

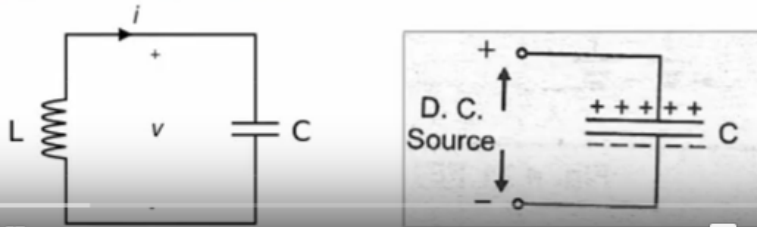
Lecture – 06
Electronic Modules for Industrial
Applications using Op-Amps

Welcome, to this module and this is in continuation with our last module. So, the idea here is that, we are looking at the summary, of indicator circuits, MOSFETs, op- amps, and their applications. The reason of revising this particular slide is that, we can use the, the knowledge that we acquire, either in the last course, or in the present modules for practical applications of op- amps. So, to understand the op amps, we need to understand the theory of op amp. Right? And that's why we are looking at the characteristics, and the parameters, of the op amps. So, in the last module what we have discussed, we are discussed, oscillators. Right? And in oscillators, we have seen that there are several kind of oscillators depending on the wave forms, depending on the frequency, depending on the components used, depending on the feedback, and then we have also seen the Barkhausen criteria. Right? Where we require, the magnitude of $A\beta$ into β , that is gained into feedback factor, should be greater than equal to 1 or, end actually not or its end. The phase shift, that is the output signal, that is feedback to the input, the phase of that output signal, that is fed back to the input, should match the input signal phase .Right? That means that feedback phase should be 0 or 360 degree, then after that we have seen RC oscillators. Right? So, an oscillator, we have seen, RC phase shift oscillator, how we can how, we can phase shift of, 180 degree signal, from the output of the inverting amplifier using RC network. And then we have also seen when we just later where, where there is no need of phase shift, and that RLC, which has a frequency sensitive arm by, changing the value of R or C , we can change the frequency. Right? So, we have also discussed that, the if I, if I, if I go and use LNC, instead of RNC, that means inductor and capacitor then the oscillators, can be used for high frequency applications. Right? So, what are high frequency applications? And how, we can design LC oscillator? So, let us see today, how we can design LC oscillators. So, if you see

Refer Slide Time :(2:45)

LC Oscillators

- The oscillators which use the elements L and C to produce oscillations are called LC Oscillators
- The circuit using L and C is called tank circuit or oscillatory circuit, which is an important part of LC oscillators. This circuit is also referred to as resonating circuit or tuned circuit.
- These oscillators are used for high frequency range from 200kHz up to a few GHz. Due to high frequency range, these oscillators are often used for sources of RF energy
- LC tank circuit consists of elements L and C connected in parallel as shown in figure. Let the capacitor be initially charged from a DC source with polarities as shown in figure

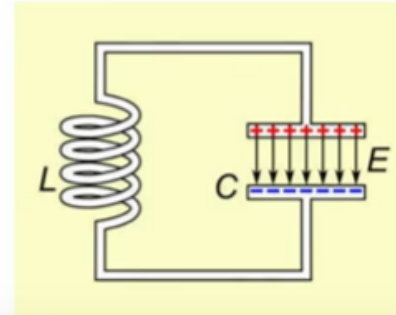


on the screen, what you see that, the oscillators which use the element L and C, to produce oscillations, are called, 'LC oscillator'. The circuit uses L and C in is called, 'Tank or circuit or oscillator circuit', which is an important part of, LC oscillator. This circuit is also referred to as resonating or tuned circuit. Right? So, you can see on the left side, L inductor, and capacitor this is a circuit used for oscillation, in the LC oscillator this, oscillators, are used for high frequency range like, we discussed from 200 kilo, Hertz to few key gigahertz. Now, since the frequency range is high, these oscillators are also referred as, RF or sources, for RF energy, or resources of RF energy, LC tank oscillator circuit consists of L and C, connected in parallel as shown in the figure, let us let the capacitor we initially charge from a DC source, which polarity as shown in figure so, supposedly C source, is there and we are charging the capacitor in the polarity shown in figure, what will happen Right?

Refer Slide Time :(3:47)

Operation of LC tank Circuit

- When the capacitor gets charged, the energy gets stored in the capacitor as electrostatic energy
- When such a charged capacitor is connected across inductor L in a tank circuit, the capacitor starts discharging through L as shown. The arrow indicates direction of flow of conventional current
- Due to such current flow, the magnetic field gets set up around the inductor L . Thus inductor starts storing the energy
- When the capacitor is fully discharged, maximum current flows through the circuit
- At this instant all the electrostatic energy gets stored as magnetic energy in the inductor L . This is shown in the Figure below



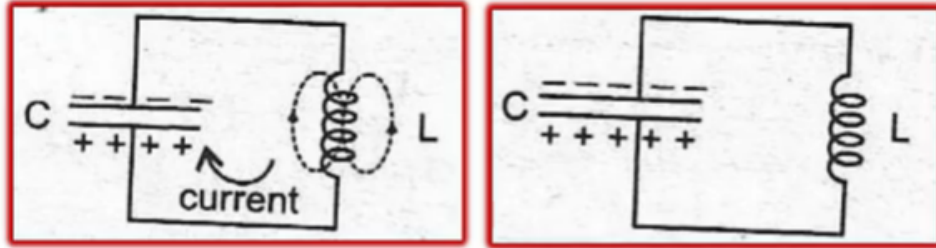
Source: Wikipedia.org

So, when the capacitor discharges when the capacitor discharges, the energy that is stored in this capacitor. Right? When the capacitor charge is let us said first when it charges what happens so, any charge is the energy stored in the capacitor is a electrostatic energy. Right? And when such a capacitor is connected across an inductor, then what we'll have, what will happen? The capacitor will start discharging so, when it starts discharging, through L . Right? The magnetic field cell gets set up, around the inductor, and thus inductor starts, storing the energy. Right? So, when capacitor is fully, discharged maximum current flows, through the circuit, at this instant all electrostatic energy is converted to magnetic energy, or stored as a magnetic energy, in the inductor.

Refer Slide Time :(4:36)

Operation of LC tank Circuit

- Now the magnetic field around L starts collapsing. As per Lenz's Law, this starts charging the capacitor with opposite polarity making lower plate positive and upper plate negative as shown



Source: Electronic Devices and Circuits II by A.P. Godse et.al

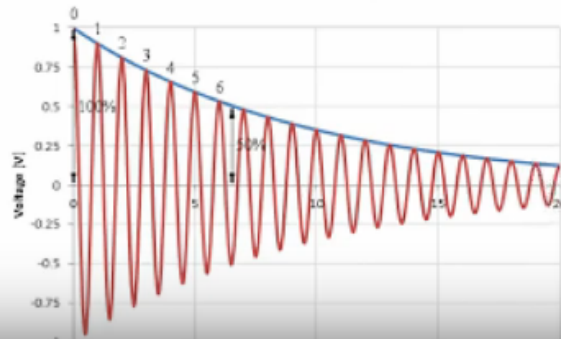
- After some time, capacitor gets fully charged with opposite polarities, as compared to its initial polarities. The entire magnetic energy gets converted back to electrostatic energy in capacitor
- Now the capacitor again starts discharging through inductor L. But the direction of current through the circuit is now opposite to the direction of current earlier in the circuit. Again electrostatic energy is converted to magnetic energy. When the capacitor is fully discharged, the magnetic field starts collapsing, charging the capacitor again in opposite direction.

Now, when the magnetic field around L starts collapsing, what will happen? As per Lenz law, this charge charging the capacitor with the opposite polarity. Right? So, now when this charge this starts collapsing, the capacitor will start charging in the opposite polarity. Right? Making lower plate more positive and upper plate negative. Right? Now, again after some time when capacitor fully gets charged, it will start discharging, and with the opposite polarities as compared to its initial polarities. Right? Initially it was plus on the top plate, minus and then bottom plate, now it is plus on the bottom plate, minus on the top plate so, now it is discharging with the opposite polarity compared to its initial polarity, and the entire magnetic energy gets converted to electrostatic energy in capacitor Wow, that is earlier we have seen and now, the electrostatic energy, when it starts discharging is converted to magnetic energy once again. Right? So, it is from when inductor discharges, it is electrostatic energy that is stored in the capacitor where the capacitor discharges, in the magnetic energy that is stored in the inductor. Right? And this keeps on, this keeps on, continuation until end and because, of this what will happen? What will happen? That

Refer Slide Time :(5:56)

Operation of LC tank Circuit

- Thus the capacitor charges with alternate polarities and discharges producing alternating current in the tank circuit. This is nothing but oscillating current.
- But every time when energy is transferred from C to L and L to C, the losses occur due to which amplitude of oscillating current keeps on decreasing every time when energy transfer takes place.
- Hence actually we get exponentially decaying oscillations called damped oscillations as shown. Such oscillations stop after sometime



Every time, when this transfer of energy occurs. Right? There is a loss, and this loss causes the amplitude of the oscillating current decreasing, see this loss because, of the inductor charging, and capacitor discharging, and capacitor charging, and inductor discharging, and again this goes on continuation what happens? Every time this discharge and charging happens, there is a loss in the circuit and this results in the lower oscillation amplitude of oscillations, gets down as you can see here, and current keeps on decreasing. Right? So, actually we get an exponential decay as you can see, from the figure oscillations and these are called damped oscillations, these are called the damped oscillations. Right? So, such oscillations stop after some time of course. Right? So, initially, you can see, and then it's after some time you can see, that these oscillations are on the edge of dying. Right? And the edge of dying.

Refer Slide Time :(6:57)

Operation of LC tank Circuit

- In LC oscillator the transistor amplifier supplies this loss of energy at the proper times. The care of the proper polarity is taken by the feedback network.
- Thus LC tank circuit along with transistor amplifier can be used to obtain oscillators called LC oscillators. Due to supply of energy which is lost, the oscillations gets maintained hence called sustained oscillations or undamped oscillations.
- The frequency of oscillations generated by LC tank circuit depends on the values L and C and is given by

$$f = \frac{1}{2\pi\sqrt{LC}} \text{ Hz}$$

where L is in henry and C is in Farad

- Depending upon the type of tank circuit used, the LC oscillators are classified as ,

1.Colpitt's Oscillator

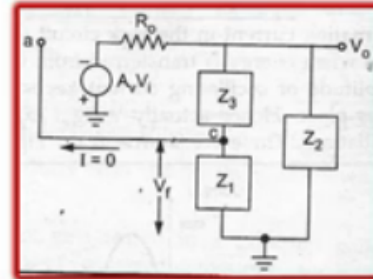
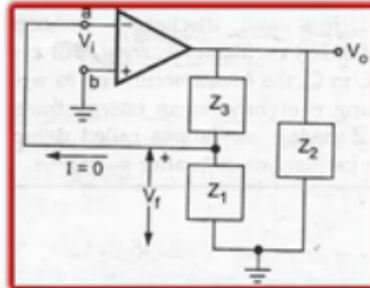
2.Hartley Oscillator

So, what will be what we can do? Right? What we can do? So, in LC oscillator, the transistor amplifier supplies, this loss of energy at proper time so, if I have a transistor amplifier then, the energy that is lost during the charging and discharging, of the inductor and capacitor. Right? Can be compensated using the transistor amplifier. Right? The LC, circuit along with on this amplifier can be used, can be used to obtain oscillators, called LC oscillators due to supply of energy which is lost the oscillation gets maintained in hence, called sustained oscillation or undammed oscillation. Here the frequency, of oscillation generated by, LC is given by, F equals to 1 by 2 pie root LC. Right? Where l is in Henry and c is in farad, depending on the type of tank circuit there's also letters are classified into two categories one is called Colpitt's oscillator, another one is called hardly oscillator,

Refer Slide Time :(7:52)

Basic Form of LC Oscillator Circuit

- In this, the LC tuned circuit forms the feedback network while an op-amp, FET or BJT can be the active device in the amplifier stage
- The figure shows the basic form of LC Oscillator circuit with the gain of the amplifier as A_v . The amplifier output feeds the network consisting of impedances Z_1, Z_2, Z_3
- We will assume an active device with infinite input impedance such as a FET or op-amp. Then the basic circuit can be replaced by its linear equivalent circuit as shown in the Figure



- Amplifier provides a phase shift of 180° , while the feedback network provides an additional phase shift of 180° , to satisfy the required condition

Now, LC or circuit forms of feedback network while an op-amp, or FET, or BJT can be active device, the figure shows here you can see, the left side of the figure. Right? Shows form of L so, later with gain of amplifier A_v . All Right? Amplifier output feeds a network consisting of impedance is Z_1, Z_2 , and Z_3 , we will assume that active device, with infinite input impedance such as FET. Right? Or op-amp and then the basic circuit can be, replaced by linear equivalent circuit so, if I want to replace this by, linear equivalent circuit I can draw like this. Right? Say its input impedance is infinite. Right? And amplifier provides a phase shift of 180 degree because, it's a inverting terminal we are applying the signal. Right? Well the feedback network provides this phase shift of poly so, here the feedback network that we are, we are designing, or will be using, will provide another phase shift of 180 degree, to satisfy the required solution that is a that total phase shift should be 360 degree.

Refer Slide Time :(8:52)

Basic Form of LC Oscillator Circuit - Analysis

Analysis of Amplifier stage

- As input impedance of the amplifier is infinite, there is no current flowing towards the input terminals. Let R_o be the output impedance of the amplifier stage
- As $I = 0$, Z_1 , Z_3 , appear in series and the combination in parallel with Z_2 . This equivalent is Z_L , the load impedance. The reduced circuit is as shown

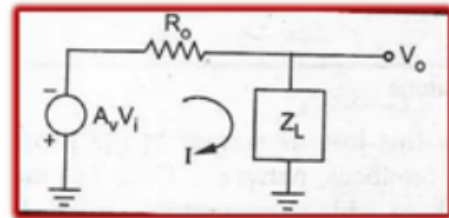
Therefore,

$$I = -\frac{A_v V_i}{R_o + Z_L}$$

And, $V_o = I Z_L$

From these two equations, Gain of amplifier is,

$$A = \frac{V_o}{V_i} = -\frac{A_v Z_L}{R_o + Z_L}$$



Where A is the gain of the amplifier stage

So, if we analyze, this amplifier stage, if we analyze this amplifier stage, what we get, what we get is that I equals to minus $A V_i$ upon $R_o + Z_L$, you can see from here. Right? And using the equation. Right? What we can get gain. Of the amplifier V_o By, V_i equals to $A V_i Z_L$ upon $R_o + Z_L$, where a is the gain of the amplifier stage. Right?

Refer Slide Time : (9:21)

Basic Form of LC Oscillator Circuit - Analysis

Analysis of Feedback Stage

- For the feedback factor (β) calculation, consider the feedback circuit shown
- From the voltage division in parallel circuit we can write

$$\frac{V_f}{V_o} = \frac{Z_1}{Z_1 + Z_3}$$

But $\frac{V_f}{V_o} = \beta$, the feedback factor

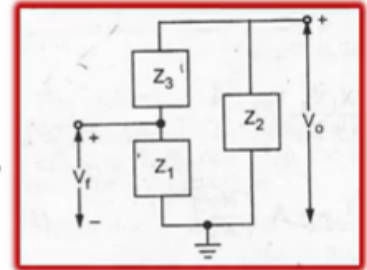
But as the phase shift of the feedback network is 180° ,

$$\beta = \frac{V_f}{V_o} = -\frac{Z_1}{Z_1 + Z_3}$$

And,

$$A\beta = \frac{A_v Z_1 Z_L}{(R_o + Z_L)(Z_1 + Z_3)}$$

This is the required loop gain. Z_L can be written as $(Z_1 + Z_3) || Z_2$



So, further when we analyze, what we get, we get beta equals to V_f by V_o and that will be nothing but Z_1 upon Z_1 plus Z_3 in terms of minus, that is 180° phase shift so, a beta would be this formula so, this is the required loop gain, this is a required loop gain Z_L can be written as Z_1 plus Z_3 parallel to Z_2 you can see here. Right?

Refer Slide Time : (9:45)

Basic Form of LC Oscillator Circuit - Analysis

Analysis of Feedback Stage Contd..

- After substituting for the Z_L value and further simplification we get $A\beta$ as

$$A\beta = \frac{A_v Z_1 Z_2}{R_0(Z_1 + Z_2 + Z_3) + Z_2(Z_1 + Z_3)}$$

As Z_1 , Z_2 , and Z_3 are pure reactive elements

$$Z_1 = jX_1, Z_2 = jX_2, Z_3 = jX_3$$

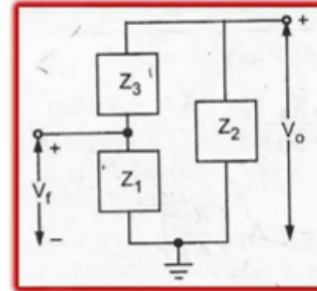
Where $X = L\omega$ (for an inductive reactance) and $X = -1/C\omega$ (for a capacitive reactance)

To have 180° phase shift, the imaginary part of denominator must be zero

$$X_1 + X_2 + X_3 = 0$$

And,

$$A\beta = \frac{A_v X_1 X_2}{X_2(X_1 + X_3)}$$



10:57 17:57 $X_1 + X_3 = -X_2$, therefore, $-A\beta = \frac{A_v X_1}{X_2}$

Source: Electronic Devices and Circuits II by A.P. Chakrabarti et al.

So, if you substitute what we get, we substitute, then finally, when we, when you solve this equation, when you solve this equation, what you get? You get is, that you're a beta. Right? Will be $AV \times 1$, by x_2 , $AV \times 1$, by x_2 and a B must be positive. Right? Here what we see is, is minus a into beta, minus a into beta, the last line we see that when we derive this, when we solve this we get minus a beta equals to $AV \times 1$, by x_2 but it cannot be minus. Right? It should be a minus a , B should be positive and must bigger than or equal to unity. Right? We have seen that it is focusing criteria so, as a B is positive minus a beta will be positive only when, only when x_1 and, x_2 will have same sign. Right? If an x_1 , x_2 have sales sign then only minus a beta can be positive. Right? This indicates that x_1 and, x_2 should be of same type of reactances, you see here again minus a beta equals to AV , into x_1 by, x_2 but minus a beta should always, be greater than equal to 1, that means x_1 and, x_2 should be same reactances. Right?

Refer Slide Time :(11:00)

Basic Form of LC Oscillator Circuit - Analysis

According to Barkhausen criterion, $-A\beta$ must be positive and must be greater than or equal to unity. As A_v is positive, the $-A\beta$ will be positive only when X_1 and X_2 will have same sign. This indicates that X_1 and X_2 must be of same type of reactances either both inductive or capacitive. While from the equation we can say that $X_3 = -(X_1 + X_2)$ must be inductive if X_1, X_2 are capacitive while X_3 must be capacitive if X_1, X_2 are inductive.

Table shows the various types of LC Oscillators depending on the design of the reactances X_1, X_2 and X_3

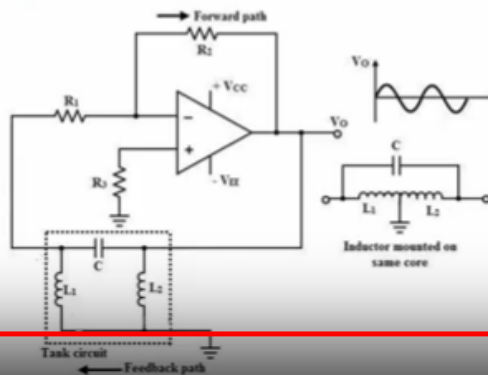
Oscillator Type	Reactance Elements in the Tank Circuit		
	X_1	X_2	X_3
Hartley Oscillator	L	L	C
Colpitts Oscillator	C	C	L

Should behave same type of reactances so, either it we can use x_1 and, x_2 as inductive, or we can use x_2 and, x_2 , x_1 and x_2 is capacitive. Right? Either x_1 or, x_2 as inductive, or capacitive. while we can also say that x_3 equals 2 minus X_1 as, oh so, that means that if x_1 and, x_2 are capacitive x_3 , should be inductive and if x_1 and, x_2 are inductive, X_2 should be, x_3 should be, capacitive. Right? So either X_1 and X_2 are inductive then X_3 , X capacitive X_3 if X_1 and, X_2 are capacitive then X_3 should be inductive. Right? Vice versa so, if X_4 and, X_2 are inductive and X_3 is capacitive it is hardly oscillator, and if X_1 and, X_2 are capacitive and X_3 is inductive it is called pitch oscillator, Right? We have seen this

Refer Slide Time :(11:59)

Hartley Oscillator using Op-amps

- The Hartley oscillator is one of the classical LC feedback circuits and used to generate high frequency waveforms or signals
- These can be implemented by using different circuit configurations. The major parts of the Hartley oscillators are the amplifier section and the tank section
- The tank section consists of two inductors and one capacitor
- Each section produces a phase shift of 180° of the AC signal voltage and hence it produces a sine wave voltage.



Now, if I want to design hudley oscillator, if I want to design hardly oscillator, then this is the way to design hardly oscillator, this is a tank circuit as we know Right? And this can be implemented by, by using two inductors and, one capacitor each section produces a phase shift of 180 degree Right? Each section produces 180 degree and, hence it produces a sine voltage Right? And produces a sine wave voltage.

Refer Slide Time :(12:32)

Hartley Oscillator using Op-amps-Operation

- The sine wave generated by the feedback circuit is coupled with the op-amp section. Then this wave is stabilized and inverted by the amplifier.
- The frequency of the oscillator is varied by using variable capacitor in the tank circuit keeping the feedback ratio and amplitude of the output constant for over a frequency range

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

Where $L_{eq} = L_1 + L_2 + 2M$ or $L_1 + L_2$

- To generate the oscillation from this circuit, the amplifier gain must be selected greater than or at least equal to the ratio of two inductances. Ie

$$A_V = \frac{L_1}{L_2}$$

- If the mutual inductance exists between L_1 and L_2 because of the common core for these two coils, then the gain becomes

$$A_V = \frac{L_1 + M}{L_2 + M}$$

Here we know, that the FO equals to, $1 \text{ upon } 2\pi$, under root of L , equivalent into C . Right? Because, there are inductors L_1 and L_2 . So, when, where is L equivalent L equivalent is nothing but L_1 plus L_2 , plus, $2M$, or L_1 plus, L_2 to generate oscillation, from this circuit, the amplifier must have be selected not less least equal to the ratio of, two inductances Right? That means that the amplifier gain should be at least equal to L_1 by, L_2 so, it should be greater than or equal to okay? So, be greater than or equal to the ratio of L_1 and, L_2 if there is a mutual inductance, if there is a mutual inductance that exists between L_1 and L_2 . Right? Because, of the common core then the gain becomes L_1 plus, M by, L_2 plus L .

Refer Slide Time :(13:21)

Hartley Oscillator using Op-amps

Advantages

- Instead of two separate coils as L_1 and L_2 , a single coil of bare wire can be used and the coil grounded at any desired point along it
- By using variable capacitor or by making core movable (varying the inductance), frequency of oscillations can be varied
- The amplitude of the output remains constant over the working frequency range
- Very few components are needed including either two fixed inductors or a tapped coil

Disadvantages

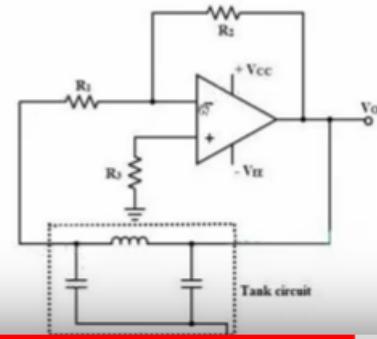
- It cannot be used as low frequency oscillator since the value of inductors become large and size of the inductors becomes bulky.
- The harmonic content in the output of this oscillator is very high and hence it is not suitable for the applications which require pure sine wave

So, what is the advantage of this oscillator? The advantage is that instead of two separate coils as L_1 and L_2 a single coil of a bare wire can be used, and the coil can be grounded, at any desired point second is by using variable capacitor or by making core movable frequency oscillations can be varied. Right? There's another abundant amplitude of the output, remains constant, over the frequency range, and finally very few components are required for including either to fix inductors or a tip coil but, there are few limitations what are limitations? It cannot be used for low frequency oscillation. Right? Since the value of inductors becomes large, and size of the inductor becomes Bulky. Right? It's obvious correct the harmonic content in the output of this oscillator is very high and hence it is not suitable for application which requires pure, sine wave there is harmonic oscillations that limits its use for pure sine,

Refer Slide Time :(14:22)

Colpitts Oscillator

- An LC oscillator which uses two capacitive reactance and one inductive reactance in the feedback network i.e. tank circuit, it is called Colpitts Oscillator
- The op-amp provides the basic amplification needed while the feedback network is responsible for setting the oscillator frequency
- In the given circuit the op-amp is connected as an inverting amplifier with a high gain as compared with transistor circuit. The LC network is placed in a positive feedback of the operational amplifier
- When the power supply is given to the circuit, there is no signal, but the small noise voltages are amplified by the op-amp. This makes the both capacitor to start charging and discharging
- The part of the signal across the capacitor C_2 is fed to the inverting amplifier. It is then amplified and keeps the network oscillating strongly



Colpitts oscillator, next is a Colpitts letter here, we are using two capacitors and one inductor in this oscillator like we see here. In the tank circuit, there are two capacitors. Right? And one inductor so, here the op-amp provides the basic amplification needed with the feedback Network in the given circuit op amp is connected as inverting amplifier, the high gain is compared with transistor circuit, when the power supply is given to the circuit, there is no signal. Right? Initially there is no signal but a small noise voltage are amplified with the help of amplifier op-amp, this makes the both capacitors to charge and discharge Right? The part of signal across the capacitor C_2 is fed to the inverting amplifier. Right? Here it is fed back to the inverting amplifier, and then amplified and keeps a network oscillating strongly Right? So, initially through the noise voltage, we're amplifying the noise voltage, with the help of amplifier, it is fed back to the tank circuit and the part of signal is fed back to the amplifier and there is a strong oscillations, which causes strong oscillations.

Refer Slide Time : (15:32)

Colpitts Oscillator

- The oscillating frequency of the Colpitts oscillator using op-amp is given by

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

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

Applications Of Colpitts Oscillator

- Colpitts oscillators are used for high frequency range and high frequency stability
- A surface acoustical wave (SAW) resonator
- Microwave applications
- Mobile and communication systems
- These are used in chaotic circuits which are capable to generate oscillations from audio frequency range to the optical band. These application areas include broadband communications, spectrum spreading, signal masking, etc.

here we have same formula but instead of L equivalent here, we have frequent and we know that C equivalent is nothing, but C 1, C 2, by C 1 plus C 2. So ,what are the applications of Colptits, oscillator Colpitts oscillator z' are used for high frequency range, in high frequency stability Right? It can also be used as a saw, resonator resurface acoustical real resonator used in micro applications mobile communications. Right? And these are used in chaotic circuits, which are capable to generate oscillation from audio frequency to the optical band; the application area includes broadband communication spectrum spreading, signal masking, etc.

So, this was the end of this particular summary of the oscillators. Right? So, if you recall, we have just understood. Right? from the indicator circuit quickly. Right? Then we went to op-amp its characteristics then we saw a few implicants, then we saw oscillators. Right? And we also saw, filters, as also saw filters now, in the in the next module, in the next module are or rather in the next lecture, we will see how we can implement design, and implement circuits using operation amplifier and like I said slowly, and gradually yeah, you will, you will understand when you, when you, read from my earlier course till now, we are slowly, and gradually increasing the tempo Right? We're increasing the tempo the reason is that we should start from basic. Right? Understand the concept grab it, and then move on to applying it so, you will see in this particular applications of op-amp, it is little bit complicated than the earlier practical's that we have seen in the last course. Right? And finally we are, actually designing a signal conditioning device, for measuring ECG, as well as heart rate. Right? And, and that is a really complicated project. So, let's see how, we go further in the next lectures, I'll see in the next lecture. Till then, you just go through all the modules. Right? Keep your basic strong. Right? Refresh it, even you know it, it is always good to refresh. Right? I'll see you next class. Till then, you take care bye.