Chapter Four

Oscillators

Need of an Oscillator

- An oscillator circuit is capable of producing ac voltage of desired frequency and waveshape.
- To test performance of electronic circuits, it is called signal generator.
- It can produce square, pulse, triangular, or sawtooth waveshape.
- High frequency oscillator are used in broadcasting.
- Microwave oven uses an oscillator.
- Used for induction heating and dielectric heating.

Types of Oscillators

- Sinusoidal or non-sinusoidal.
- An oscillator generating square wave or a pulse train is called multivibrator :
  1. Bistable multivibrator (Flip-Flop Circuit).
  2. Monostable multivibrator.
  3. Astable multivibrator (Free-running).
- Depending upon type of feedback, we have
  1. Tuned Circuit (*LC*) oscillators.
  2. *RC* oscillators, and
  3. Crystal oscillators.

Using Positive Feedback

- The gain with positive feedback is given as

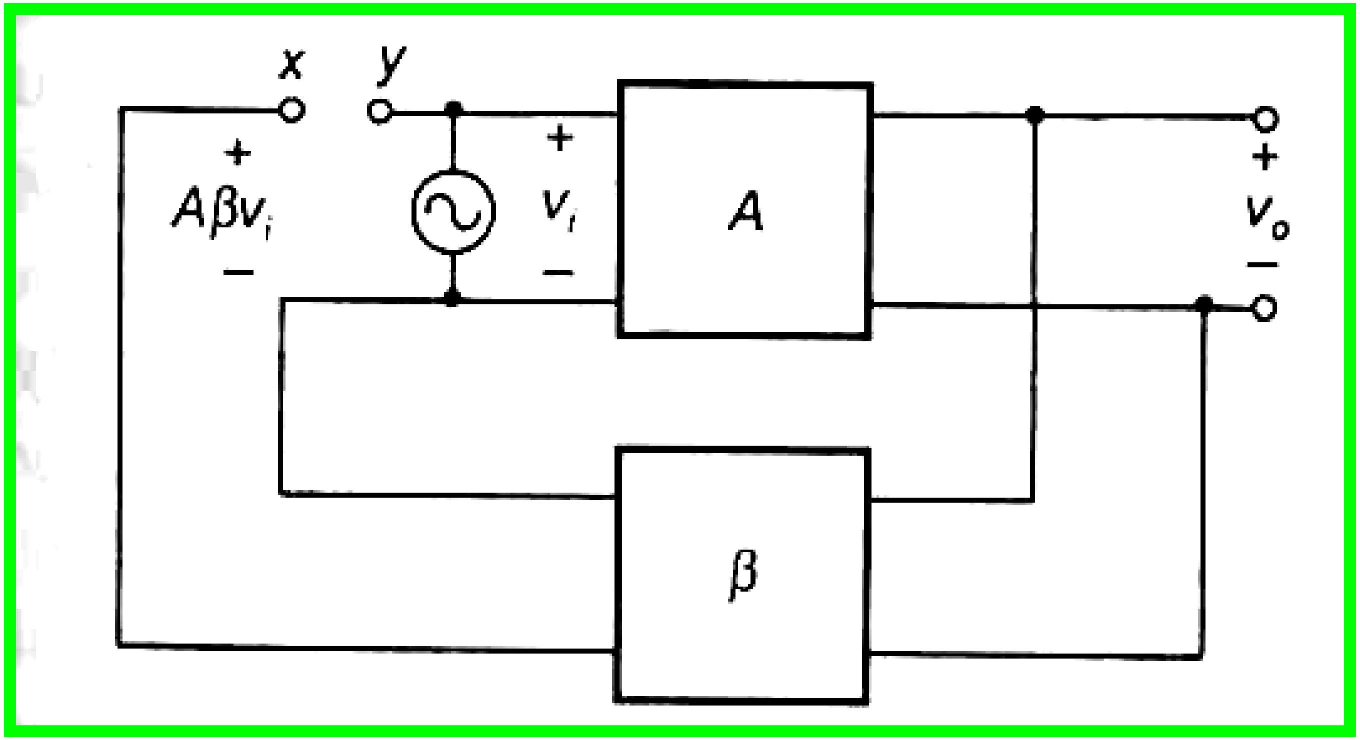
$$\boxed{A_f = \frac{A}{1 - A\beta}}$$

- By making $1 - A\beta = 0$, or $A\beta = 1$, we get gain as infinity.

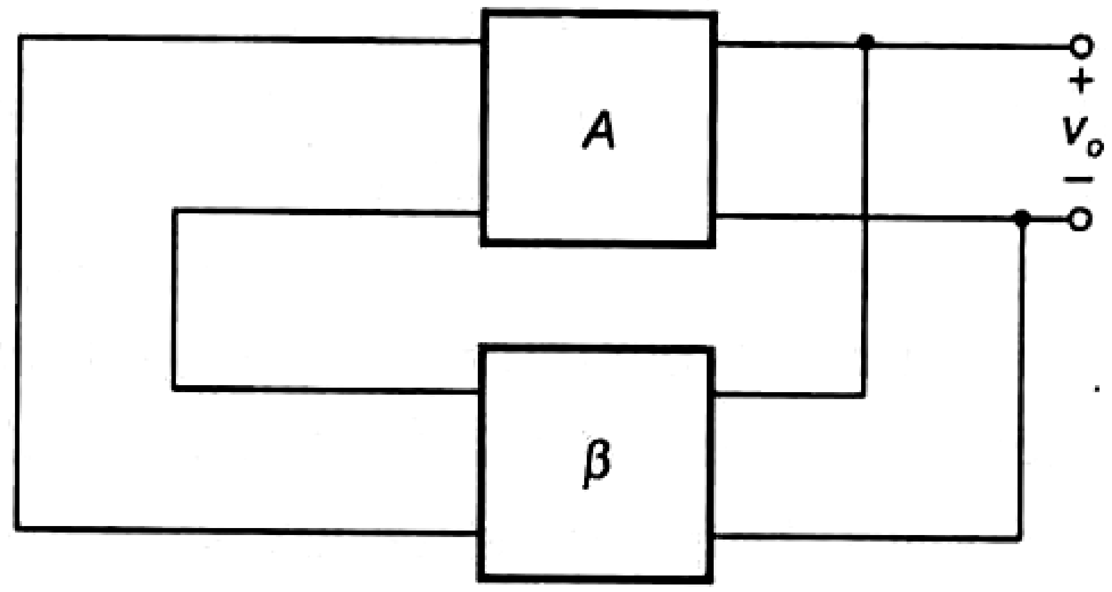
- This condition ($A\beta = 1$) is known as Barkhausen Criterion of oscillations.

- It means you get output without any input !

How is it Possible ?

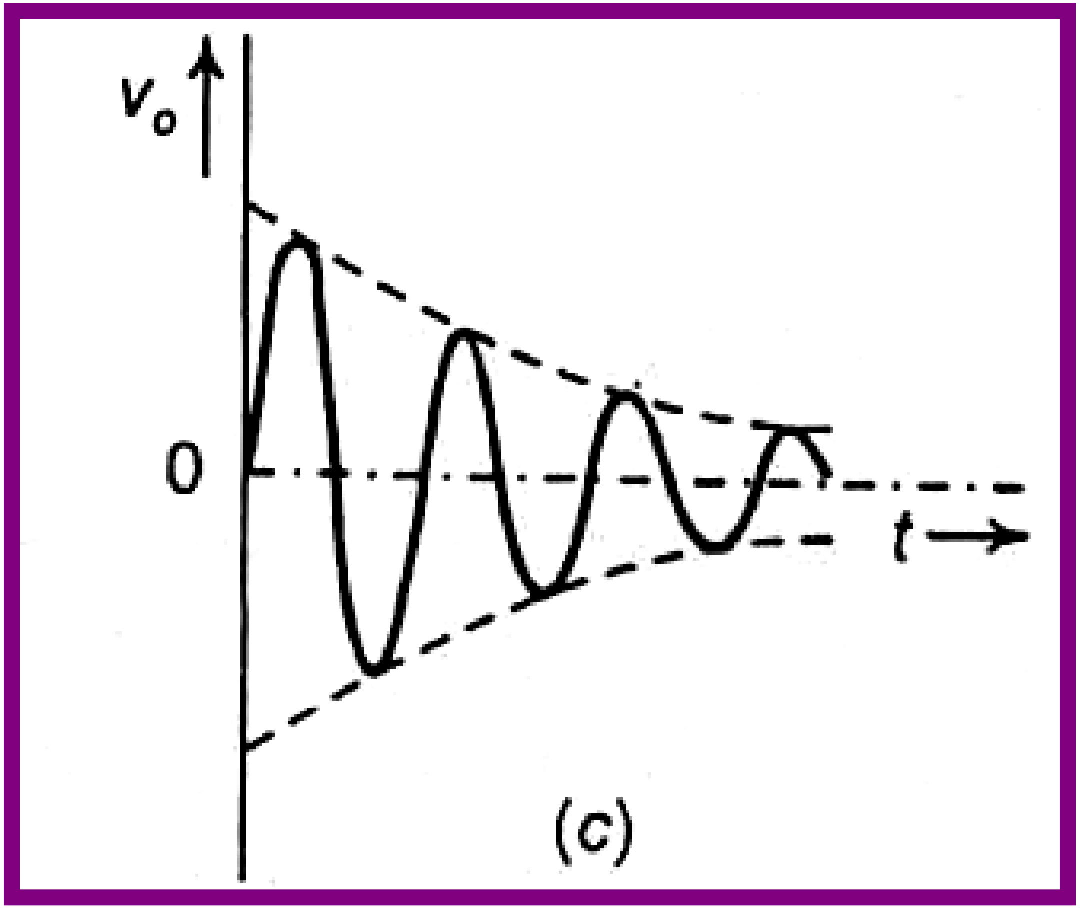


Connecting point *x* to *y*, feedback voltage drives the amplifier.

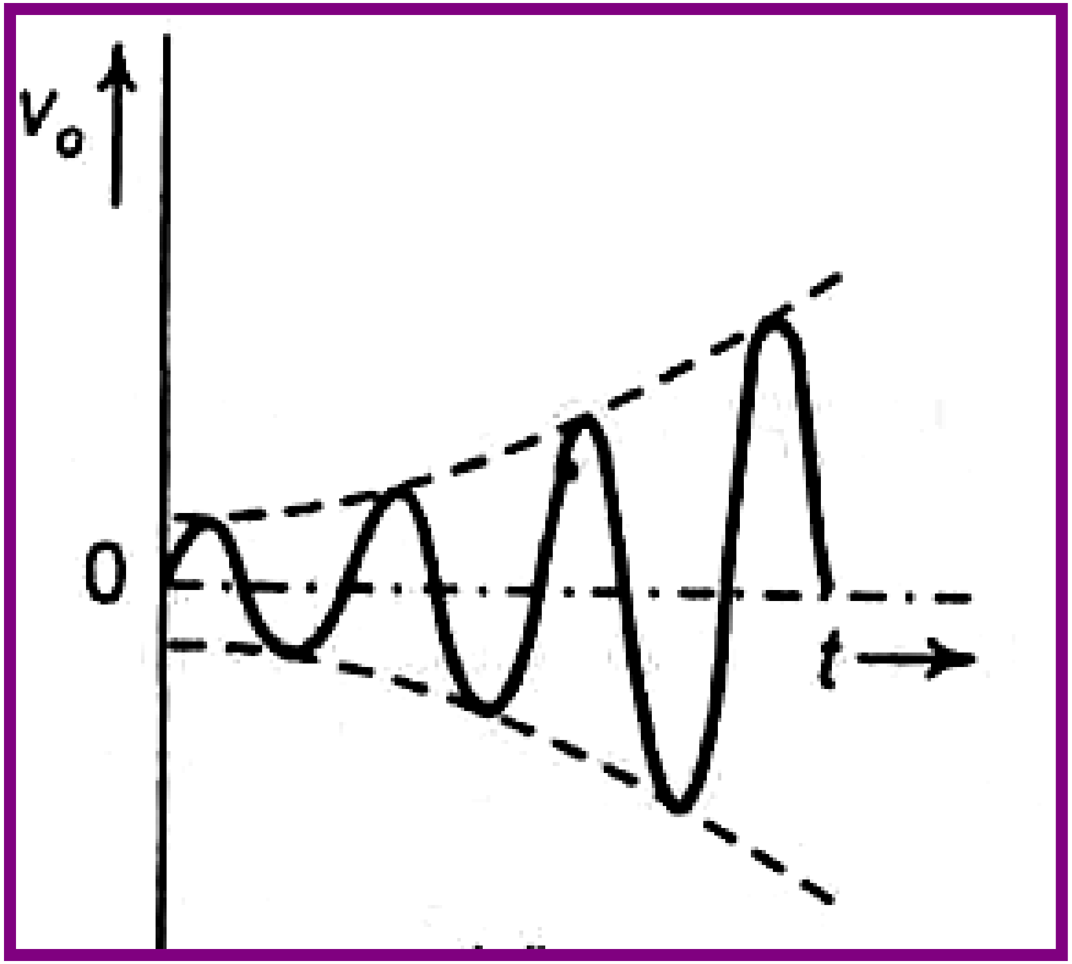


- What happens to the output ?
- There are three possibilities.

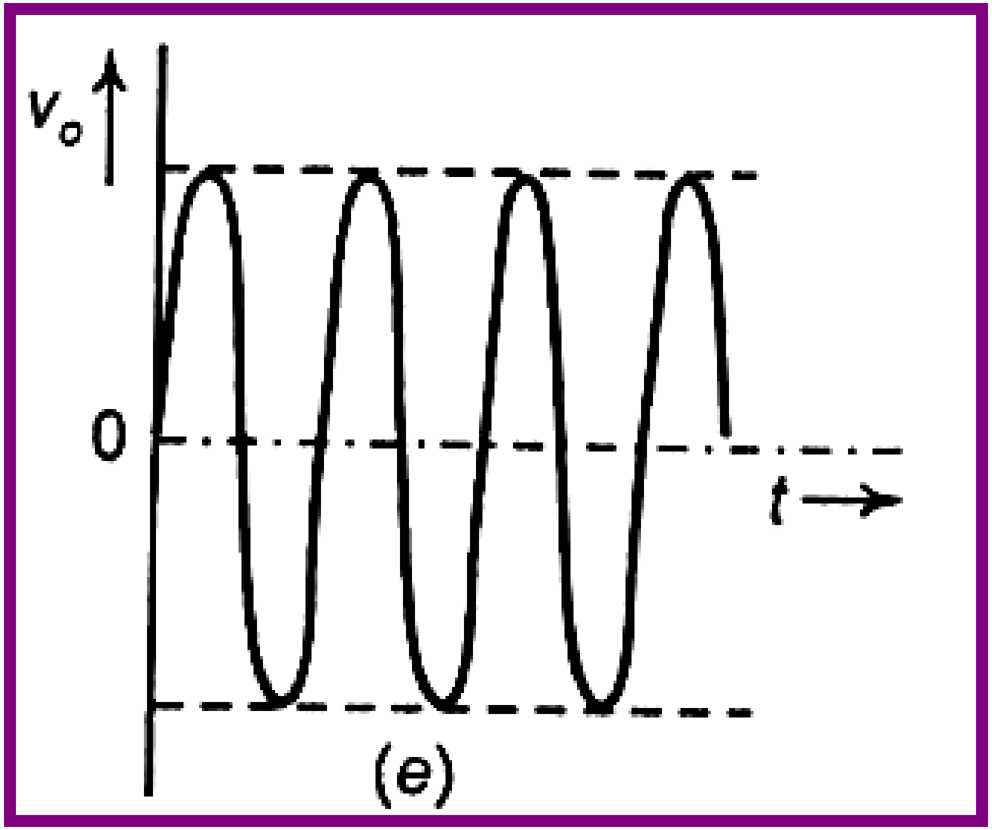
(1) If $A\beta < 1$, we get decaying of damped oscillations.



(2) If $A\beta > 1$, we get growing oscillations.



(3) If $A\beta = 1$, we get sustained oscillations. In this case, the circuit supplies its own input signal.



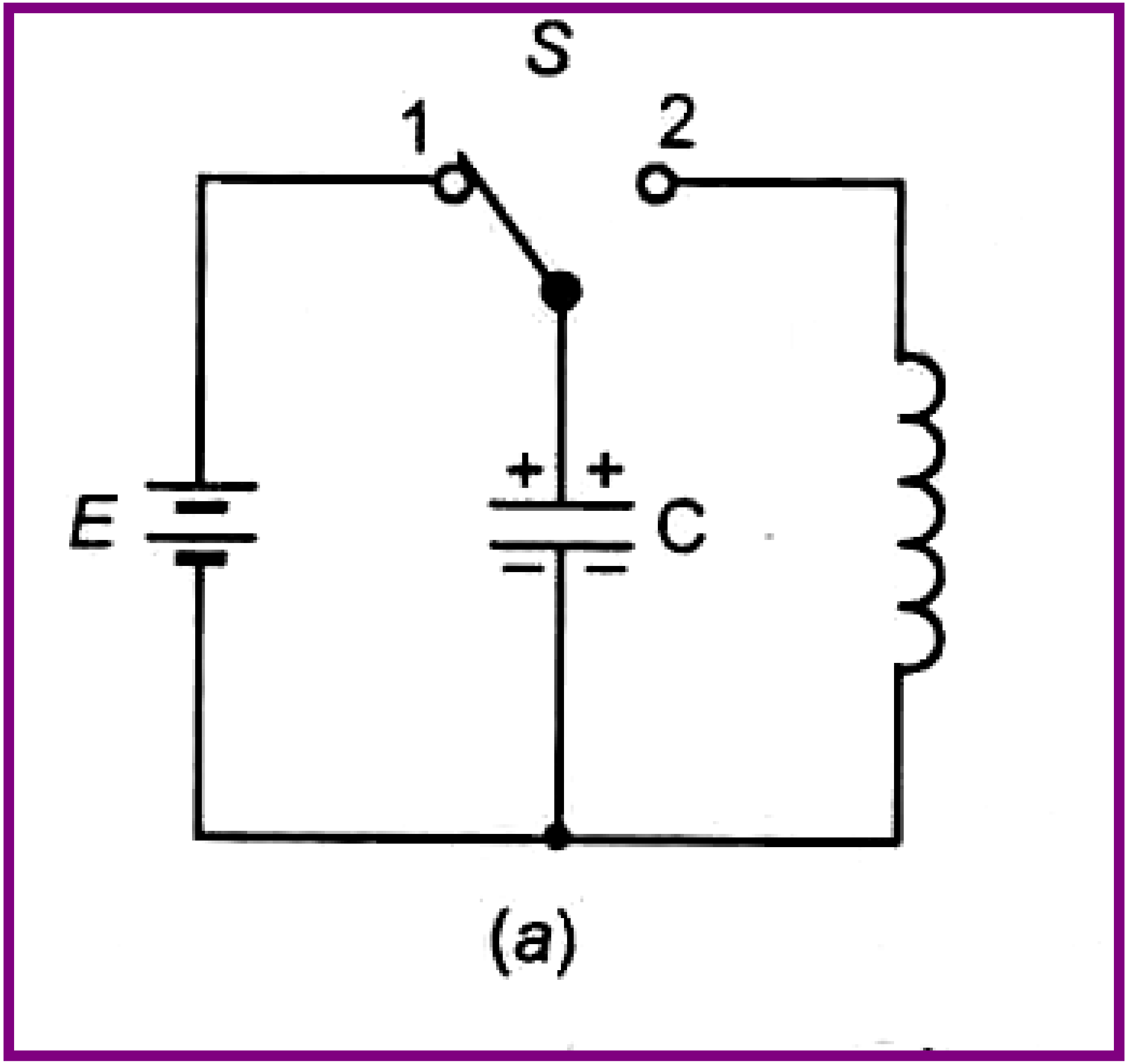
Wherefrom comes the starting voltage ?

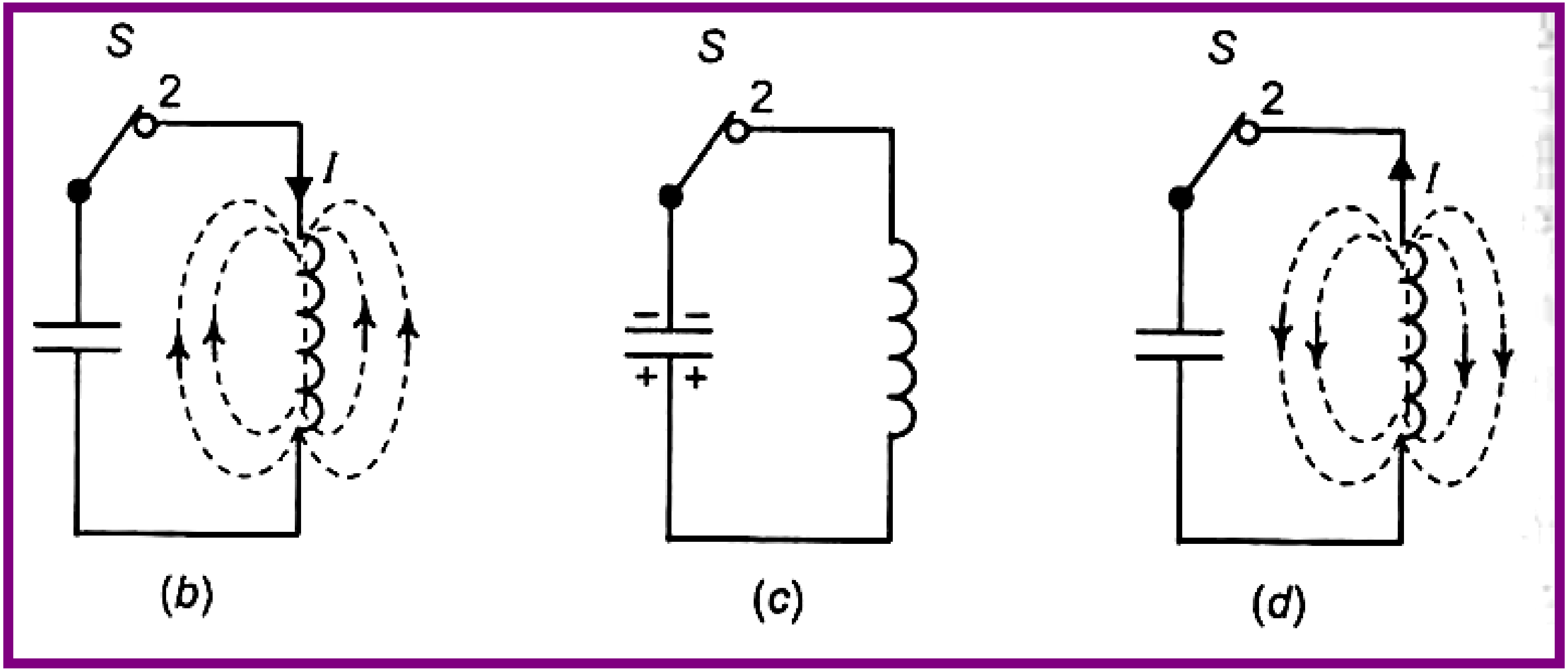
- Each resistor is a noise generator.
- The feedback network is a resonant circuit giving maximum feedback voltage at frequency f_0, providing phase shift of 0° only at this frequency.
- The initial loop gain $A\beta > 1$.
- The oscillations build up only at this frequency.
- After the desired output is reached, $A\beta$ reduces to unity.

Tank Circuit

- *LC* parallel circuit is called tank circuit.
- Once excited, it oscillates at

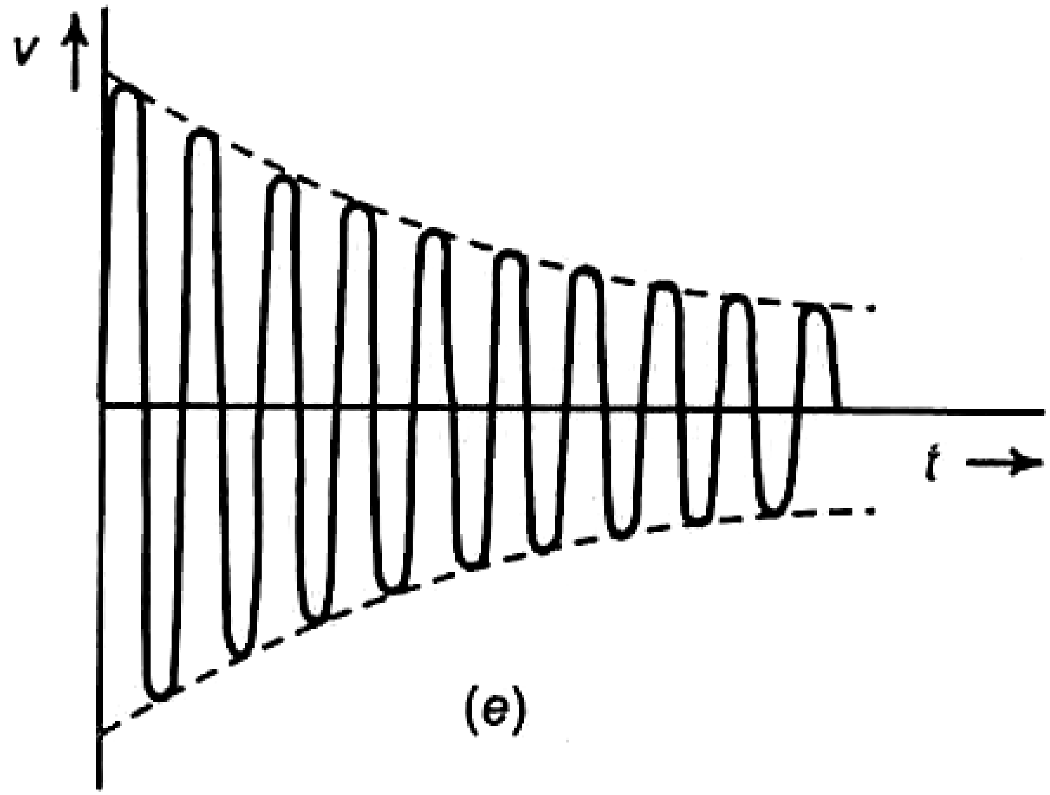
$$\boxed{f_0 = \frac{1}{2\pi\sqrt{LC}}}$$


S
1
2
E
C
+
+
(a)

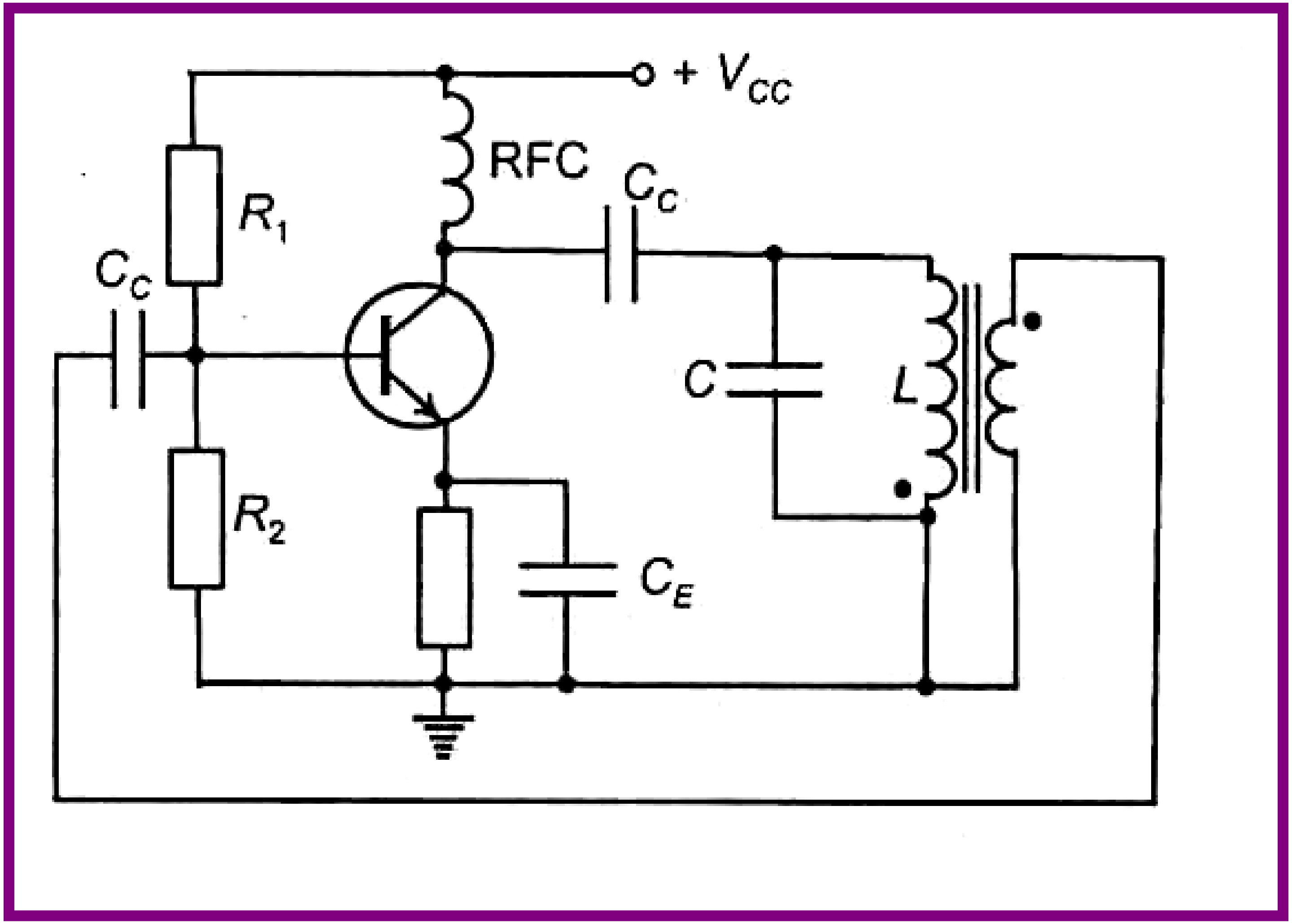


The energy keeps oscillating between electric potential energy and magnetic filed energy.

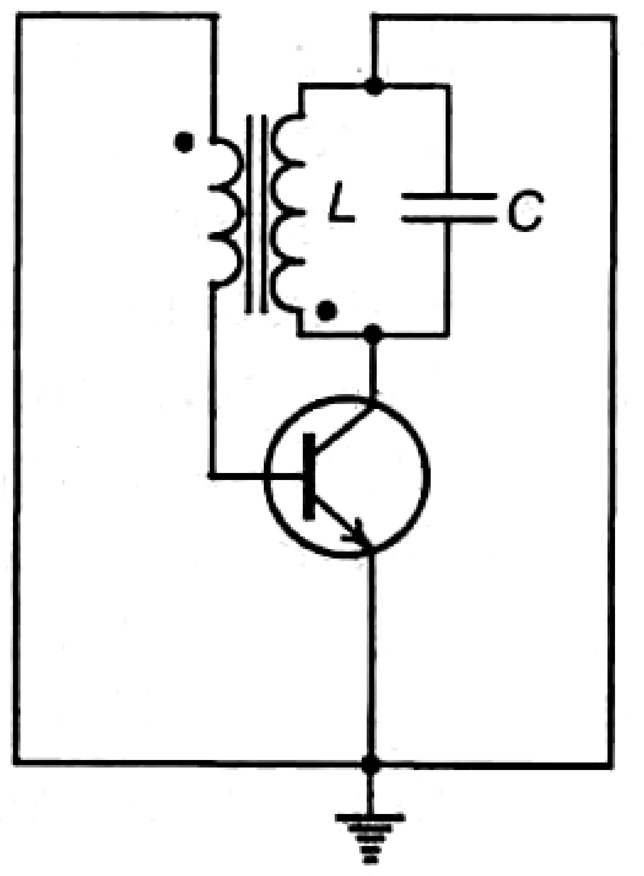
Damped oscillations are produced.



Tuned Collector Oscillator



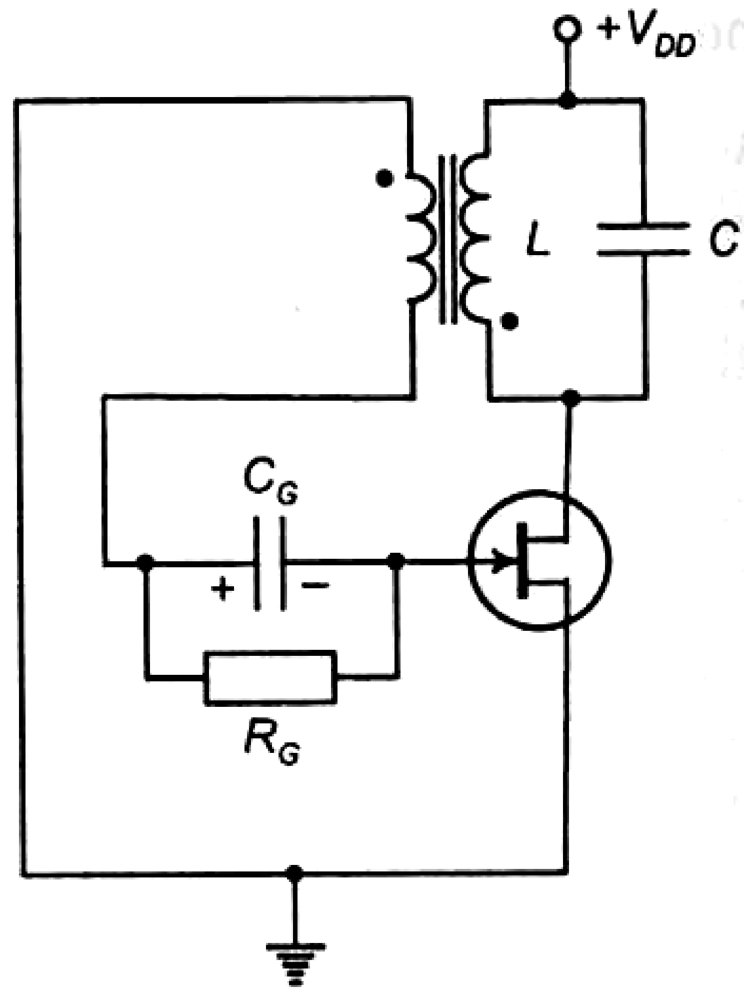
Same circuit from ac point of view.



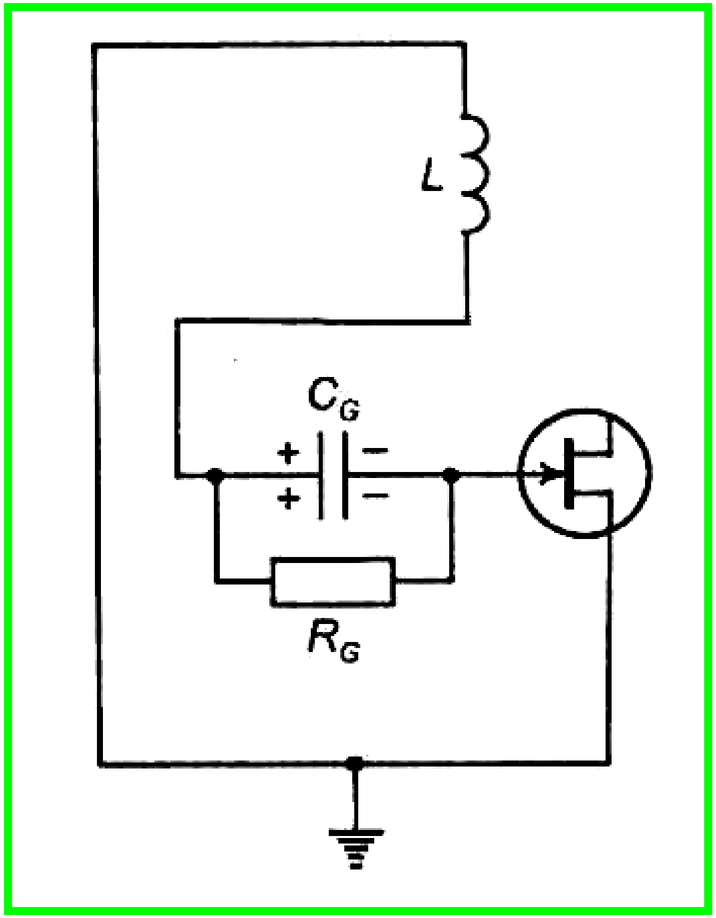
$$\beta = \frac{M}{L}$$

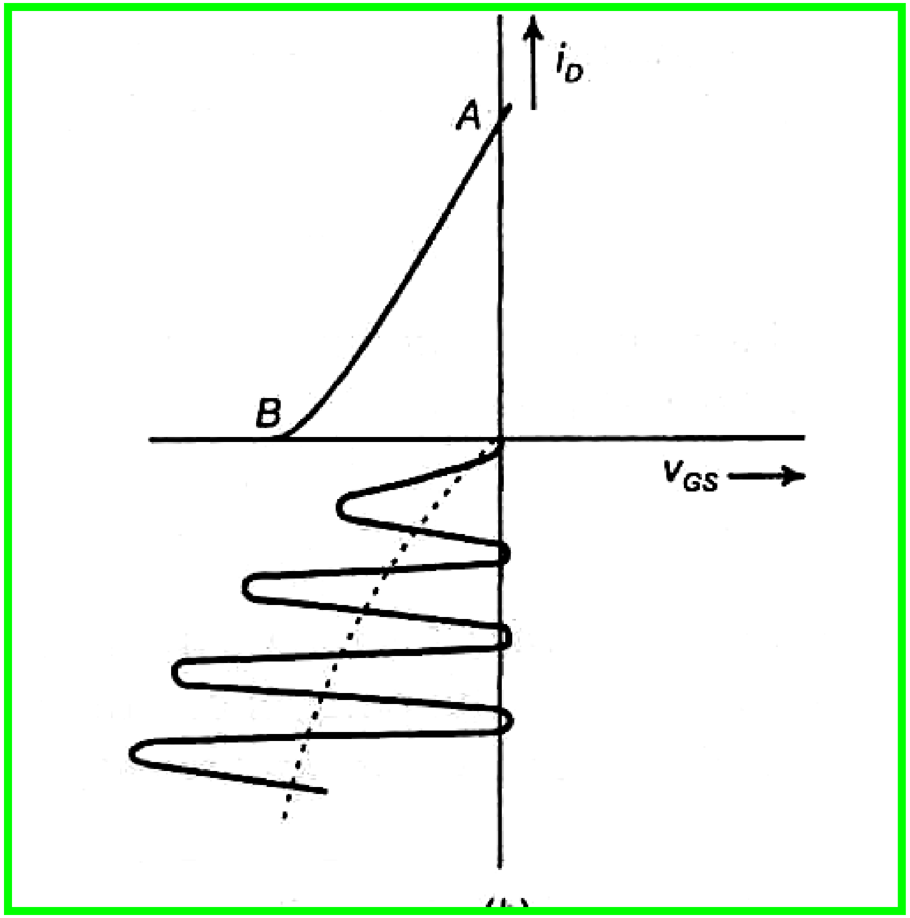
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Tuned-Drain Oscillator

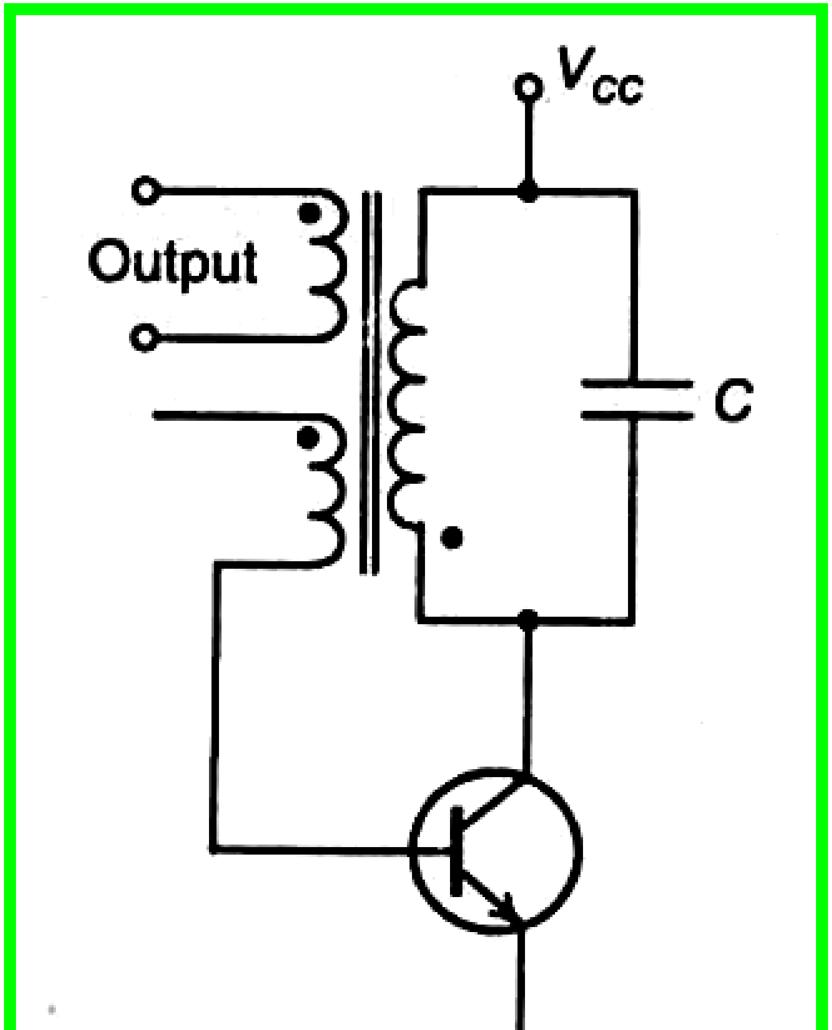


Building of oscillations using gate-leak biasing





How to take Output ?



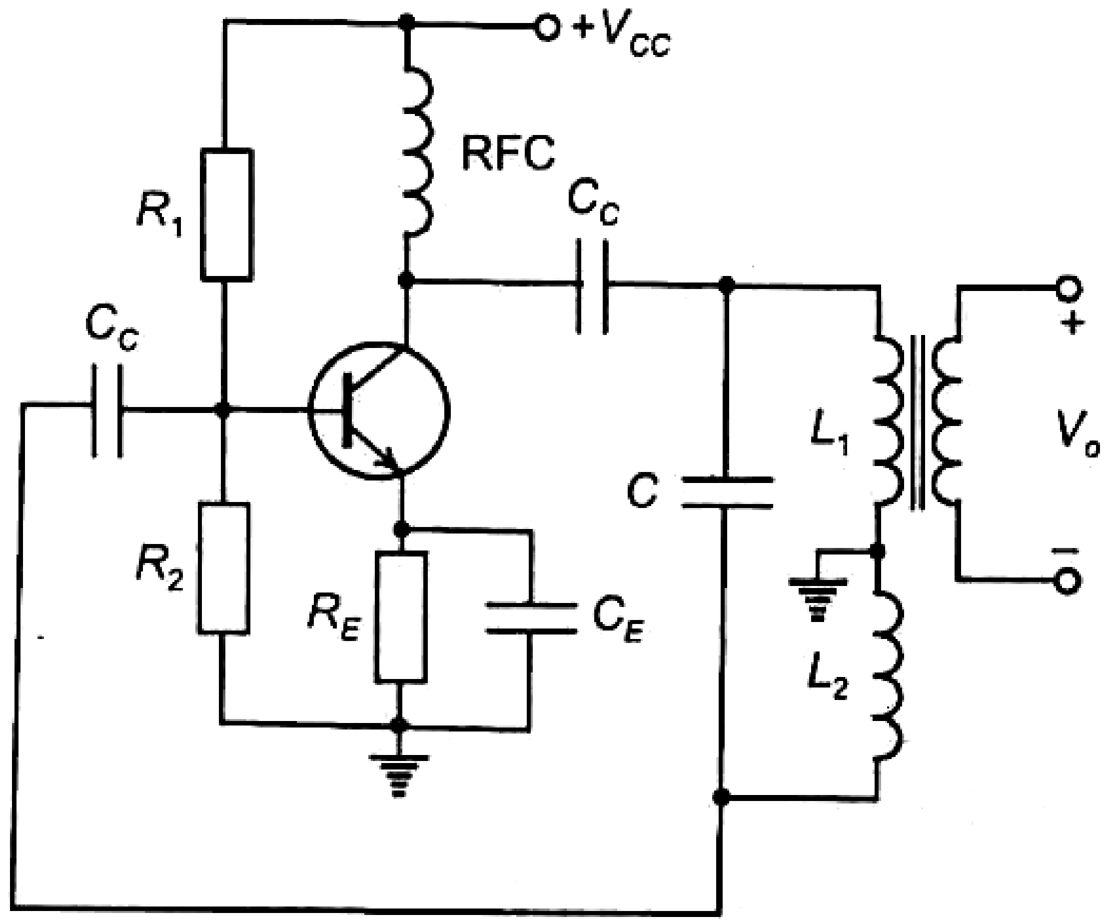
Example 12.1 The local oscillator of a radio receiver is a tuned-collector oscillator circuit with $L = 55\ \mu H$, and $C = 300\ pF$. Calculate the frequency of oscillations.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{55\times10^{-6}\times300\times10^{-12}}} = \mathbf{1239\ kHz}$$

Hartley Oscillator

- Note that in the collector-tuned circuit, two inductor coils are used.
- One end of these coils is grounded.
- If we make the tickler coil an integral part of the circuit, we get Hartley Oscillator.

Hartley Oscillator



- When the tank circuit resonates, the circulating current flows through L_1 in series with L_2. Hence the equivalent inductance is

$$\boxed{L = L_1 + L_2} \Rightarrow \boxed{f_0 = \frac{1}{2\pi\sqrt{LC}}}$$

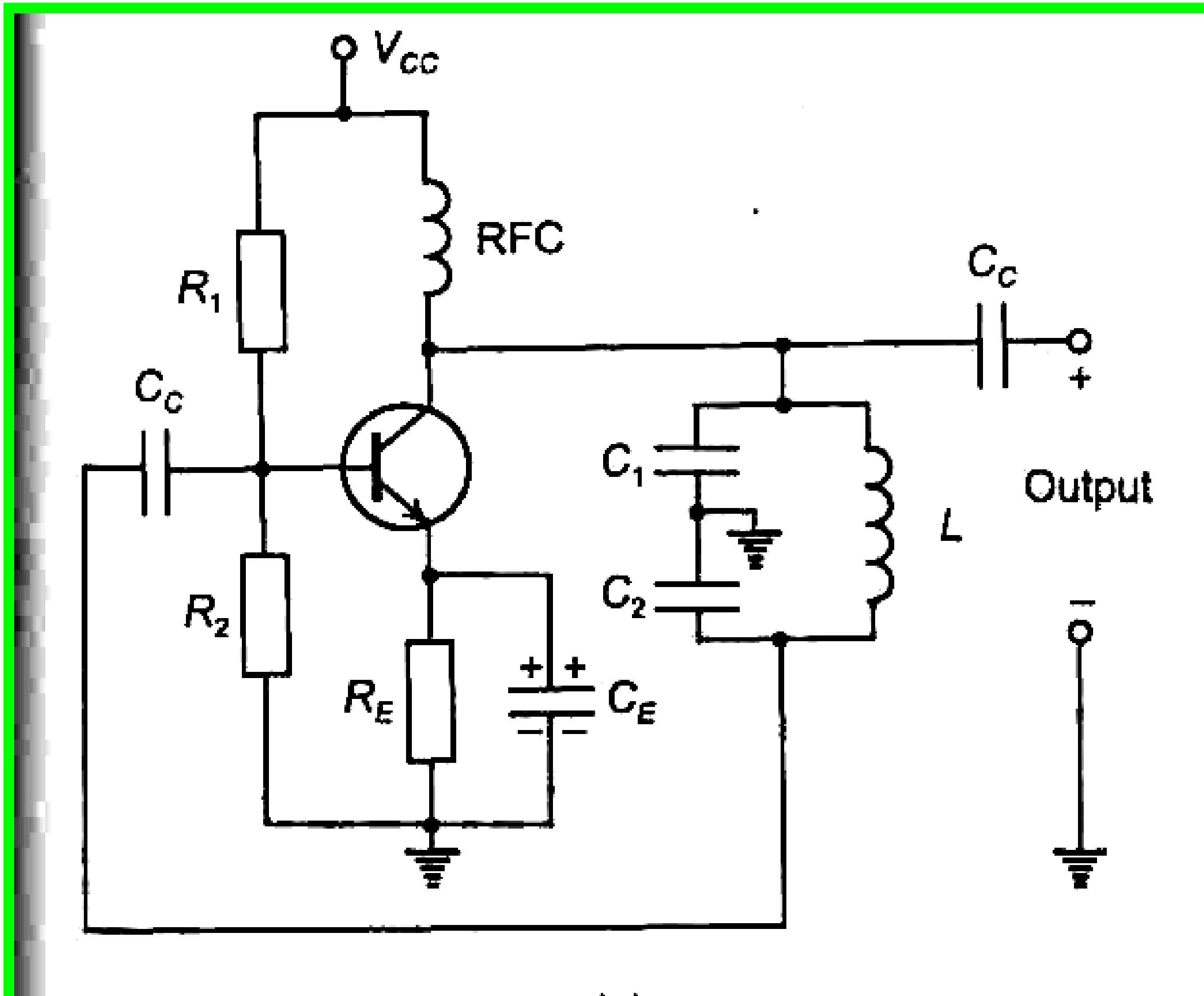
The feedback factor is

$$\boxed{\beta = \frac{L_2}{L_1}}$$

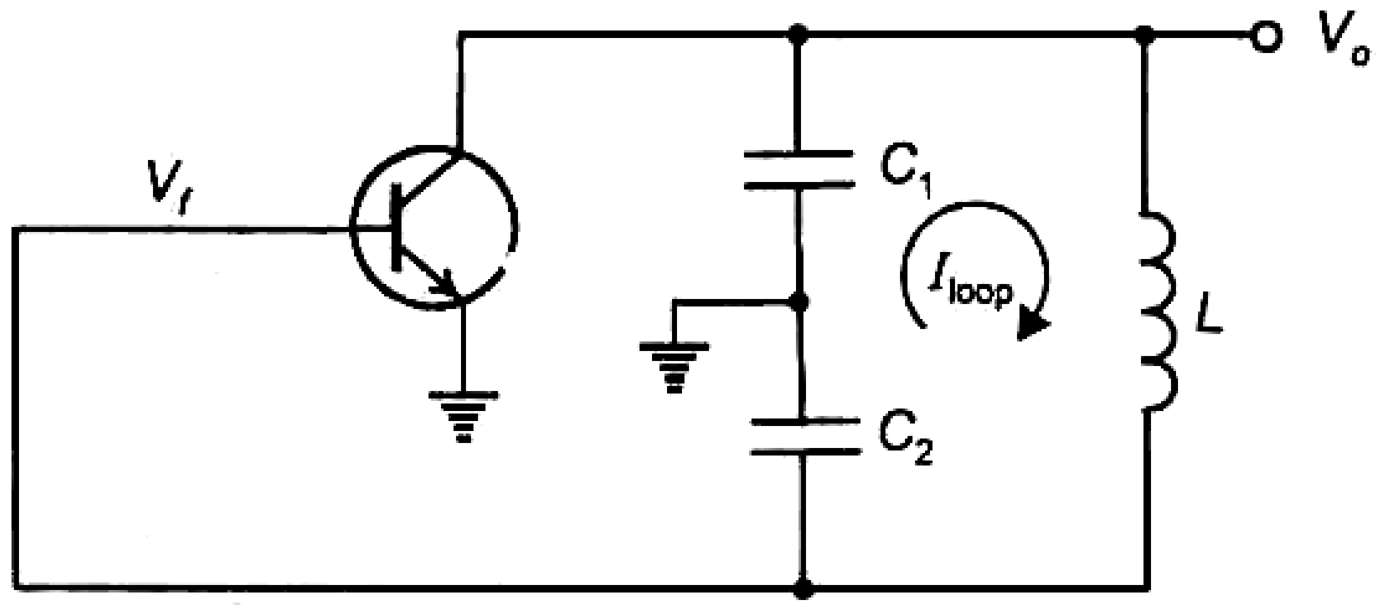
Colpitts Oscillator

- An excellent circuit.
- Widely used in commercial signal generators.
- Uses two capacitors instead of the inductive voltage divider.

Colpitts Oscillator



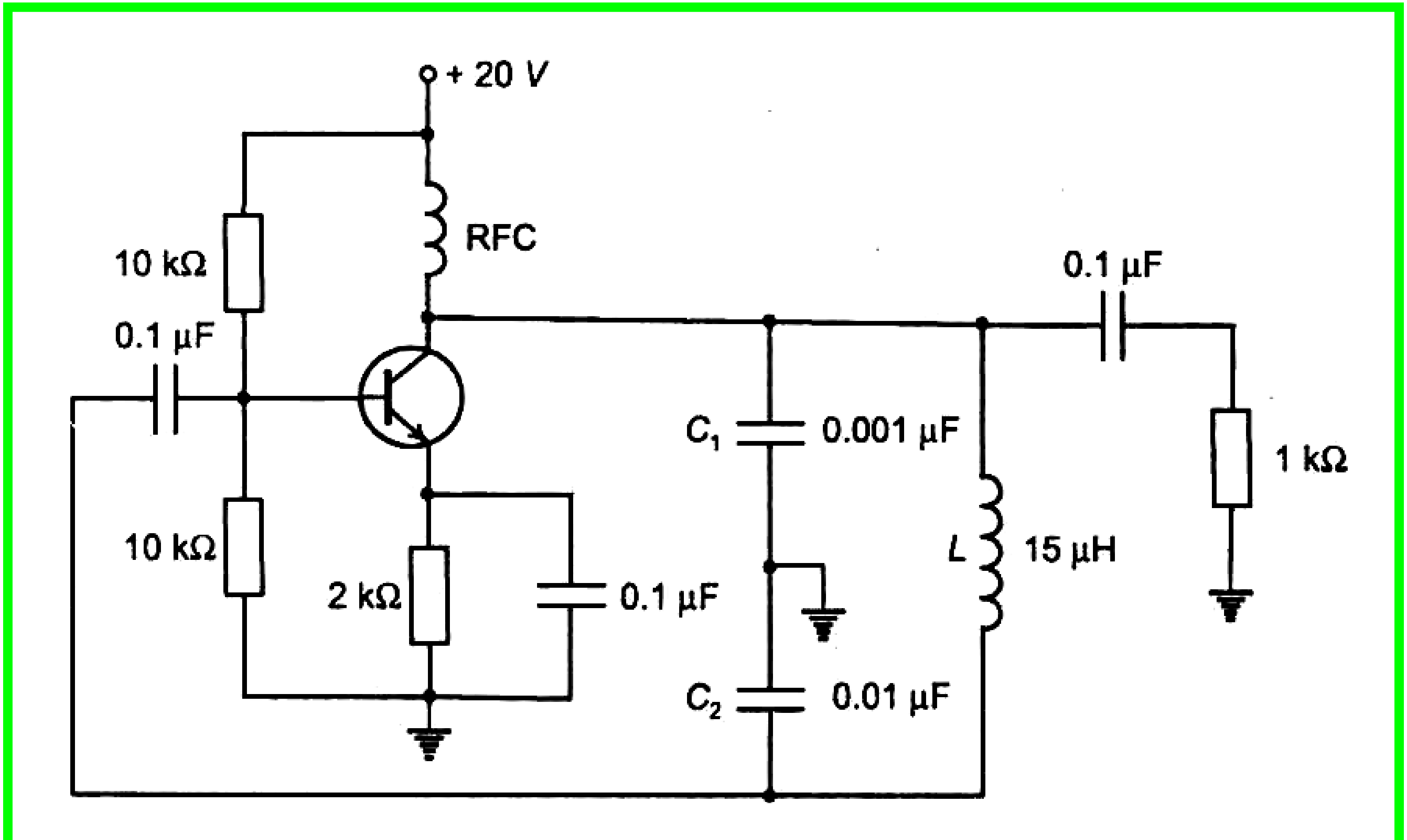
Its AC Equivalent



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

$$\beta = \frac{1/\omega C_2}{1/\omega C_1} = \frac{C_1}{C_2}$$

Example 12.2 For the oscillator circuit given in Fig. 12.10, calculate (a) the frequency of oscillation, and (b) the feedback factor. (c) How much voltage gain does the circuit need to start oscillating ?



Solution :

The equivalent capacitance of the tank circuit is

$$C = \frac{(0.001\,\mu F)(0.01\,\mu F)}{0.001\,\mu F + 0.01\,\mu F} = 909\,pF$$

(a) Since the inductance is 15 µH, the frequency of oscillation is given as

$$f_0 = \frac{1}{2\pi\sqrt{(15\,\mu H)(909\,pF)}} = \mathbf{1.36\ MHz}$$

(b) The feedback factor is given as

$$\beta = \frac{C_1}{C_2} = \frac{0.001\,\mu\text{F}}{0.01\,\mu\text{F}} = \mathbf{0.1}$$

(c) minimum voltage gain of

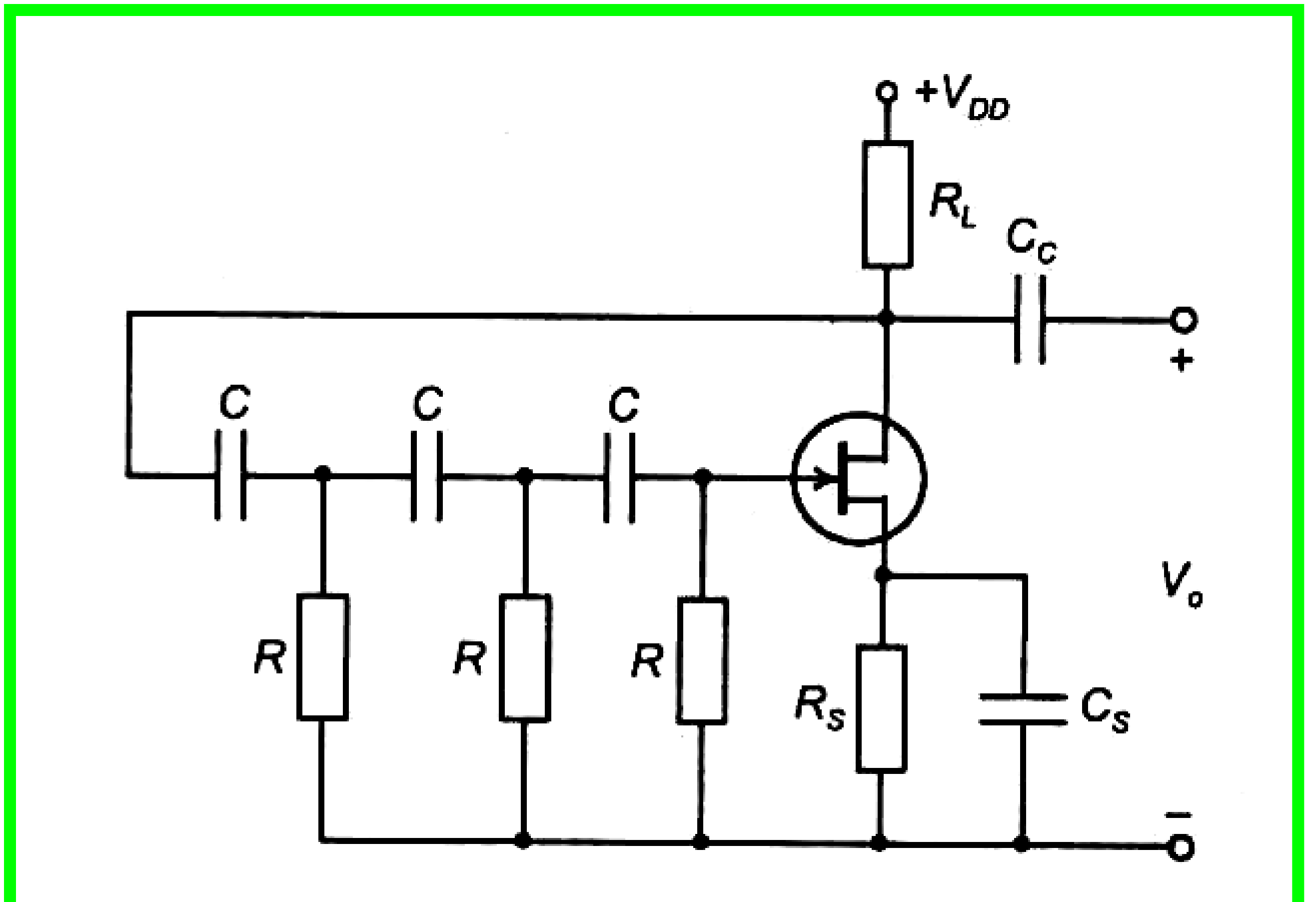
$$A_{\min} = \frac{1}{\beta} = \frac{1}{0.1} = \mathbf{10}$$

RC Oscillators

- Two types :
  1. *RC* Phase shift Oscillator.
  2. Wein Bridge Oscillator.

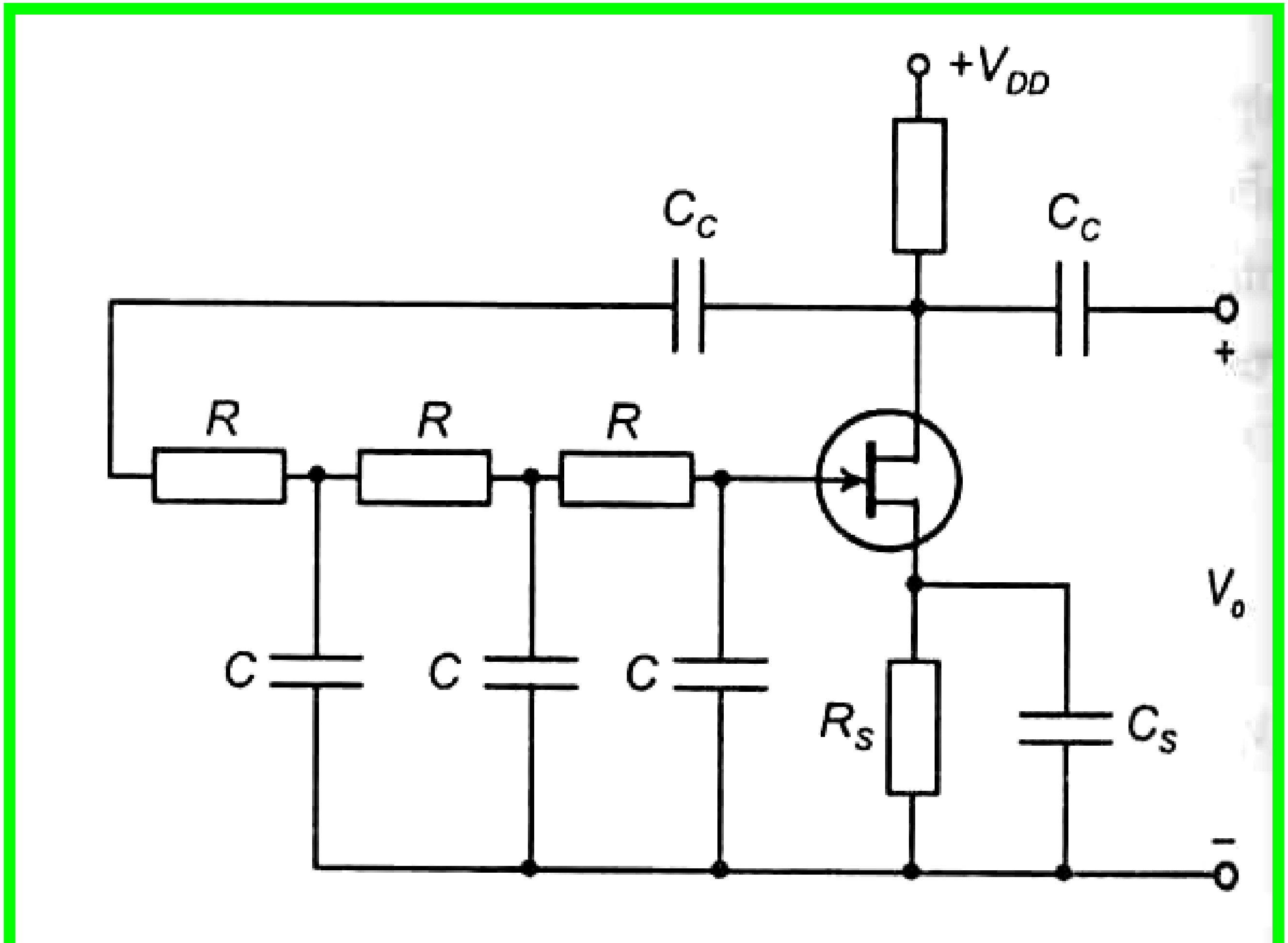
RC Phase shift Oscillator

(Using phase-lead circuits)



RC Phase shift Oscillator

(Using phase-lag circuits)



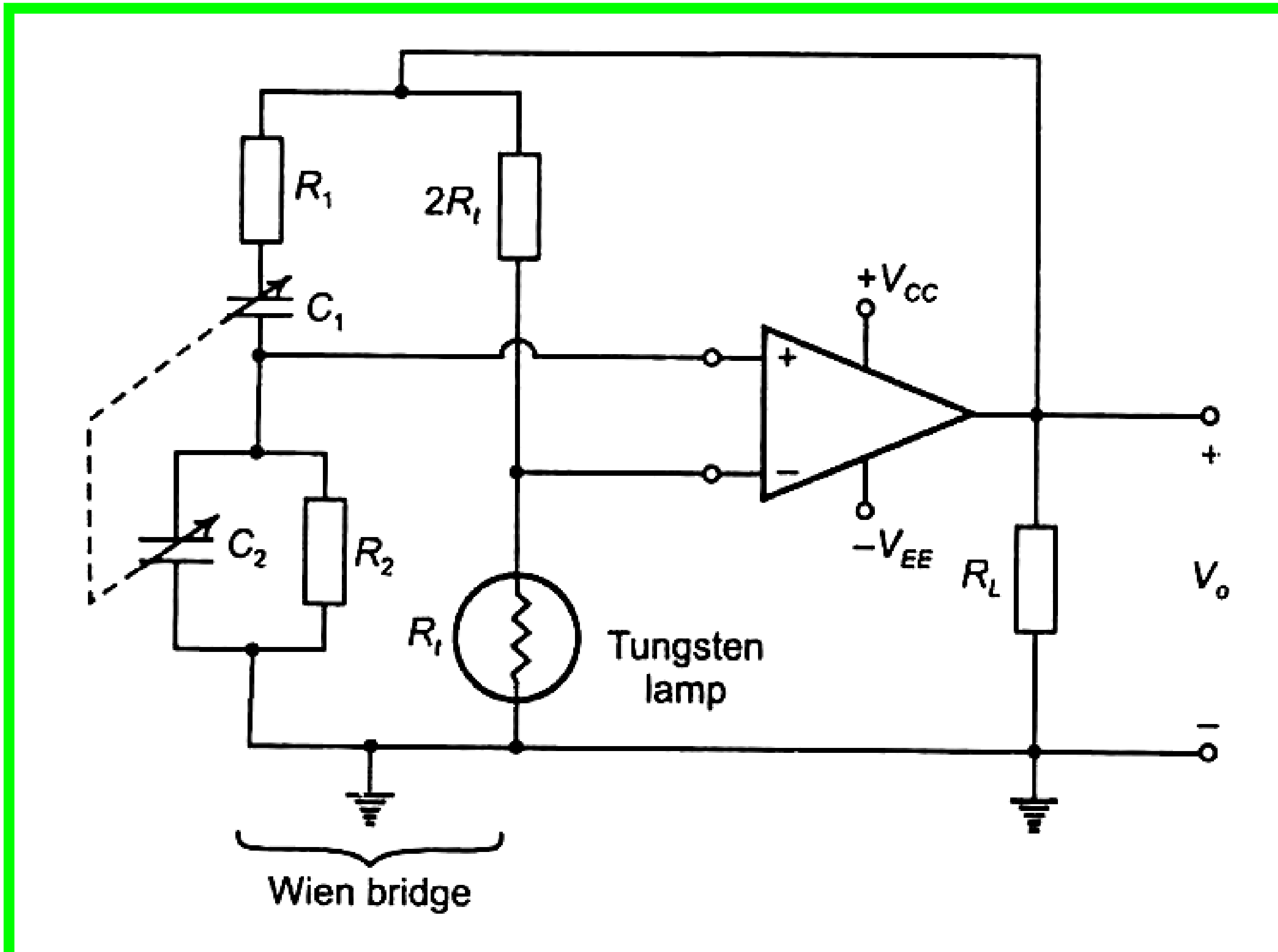
- A phase-lead or phases-lag circuit can provide phase shift between 0° and 90°.
- For total phase shift 180°, we use three identical sections each giving a phase shift of 60°.

$$\boxed{f_0 = \frac{1}{2\pi RC\sqrt{6}}} \quad \& \quad \boxed{\beta = \frac{1}{29}}$$

- It means in the beginning the gain of the FET amplifier must be greater than 29.

- Not very popular, as the frequency cannot be adjusted over large range.

Wien Bridge Oscillator



- The two arms on the left of the bridge make lead-lag circuit.
- The two arms on the right, are $2R_t$ and R_t, making a potential divider.
- It has both positive and negative feedback paths.
- Initially, when switched on, there is more positive feedback than negative feedback.
- Oscillations build up.
- Negative feedback increases, making $A\beta = 1$.

- The reason why the loop gain reduces to unity :
  1. Initially tungsten lamp has low resistance; giving low negative feedback.
  2. Thus, loop gain $A\beta$ is greater than unity.
  3. As oscillations are built up, the tungsten lamp heats up increasing its resistance.
  4. Negative feedback increase to make $A\beta = 1$.
- With sustained oscillations, the resistance of the lamp increases to exactly R_t, so that the gain becomes :

$$A = \frac{2R_t}{R_t} + 1 = 3$$

- At resonance, the voltage ratio or feedback factor of the lead-lag circuit is $^1/_3$.
- Therefore, loop gain becomes unity.
- The oscillation frequency is the same as that of the lead-lag circuit,

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \Rightarrow f_0 = \frac{1}{2\pi RC}$$

Example 12.3 An FET phase-shift oscillator uses three identical *RC* phase-lead circuits in its feedback network. The values of the components are $R = 10\ \text{k}\Omega$ and $C = 0.01\ \mu\text{F}$. Calculate the frequency of oscillation.

Solution : The frequency of oscillation

$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$

Here, $R = 10\ \text{k}\Omega = 10^4\ \Omega$; $C = 0.01\ \mu\text{F} = 10^{-8}\ \text{F}$.

$$f_0 = \frac{1}{2\pi \times 10^4 \times 10^{-8} \times \sqrt{6}} = 649.7\ \ \text{Hz}$$

Example 12.4 The RC network of a Wien bridge oscillator consists of resistors and capacitors of values $R_1 = R_2 = 22\ \text{k}\Omega$ and $C_1 = C_2 = 100\ \text{pF}$. Calculate the frequency of oscillaton.

Solution :

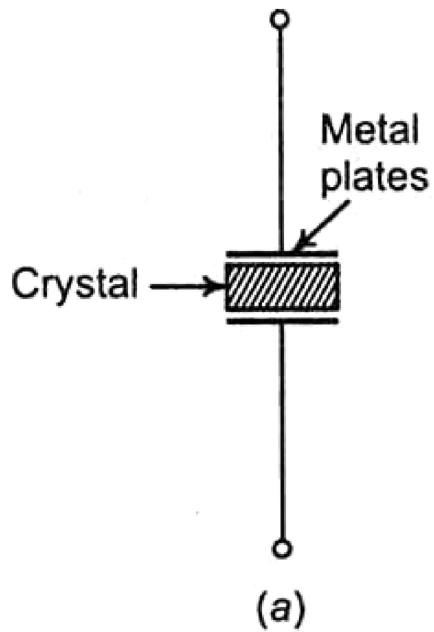
Here, $R = 22\ \text{k}\Omega = 22 \times 10^3\ \Omega$ and $C = 100\ \text{pF} = 10^{-10}\ \text{F}$.

$$f_0 = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 22 \times 10^3 \times 10^{-10}} = \mathbf{72.34\ \ kHz}$$

Crystal Oscillator

- Used when accuracy and stability of f_o is utmost important.
- Where do you need such high stability of frequency of oscillations ?
- Instead of an inductor, it uses a crystal of quartz, tourmaline, or Rochelle salt.
- Piezoelectric effect.
- The crystal is suitably cut and then mounted between two metallic plates.
- The fundamental frequency is given as

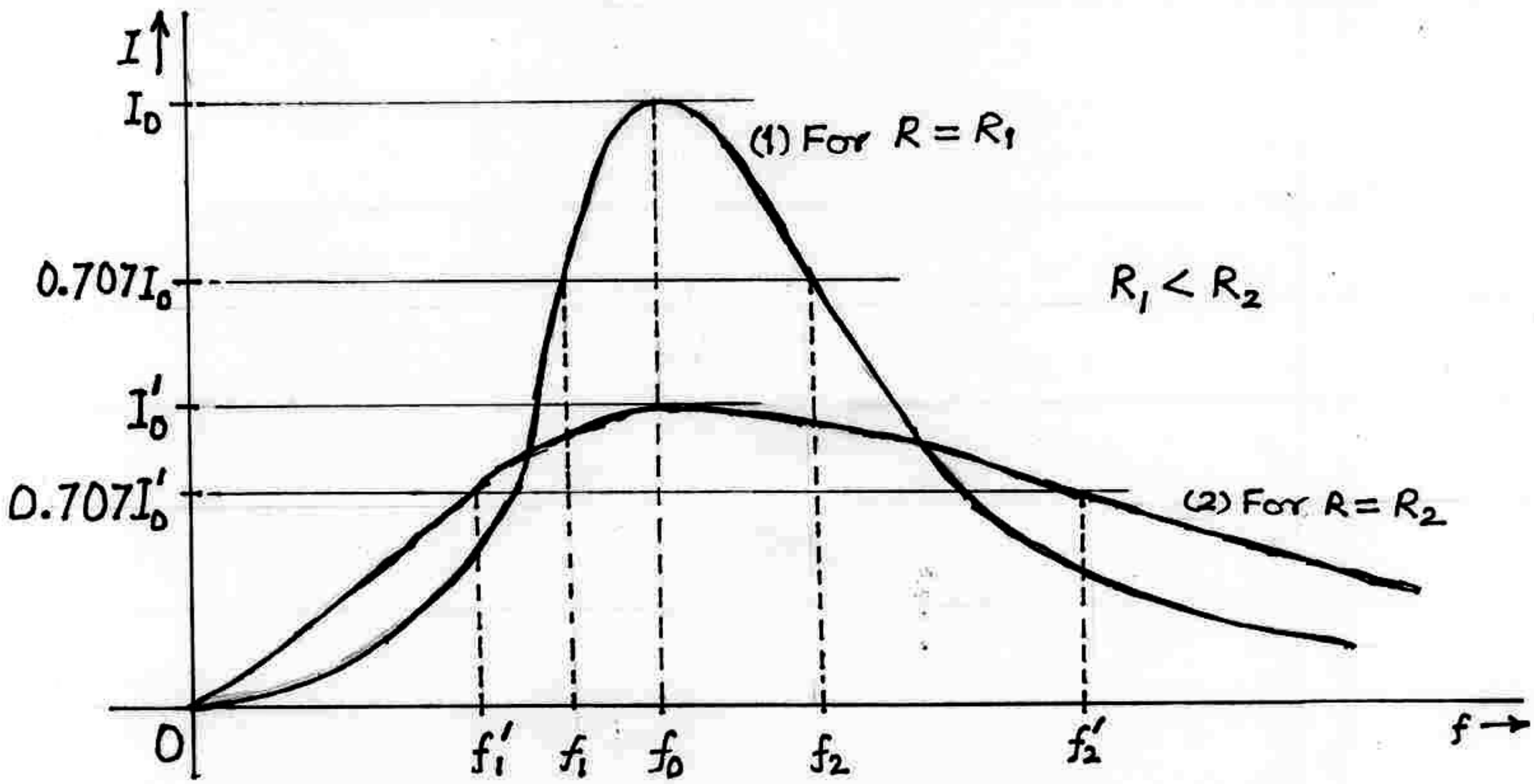
$$f_0 = \frac{K}{t}$$



C_m (mounting capacitance) = 3.5 pF;

C_s = 0.0235 pF; L = 137 H; R = 15 kΩ

- Crystals have incredibly high *Q.*
- For the given values, $Q = 5500$.
- Q as high as 100 000 can be possible.
- An LC circuit has Q not greater than 100.
- The extremely high value of Q makes f_o highly stable.


I
I_0
(1) For $R = R_1$
$0.707 I_0$
$R_1 < R_2$
I'_0
$0.707 I'_0$
(2) For $R = R_2$
O
f'_1
f_1
f_0
f_2
f'_2
f

Series and Parallel Resonance

- First, resonance occurs at f_s for the series combination of L and C_s.
- Above f_s the series branch LC_sR has inductive reactance.
- It then resonates at f_p , with C_m.
- For this parallel resonance, equivalent series capacitance is C_p.

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

$$\boxed{C_p = \frac{C_m C_s}{C_m + C_s}}$$

$$\boxed{f_p = \frac{1}{2\pi\sqrt{LC_p}}}$$

- Normally, C_s is much smaller than C_m.
- Therefore, C_p is slightly less than C_s.
- Hence, the frequency f_p is slightly greater than f_s.
- The crystal is inductive only between the frequencies f_s and f_p.
- The frequency of oscillation must lie between these frequencies.
- Hence the stability.

Example 12.5 The ac equivalent circuit of a crystal has the values : $L = 3$ H, $C_s = 0.05$ pF, $R = 2$ kΩ, and $C_m = 10$ pF. Determine the series and parallel resonant frequencies of the crystal.

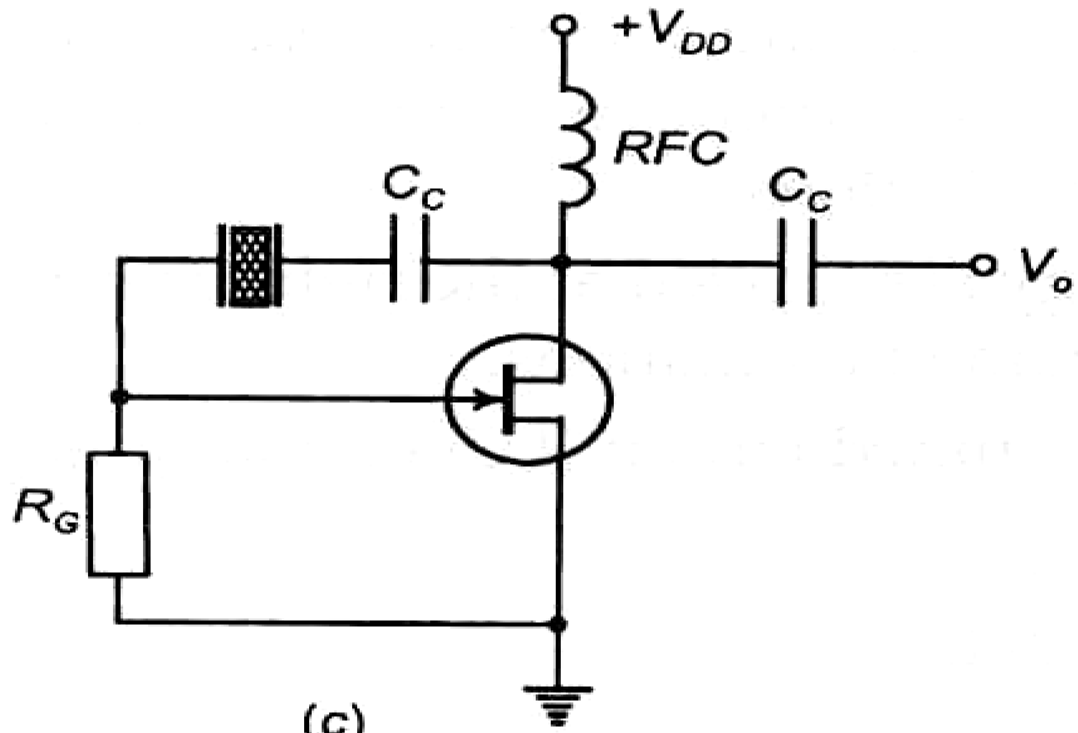
$$f_s = \frac{1}{2\pi\sqrt{LC_s}} = \frac{1}{2\pi \times \sqrt{(3)\times(0.05\times 10^{-12})}} = \mathbf{411\ kHz}$$

$$C_p = \frac{C_m C_s}{C_m + C_s} = \frac{(10\,\text{pF})(0.05\,\text{pF})}{10\,\text{pF} + 0.05\,\text{pF}} = 0.0498\ \text{pF}$$

$$f_p = \frac{1}{2\pi\sqrt{LC_p}} = \frac{1}{2\pi \times \sqrt{(3)\times(0.0498\times 10^{-12})}} = \mathbf{412\ kHz}$$

The f_o is between 411 kHz and 412 kHz.

Crystal Oscillator Circuit.



g. 12.18 Crystal oscillators : (a) Colpitts: (b)

Review

- Need of an Oscillator.
- Types of Oscillators .
- Using Positive Feedback.
- Barkhausen Criterion of Oscillations.
- Starting Voltage .
- Tank Circuit.
- Tuned Collector Oscillator.
- Tuned-Drain Oscillator.
- Hartley Oscillator.
- Colpitts Oscillator.
- *RC* Phase Shift Oscillator.
- Wien Bridge Oscillator.
- Crystal Oscillator.
- Series and Parallel Resonance