output tend to increase more current would provide negative feedback.

This brings back the output to its original value.

- A reverse action would take place if the output tends to decrease.

Conditions for sustained oscillations

- First condition is
  - $$\frac{R_1}{R_2} = 2$$

- The second condition is that the zero phase shift is obtained by both the transistor and the tank circuit in the feedback.

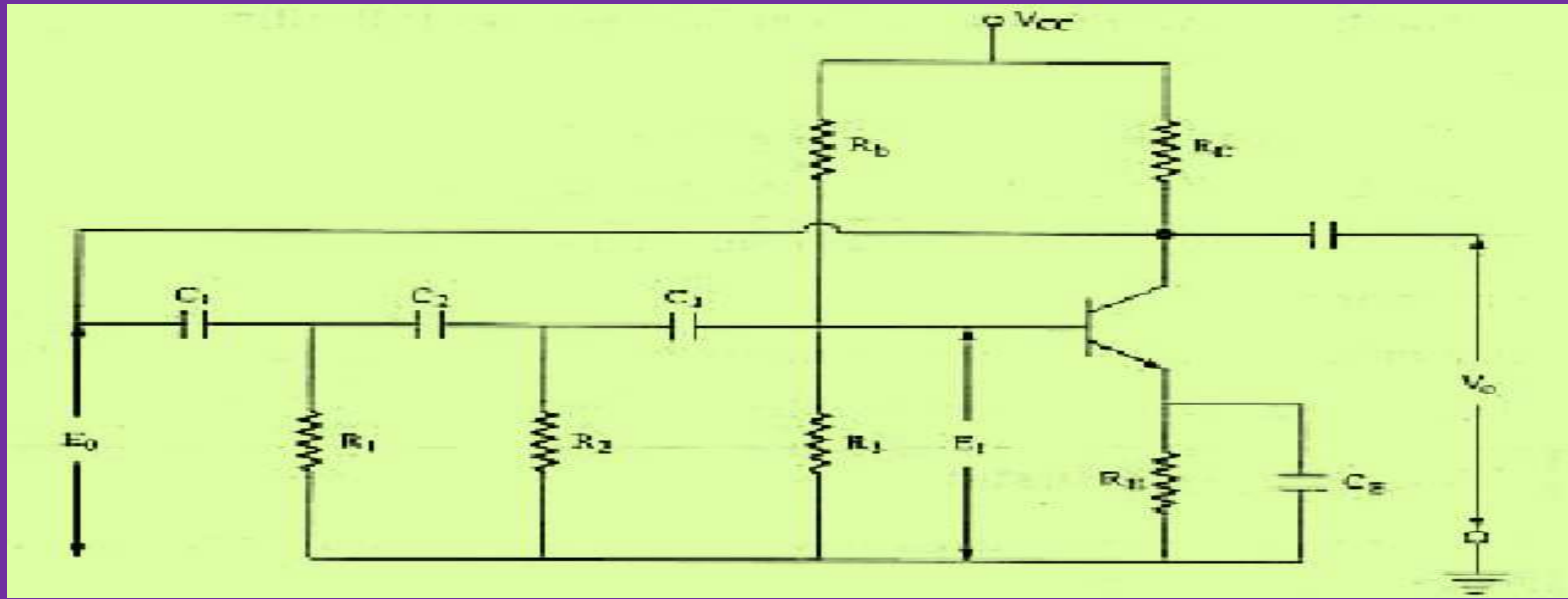
Advantages

- Output is constant.
- Its working is quite simple and easy.
- Overall gain is high.
- It has far better stability.
- Frequency of oscillations can be easily adjusted.

Disadvantages

- Cannot be used to generate very high frequencies.
- Costlier, as more components are used.

RC Phase Shift Oscillator



- It consists of a conventional single transistor amplifier and a RC phase shift network.
- The phase shift network consists of three sections R_1C_1,$R_2C_2$and R_3C_3.

- At some particular frequency f_o,the phase shift of each section is 60^o,so that the total phase-shift produced by the RC network is $(3*60^o)=180^o$.
- The frequency of oscillations is given by

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

Where $R_1=R_2=R_3=R$

$C_1=C_2=C_3=C$.

Circuit Operation

- When the circuit is switched on it produces oscillations.
- The output E_o of the amplifier is fedback to RC feedback network.
- This network produces phase shift of 180º and a voltage E_1 appears at its output which is applied to the transistor amplifier.
- The feedback factor $\beta=E_1/E_0$.
- The feedback factor β=1/29, has an important significance.

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Circuit Operation

For self starting the oscillations, we must have $A\beta > 1$, it means the gain A of the amplifier must be greater than 29 only then the oscillations can start.

- A phase shift of 180^{o} is produced by the transistor amplifier.
- A further phase shift of 180^{o} is produced by the RC network.
- As a result the phase shift around the loop is 360^{o}.

PHASE SHIFT NETWORK

- A phase shift circuit essentially consists of an RC network. Fig.2.(b) shows a single section of RC network.

- It can be shown that alternating voltage V_1' across R leads the applied voltage V_1 by an angle θ.

- The value of θ depends upon the value of R and C.

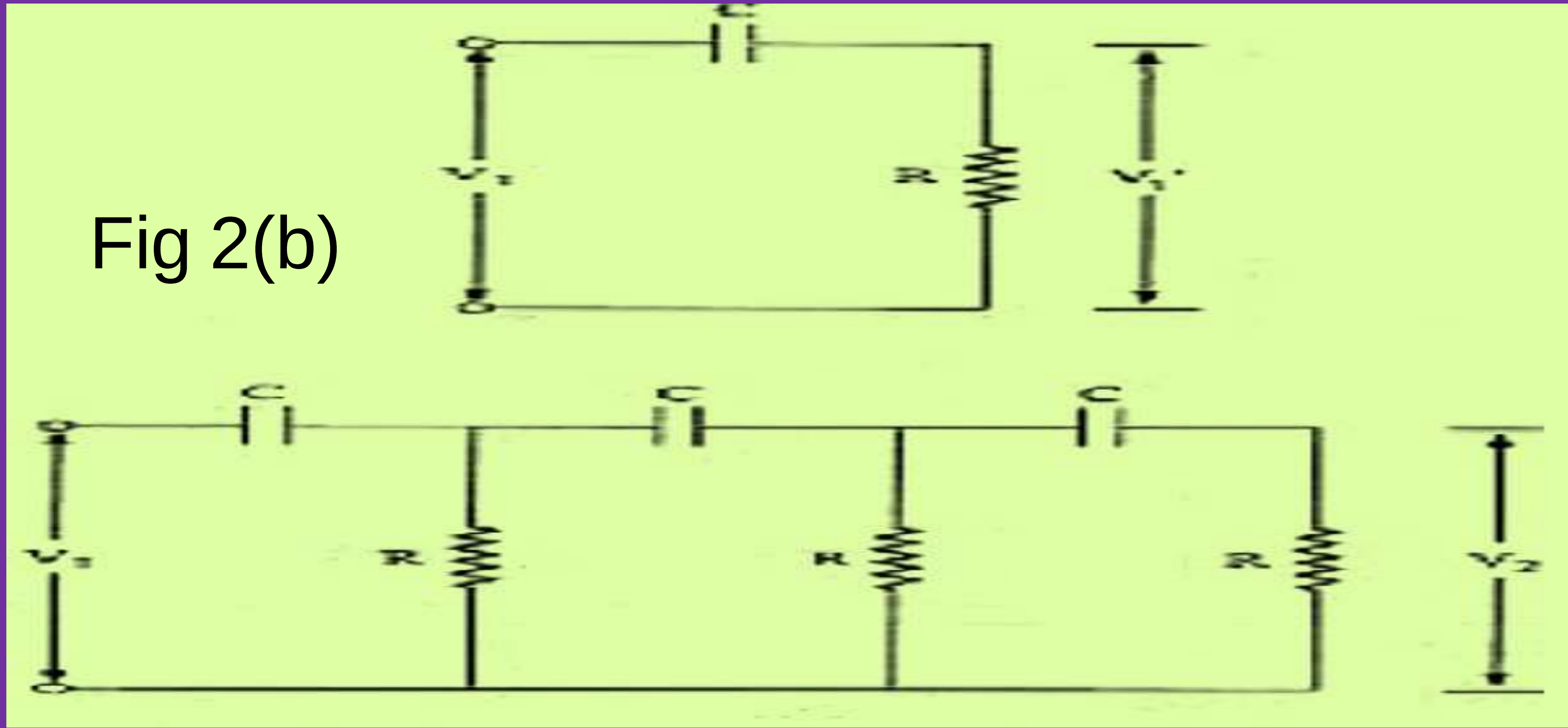

Fig 2(c)

- If resistance R is varied, the value of θ also changes.
- If R were reduced to zero V_1' will lead V_1 by 90 that is θ=90º.
- By adjusting the value of R the value θ can be obtained to 60º.

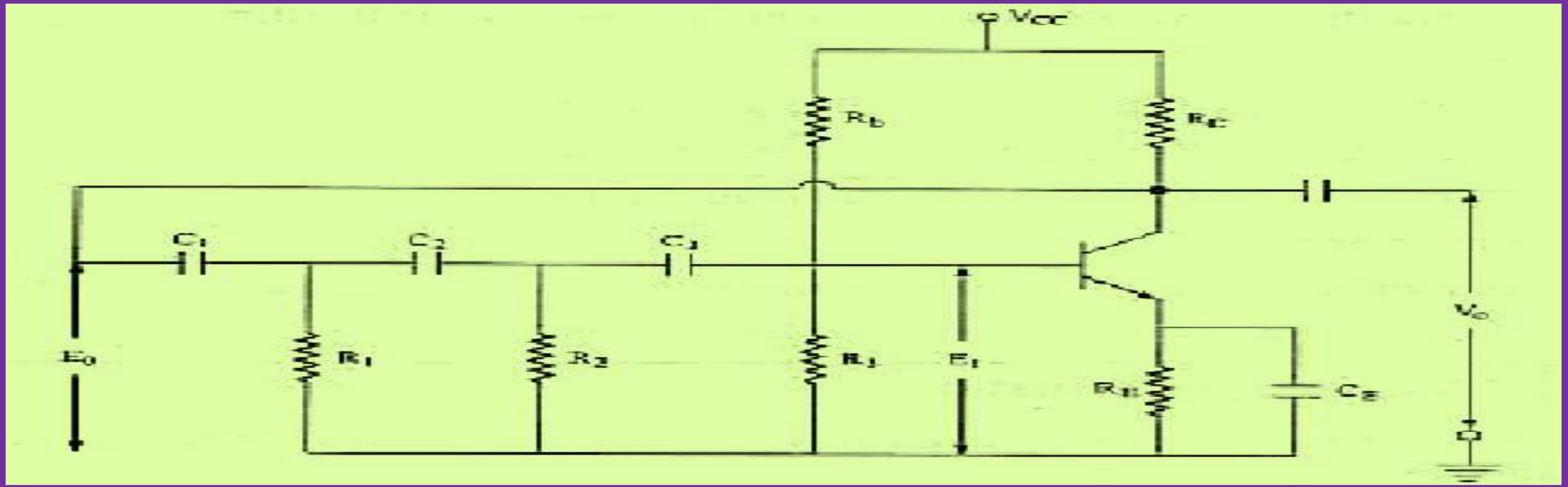

Fig 2(a): R C PHASE SHIFT OSCILLATOR.

- Fig.2. (c) shows the three section of RC network.
- Each section produces a phase shift of 60º.
- Consequently, a total phase shift of 180º is produced i.e voltage V_2 leads the voltage V_1 by 180º.

Condition For Sustained Oscillations

Condition:1

- From fig 2(a) of RC phase shift oscillator,
- A phase shift of 180^0 is produced by the transistor amplifier.
- A further phase shift of 180^0 is produced by the RC network.
- As a result the phase shift around the Loop is 360^0.
- Hence total phase shift around the loop is zero.
- Therefore the sustained oscillations are produced in sinusoidal oscillators.

Condition For Sustained Oscillations

Condition: 2

- The feedback factor $\beta = E_1/E_0$. It can be shown that the feed back factor of the RC network is $\beta = 1/29$.
- This expression has an important significance.
- For self starting the oscillations we must have $A\beta > 1$.
- It means that gain A of the amplifier must be greater than 29. Only then oscillations can start.
- Therefore, the sustained oscillations are not produced, if at the oscillation frequency the magnitude of the loop gain i.e. the product of the transfer gain A of amplifier and magnitude of the feedback factor β of the feedback network is less than unity.

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ADVANTAGES

- It does not require transformers or inductors.
- It can be used to produce very low frequencies.
- It provides good frequency stability.
- Pure sine wave output is possible.

DISADVANTAGES

- It is difficult for the circuit to start oscillations as the feedback is generally small.
- The circuit gives small output.
- It requires high voltage battery V_{CC} =12V .

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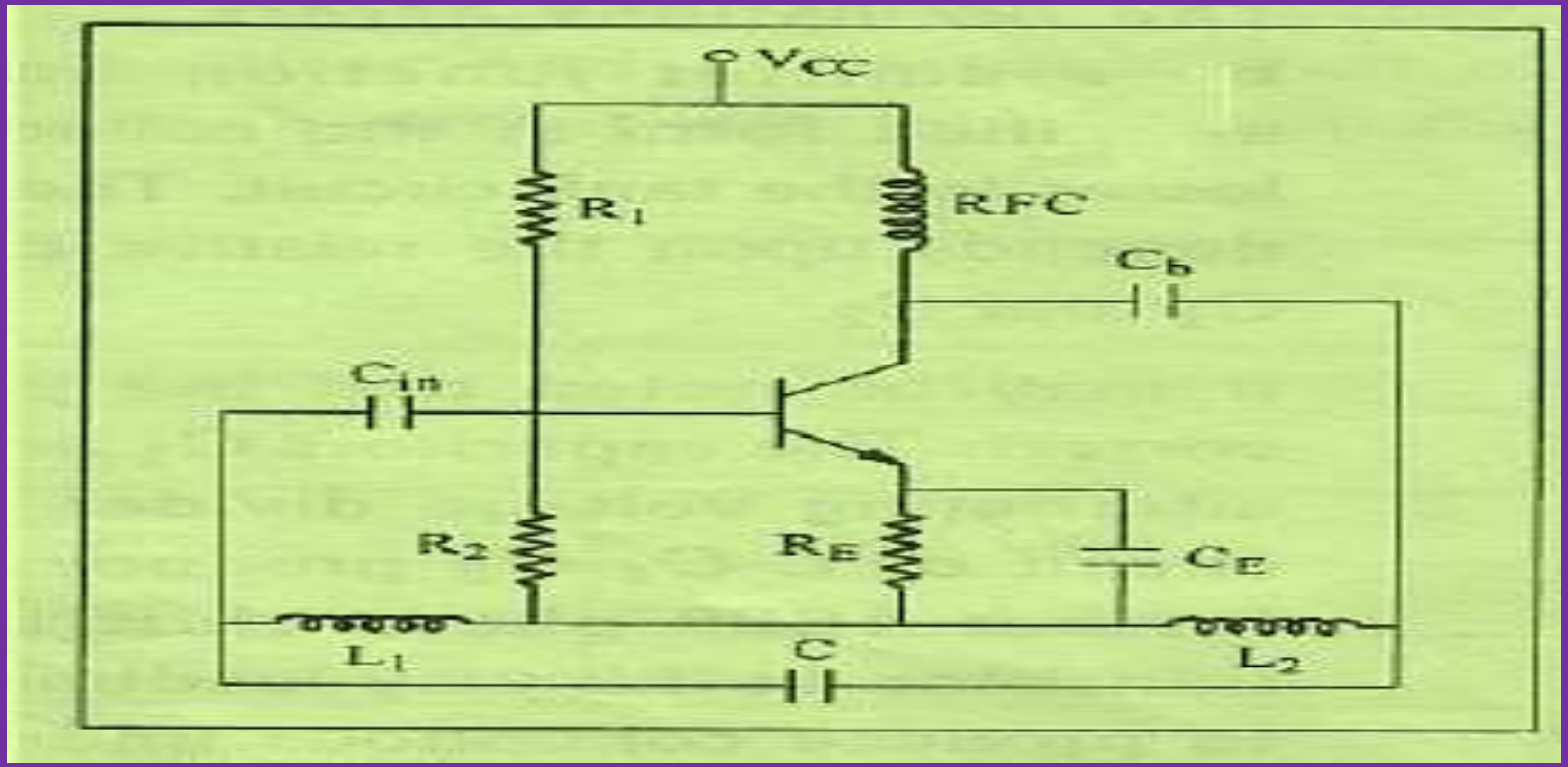
Hartley Oscillator



- This oscillator is very popular
- This is used as local oscillator in radio receivers.
- It uses inductive feedback

Circuit analysis

- Fig (1) shows the circuit of Hartley oscillator.
- The tank circuit is C, L_1 and L_2.
- The coil L_1 is inductively coupled to L_2, the combination functions as an autotransformer.
- The self bias is provided here for biasing.
- The capacitor C_b blocks the DC components

Circuit operation

- When the power is ON, collector current starts rising and charges the capacitor C.
- When this capacitor is fully charged, it discharges through coils L_1 and L_2 setting up Oscillations of frequency at

$$f = \frac{1}{2\pi\sqrt{(L_1 + L_2)C}}$$

- The oscillations across L1 are applied to the base emitter junction and appears in the amplified form in the collector circuit.

Circuit operation

- The coil L_2 couples the collector circuit energy back into the tank circuit by means of mutual inductance between L_1 and L_2.
- So energy is being continuously supplied to the tank circuit to over come the losses.
- The phase shift produced in the tank circuit constituting of C, L_1 and L_2 is (i.e, phase shift between the voltages developed across both the Inductors L_1 & L_2 is) 180^0.
- A further phase shift of 180^o is produced by transistor circuit.
- In this way energy fedback to the tank circuit is in phase with oscillations.

Condition For Sustained Oscillations

(Barkhausen Criterion)

Condition 1:

- Ignoring loading effect of the base, the feedback fraction is given by

$$\beta = L_2/L_1.$$

- For oscillations to start , the voltage gain must be greater than 1/ β which is equal to L_1/L_2.
- Sustained oscillations are produced if at the oscillation frequency the magnitude of the loop gain that is the product of the transfer gain A of amplifier and the magnitude of feedback factor β of the feedback network is greater than unity.

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Condition 2:

- Phase shift in Auxiliary Oscillators Circuit should be 180º.
- A further phase shift of 180º is produced by transistor circuit.
- In this way energy feedback to the tank circuit is in phase with oscillations, so phase shift between the input and output signals is equal to 360° or 0°.
- Sustained oscillations are produced in this Hartley oscillator at a frequency for which the total phase shift introduce has the signal travels from the input terminal through the basic amplifier feedback network and mixing network back to the input terminals is precisely zero or an integral multiple of 2π radians.

Expression for frequency of oscillations

- The frequency of oscillations produced in the tank circuit of Hartley oscillator is given by

$$f = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

Where $L = L_1 + L_2 + 2M$

$= L_1 + L_2$ (if the mutual inductance M neglected).

Advantages

- Easy to tune.
- Adaptability to a wide range of frequencies.
- Used as a local oscillator in radio receivers.
- The frequency is varied using a variable capacitor.
- The output amplitude remains constant over the frequency range.
- The feedback ratio of the tapped inductor remains constant.

Disadvantages

- Harmonic-rich content of the output.
- It is not suitable for a pure sine wave.

Uses

The Hartley oscillator was extensively used on all broadcast bands including the FM 88-108MHz band.

COLPITS OSCILLATOR

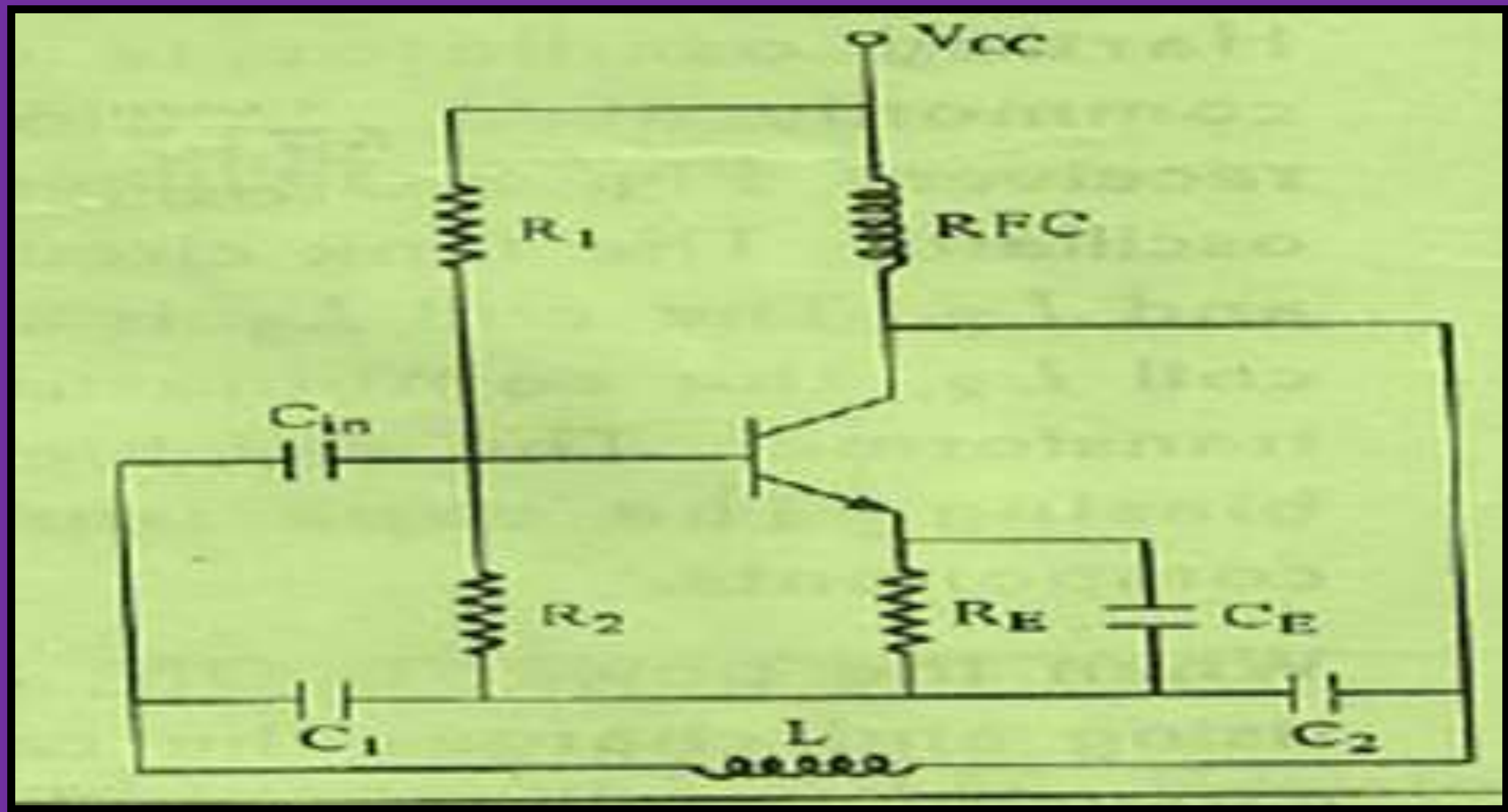


Fig.1

- Fig.1 shows the circuit of Colpitts oscillator.
- The tank circuit is made up of C_1, C_2 and L.

Circuit operation

- When power is ON, collector current starts rising and charges the capacitor C_1 and C_2.
- When these capacitors are fully charged, it discharges through coil L_1 setting up oscillations.
- The oscillations across C_2 are applied to the base-emitter junction and appears in the amplified form in the collector circuit to supply losses to the tank circuit.
- The amount of feedback depends upon the values of C_1 and C_2.
- The phase of feedback is correct, the tank circuit comprising of L, C_1 and C_2 produce 180^o phase shift.
- A further 180^o phase shift is provided by the transistor.
- In this way feedback is properly provided to produce continuous undamped oscillations.
- The frequency of oscillations is given by

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

Where

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

Condition For Sustained Oscillations

(Barkhausen Criterion)

Condition 1:

- Ignoring loading effect of the base, the feedback fraction is given by $\beta = C_1/C_2$.

- For oscillations to start, the voltage gain must be greater than 1/ β which is equal to C_2/C_1.

- Sustained oscillations are produced if at the oscillation frequency the magnitude of the loop gain that is the product of the transfer gain A of amplifier and the magnitude of feedback factor β of the feedback network is greater than unity.

Condition 2:

- The phase of feedback is correct , the tank circuit of L ,C_1 and $C_2$are 180° out of phase.
- A further phase shift of 180° is produced by transistor circuit.
- In this way energy feedback to the tank circuit is in phase with oscillations so phase shift between the input and output signals is equal to 360° or 0°.
- Sustained oscillations are produced in this colpittsoscillator at a frequency for which the total phase shift introduce has the signal travels from the input terminal through the basic amplifier feedback network and mixing network back to the input terminals is precisely zero or an integral multiple of 2π radians.

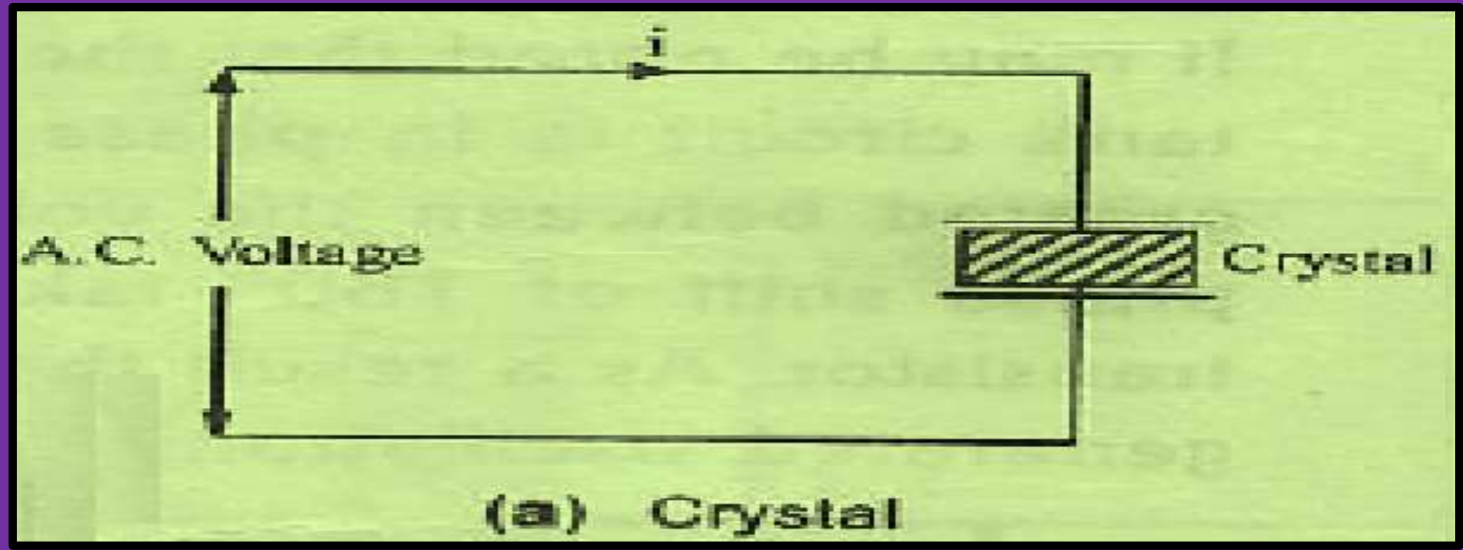
Piezo Electric Crystals

- Certain crystalline materials, exhibit the piezoelectric effect. Namely rochelle salt, quartz and tourmaline.
- When we apply an A.C. voltages across them, they vibrate at the frequency of the applied voltage.
- If the crystals are forced mechanically to vibrate, they generate an E.M.F at the fundamental frequency of the crystal.

Piezoelectric Effect

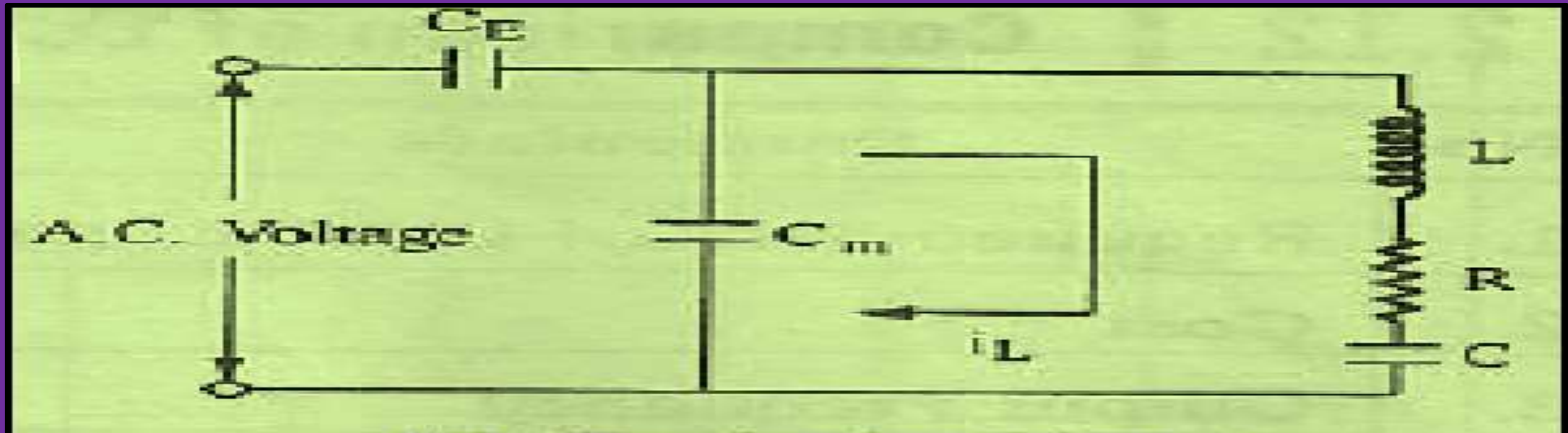
- Removal of the forces releases strain within the crystal, and hence current flow to re-establish zero potential across the electrodes.
- Mechanical to electrical energy conversion (generator action) occurs if alternating tensile and compressive forces are applied.
- Application of a voltage across the electrodes can have a reverse effect, inducing mechanical deformation of the crystal and hence electrical to mechanical conversion (motor action)

Working of quartz crystal



- In order to use crystal in an electronic circuits, it is placed between two metal plates.
- The arrangement then form as a capacitor with the crystal as the dielectric as shown in figure.
- If an ac voltage is applied across the plates, the crystal will start vibrating at the frequency of applied voltage.

- However , if the frequency of applied voltage is made equal to the natural frequency of the crystal resonance takes place and crystal vibrations reach maximum value.
- This natural frequency is almost constant.
- Effects of temperature change can be eliminated by the crystal in a temperature-controlled oven as in radio and television transmitters.



(b) Equivalent Circuit

Equivalent circuit of crystal

- Although the crystal has electromechanical resonance, we can represent the crystal action by an equivalent electrical circuit.
- When the crystal is not vibrating , it is equivalent to capacitance Cm because it has two metal plates separated by a dielectric.
- This capacitance is known as mounting capacitance.
- When a crystal vibrates, it is equivalent to R-L-C series circuit.
- Therefore, the equivalent circuit of a vibrating crystal is R-L-C series circuit shunted by the mounting capacitance Cm as shown in figure.

- The frequency at which the vibrating crystal behaves as a parallel resonant circuit is called parallel resonant frequency f_p.

$$f_p = \frac{1}{2\pi\sqrt{LC_T}}$$

where

$$C_T = \frac{CC_m}{C + C_m}$$

- Two uses for this device :
  - Used to clock the microcontroller.
  - Used to modulate the driver signal in the range between 10MHz and 50MHz.

Frequency response of crystal

- The capacitance values of C_s and C_p are relatively low.
- As frequency is increased RLC branch approaches its resonant frequency.
- At some definite frequency the reactance X_L will be equal to X_{cs} the crystal now act as series resonant circuit.
- For this condition the impedance of the crystal is very low being equal to r.
- The frequency at which the vibrating crystal behaves as a series resonant circuit is called series resonant frequency f_s

$$f_s = \frac{1}{2\pi\sqrt{LC_s}}$$

Frequency response of crystal

- At a slightly higher frequency the net reactance of branch RLC becomes inductive and equal to X_p
- The crystal now acts as parallel resonant circuit.
- For this condition the crystal offers very high impedance.
- The frequency at which the vibrating crystal behaves as a fp.

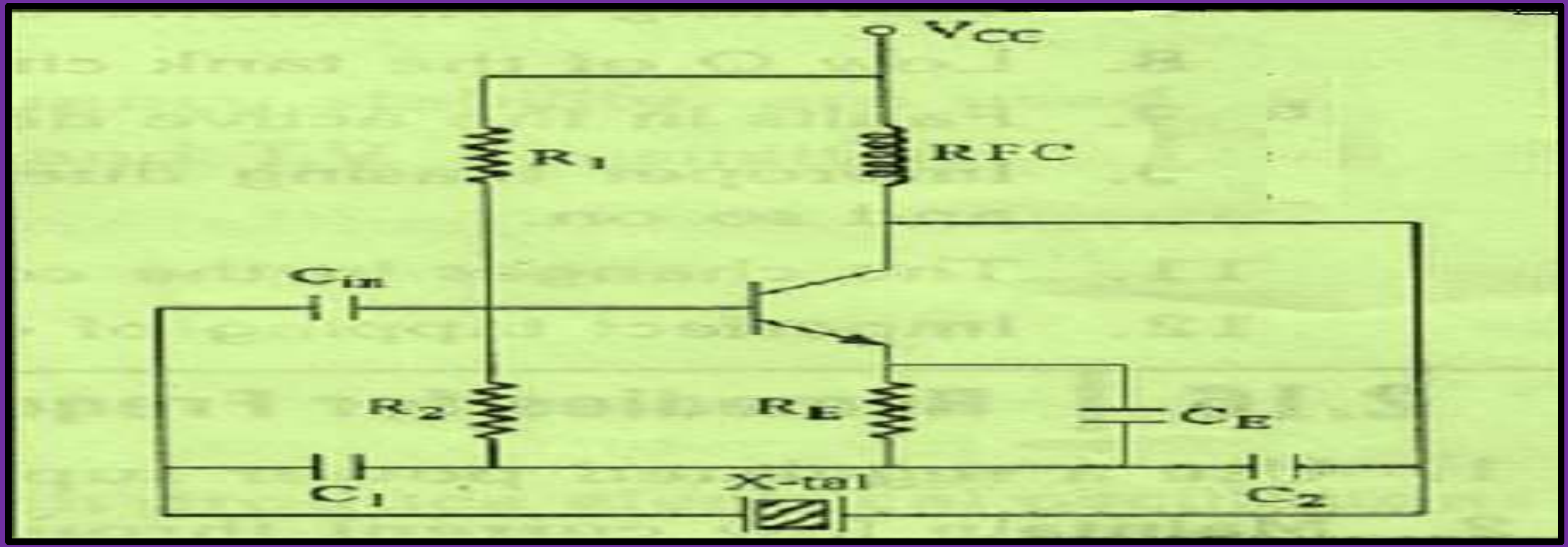
$$f_p = \frac{1}{2\pi\sqrt{LC_T}}$$

where $$C_T = \frac{C_s C_p}{C_s + C_p}$$

Frequency response of crystal

- Since C_T is less than C_s, f_p is always greater than f_s note that frequencies f_s and f_p are close to each other.
- At frequencies greater than f_p the value of X_p drops and the crystal act as short circuit.
- In order to use the crystal properly it must be connected in a circuit so that its low impedance in the series resonant operating mode or high impedance in the parallel resonant operating mode is selected.

Transistor Crystal Oscillator



- This circuit is same as Colpitts oscillator.
- The crystal is mounted to act as an inductor which forms the tuned circuit with C_1 and C_2
- The positive feedback is provided by the capacitive voltage divider network.
- The crystal now act as an inductor that resonant with C_1 and C_2

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Transistor Crystal Oscillator

- The oscillating frequency of the circuit now lies in between series and parallel resonant frequencies of the crystal.
- In this circuit the crystal is connected as a series element in the feedback path from collector to the base.
- The resistors R_1, R_2 are usedfor biasing and R_E for stabilization.
- The CE configured transistor provides 180^0 phase shift where as the remaining 180^0 phase shift is provided by the feedback network.

Advantages

- It can produce highest oscillating frequencies.
- The quality factor (Q) of the crystal is very high.
- They have a high order of frequency stability.
- Low cost.
- Simple in construction.

Disadvantages

- They are less fragile and consequently can only be used in low power circuits.
- The frequency of oscillations can not be changed appreciably.

Applications of crystal oscillators

The crystal oscillator because of its excellent frequency stability, are used

- For generation of carrier frequencies in radio and T.V transmitters.
- In temperature controlled ovens.
- In precision electronic wrist watches.
- In digital clocks.
- In maintaining precision time standards.

Frequency Stability

- The ability of an oscillator to maintain a constant frequency of oscillations is called frequency stability.

Frequency Instability

- Over a period of time the output of an oscillator may not remain constant for various reasons.
- The change in frequency of oscillations in an oscillator over a period of time is known as frequency instability.

Reasons for frequency Instability

- Oscillators in which the oscillations were produced by the oscillatory circuit containing R C or L C were discussed.

THANKS!