Basic Electronics
Learning by doing
Prof. T.S. Natarajan
Department of Physics
Indian Institute of Technology, Madras

Lecture – 35
Oscillators
(Phase shift, Wein bridge, Twin – T ….)

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. Before we do that let us quickly recapitulate what we discussed in our previous lecture. You might recall that we discussed about an active diode circuit.

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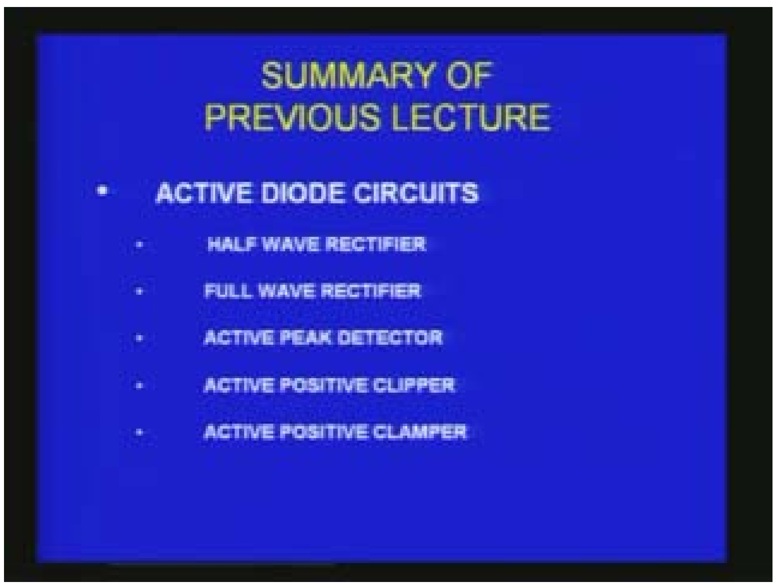

Have a normal semiconductor diode can be improved to become almost an ideal diode and making use of such an ideal diode which is actually a normal diode along with an operational amplifier. This ideal diode was used in different applications like making an half wave rectifier; then how a full wave rectifier can be implemented using such an op amp along with the diode to make an ideal diode. Then we also saw some variations of these like the peak detector and the active positive clipper and clamping circuits which are very useful in different wave shaping circuits.

Let us move on to the next important topic basically in electronics that is design of oscillators. Oscillators are basically circuits which will convert the dc voltage into a sinusoidal voltage. You know about rectifiers. Rectifiers convert an ac voltage into a dc voltage. The oscillators will do just the reverse. It takes the power supply from the dc power supply and the output of an oscillator will be sinusoidal; most of the time it will be a sinusoidal wave form, sine wave. Oscillators are very, very useful for different applications especially in radio communications. Let us see how we can build oscillators using operational amplifiers. That is what we are going to discuss this time.

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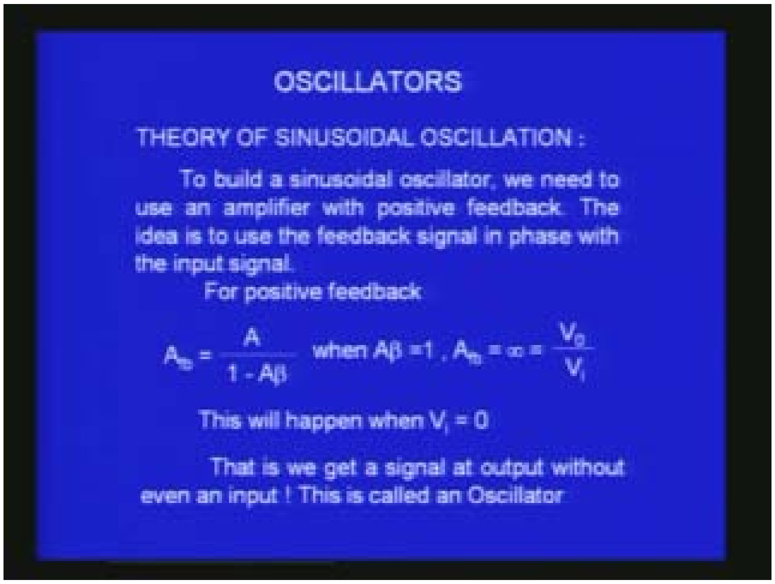

In order to build sine wave oscillators as you can see on the screen we need to use the well known amplifier. Any amplifier can be converted to become an oscillator but you have to give the feed back. To become an oscillator an amplifier should be given a feedback. When I give negative feedback many of the characteristics of the amplifier will improve. We never discussed about the positive feedback. We only talked about negative feedback. Negative feedback means what? Take the output invert it in phase by 180 degrees with reference to the input and give. Then you get a negative feedback. The fed back voltage should be out of phase with the input voltage and this negative feedback improves several characteristics of the amplifier like input resistance, bandwidth, output resistance, distortion, etc. But if I now take the path of the output voltage and give it in phase with the input voltage then it becomes positive feedback. In an amplifier if I implement positive feedback it normally results in oscillation. When I want to use the amplifier for the amplification purposes we will not use the positive feedback. We will only use negative feedback. But when we want to convert an amplifier into an oscillator then you go in for positive feedback. We have also derived one of the earlier lectures the condition for a gain of an amplifier with feed back and that you can see in the screen.

A by one plus A beta; you may remember that expression. A_{fb} which is the gain with feedback is equal to A, the gain without feedback divided by 1 minus A beta where beta is the feedback ratio, the fraction of the output which was given at the input. This minus sign is what you get for positive feedback. For negative feedback the sign in the denominator will be plus. For amplifiers you would have used the formula A_{fb} is equal to A by 1 plus A beta. But when you want positive feedback, the same derivation you can do, it will become 1 minus A beta when you impose the condition the output should be in phase with the input which is corresponding to positive feedback. Because you have a minus sign it introduces very interesting situation here. ‘A’ generally is a large number, gain. Beta is a small fraction. Sometimes it may so happen that when A beta becomes equal to 1. That is when A is equal to 1 by beta then A beta becomes 1. When A beta becomes 1 what happens to the denominator? A by 1-1; 1-1 is zero. The denominator becomes zero. In any fraction if the denominator becomes zero it becomes infinity. The gain with the feedback is now infinity. What do you mean by that? Infinite means very large number or what is feedback in general? What is gain in general? Output voltage by input voltage; that is the voltage gain.

When will the output voltage divided by the input voltage become infinity? It will become infinity only when the denominator becomes zero. The denominator in this case is V_i, the input voltage. What it means is when I make positive feedback in an amplifier, when I provide positive feedback and make the product A beta equal to 1 it is equivalent to saying I get an output voltage with zero input voltage. That is the denominator becomes zero in this expression. When the denominator becomes zero, expression becomes infinity and you get only output voltage. That means what? Without giving any input voltage you are getting an output voltage. This is what we call oscillator. It is an amplifier in which you don’t have to give any input but you get an amplified output signal, ac signal. Where from it is coming? It is generated out of the power supply voltage that you have given. I call that as a converter of a dc into an ac. You give only a dc supply for energizing the amplifier circuits. But you have implemented a positive feedback and you have made sure the feedback ratio is in such a way that the gain into the feedback fraction is equal to 1. If you do that you get the output sine wave without any input. That means it becomes an oscillator.

This A beta condition you will not get all the time. It has to be satisfied only at one particular frequency. This feed back will have to be given through some frequency sensitive components, reactive components and this condition will be true only for one specific value of frequency corresponding to the reactants. Only that frequency will be preferentially provided and the output will be having that frequency. If you want to vary the frequency correspondingly you have to vary the reactive components that you have in the circuit. But in principle what I have so far explained is the most important criteria or the principle of oscillators. This condition A beta should be equal to 1 in an amplifier with the positive feedback for generating oscillator is called Barkhausen criterion. What happens to the output voltage?

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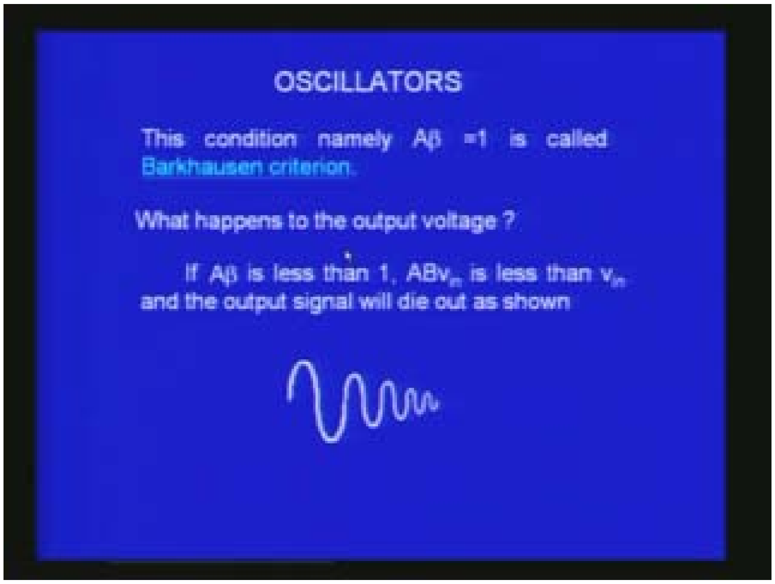

For different values of A beta if A beta is less than 1 then the gain will be increasing. ABV_{in} is less than V_{in} and the output signal will slowly die out and that is what is shown here. The initial sine wave keeps on decreasing because it is less than 1 subtracting being subtracting. If the A beta value is greater than 1 then A beta V_{in} is greater than V_{in} and the output voltage keeps on building up. When you give feedback larger portion comes through the feedback. It increases the input voltage and the output will still further increase because it is just an amplifier. The sinusoidal voltage which starts with a small amplitude will start building up. This also is not a very desirable feature. The previous one where the amplitude decreases is not also what we want.

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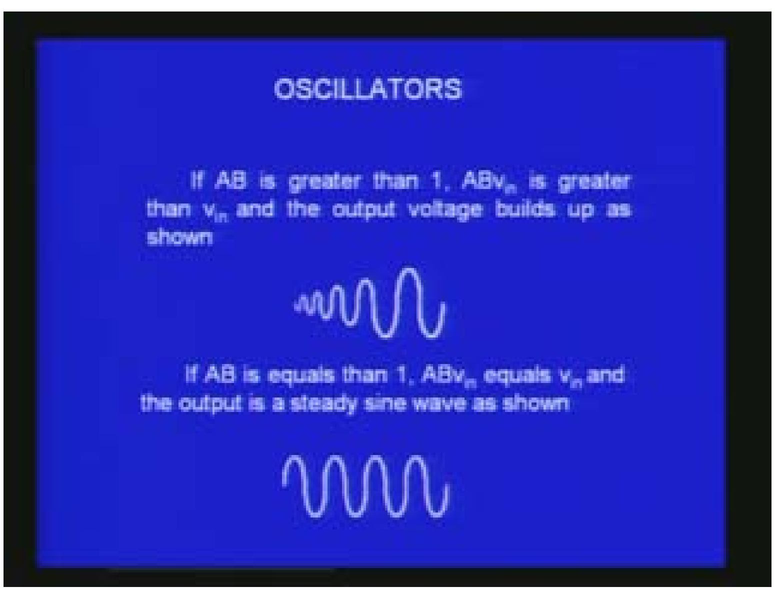

What we want is something which will sustain the oscillations with constant amplitude. That happens when AB is equal to 1. Then ABV_{in} is also equal to V_{in} because A beta becomes 1. Both are V_{in} and there is no loss. There is no decrease there is no increase. It maintains the same input. You will get the same output. That means you get a steady output sine wave. That is what is shown in the picture at the bottom. This is basically the idea behind that of the oscillators. But if you actually take any amplifier for example RC coupled transistor amplifier the output is always 180 degrees out of phase with reference to the input. This is a characteristic of the RC coupled amplifier when you have common emitter configuration. This 180 degree shift is already built into the amplifier configuration due to the common emitter configuration.

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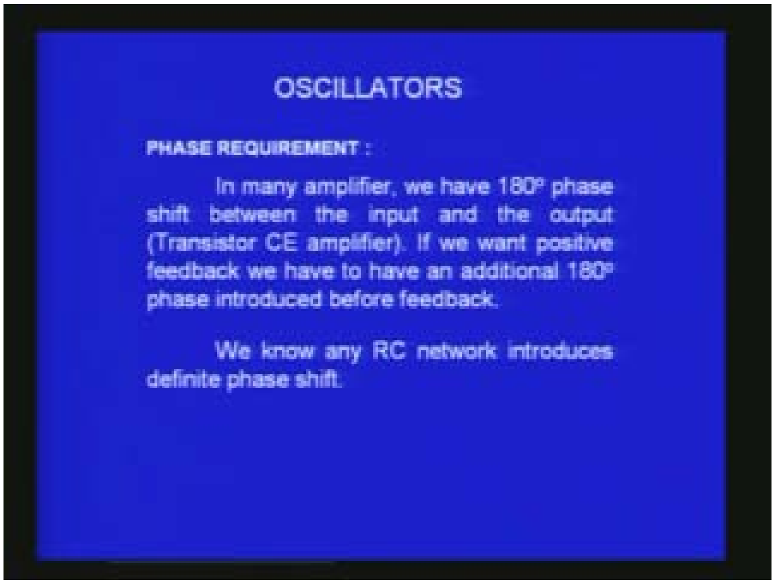

If we want to have a feedback the feedback should be positive. That means the input voltage should be in phase with the voltage fed back from the output. If we take the output directly from this amplifier and give it at the input it is 180 degrees out of phase. It will not be positive feedback but it will only be a negative feedback. That is what we do in many amplifiers. For making positive feedback you should introduce a phase shifting network between the output and the input and then only give the feedback voltage. That phase shifting network you should make sure produces another 180 degree phase shift so that the total phase difference becomes 360 degree which is equal to zero degree phase shift. This is the idea; use a normal amplifier which has got 180 degree phase difference between the input and output, use a separate network using some combinations of reactive components so that it produces another 180 degrees in addition and together both of them will provide 360 degree phase difference and if you now give this fraction to the input and make sure that it is equivalent to the input voltage then you can slowly remove the input and this positive feedback alone will sustain the oscillations and you will get steady sine wave at the output. That is the basic principle of an oscillator.

How do we introduce that additional phase difference of 180 degrees? The simplest method is to use resistance and capacitance in combination. A RC network, which we have already discussed when we discussed about the frequency response of amplifiers, a lead network and the lag network about which we talked about you can use any one of these. Either the lead or a lag both of them introduces a phase difference. Any RC combination produces the phase. I have shown you on the screen a very simple scheme with the capacitor and R in series and you take the output across the resistor.

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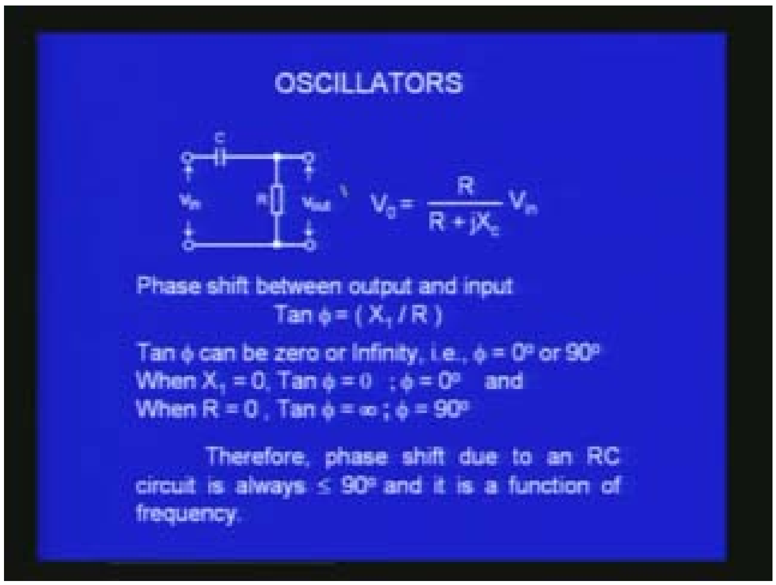

What is the output voltage? The output voltage is the output resistance R divided by R plus jX_c into V_{in}. This is a potential divider. This C and R reactive component and the resistive component form a series circuit as a potential divider and you are taking the output across the R resistance and the formula is R divided by R plus jX_c into V_{in}. The jX_c is actually the reactive impedance of the capacitance. X_c is 1 by omega c. What is the phase shift in this case? It is X_c by R. We have written here X_1 by R. That is the phase difference phi. This simple RC network will automatically give a phase shift of X_1 by R where X_1 is 1 by omega c where omega is the angular frequency which is equal to 2 pi f where f is the frequency of the input sine wave and for a given frequency the X_1 will be different. Capacitive reactance is a function of frequency. Depending upon the frequency the reactance will change and hence the phase difference should change and in this case tan phi can be zero or infinity or any other value in between. If phi is equal to zero or 90 degree then X_1 is equal to zero. When X_1 is equal to zero, tan phi is equal to zero in this equation, in this formula and phi is equal to zero degree. When R is equal to zero in the denominator then the tan phi becomes infinity and phi becomes 90 degree. Using one RC combination you can have any phase difference between zero and 90 degrees only; not more. You can always have less than 90 degrees but you cannot have more than 90 degrees by using just one RC. Even 90 degree is an extreme case. Zero degree and 90 degree are two extreme cases. A phase shift due to an RC circuit is always less than 90 degrees and it is also a function of frequency. These two important points we should remember before we go into the design of oscillators.

If you want in an amplifier like a common emitter amplifier which produces 180 degree phase shift between the input and output and if you want another additional phase shift of 180 degrees then how many RC networks you require to have additional 180 degree? What will be the answer? One RC network can only provide at the maximum of 90 degrees. It is always going to produce a phase shift which is less than 90.

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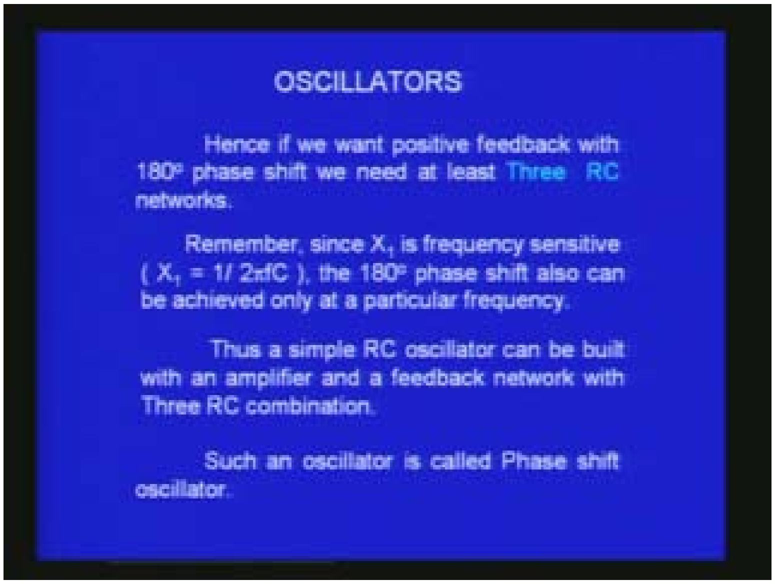

When it is less than 90 even 2 RC networks cannot give 180 degrees and a minimum of 3 RC networks are required to produce total 180 degree phase shift for a given frequency. This is the principle of a phase shift oscillator. I will talk about it now. Let me show you the circuit of the phase shift oscillator with transistors. Then we will go on to the op amp because the principle is the same. You have here a transistor and if you look at only the first part where I show with the pointer this is nothing but an amplifier with a voltage divider bias R_1 and this variable R. R_c is the collector resistor, R_eC_e gives you the emitter bias. This is basically an amplifier, single stage RC coupled amplifier because you are coupling with the C here RC coupled amplifier.

What we are doing is we are taking the output and it is brought back through this wire to the input and at the input you are combining series of RC circuits. C R that output is taken and given to another C R. That output from the R is taken to another CR and that output is given to the input. Between this base which is the actual input of the amplifier and the collector there is 180 phase shift and that 180 degree phase shift voltage is applied here. With these three combinations of RC, RC, RC you try to produce another 180 degree so that totally it becomes 360 degrees and then this voltage which comes from the output becomes in phase with the input that you should have given at the beginning. You have not given anything. This happens very fast.

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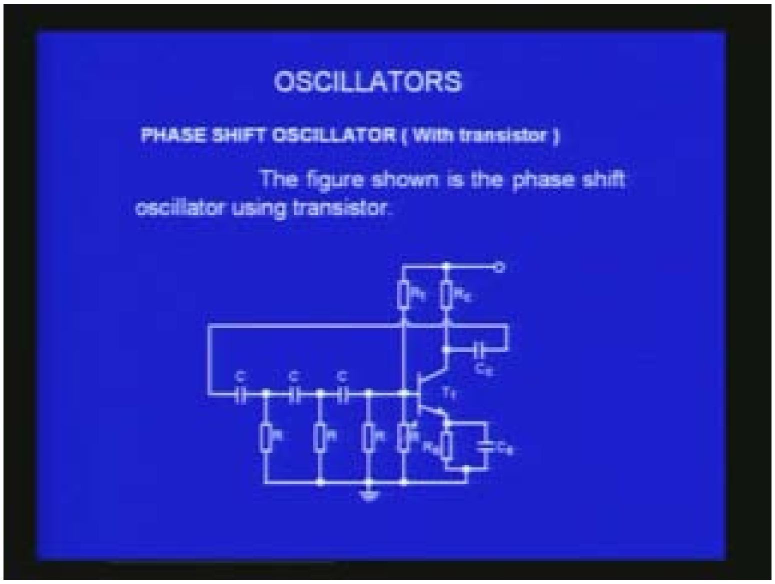

I will explain to you how this happens? This becomes the input voltage and if the conditions are fine, ideal then this input will get amplified enough so that after passing through these three, again it becomes the same value as the initial value. You get a constant input voltage and this RC, three of them provide 180 degrees in addition to the 180 degree that is produced by the RC coupled amplifier the total …. 360 degree provides the necessary positive feedback and the output you take now here from another wire and connect it to an oscilloscope it will start oscillating. If it is not oscillating, all that you have to do is in one of the bias resistors I have put variable; you vary this slightly. Then at some position of this resistance when the conditions are proper, when the gain becomes sufficient you will get a sine wave coming at the output. This is a simple RC coupled amplifier, RC phase shift oscillator constructed using a simple RC coupled common emitter amplifier.

How will we do that using operational amplifier? In operational amplifier we have another advantage. The advantage is we have both the inverting and the non-inverting inputs so that whatever type of voltage feedback you want to give you can give in principle. But now what we are going to do is we are still going to use the 180 degree out of phase as we did in the phase shift oscillator I showed. There is a 180 degree phase shift. That output is now taken and given to combination of three RC networks here so that the phase here becomes 180 degrees, additional 180 degrees and it will be in phase with the input and then this will sustain oscillation and you will get the output.

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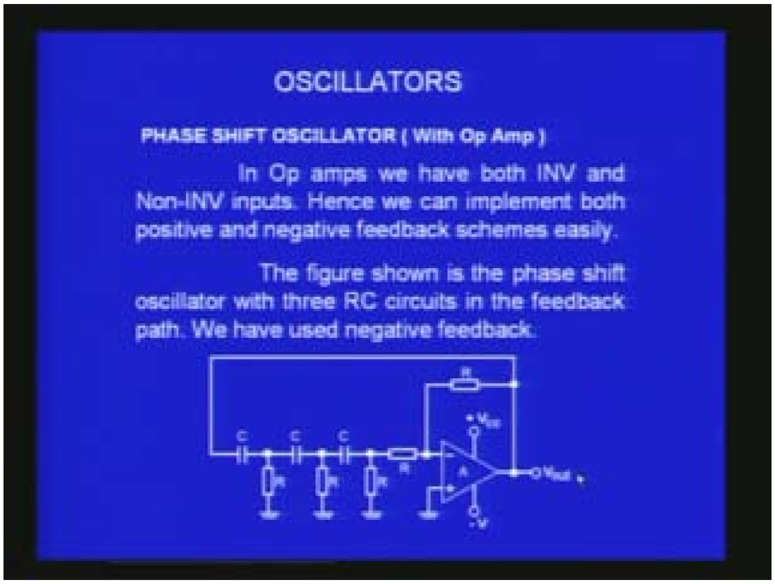

This is the circuit corresponding to a phase shift oscillator using op amp. You didn't find much difference with the transistor amplifier except that I have removed the transistor common emitter amplifier and in place of that I have introduced an inverting amplifier using op amp.

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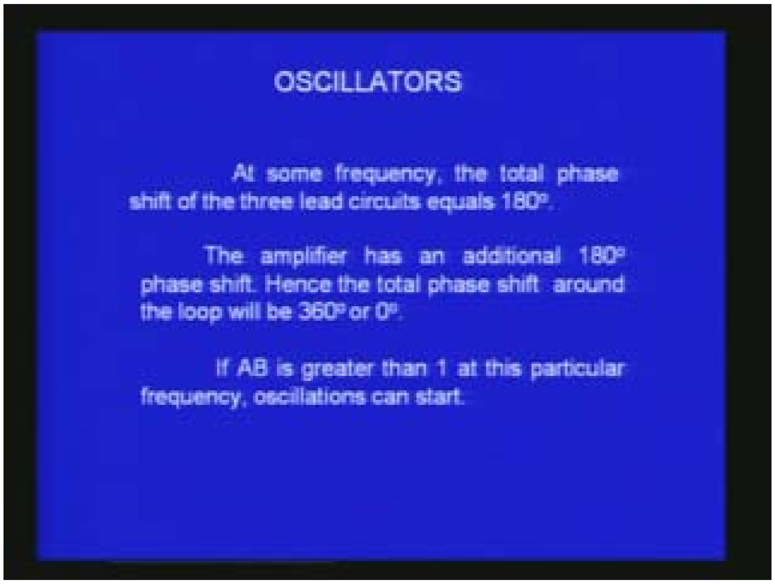

At some definite frequency f, 2 pi f will be omega and that will introduce at that frequency exact 180 degree phase difference with the combination of three RC networks. Once that happens you get the oscillations and when the AB is just the right value equal to 1 corresponding to Barkhausen condition the oscillations will start and you will get the output. You also should remember one important point in this and that is there is a minimum gain that I must ensure in this circuit, the phase shift oscillator so that the oscillations will be produced. It is not just one condition that the output should be fed back in phase there should be a positive feedback. That is one of the conditions. The second important condition is it should have sufficient gain the amplifier as such should have sufficient gain. Why is it so? To explain that I have shown you a circuit on the screen. What you are doing is you are feeding the output voltage at this network.

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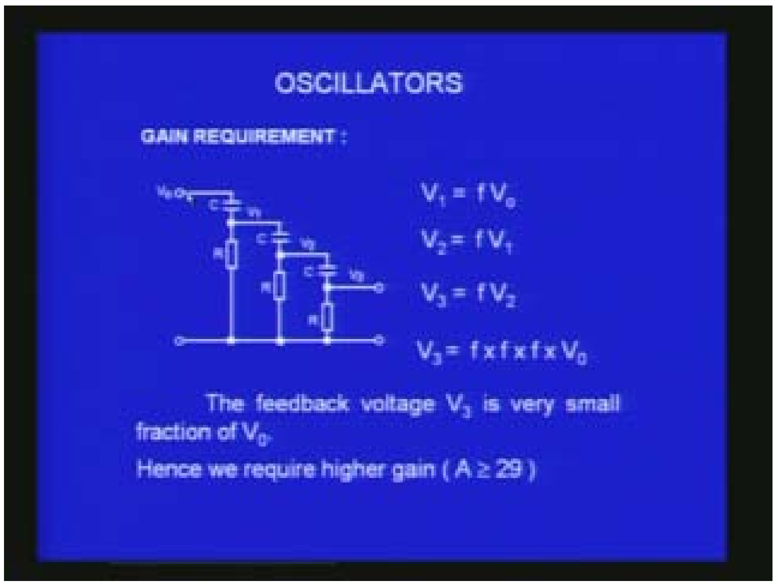

You have got a potential divider with one reactive and resistive component and take the output across the resistive component connect to one more RC. Then take the R output and again connect to one more. You have three stages of potential division. You divide it once into V_1. Then again divide into V_2 then again divide into V_3. What happens is for example if V_1 is 50%; if V_1 is 50% with reference to V output then V_2 will be half of that. That means $1/4^{th}$ of V_o. If every one of the network gives 50% let us assume then the first network will give half of the input. The second network will be $1/4^{th}$ of the input V_o and the third will be $1/8^{th}$ of this. There will be a continuous reduction and you have to amplify this to bring it to some level so that A beta becomes equal to 1. Whatever is the reduction that happens here you should amplify. If it is 8 times you should try to amplify by 8 so that you will get A beta equal to 1. That is the whole idea behind this phase shift oscillator. I call f as the fraction of the output not the frequency. V_1 is fraction of the V output. V_2 is fraction of V input, V_1; V_3 is fraction of V_2 and the total is f_1, f_2, f_3 times V_o. This f_1, f_2, f_3 is same like 0.5 that I mentioned and it becomes $1/8^{th}$. The V_3 that is actually applied at the input is very, very small because it has gone through three levels of potential division and when you are analyze the circuit you would get an expression where the gain of the amplifier for the phase shift oscillator to work should be greater than or equal to 29 to make the A beta equal to 1.

Why is it so? We will try to derive the expression also later on and we also should remember the frequency of this will be given by an expression f is equal to 1 by 2 pi root 6 RC.

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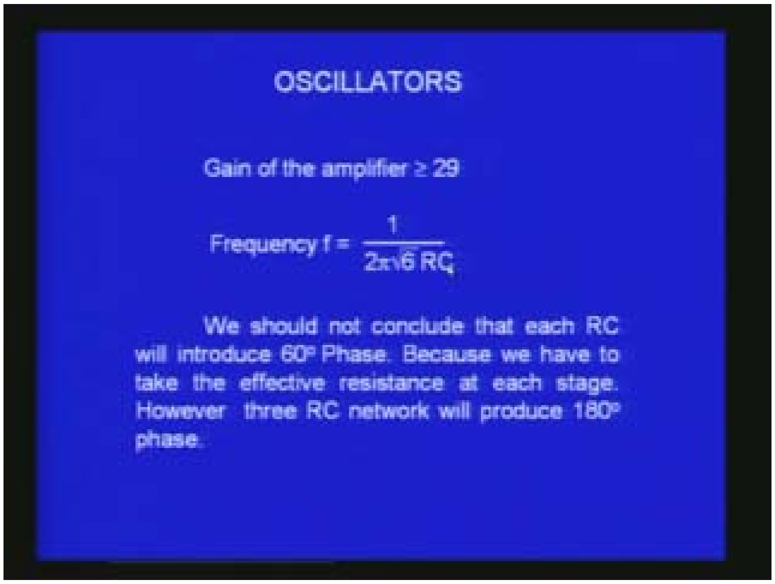

The root 6 is a factor which is coming in addition to the normal 1 by 2 pi RC term. When you use 3 RC phase shifting network the oscillator works when you maintain a gain which is larger than 29 and the frequency will be given by the expression 1 by 2 pi root 6 RC where R and C I assume are equal. You can also choose R_1 C_1, R_2 C_2, R_3 C_3. Then this expression will be much more complicated bigger expression. So usually everybody will try to do simple equal values of R and C for all the three networks. When I give equal values for all the three networks RC each of these will produce 60 degrees phase shift. First one produce 60 degrees the second one produce another 60 degrees and the third one produce 60 degrees. That is what we all assume. In principle it should be something like that. But in practice it is not. Ideally it is like that but in actual case it is not like that because if I take this R the potential divider is between the C and this R. That is what we have assumed. That will be true only if you don't take into account the effect of the presence of this other RC network. Because they are all connected they are all connected in parallel. The value of R will be affected by these two because they are in parallel combination. Again this R is affected by this RC, etc and you would not get the same R in each of the stages because of the presence of the other components and they will be never be equal to 60 degrees. You will get almost close to 60 degrees if you observe but it is not equal to 60 degrees.

If you really want to make them equal then what we have to do is we should isolate each of the RC networks from the other. For that I have used a buffered phase shift oscillator which you can see here. What I have done is the output voltage I connect to RC but I make sure the presence of other RC are not felt at this point.

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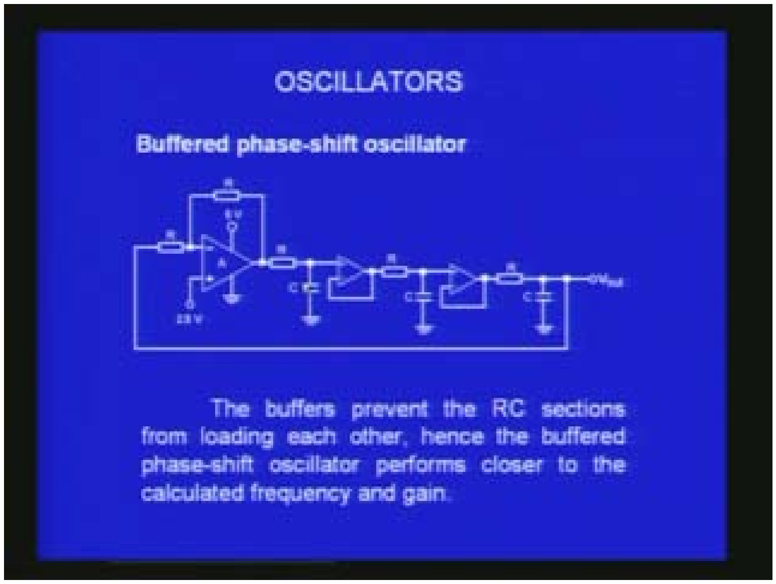

For that I have used a unity gain buffer which is very good circuit to produce very high input impedance and very low output impedance with a gain 1 and they only provide high input impedance here. It is so high that the reactive component due to C is the only contribution to the resistance here and the effect of all the rest of things that you have connected will not be felt here. This way I isolate segments from the other and thereby I have used two isolators here, buffers and if I measure the phase shift due to each of the RC network in this case it will exactly be 60 degrees for a given frequency. This is what is called a buffered phase shift oscillator. Let us try and see whether we can derive the expression for the phase shift oscillator.

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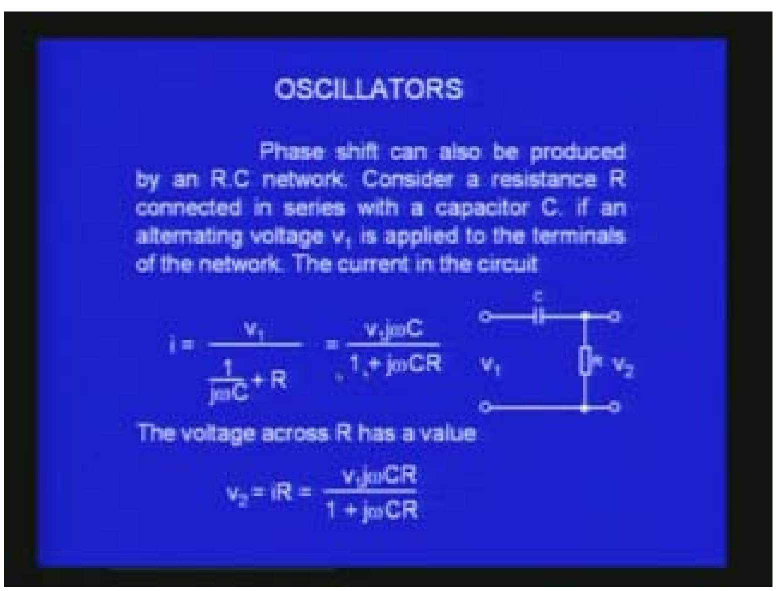

I will not give too many details. I will quickly skip some of the intermediate steps. I would expect that you would try to do it on your own and learn. I will give you all the principles involved in that. I take one RC network here C and R and what is the current? The current is voltage V_1 divided by the total resistance, by Ohm's law. Total resistance is R in series with capacitance R plus 1 by j omega C. 1 by j omega C is the capacitive reactance. When I simplify this it will become V_1 j omega C divided by 1 plus j omega CR. This is what I get. The voltage across R has a value V_2 is equal to current into resistance, again Ohm's law, I into R. Now if you multiply this I by R you get V_1 j omega CR divided by 1 plus j omega CR. You can get the value of the output voltage with reference to the input voltage when I apply it across a simple CR network.

I am going to connect like this three such networks.

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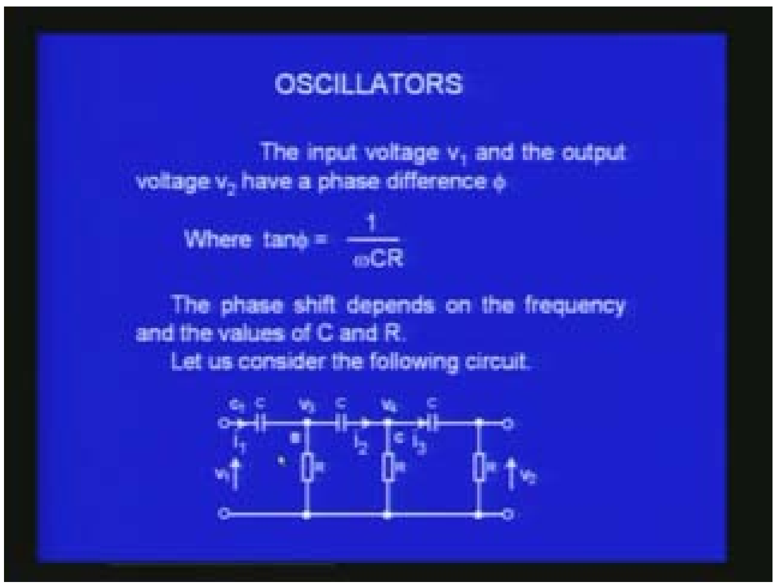

This is V_1, V_2, V_3 etc. I am calling this V_2 and this I call V_4. At this point it is V_3 and here I have V_1. The phase difference due to one of them is 1 by omega CR. We have already seen that tan phi is equal to 1 by omega CR. Let us try to derive the expression. What is V_4? V_4 is equal to V_2 plus i_3 divided by j omega C. Why is it like that? V_4 is here. What is V_4? V_4 is the voltage across R plus the voltage across C. The voltage across the R is V_2. The voltage across C is i_3 into reactance provided by C. Reactance provided by C is 1 by omega C. V_4 is equal to V_2 the voltage across R plus i_3 into 1 by j omega C; i_3 by j omega C.

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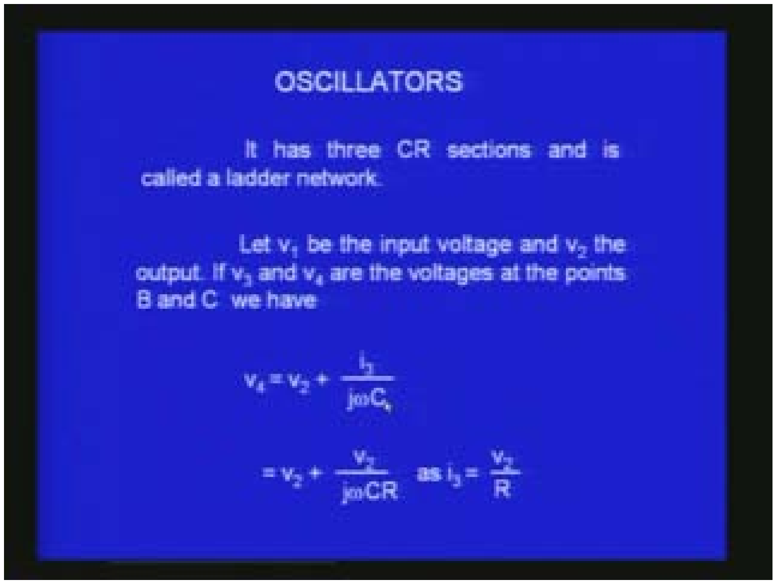

What is i_3? i_3 is V_2 by R. This is i_3, this current and it should be V_2 by R. If I substitute this it becomes V_2 plus V_2 by j omega CR. i_3 I have replaced. This is the voltage at V_4. I want to look at the next current i_2 in the circuit which is this current. I want this current i_2. This current i_2 is i_3 plus the current through this. i_3 is already known; we have already derived. This current is V_4 by R. That is what I am going to use now.

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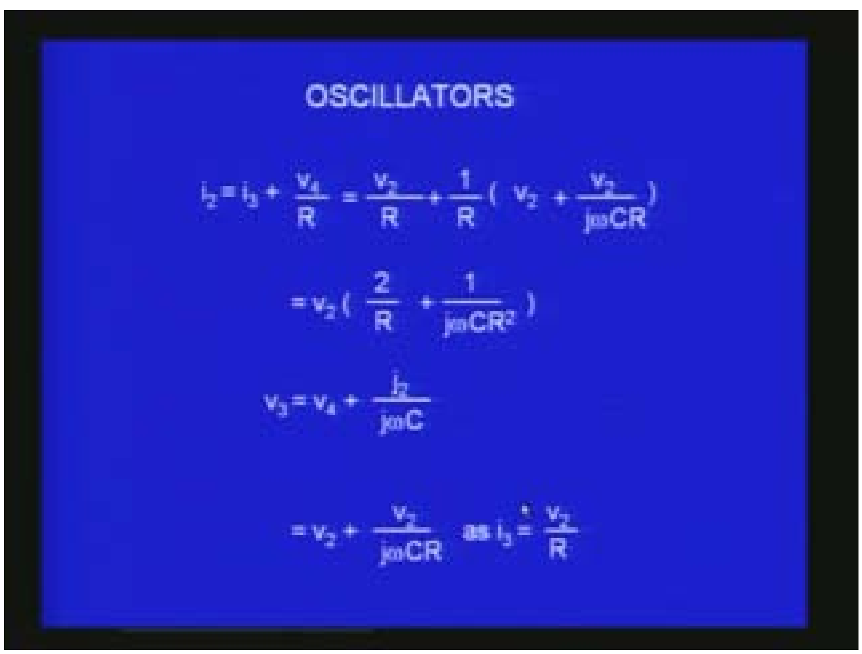

i_3 plus V_4 by R is i_2. I now substitute for i_3 which we have already got and i_3 is V_2 by R plus 1 by R into V_2 plus V_2 by j omega CR. That is V_4. We have calculated this. When you now combine and then simplify this V_2 is common every where. V_2 into this is 1 by R, 1 by R; 2 by R plus 1 by j omega CR square. These two R will become R square. This is what you get. V_3 is I have to multiply this by corresponding number V_4 plus i_2 into 1 by j omega C. You substitute for that again from the earlier expression for V_4 and you will get this expression and similarly you go for one more stage. i_1 is i_2 plus V_3 by R and you substitute you get this big expression and finally you can write V_1 in terms of V_2.

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If you go back and look at the circuit V_1 and V_2 are the two things that we want. When I apply V_1 what is the output? V_2. In the final expression V_1 is equal to V_2 into 1 plus 6 by j omega CR minus 5 by omega square C square R square minus 1 by j omega cube C cube R cube. That is what I get. What is the condition? The output voltage should be real and I should make sure the imaginary components in this expression become zero. The imaginary components are basically the second term 6 by j omega CR and 1 by j omega cube C cube R cube. These two terms together should become equal to zero. That is what I have written. 6 by j omega CR minus 1 by j omega cube C cube R cube should be equal to zero.

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If you simplify this you get omega square is equal to 1 by 6 C square R square and omega is 1 by root 6 CR and omega is 2 pi f. f is equal to 1 by 2 pi root 6 RC or CR. This is the expression for frequency. The expression for frequency comes from the condition that the network should have imaginary component zero. If you do that automatically you will get the frequency component. At this frequency what happens? This happens only for one frequency you should remember that. At this frequency I can now substitute that value in this expression and you will be taking only the real part because the imaginary part has become zero. You have 1 minus 5 by omega square C square R square. But what is omega square C square R square?

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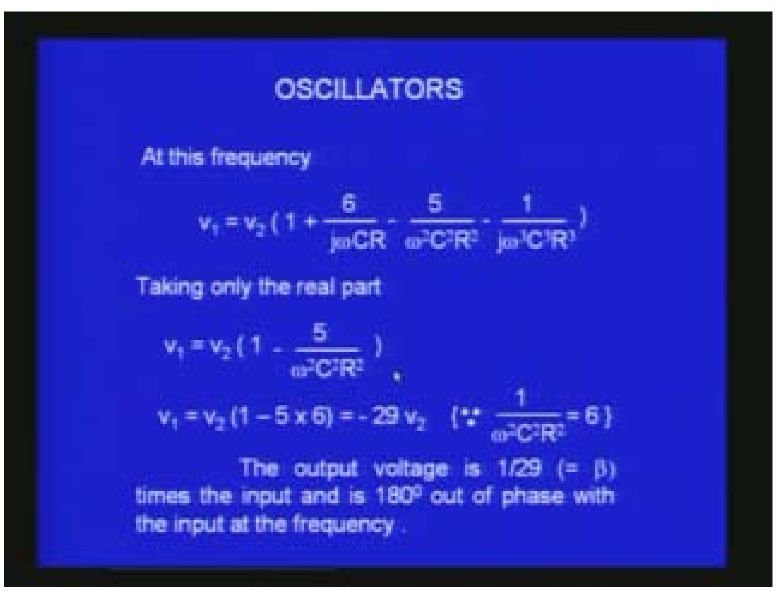

From this expression omega square C square R square is nothing but 6. When I take this omega square to the denominator 6 comes over on to the left side and the expression becomes 5 into 6 because 1 by omega square C square R square is equal to 6. That is 1 minus 30 is $-29V_2$. The output becomes V_1 is equal to -29 times V_2 or V_2 is 1 by 29 times of V_1 with a 180 degrees phase difference. Minus shows it is phase difference also. When will this become equal to 1? Only when the gain becomes 29; this is the beta factor 1 by 29. When the gain becomes 29 A beta becomes 29 into 1 by 29 which is equal to 1. It will satisfy the Barkhausen condition, you will get 180 phase also and the oscillations will be sustained. This is what we have in the RC phase shift network.

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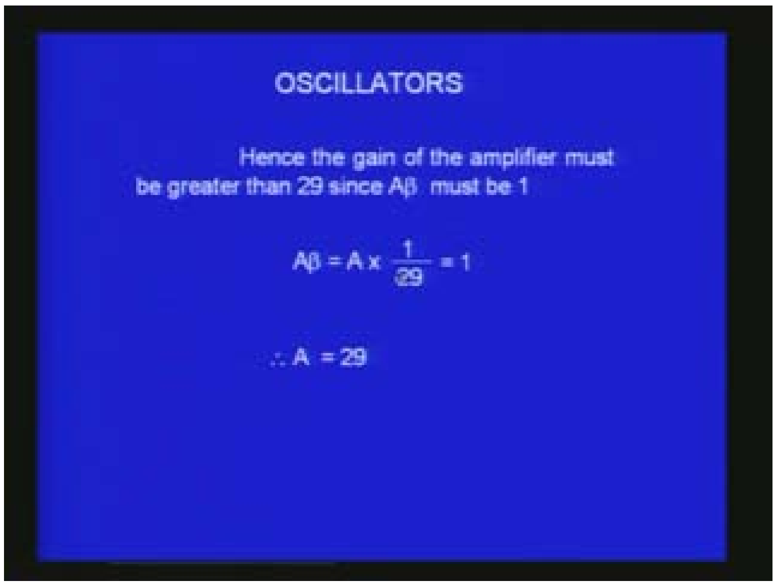

When A is equal to 29 this product becomes 1 but has satisfied the Barkhausen condition. With this back ground we have now discussed how you can make the phase shift oscillator using an operational amplifier using three RC network and it is very convenient because R, C are all very cheap components. You don't have to have very expensive gains and then you can easily vary them, change them and modify the frequency of the output waveform and it is very convenient to design, simple to design and I will show you a demonstration of the phase shift oscillator using operational amplifier.

Here the circuit is the same circuit which I showed you on the screen. You have the operational amplifier in the inverting mode with R_1 R_2. This is 2K and this is 100K. There is a gain of about 50. You can even make this as variable. I have used it as a variable potentiometer here and when I vary this I can get a gain which is larger than 29 very easily by modifying this R_2 by R_1 ratio. This is an inverting amplifier because you are connecting to the minus input. It is an inverting amplifier; there is 180 degree phase shift here. That output I take and give it to series of three RC. They are all 0.1 micro farad, 1K equal values.

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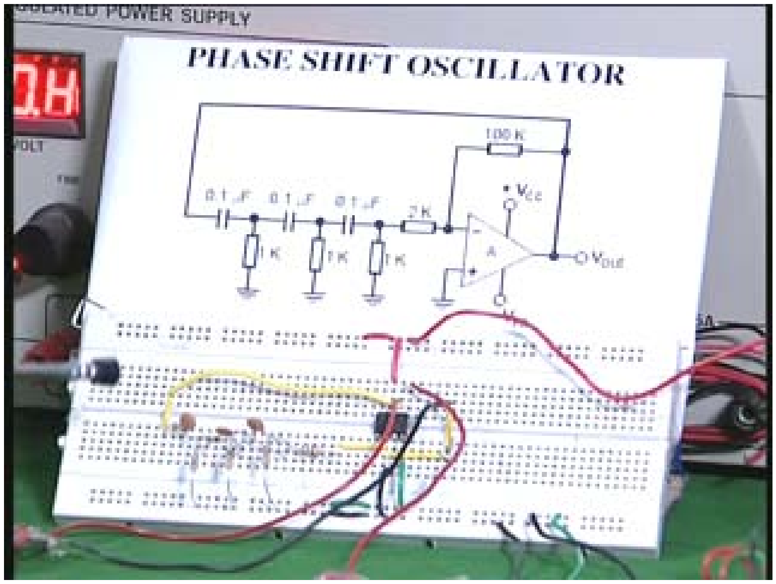

You can see in the circuit here three 1K resistors and three 0.1 micro farads here and that output is connected to the input pin number 2 of the operational amplifier that you see here and for the feedback resistor I have used a potentiometer, carbon resistor here and the output is monitored by using the oscilloscope. To determine the frequency of the oscillation I am also connecting a function generator here. You can see that this is the function generator. You can select different frequency scales here 1, 10, 100, etc and you can vary the frequency using these two knobs. One if for fast variation the other one is for slow variation; coarse and fine and you have here output voltages which is again for coarse and fine. You can vary the amplitude and the output of this I connected to another channel of the oscilloscope. In the oscilloscope you see two channels. If I change the frequency in the oscilloscope the two signals are same.

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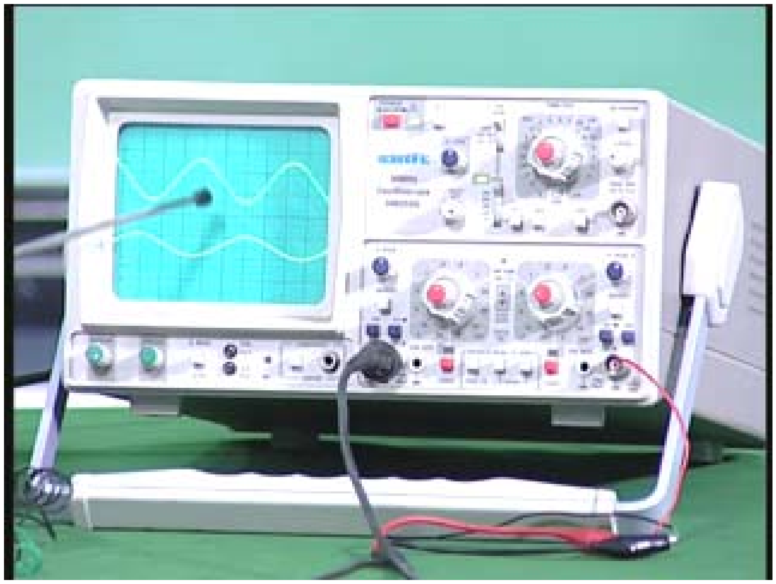

This steady one is due to the oscillator that we have constructed. This one is from the standard oscillator that I have used. What I am trying to do is I am trying to superpose them and measure the frequency. I am using the oscilloscope to bring them together and if necessary increase the amplitude, make the amplitude equal. I have made them almost equal amplitude and then I will slowly change the frequency till you get some coincidence. This almost coincides. When it is coinciding there is a continuous phase factor which is coming. That is why it keeps on moving. If you arrest them both the frequency is almost the same.

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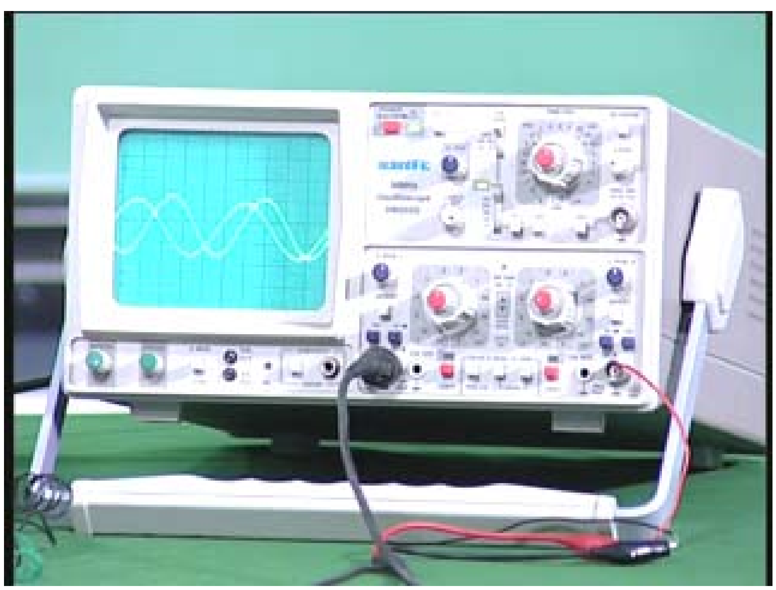

It is around 636. That is what you see here. This is the frequency and if you actually calculate 1 by 2 pi RC with R 1 kilo ohm and C 0.1 you will get close to 600 hertz but you may not get exact value and that is because there is also a tolerance of these resistors and the capacitors. Because of that you will not get an exact value but you should get very close value corresponding to 600 hertz.

How do you know that the output wave form that I get is due to the oscillator? I am varying the gain factor here. I get very high amplitude. When I change that now I don’t get any oscillation. When I change it, in the right gain of about 29 you see on the oscilloscope a building up of the sine wave.

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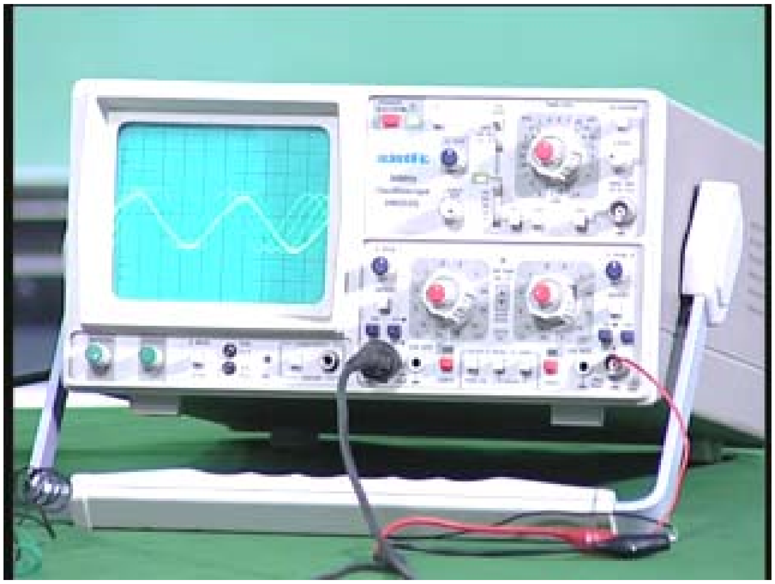

The sine wave builds up and if I now reduce it goes to zero. It is only the output from the circuit that I get on the oscilloscope. When I change it to X-Y mode then you get a straight line. We have to get the wave form back and then adjust the frequency. I am now making it X and Y and try to adjust till I get a circle. You get a circle here. When will you get? This is Lissajous pattern. When the frequency of the oscillator that we have constructed using the operational amplifier and the frequency from the function generator when both of them match I will get a circle on the screen.

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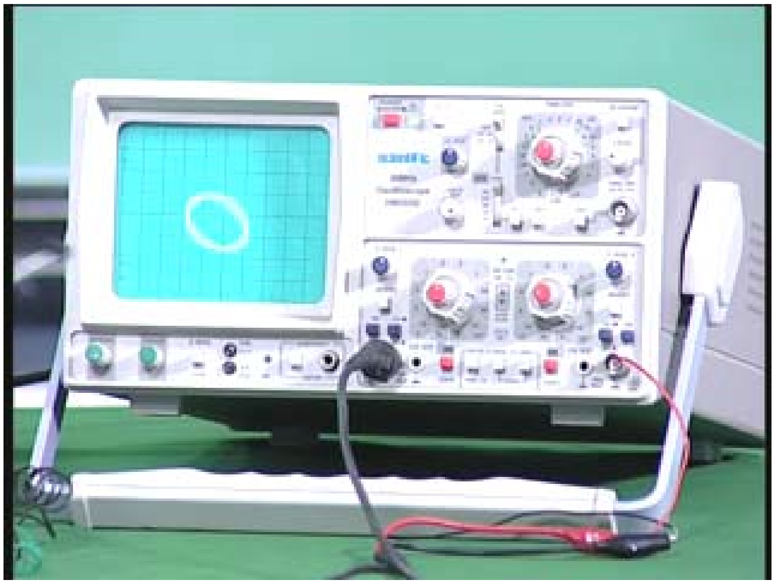

That shows the two frequencies are equal. Now if I make it into a dual slope both the sine waves are almost coinciding and the frequency is the same.

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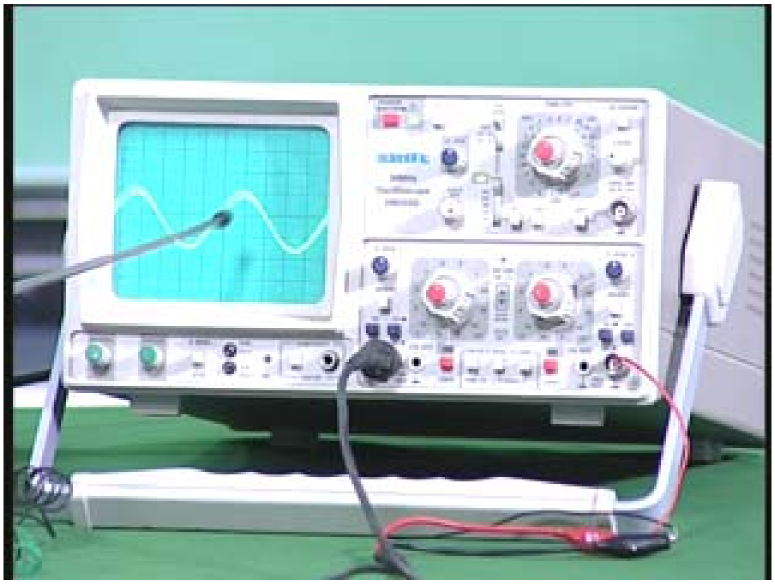

There are two ways in which you can measure the frequency. One is by comparing with another oscillator. The other one is using the X–Y mode and trying to generate the Lissajous pattern. That is what we have just now done. You have a phase shift oscillator here using op amp and the output to be measured in the frequency also has been measured. We will go on to the next circuit which is again an oscillator and again it uses RC networks and that is called Wein's bridge oscillator. What is a Wein's bridge? You can see on the screen a combination of RC again. But one RC is in series the other RC is in parallel.

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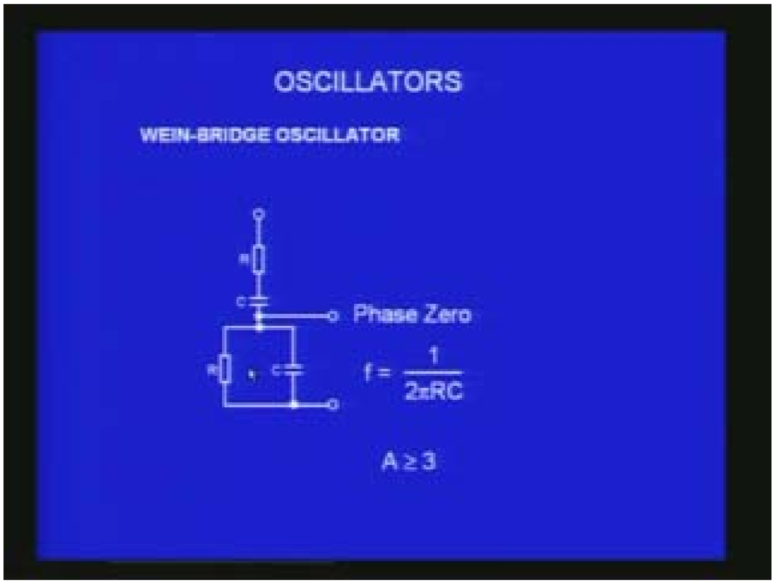

When I have RC in series and RC in parallel this combination is what is called the Wein's network. Wein is the one who found that when I give an input here the output that comes from this will be at zero phase for a given frequency. That is the property of this Wein's network and phase is zero and the frequency is 1 by 2 pi RC and when you do the investigation just as you did for the case of the phase shift oscillators, the gain will have to be at least 3; either equal to or greater than 3. These are the important points with reference to the Wein's bridge and one can also obtain the expression, I have given just the expression which you can test later on. This expression can be worked out on your own and this will also lead to the corresponding gain which should be greater than 3 and the phase shift will become zero. This RC Wein's bridge network can be used for generating frequencies in the range nearly 5 Hertz to 1 Mega Hertz. This is the greatest advantage of the Wein's bridge oscillator built on the Wein's network.

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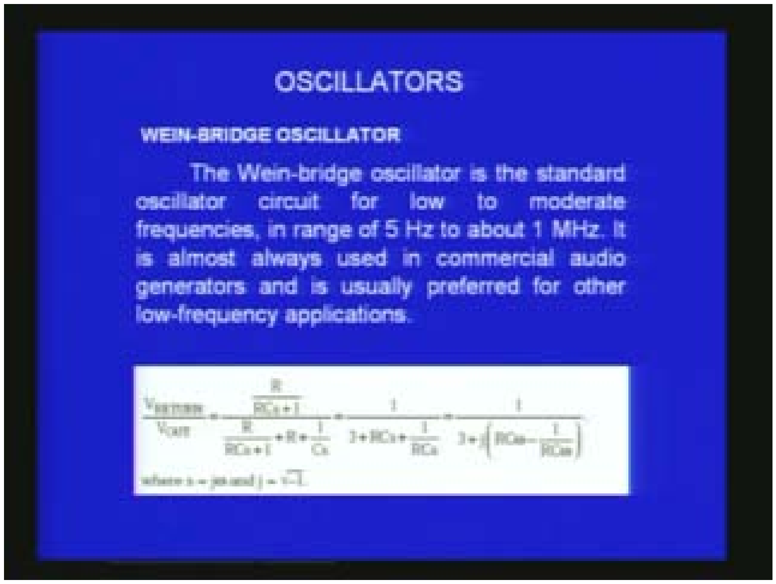

Everybody wants a variable frequency oscillator. Just now you saw a function generator which I used where I was turning a knob and the frequency was changing. If you want to do that in the RC phase shift network you have got three resistors and three capacitors. You have to adjust all of them either equally or differently. It becomes very cumbersome to have too many components to vary. In the case of Wein's bridge we have only two R and two C. Usually C is switched for decades and the resistance is varied for changing the frequency in between. It is very convenient, more convenient than RC phase shift network to use the Wein's bridge in the oscillator circuit. I have also shown a small analysis.

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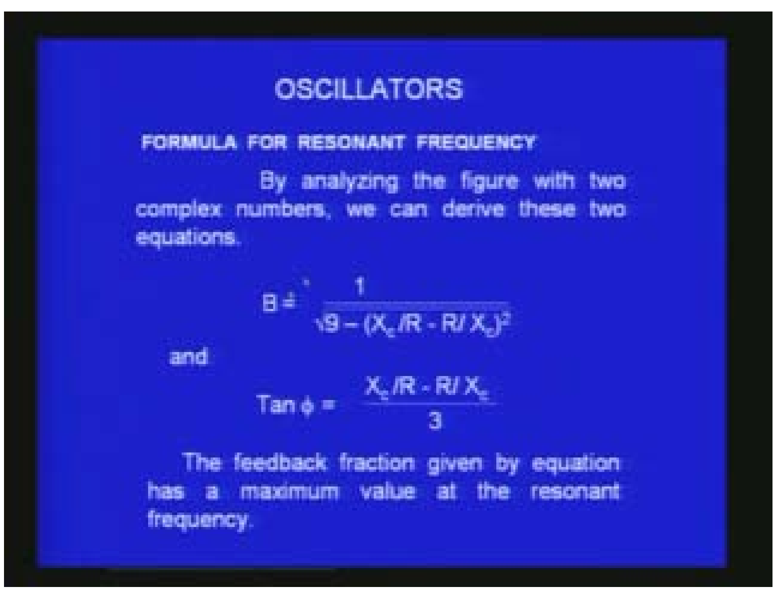

If you do that the beta factor will be 1 by root 9 minus X_c by R minus R by X_c whole square. The phase factor tan phi is equal to X_c by R minus R by X_c whole value divided by 3. These two expressions can be derived by using a simple network idea. I leave it to you as an exercise and what is important is when X_c becomes R that corresponds to a condition R is equal to 1 by 2 pi f_r C where f_r is the critical frequency.

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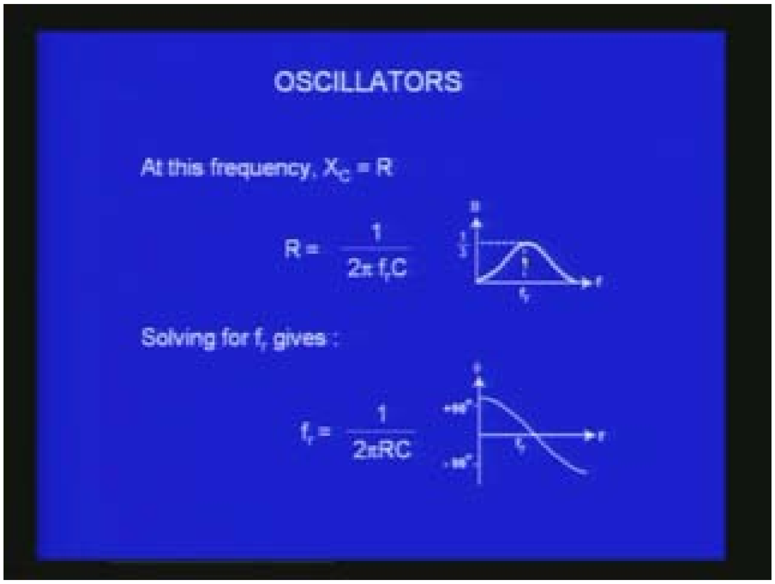

You get a maximum at that point, the fraction and that corresponds to 1 by 3. Beta will become 1 by 3. From this expression frequency is 1 by 2 pi RC and the phase actually goes at that frequency. X-axis is the frequency. At that frequency the phase goes to zero. Before it is +90 and beyond it is -90 and in between it crosses the zero and when it crosses the zero the corresponding factor is 1 by 3, the feedback ratio and that gives me an expression for the frequency as 1 by 2 pi RC.

I have now shown you the full circuit using op amp. This also can be constructed using transistors. When I have the Wein's bridge oscillator I have an op amp and you can see the Wein's bridge component coming here. RC in series and RC in parallel and the output at 1 with reference to 3; 3 is the output voltage of the op amp. 1 is the feedback voltage that is given. Because it is in phase the feedback is given to the plus. Already it is zero. There is no need to provide any additional feedback as in the case of the phase shift network. The output one is directly connected to the plus terminal in the picture and it becomes positive feedback. In the negative side I have used 2R prime and R prime and I don't know whether you are able to recognize the configuration. I am giving the signal to the non-inverting input and the inverting input is grounded through a resistor R prime and 2R is the feedback resistance.

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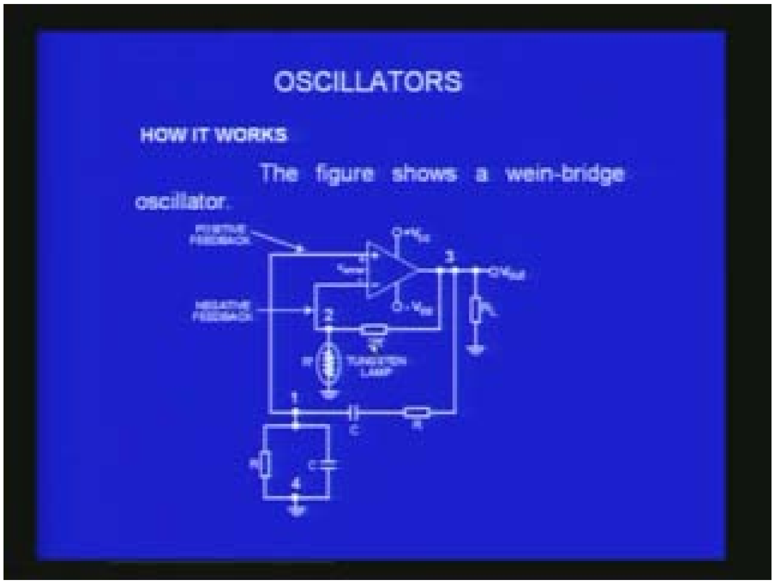

The gain of this will be 1 plus R_2 by R_1; we all know that for non-inverting amplifier. R_2 is 2R; so 2R prime by R prime is 2. 1 + 2 is 3. The gain will be 3. That is what Wein's bridge condition says; the gain should be greater than 3. You also normally have here the resistance which is connected to the inverting input. You don't use normal resistor. You use a tungsten lamp, a small lamp you can put. Why do you put the tungsten lamp? When the resistance is there the bulb will not glow at all. For the low current that we are going to send the bulb will not glow. But then when the current flows through that it will produces a heat. When the heat is produced the resistance becomes larger due to thermal effect and when the resistance becomes larger it will control the gain. The 2R by the R factor will become smaller and it will provide a negative feedback to introduce the stability in the amplifier oscillator and it is normal to use a tungsten lamp here. We will use without the tungsten lamp but one can also use the tungsten lamp and the expression becomes very simple. I have shown the same circuit. It is the same circuit but I have shown it in the form of bridge because we all know the Wheatstone's bridge; this is Wein's bridge.

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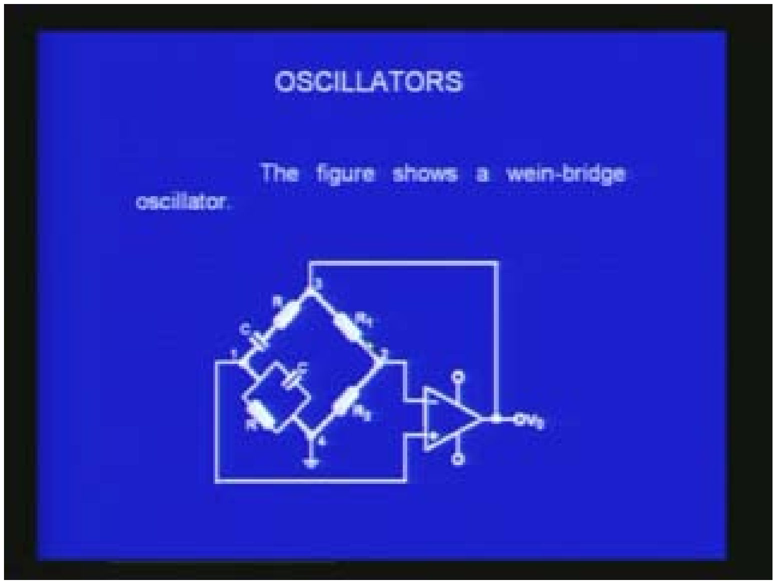

We have R_1 R_2. R and C in series, R and C in parallel forming the four arms of the Wheat stone's bridge and the first two arms are given to the output on the ground and the other one is given to the two inputs. This is a Wein's bridge oscillator and it uses positive feedback and also negative feedback for stability and it is a very, very simple circuit to get oscillations at the output and here again AB should be equal to 1 and that is what I have shown here.

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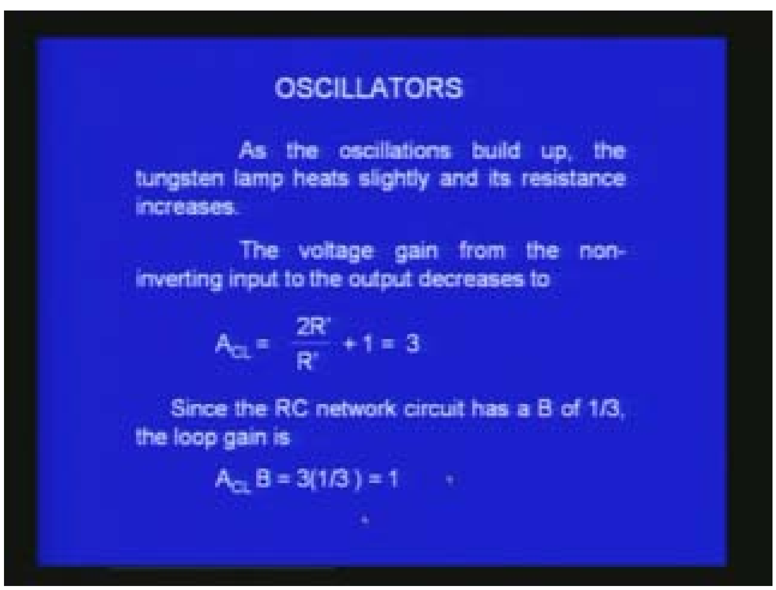

The closed loop gain is 2R prime by R prime plus 1 which is equal to 3 in this case and beta is 1 by 3. 3 into 1 by 3 is 1. That corresponds to Barkhausen's condition.

Let me show you an actual working circuit of the Wein's bridge oscillator. We have seen now two different types of oscillator circuits. One is RC phase shift oscillator the other one is Wein's bridge oscillator. Both are RC oscillators. I want to show you a third type of RC oscillator which is called Twin-T oscillator. It is called Twin–T because there will be two T networks. You have got two capacitors connected in series and one resistor here in the form of a T network. We also see two resistors connected in series and a capacitor is at the stem.

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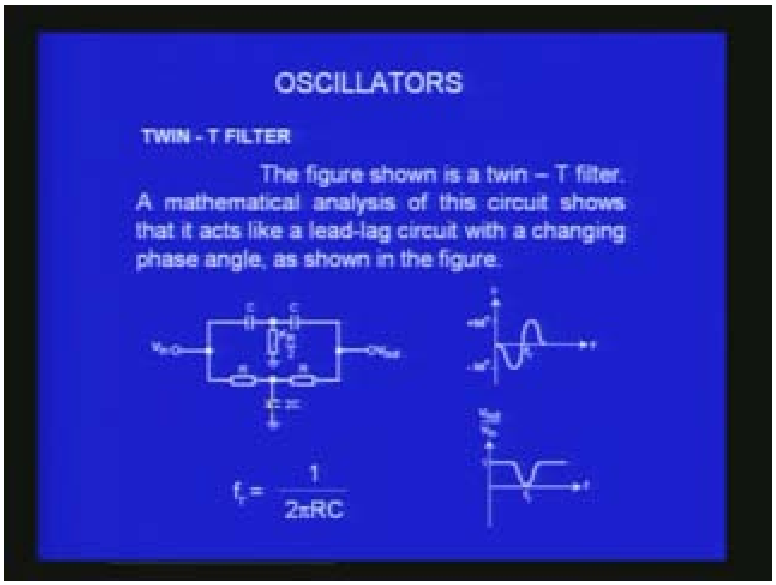

This is one T. This is another T. Both of them are combined together to form a network. This network is called Twin–T; one T here one T here. Two T's what we called Twin-T. The Twin-T network also like the Wein's network provides zero phase shift. V_{in} is there V output is there. They are in phase for a given frequency. It is a very simple scheme and I have shown here how the phase is varying. For example from zero it goes to maximum -90 and comes to zero again and goes to +90 and zero. This point where it crosses it gives zero output. It is actually a notch network. It will pass everything else except that frequency. It will not pass at that stage. It gives zero output at this point. V output, V_{in} gain is zero for that particular frequency. Phase is also zero output is also zero and the condition is frequency is 1 by 2 pi RC. It is very similar to Wein's bridge very simple to construct and this is also a very useful circuit.

We have formed a simple Wein's bridge network here and the circuit is very similar to what we have done in the case of Wein's bridge. We take the output and give through the twin T network and connect it to the input. This is used in the feedback network with zero phase shift.

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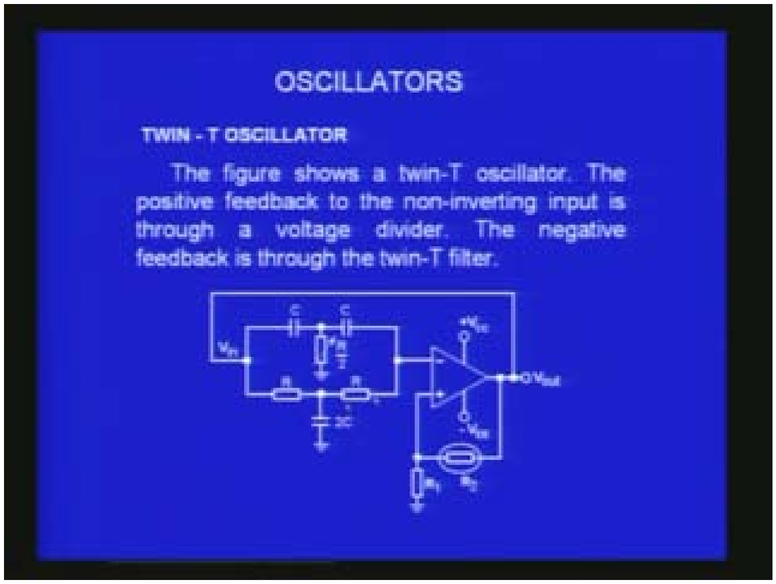

Once you do that you get an oscillator output which is again in the form of sine wave and the values of the capacitor and C is given here. If the value of the capacitor is C in the T network then in the other network it has to be 2C and the resistor R R and in the other network it will be R by 2 and you have the twin T network connected having the feedback point of the operational amplifier and you get an output which is corresponding to the twin T oscillator. I will show you the demo. Here I have the circuit of the Twin-T network.

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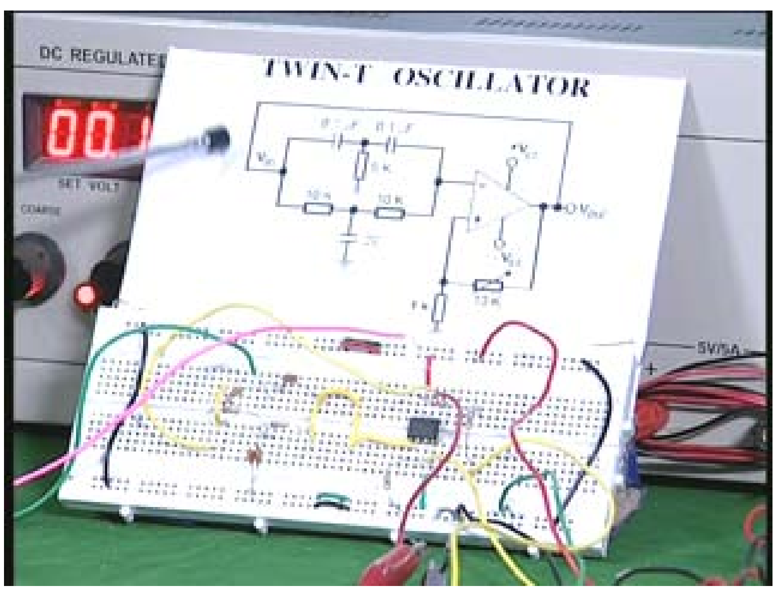

You can see the one T here one T here. The corresponding circuit is shown with two resistors and one capacitor and the two resistors and one capacitor here. This is the Twin-T network and you have the operational amplifier and one of the resistors here is made as a variable resistor for adjusting the gain and you observe in the oscilloscope the sine wave generated due to the twin-twin network.

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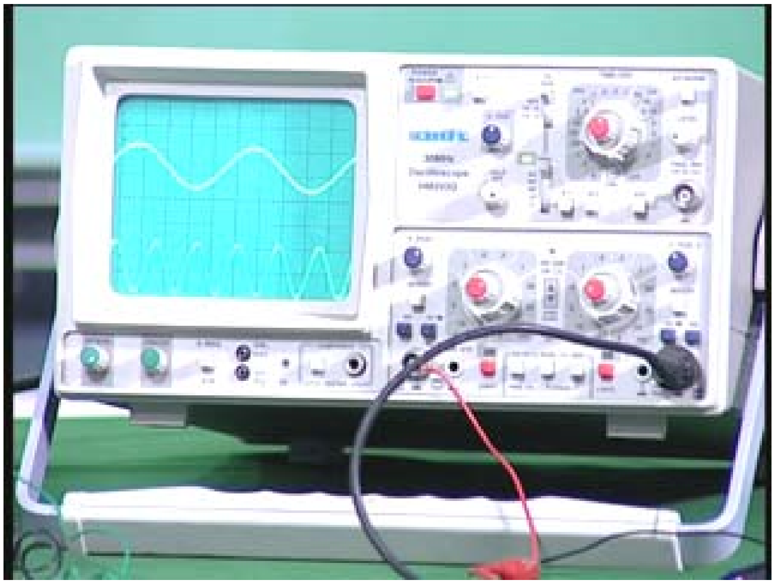

If I vary the potentiometer I will be able to get the oscillations. I have got the two channels for the oscilloscope I have connected this is the output from the oscillator This is the output from the standard oscillator this is from the circuit and I want to compare the frequencies. I will adjust the frequency to larger values. I keep adjusting the frequency so that they both match. If I coincide them and make them go slowly the two frequencies will almost match. The better way is to use the circle. When I get a circle, Lissajous pattern the frequencies should be matched perfectly. The frequency is about 1.84 kilo hertz for the component that I have used. The two frequencies matched very well even when I put it that way. The values of the resistors are 10K and 0.1 micro farad.

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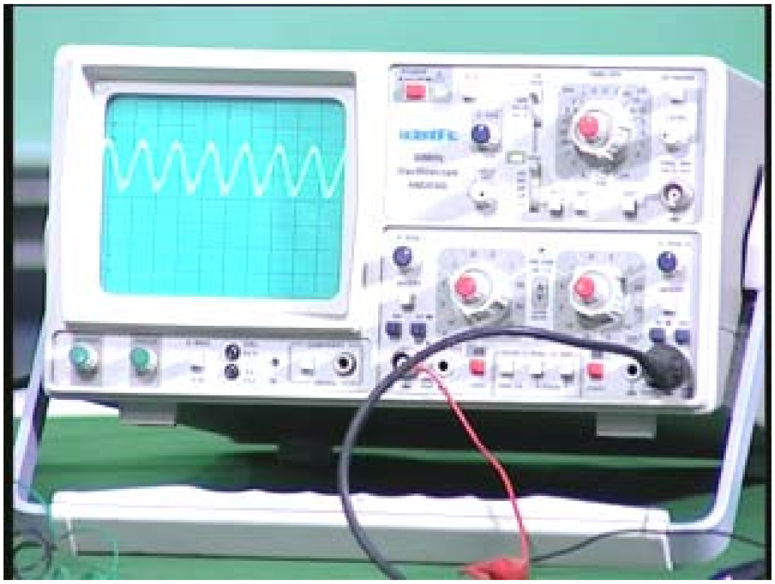

This is 10K the two resistors and the capacitors are 0.1 microfarad and this will be 2C. That means 2 times 0.1; 0.2 micro farad. Actually parallel capacitors are put there to add and this is 5K. They have put again resistors in parallel to make these 5K or you can use 4.7K. A very simple sinusoidal oscillator can be constructed using Twin-T network.

We have seen in this lecture three different types of oscillator circuits built using op amp. One is the RC phase shift oscillator the other one is Wein's bridge oscillator and the third one is Twin-T network oscillator. All the three are very useful but the most useful among them will be the Wein's bridge because it is much easier to vary the R and C component. You can have ganged resistors and ganged capacitors and most of the oscillators that you get commercially in the low frequencies less than 1 mega hertz are based on Wein's bridge oscillator. Thank you!