Electronics for Analog Signal Processing - II

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Lecture - 14
Oscillators

Let us consider sinusoidal oscillators. We had already seen that sinusoidal oscillator...or that function can give us a solution, straightaway sinusoidal value, is d square V naught by d t square plus Gamma V naught equal to zero, which is the harmonic equation; and solution to that is V naught is equal to some V t sine Omega t. Omega is equal to root Gamma. We have seen this and we said such a thing can be simulated; but if we want really a practical oscillator, we must have d v naught by d t term. But the co-efficient Alpha should start from a small negative value and should go to zero at the required amplitude of oscillation. This is the basic requirement for buildup of oscillation.

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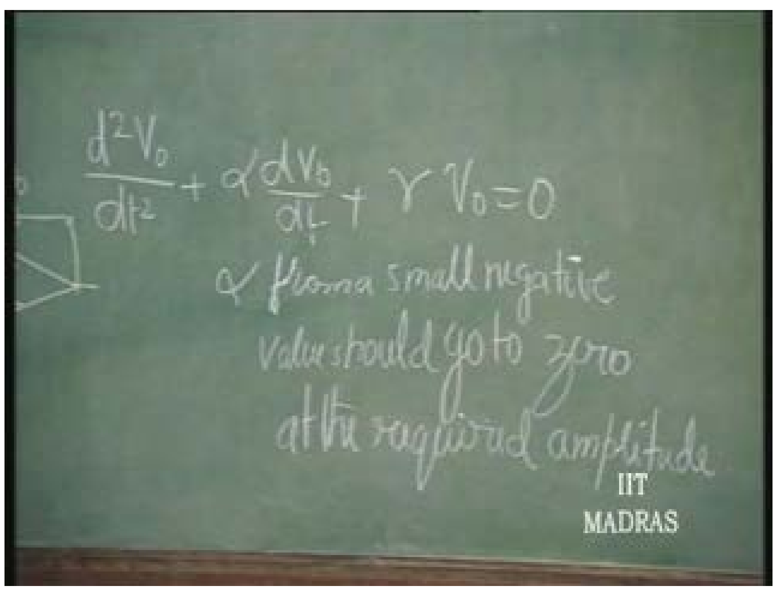

So, how do we really come out with simulation of such a thing? This, we had seen. Earlier, I had explained to you how to simulate second order differential equation.

I start with the assumption that d squared V naught by d t square is available. Then, this will be minus 1 over R 1 C 1 d v naught by d t, one integration; and this will be again plus 1 over R 1 C 1 R 2 C 2, again integration, V naught.

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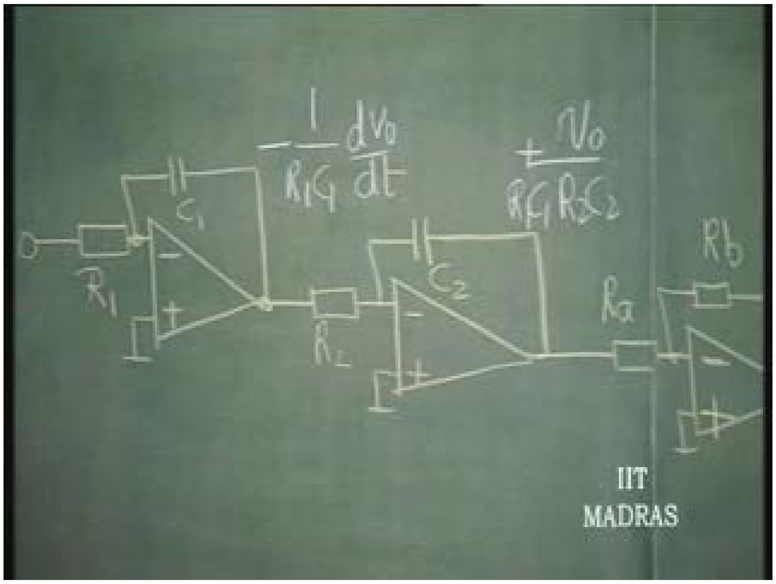

And at this point, it will be just inversion with R b by R a V naught divided by...this is going to be inverted; R 1 C 1 R 2 C 2.

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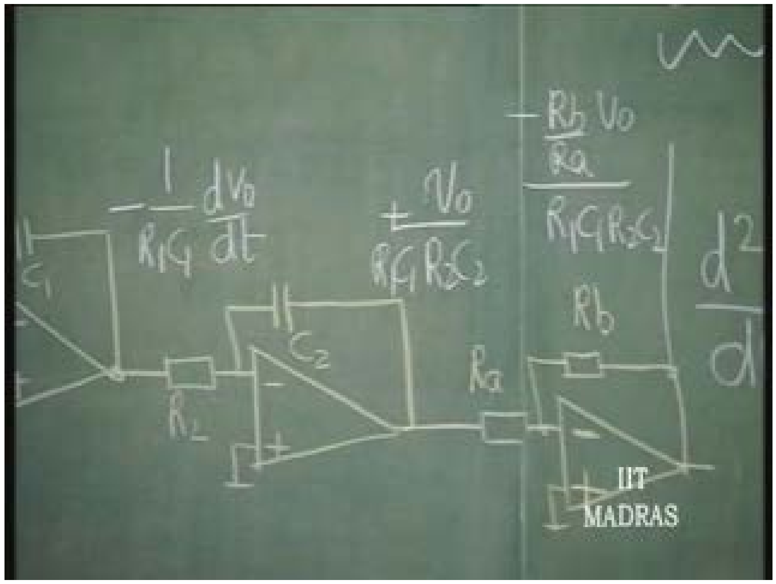

So, if you start with d square V naught by d t square, one differentiation integration will give you minus 1 over R 1 C 1 d V naught by d t; another integration will give you V naught by R 1 C 1 R 2 C 2 and then minus R b by R a is the gain this stage; and ultimately, we have an equation here – d squared V naught by d t square equals...if you ignore this, minus Gamma V naught. So, that minus Gamma V naught we have got here...

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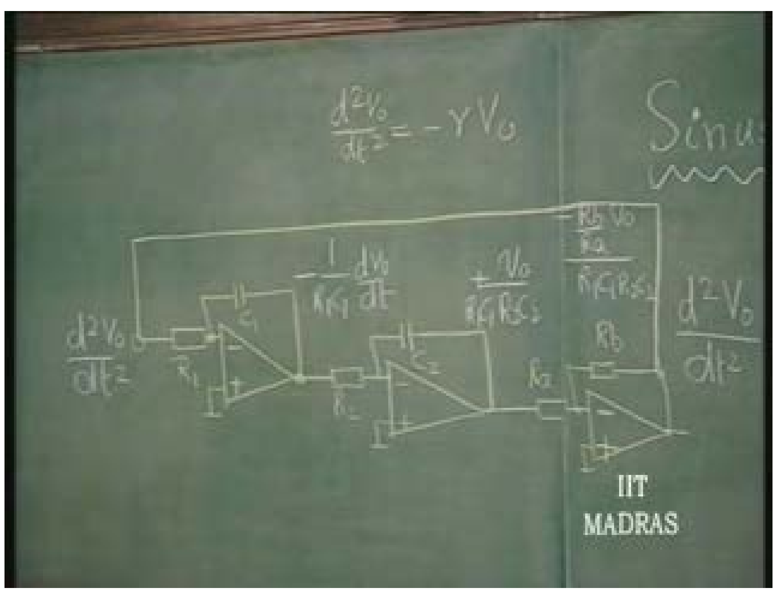

So, we can connect this; and this connection will make d square V naught by d t square equal to minus Gamma V naught, where Gamma according to us is nothing but R b by R a divided by R 1 C 1 R 2 C 2. This is also called Omega naught square, the frequency of oscillation being Omega naught; root Gamma is the frequency of oscillation.

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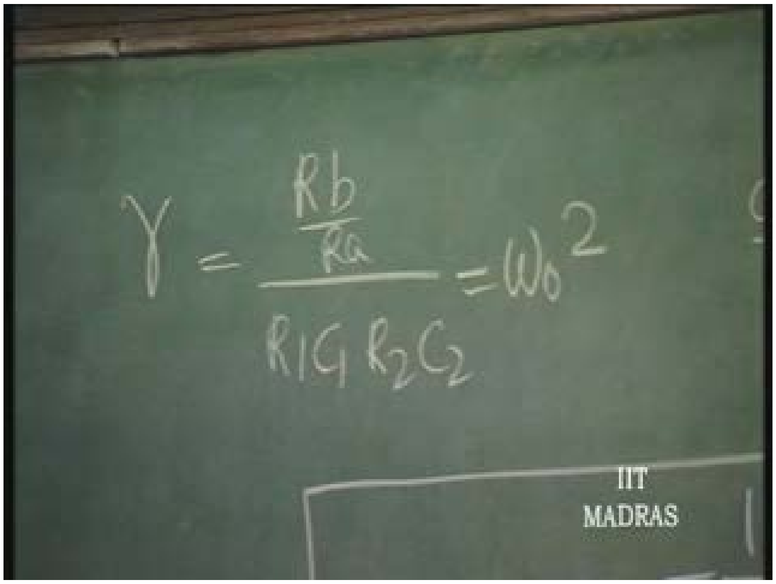

So, we get, using this structure and oscillator, which is called quadrature oscillator or this is also called double integrator oscillator.

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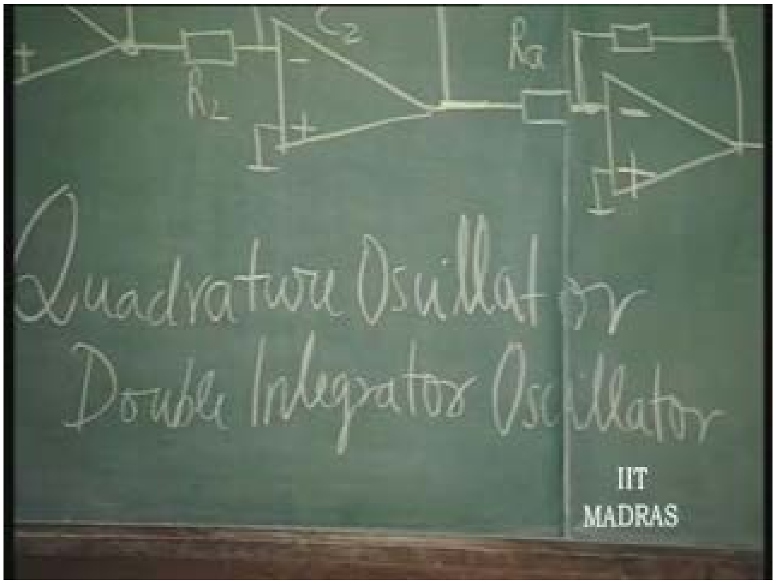

Quadrature because if this is V t sine Omega t, this will be V t cos Omega t. V t dash cos Omega t; and therefore, frequency of oscillation, Omega naught in this case, is root of R b by R a R 1 C 1 R 2 C 2.

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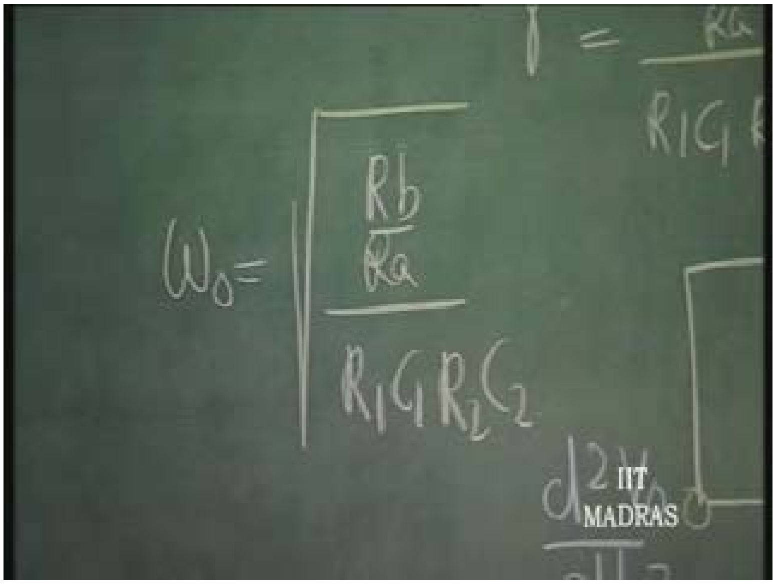

Now, if therefore output can become equal to input in magnitude...by connecting this, if I break the loop and then at a certain frequency if output can become equal to input in magnitude and have zero phase, then I can close the loop and make an oscillator out of it; or, if the loop gain, the loop gain becomes equal to 1 at Omega naught, only at Omega naught, then it becomes a sine wave oscillator at Omega naught.

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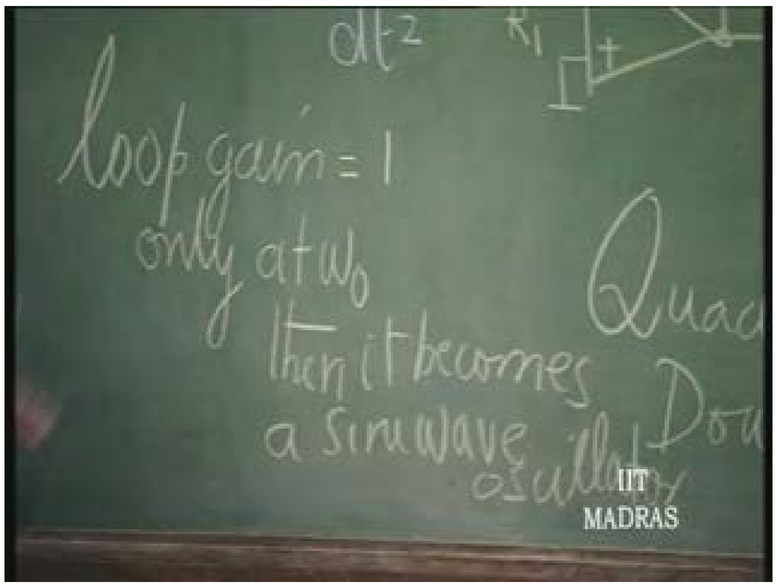

We can see here. This is...to start with, if you call this as V i, I break the loop, call this V i; this is minus V i by S C 1 R 1. This is plus V i by S squared C 1 C 2 R 1 R 2. This is minus R b by R a divided by S squared C 1 C 2 R 1 R 2. S squared - you replace it by g Omega. Therefore, that factor becomes minus R b by R a minus Omega naught squared. This becomes plus, C 1 C 2 R 1 R 2. That is the loop gain. It becomes equal to 1 at Omega naught square equal to R b by R a R 1 C 1 R 2 C 2.

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So the loop gain...that is, now I can close the loop and it will act as an oscillator. So, this is another way of looking at the oscillator.

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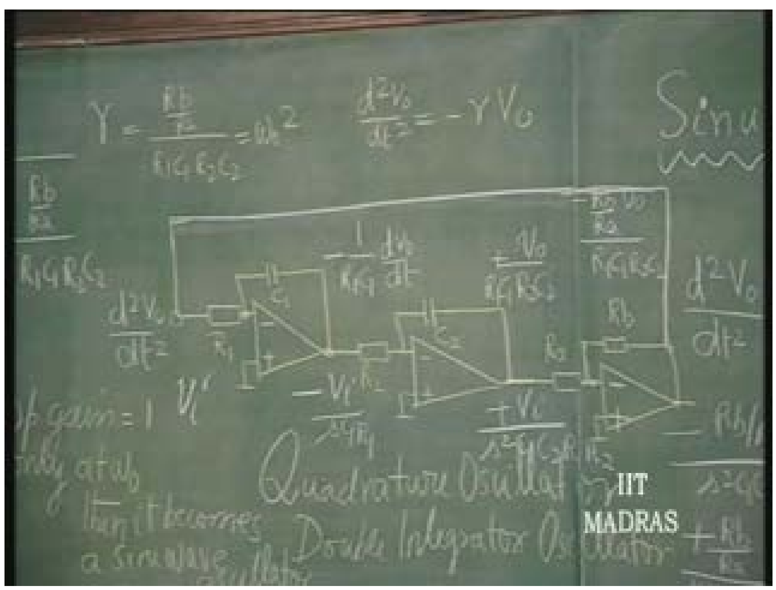

If I can make the loop gain in any loop equal to 1, that means magnitude should equal 1, phase shift should equal zero. That means output should become equal to input, in a loop, when it is broken, only at a certain Omega naught, then it becomes a sine wave oscillator. This is a classic case of such a circuit.

There is another way of looking at oscillators. One way of looking at oscillators is this way. That it is simulating a second order differential equation with Alpha going to zero. Another way of looking at is in terms of loop gain by saying that if I break the loop, if I apply voltage here, output becomes equal to input, both in phase as well as in magnitude. Then, I can close the output and input and it becomes an oscillator.

So, what it means is, initially I apply voltage. Output becomes then equal to input at a certain frequency. Then this voltage source need not be connected at all. First, we can connect the output input and then take away this input voltage. It does not know that input voltage has been taken away; and therefore, it sustains the oscillation Omega naught. So, this kind of analysis also can be adopted in coming up with new oscillator circuits. And, only one thing... In this circuit, suppose we have to introduce this Alpha. What should I do?

That means d squared V naught by d t square is minus Gamma V naught and minus Alpha d v naught by d t. In order to make it go into oscillation, in practice, we need a small negative value here which will ultimately go to zero, at the required amplitude.

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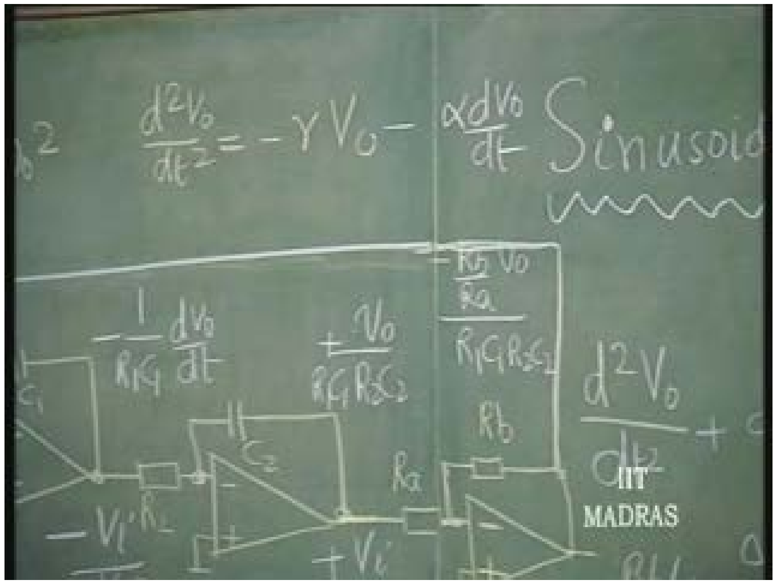

So, how do I make that? I have minus 1 over R 1 C 1 d v naught by d t here. I already have minus Gamma V naught here. Therefore, I had to take portion of this and bring it over here. So, this is what is necessary. This is d square V naught by d t square. This is minus 1 over R 1 C 1 d v naught by d t. If Alpha is to be negative, then this should be negative; and this will be plus. Alpha is to be negative.

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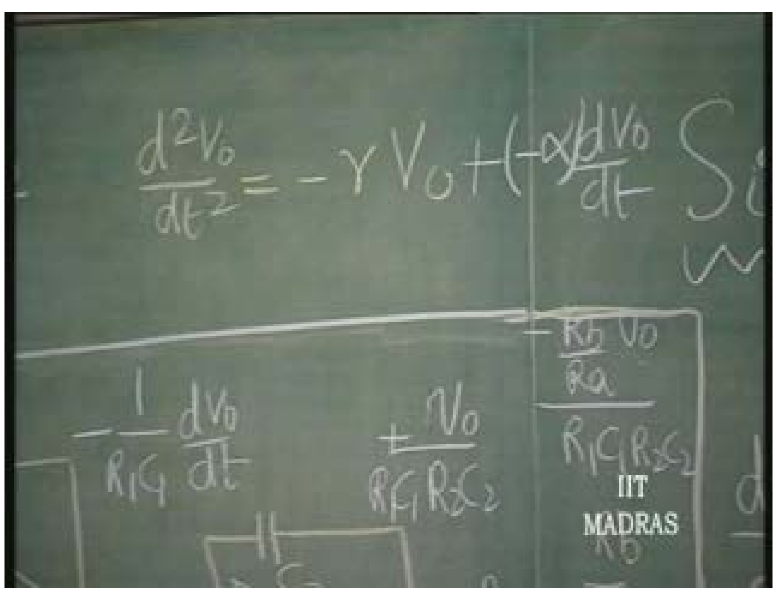

So, I can simply add from here, resistance. Let us call this R C.

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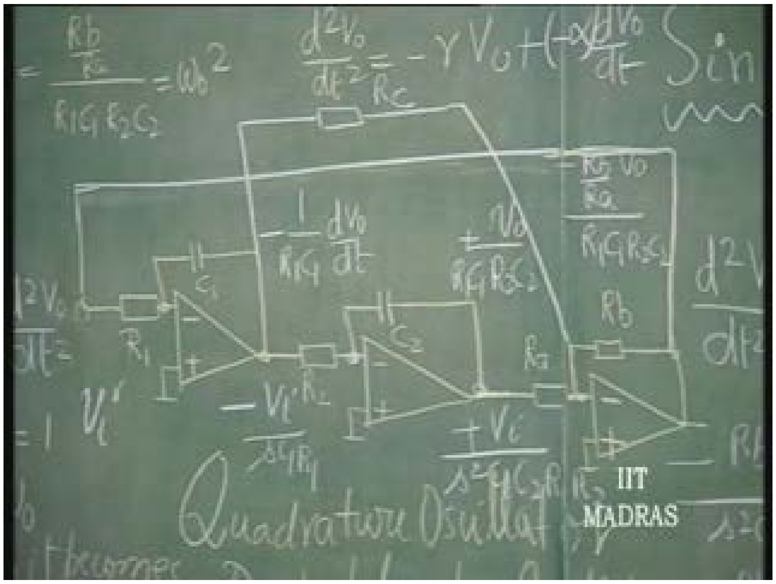

So, what happens to the output here? It is now...this is going to have, apart from this, plus Gamma...this thing...plus...from here, one inversion. Let us call this R C. So, R b by R c divided by R 1 C 1 into d v naught by d t.

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So, you can get negative value for the entire thing now, through this kind of feedback. So, this is going to introduce the negative Alpha on to the...this side; and already we had seen how a positive sort of Alpha can be obtained by feeding back at this point. So, that will make a filter get design. This will make an oscillator get design for you. So, if it does not oscillate, simply put a large value resistor between this and this and adjust the value of resistor until it starts oscillating.

So, this resistance R C should go to infinity as amplitude builds up, ultimately locating the poles of this system on the imaginary axis. By putting R C, I have made sure that the system pole to start with is on the right half of the S plane. So, this is one type of oscillator.

Let us now use the concept that we have just now learned about making the loop gain equal to 1 at a certain frequency; only at one frequency. That is, output is in phase with input and output is equal to input in magnitude.

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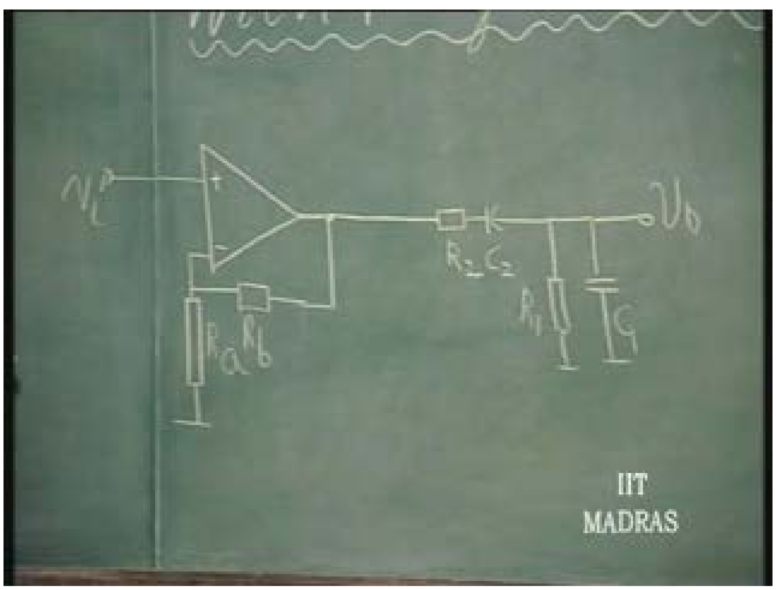

If that is the case, then I can connect the output to input and have an oscillator. So, if this is V i, we know that I use a non-inverting amplifier here. I get a gain of 1 plus R b by R a times V i here. This is a non-inverting amplifier of gain 1 plus R b by R a.

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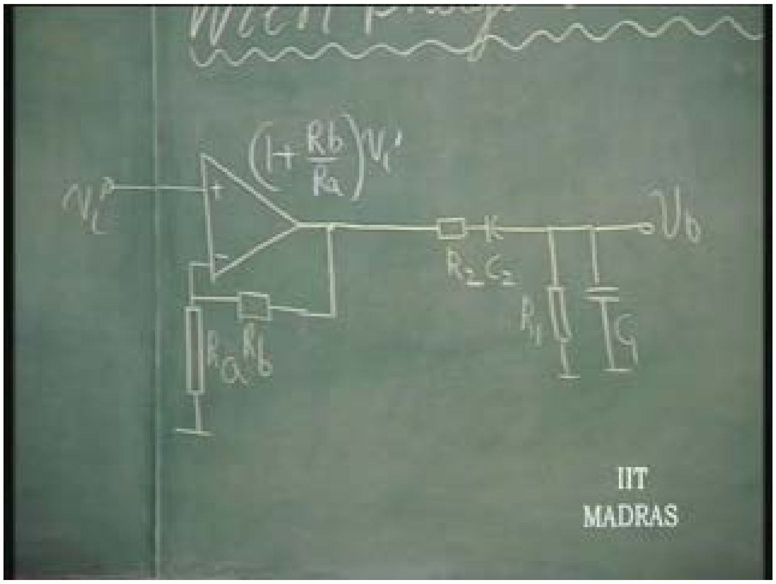

As far as this network is concerned, if you call this as Z 1 and this as Z 2, the attenuation here is going to be Z 1 divided by Z 1 plus Z 2.

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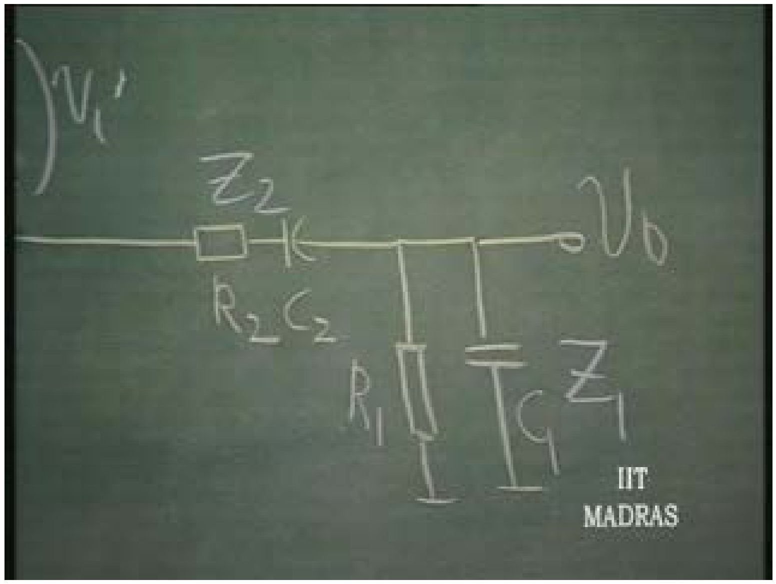

So, output V naught is going to be 1 plus R b by R a times V i, which is the input to be Z network, into Z 1 by Z 1 plus Z 2; or, this is also equal to 1 plus R b by R a into V i; dividing by Z 1; 1 plus Z 2 into Y 1. So, this is equal to 1 plus R b by R a into V i...1 plus Z 2 is R 2 plus 1 over S C 2; R 2 plus 1 over S C 2. Y 1 is 1 over R 1 plus S C 1; 1 over R 1 plus S C 1.

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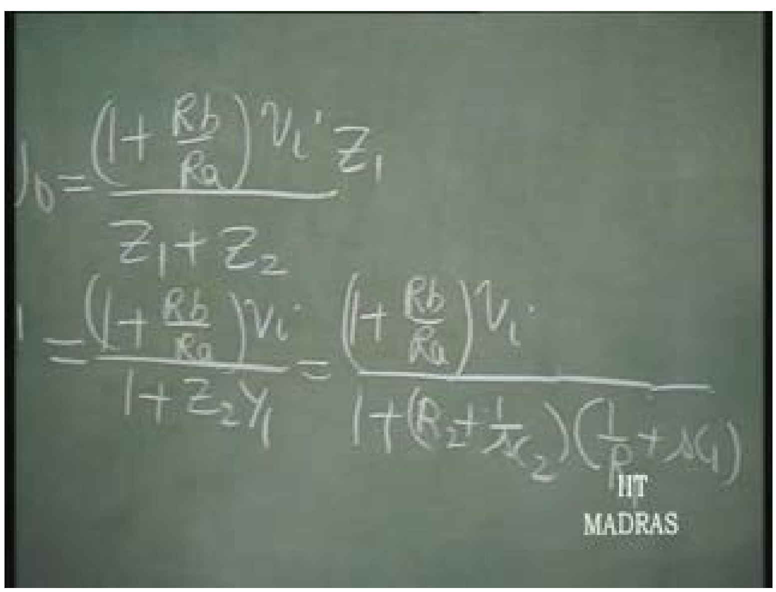

So, you get this...here V naught, as being equal to 1 plus R b by R a into V i divided by 1 plus R 2 by R 1 C 1 by C 2 plus 1 over S C 2 R 1 plus S C 1 R 2.

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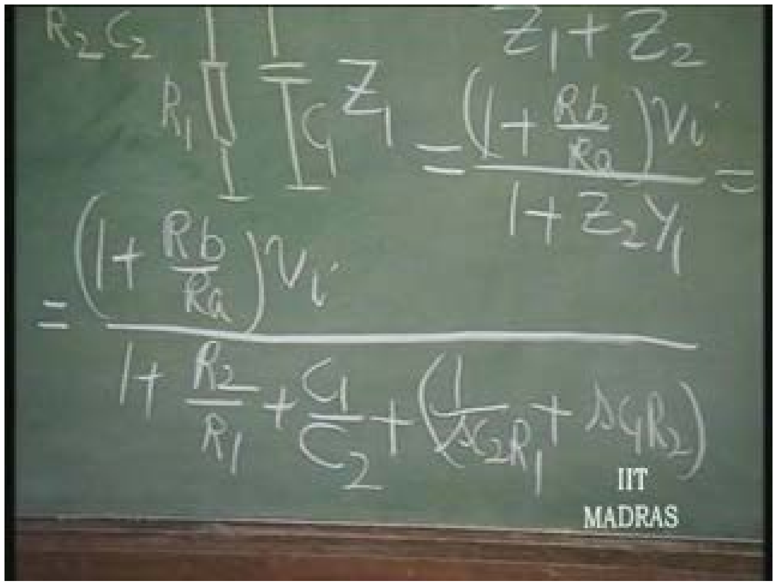

And now you can substitute S equal to j Omega. j Omega. This is also j Omega; or you can actually bring this j out here. So, this becomes minus. So, you can make this quantity within j zero at one frequency.

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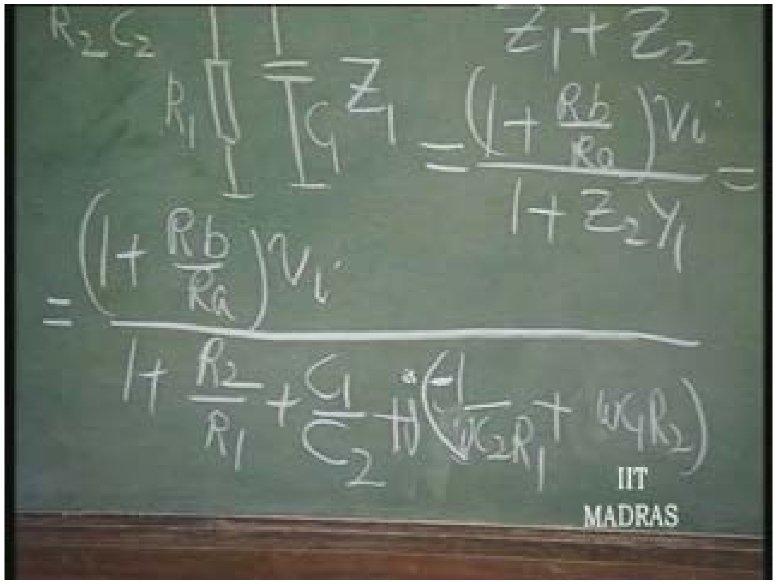

That means it will be in phase; output will be in phase with the input at that frequency. So, this quantity is the one which contributes to phase shift. So, that happens equal to zero when Omega naught is equal to 1 over root of C 1 C 2 R 1 R 2. That is the frequency of oscillation.

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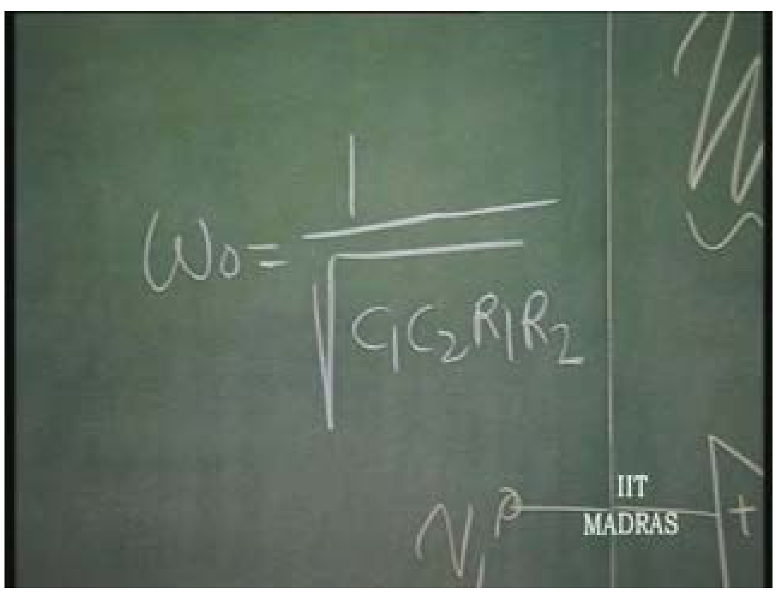

At that...when this is becoming equal to zero, the attenuation is 1 plus R b by R a divided by 1 plus R 2 over R 1 C 1 over C 2. If this becomes equal to 1, then output is equal to input and it is in phase.

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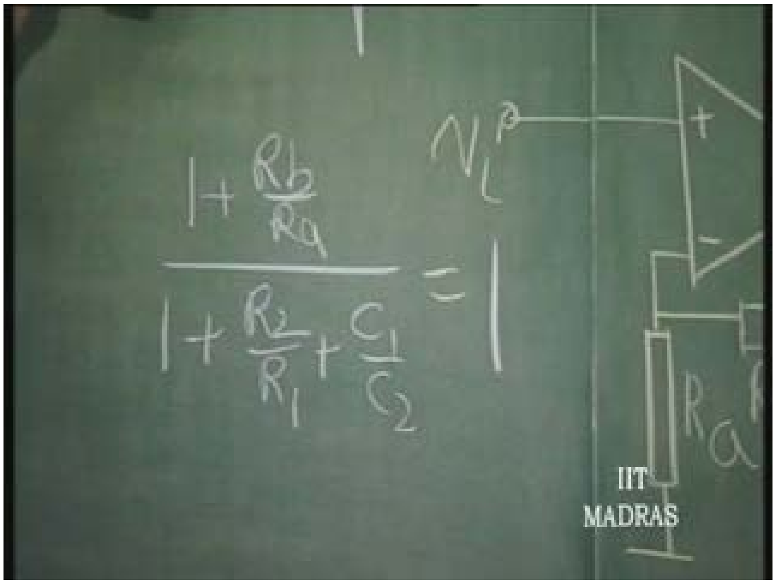

So, I can now connect the output to the input. It will oscillate at Omega naught equal to 1 over root of C 1 C 2 R 1 R 2.

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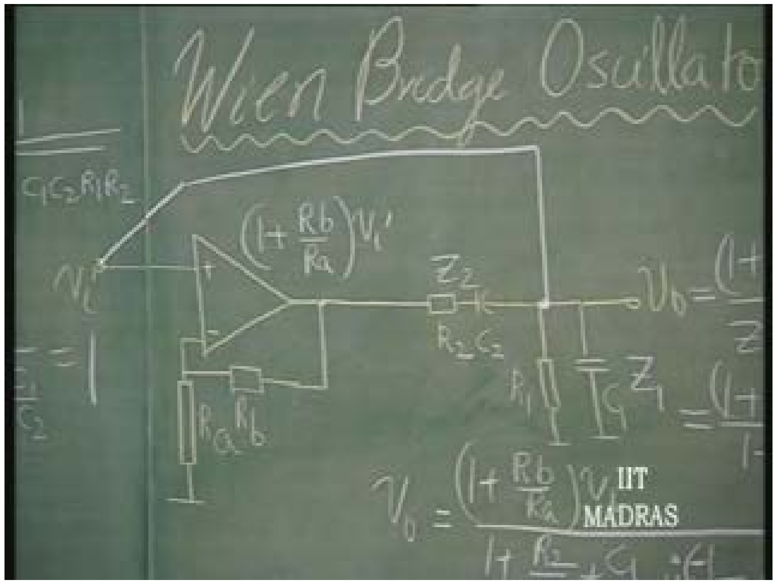

So, the condition for oscillation is that R b by R a has to be made equal to R 2 by R 1 equal to C 1 over C 2. This is easily done by setting R 2 equal to R 1, C 1 equal to C 2. R b by R a has to be then equal to 2. So, if R 2 equals R 1 equals R, C 2 equals C 1 equals C, then the frequency of oscillation Omega naught is 1 over R C; and the condition for oscillation is that this is equal to 2.

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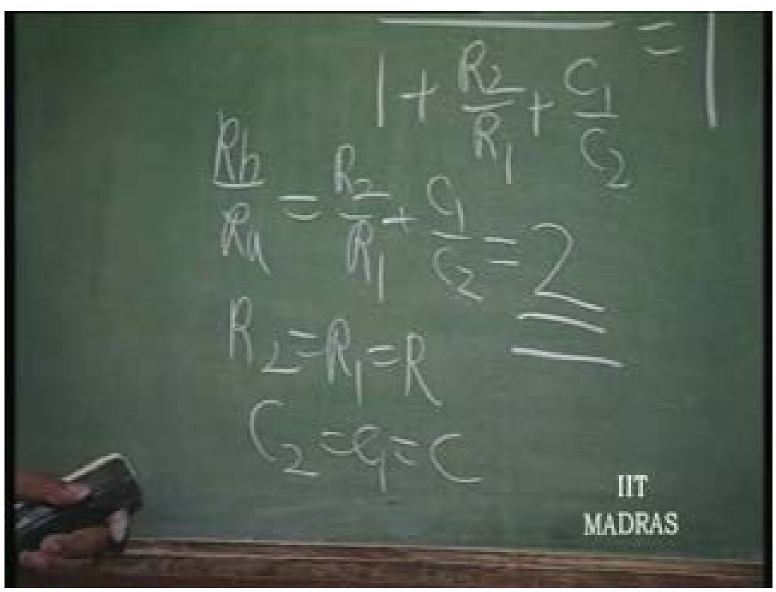

So, if it is greater than 2, R b by R a is greater than 2, it will start building up oscillation. Gain is greater than 2. If it is less than 2, it will start decaying. If it is exactly at 2, it is having poles on the imaginary axis. This system with this kind of feedback will have poles on the imaginary axis. So, this is an oscillator.

This is called Wien bridge because this arm and this arm, and this arm and this arm, form a bridge between which we have introduced an operational amplifier. So, this arm and this arm, this arm and this arm, form a Wien bridge; very famous oscillator.

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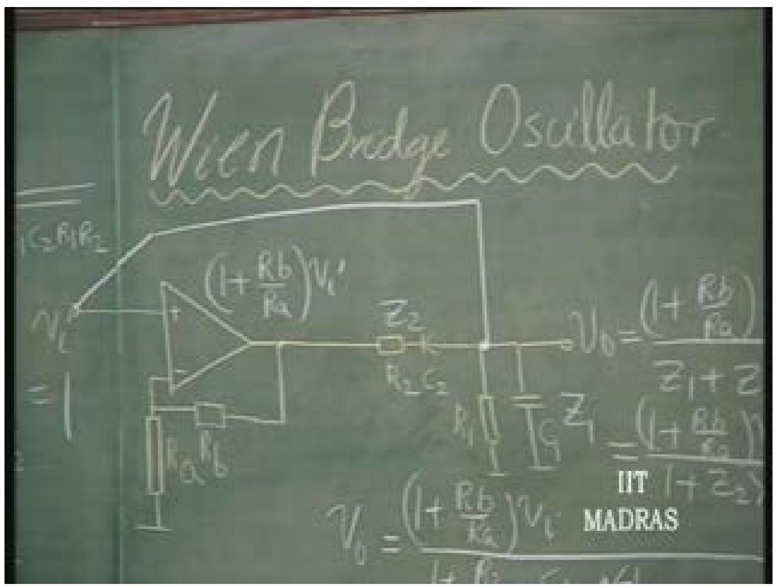

This is the oscillator circuit which is commonly used in all test oscillators, sine wave oscillators available as test oscillators, wherein you can gang these capacitors and vary it in steps for differ...getting different ranges and gang these resistors and vary this continuously in order to vary the frequency of oscillation continuously.

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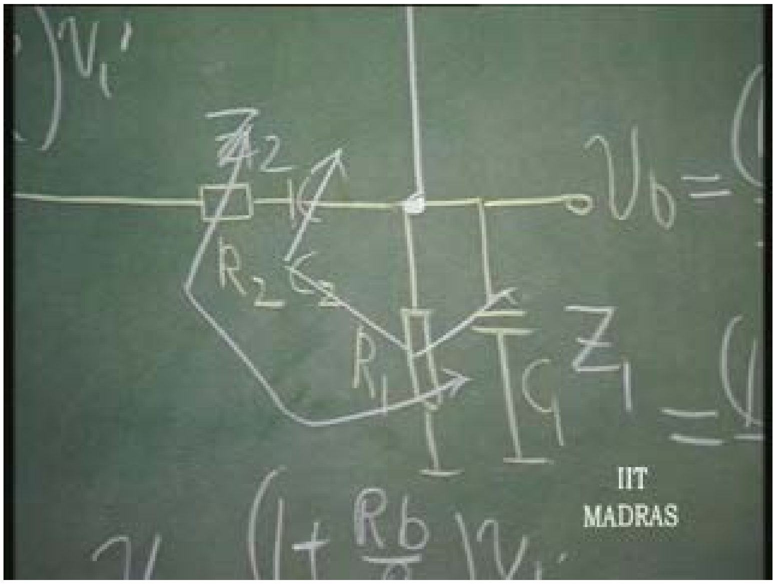

This ganging becomes necessary because R 2 by R 1 plus C 1 by C 2 should be equal to 1; R 2 by R 1 C 1 by C 2, both should be equal to 1 and total should be equal to 2; so the ganging becomes necessary.

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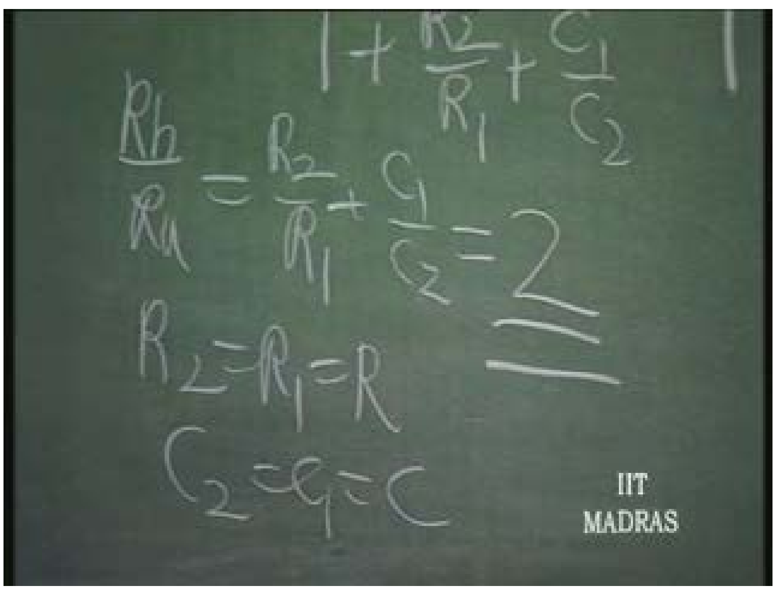

Now let us consider another oscillator. Once again, I am going to break the loop here. Let us assume that this loop is broken here. This resistance of R is going to really appear as resistance to ground here; this much of ground. So, in effect, this loading effect of the input resistance of the amplifier is coming here as R. So, actually speaking, so V i is going to be developed there.

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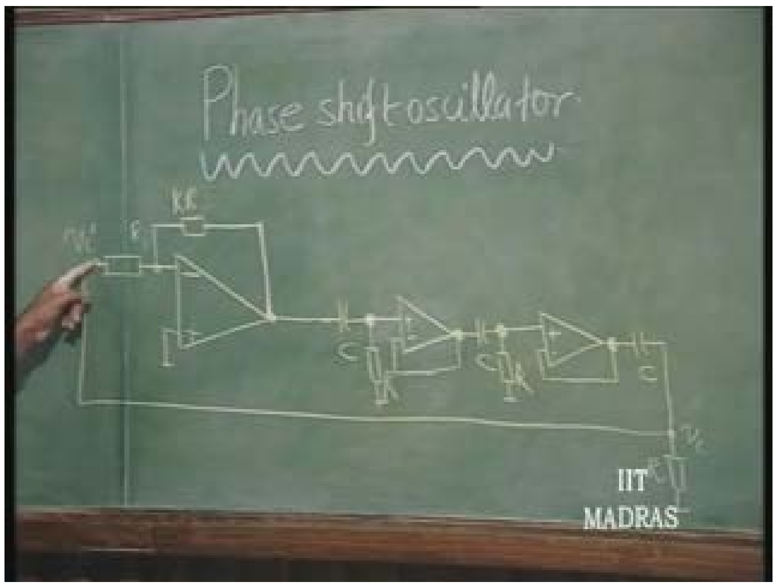

We have to see whether V naught developed here is same as V i. So, if V...this is V i; this is minus K times V i. This we have seen. As an inverting amplifier, if this is V i, this is ground; this is virtual ground. Current in this is V i by R; the same current will flow through this and develop the potential here, which is negative; and minus K times V i is the output here.

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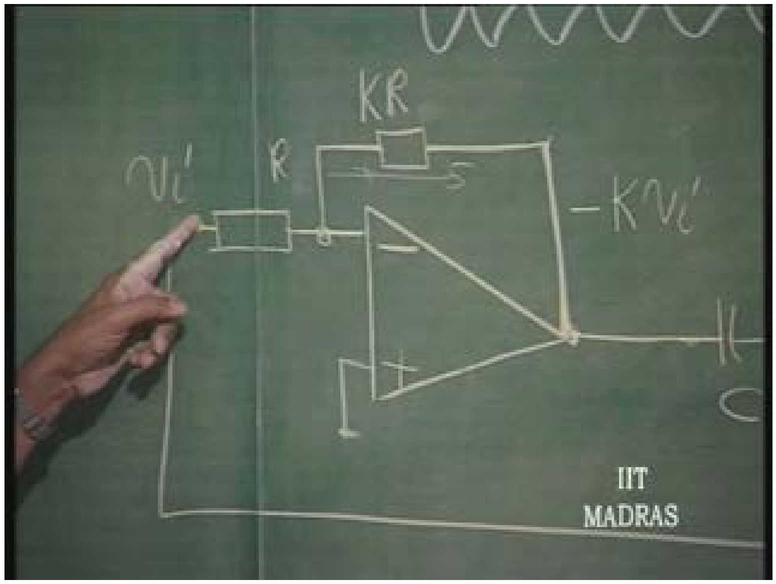

So, we have got a 180 degree phase shift which is independent of frequency here. In order to make it now come in phase, we have to provide additional phase shift of 180 degrees. That is why this is called phase shift oscillator. Additional phase shift can be offered by three such R C networks, in order to prevent this from loading. Otherwise, I might have to use a higher gain amplifier here. I am using buffer stages. This is only illustrating the principle of phase shift oscillator.

So, one by one, that is, this phase shift is S C R divided by S C R is the transfer function from here to here. So, that...this is minus K V i...into minus K times V i. So, this single network can give a phase shift of...from starting from, let us say, 90 degrees at low frequency to let us say, at very high frequency, it can go up to 180 degrees; but it cannot... that is, going to be only at infinite frequency.

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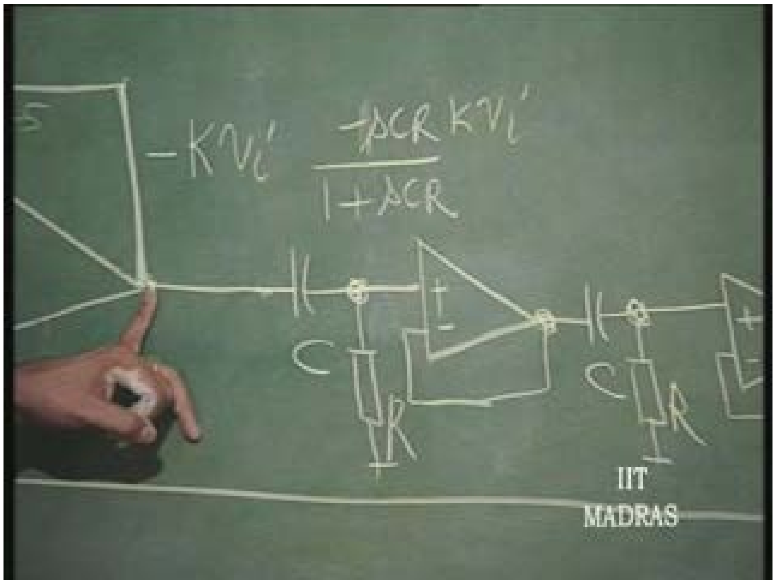

So, I put two such networks. So, we get here minus S squared C squared R squared divided by 1 plus S C R whole square, the gain; into K times V i here; and at...that is at this point also, it is going to be the same because of the buffer.

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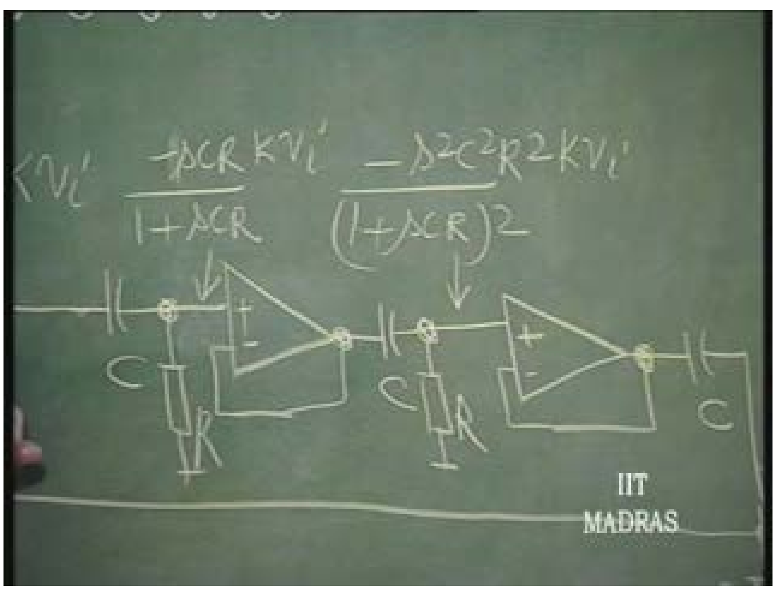

And then, at this point it will be minus S C R whole cube by 1 plus S C R cube K times V i. That should become equal to V i. That is...

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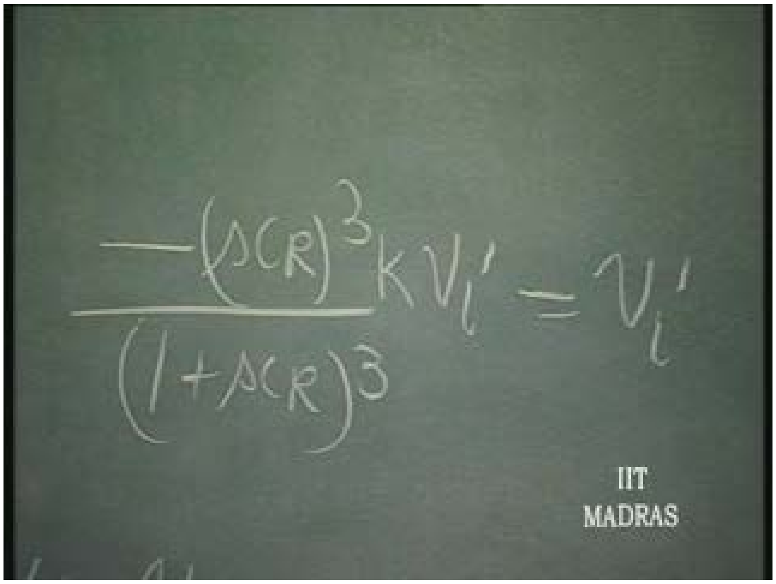

So, let us now rewrite the whole thing. Minus S C R whole cube into K divided by 1 plus S C R whole cube should become equal to 1; V i V i getting cancelled. So, 1 plus S C R whole cube plus S C R cube into K should be equal to zero.

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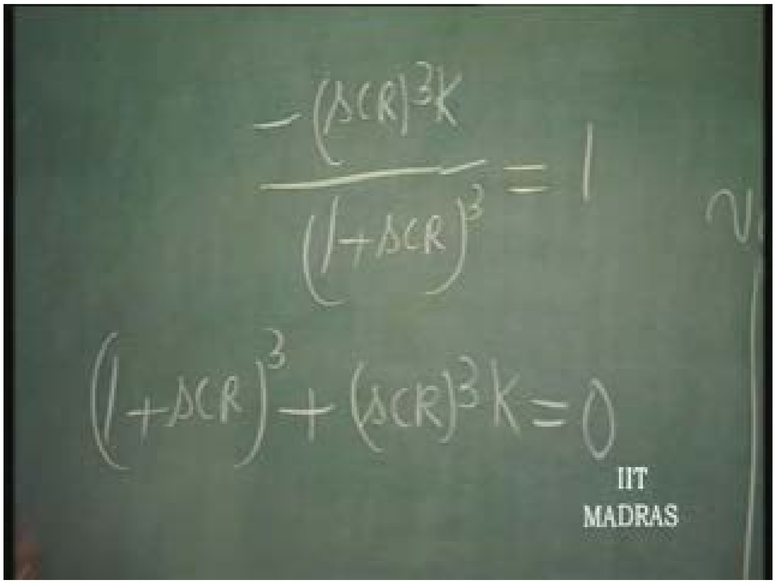

This cubic equation 1 plus 3 S C R squared plus 3 S C R plus S C R whole cube will come out of this, plus K. So, K plus 1 into this should be equal to zero. Now put S is equal to j Omega. So, we get 1 minus 3 Omega squared C squared R square plus 3 j Omega C R plus... That is actually minus, j S cube C cube R cube. One j square will give you minus and another j will remain K plus 1.

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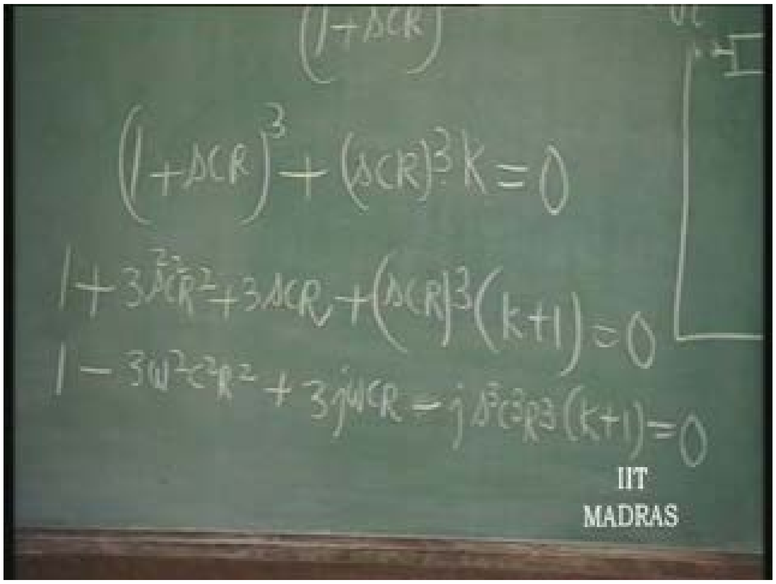

So, this is going to be equal to zero. If the real part becomes equal to zero, simultaneously, the imaginary part also should become equal to zero. So, we get Omega naught equal to, from this.1 divided by 3, root 3, C into R; making this equal to zero, we will get Omega naught, frequency of oscillation, is equal to 1 by root 3 into C R.

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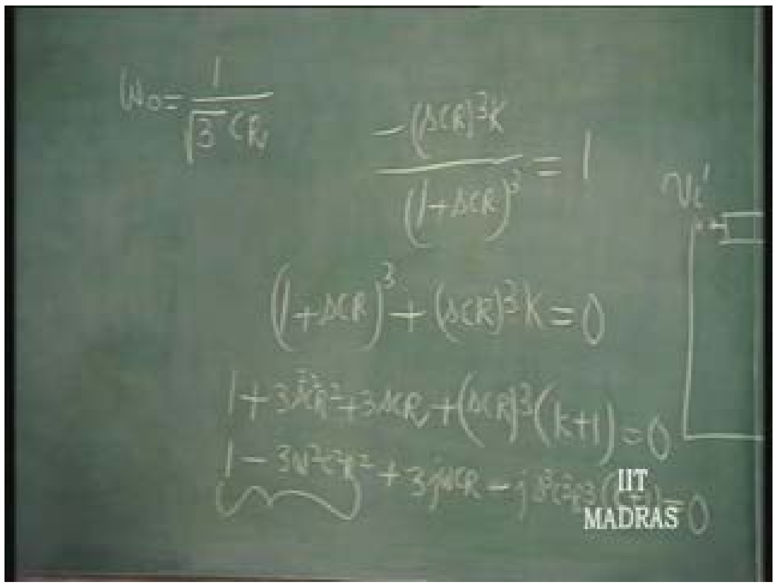

And then here Omega C R. This is Omega cube C cube R cube. So, Omega C R goes, j goes. So, 3 minus Omega squared C squared R squared into 1 plus K also should become equal to zero; or this should become equal to this. Already we know that Omega squared C squared R squared has become equal to 1 over 3. Omega squared C squared R squared has already become equal to 1 over 3, from this equation. So, K plus 1 becomes equal to 9; or K has to be equal to eight. Amplifier gain has to be equal to 8. Then, the frequency of oscillation is going to be equal to be 1 over root 3 into C into R.

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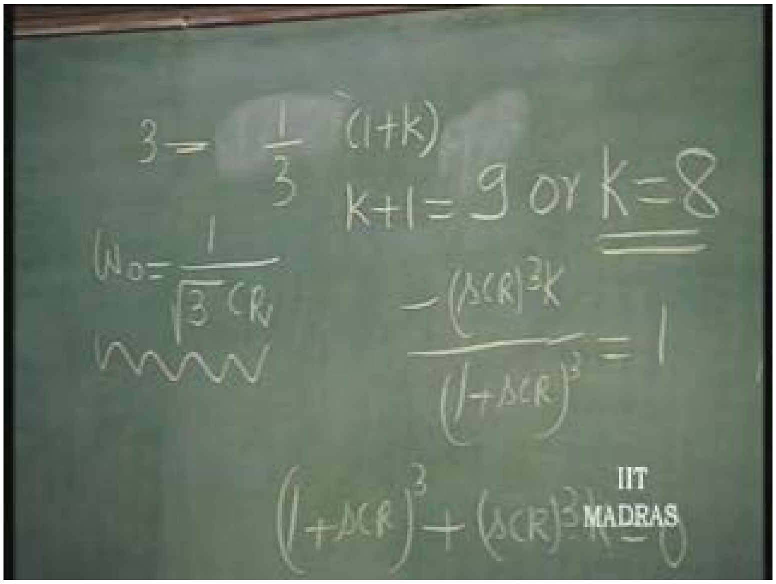

So, this is the phase shift oscillator which, of course, gets modified. I would like you to therefore work out this problem where this buffer stage is removed. So, this is going to load this and this also is removed so that, in fact, use only one op amp and three R C networks like this, in order to come up with... So, this circuit has this R already being provided here. Once you close the loop, this is there and this satisfies this relationship.

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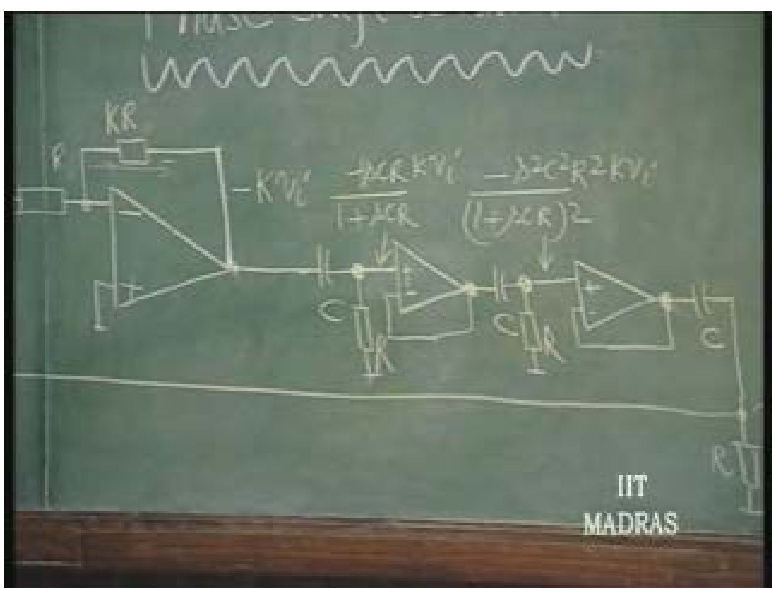

This is a phase shift oscillator. Again, you can have the phase shift as being brought about by R here, C here, R here, C here, all that. That will bring about, instead of this, root 3 divided by C R; and the K is going to be same as 8.

Now, let us try to understand this oscillator in terms of the two port theory that we have studied in the case of amplifiers.

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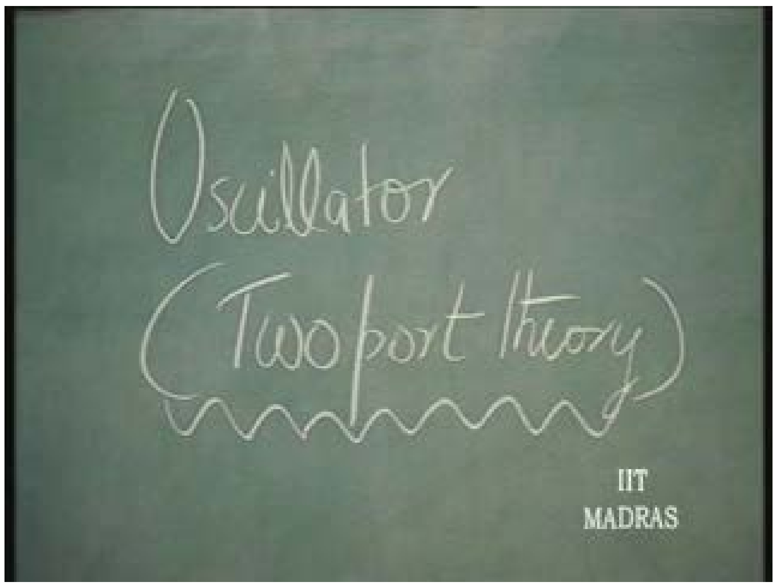

So, let us consider that my active device which is a transistor, for example, with all this biasing and all other things put here, which will comprise of the admittance now. It may be now, not just resistance because it obviously...we have to make the loop gain equal to 1 only at a certain frequency. That is possible only by putting resistors and inductors. So, this is an admittance.

Let us say, this we will call as Y a. This will contain the load and admittance at the output, etcetera. We will call it altogether Y b; and this may have a feedback also. So, Y c. So, this is the active device which is supposed to make it going to oscillation. This does not have any feedback. It is biasing circuit and input reactances and output secured load and output reactances and the feedback reactance, in general, have been incorporated here.

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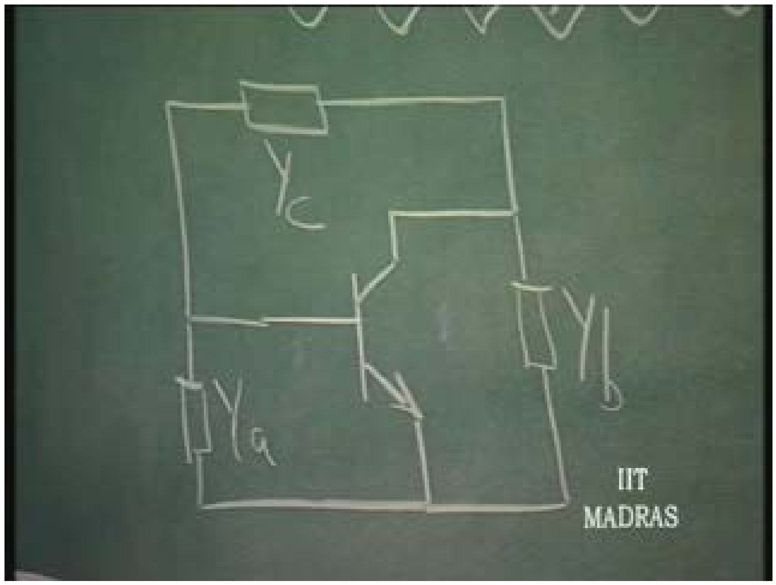

I would like to know whether such a circuit can be made into an oscillator. How do I analyze such a thing? Obviously, let us say, as far as this equivalent circuit is concerned, it could be, FET or a bipolar structure here. If it is, let us say, a bipolar structure, we will put it as an equivalent circuit here. We will put r e into Beta plus 1 and then here we will put this. If this V, we will put g m into V here as the current, source current. If you want to include the output impedance of this structure, you can also put r c e.

In the case of a F E T, this will be infinity and again g m into V and R d S will be put here. So, that is the only difference. So, for such a circuit now, I would like to analyze and find out the condition for making an oscillator out of this. This is a general two port.

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So, this is, let us say, input port; this is output port; this is the feedback. So, in a two port theory, how do I make sure that the loop gain is equal to 1 at a certain frequency? Loop gain, when it comes to loop gain, we saw that if I write down the matrix of the entire parameter... now I consider this a Y parameter and I have Y i here Y naught here.

This Y i can include the source impedance and Y naught can include the load impedance. In this case, since it is an oscillator, it is not going to be driven by a source. So, this will be the self input admittance short circuit. This will be self output admittance short circuit and this is the feedback and this is the feed forward.

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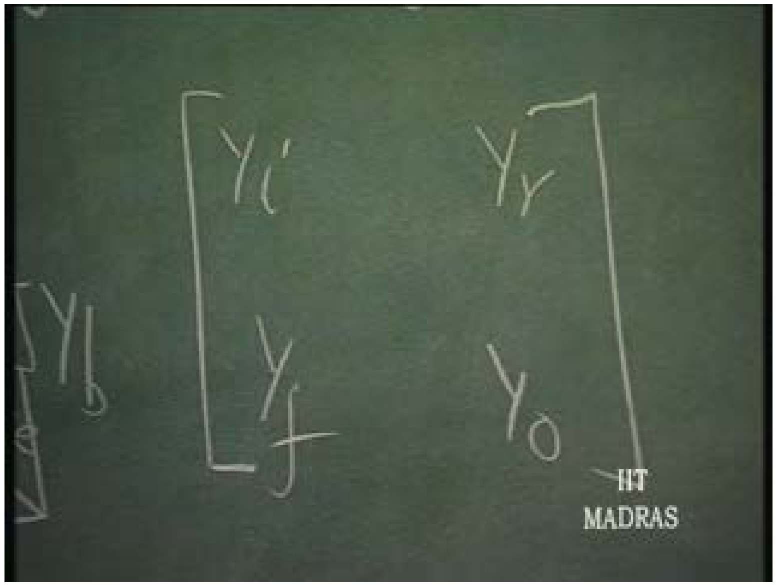

In such a situation, what is the loop gain? We have seen that Y f Y r divided by Y i Y naught is the loop gain; Y f Y r divided by Y i Y naught is the loop gain; and that loop gain has to be made equal to 1; or 1 minus Y f Y r divided by Y i Y naught should be equal to zero; or Y i Y naught minus Y f Y r should become equal to zero, Assuming that Y i and Y n naught do not go to zero at any frequency.

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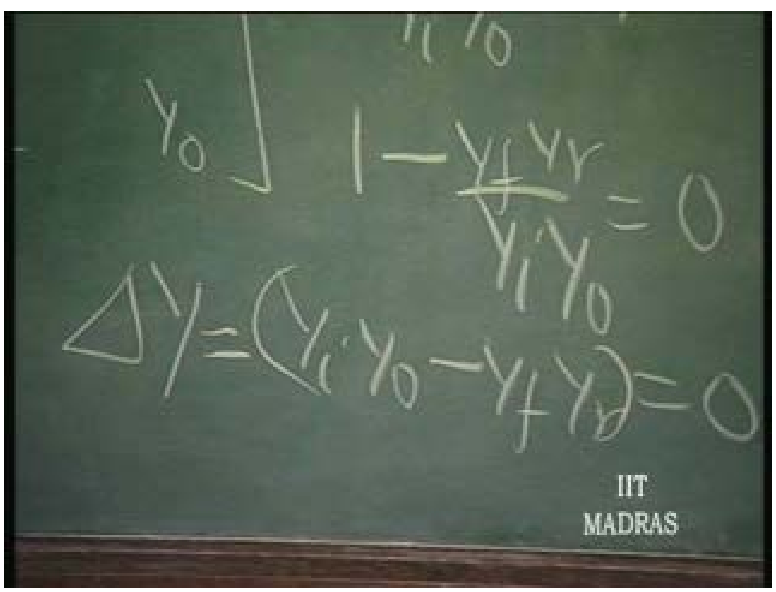

That means what is this? This is nothing but capital Delta Y. So, the condition for any oscillator according to two port theory is that the Delta Y should go to zero at Omega equal to Omega naught; a single frequency.

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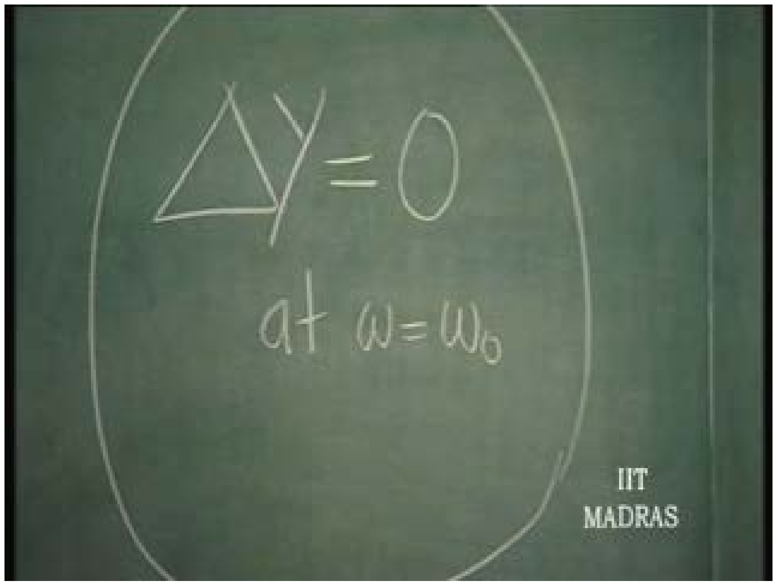

This is an important condition. So, let us consider that for this network.

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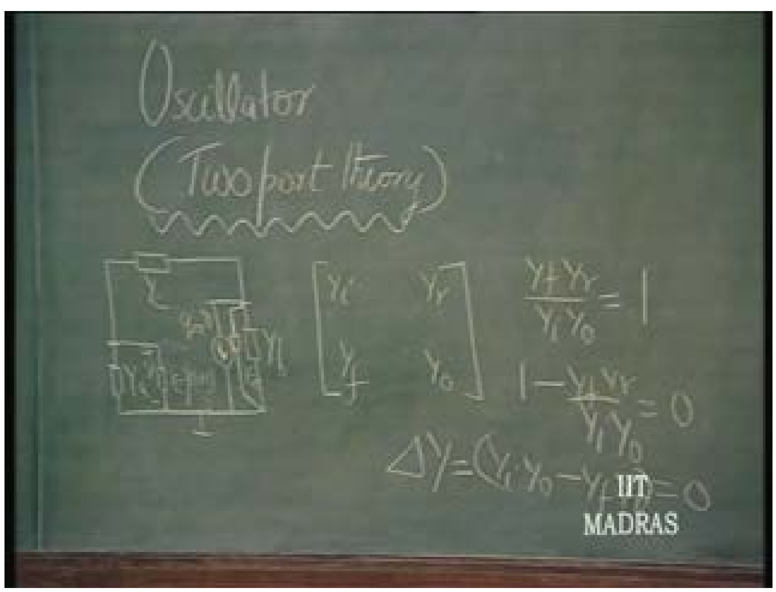

So, as far as this network is concerned now, the composite Y matrix can be written here. Input Y i is Y a plus 1 over r e into Beta plus 1 plus Y c; and this is shorted. That is all. And feedback factor is only minus Y c. This is the only admittance connected; so, minus Y c. So, this is from V naught. Even if I apply V naught, what is the current in this? Short circuit; V naught by Y c in the opposite direction to the positive direction, so, minus Y c.

Now, feed forward part. When I apply V and short circuit, what will be the current? I have a V applied here. So, this is the same V and g m into V is the short circuit current coming in. So, it is positive, g m. Apart from that, minus Y c is also going to be there. That is all. Then, admittance at the output when this is shorted will be again 1 over Y b. That is Y b plus 1 over r c e plus Y c. That is all.

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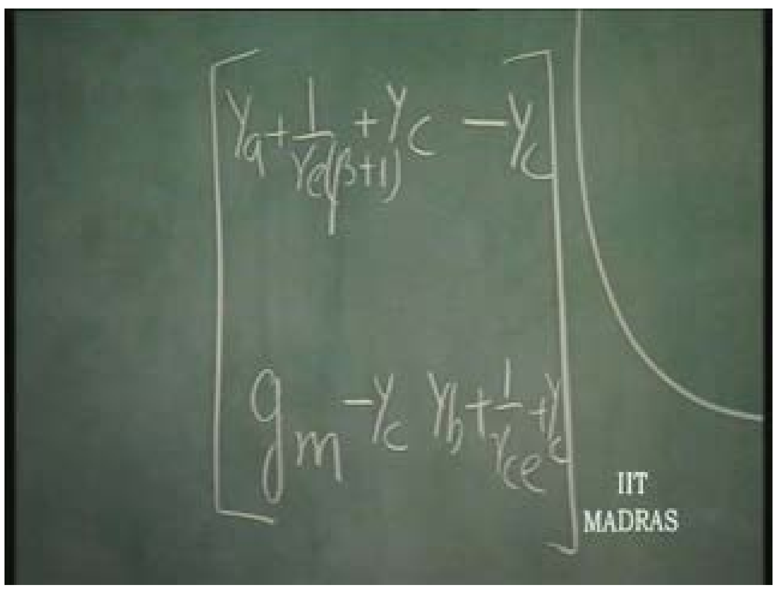

So, what is Delta Y now? Delta Y is this into this minus this into this. So, Y a plus 1 over r e into Beta plus 1 plus Y c into Y b plus Y c plus 1 over r c e minus... minus, minus, becomes plus. So, Y c g m minus Y c. So, this should be equal to zero at a certain frequency. This will give you both frequency of oscillation and condition for oscillation, depending upon how you select Y a, Y b and Y c.

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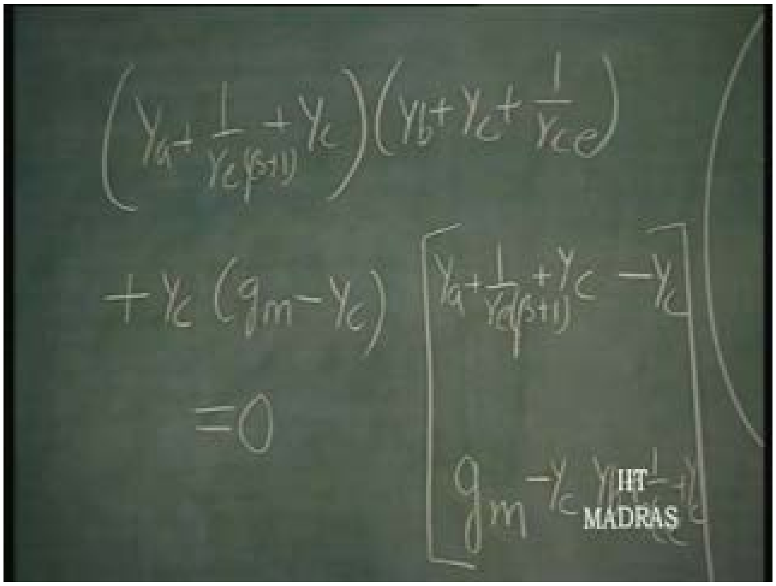

So, this is what is going to be equal to be zero. Simplifying this, this will give me Y a into Y b; Y a into Y b; Y a into Y c. That is exhausting. This plus Y c into Y b plus, Y c squared gets cancelled with Y c squared here. So, that is all.

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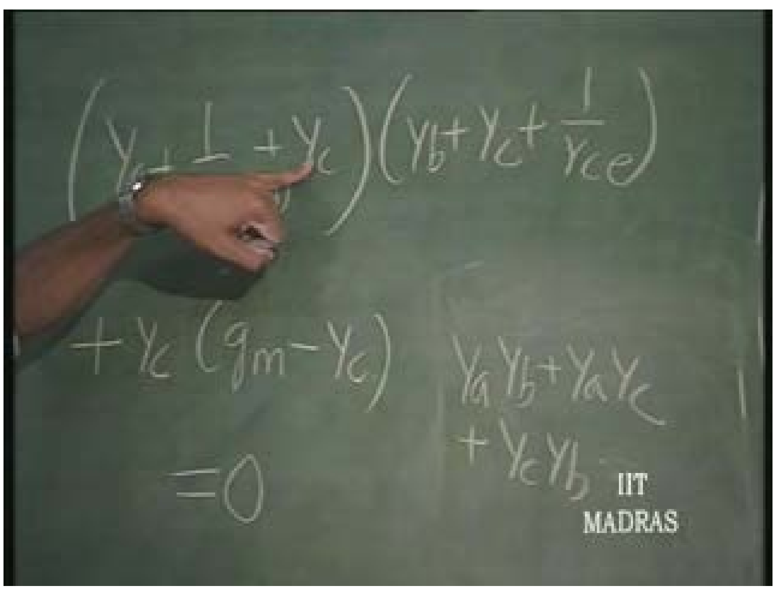

This can be put totally as sigma Y a into Y b. Y a Y b plus Y b Y c plus Y c Y a. What... That is what it means. Sigma Y a into Y b means Y a Y b plus Y b Y c plus Y c Y a. Then, the rest of the factors will be dependent upon this; 1 over r e into Beta plus 1, into Y b plus Y c plus 1 over r c e into Y a plus Y c.

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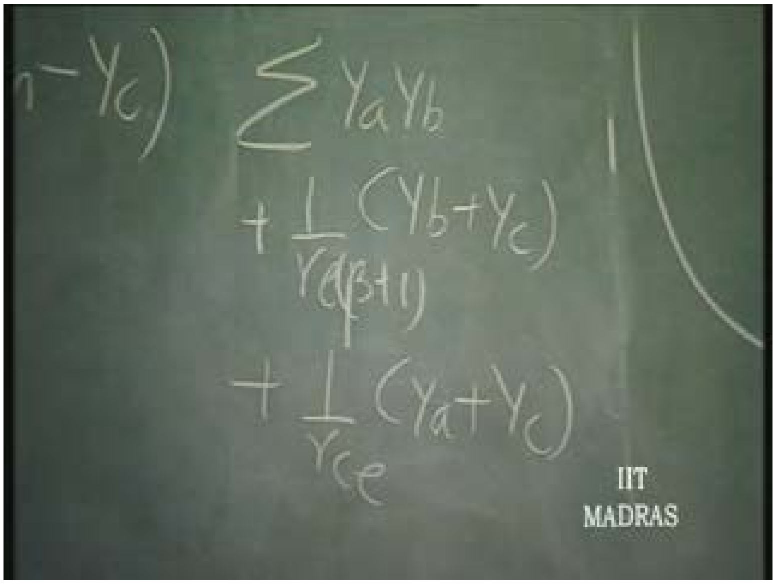

And then a factor which is independent of this Y, which is 1 over r e into Beta plus 1, r c e. So, those are the factors, I think... Yes. All these things are taken into account. Next, Y c into g m that should be equal to zero.

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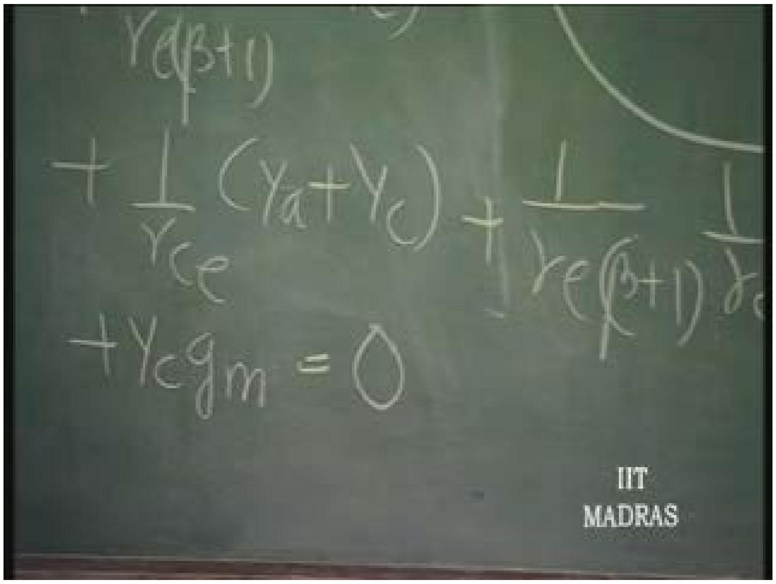

Now, when such a condition is to be satisfied, we have to see that it is possible. What does it mean? This will obviously have real part and imaginary part and this should be possible to make the real part go to zero and imaginary part also go to zero. Now, that can be done by selecting one possible combination – Y c as being equal to 1 over j Omega L and Y a equal to, let us say, j Omega C 1 and Y b as j Omega C 2.

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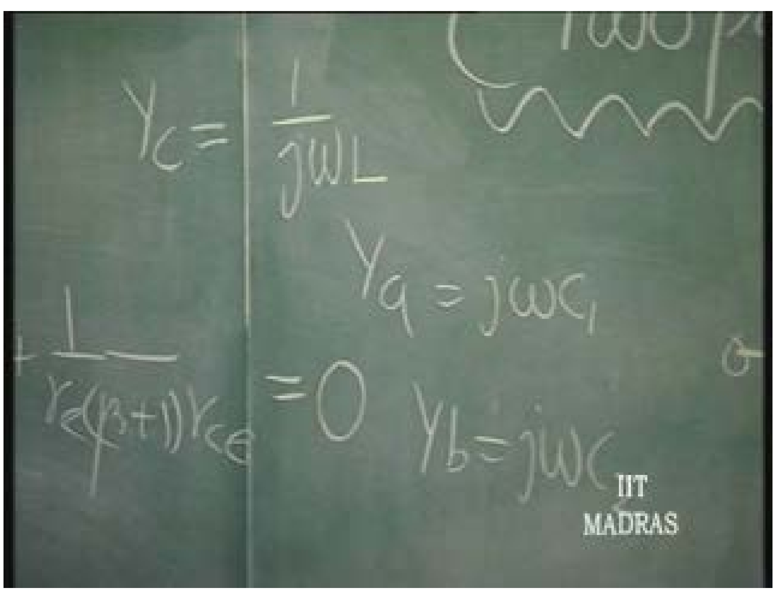

That means two of them are capacitive and one is inductive; or, this is in a capacitive and the other two are inductive. The feedback element should be of one type and the other two should be of the opposite type. So, that way, we will see that we have two types of oscillators. One – Y c is inductive, Y a and Y b are capacitive; another – Y c is capacitive, Y a and Y b are inductive.

We will now consider the first one. So, because of this, you get here, both real part positive as well as negative, which can actually independently go to zero; and the imaginary part which is going to be remaining here because this, these terms contribute to only imaginary part; that also has to be independently going to zero. Apart from that, this will also contribute to some amount of real part.

So, let us see that .Y a Y b... Y a Y b is going to give me Omega square C 1 C 2 which is negative; and Y b plus Y a into Y c, Y b plus Y a which is C 1 plus C 2 divided by L.

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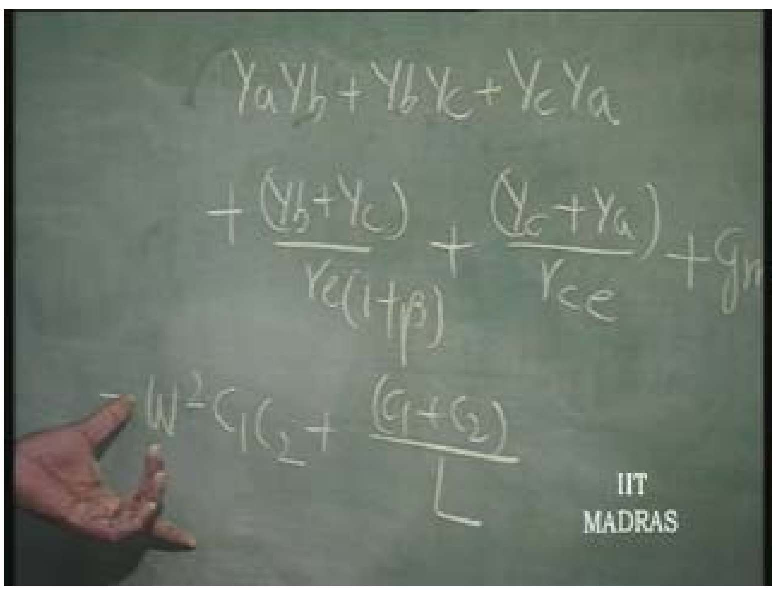

So, that is the real part which is positive. This is negative. Apart from this, we will also have this 1 over r e into Beta plus 1 r c e. This should be equal to zero.

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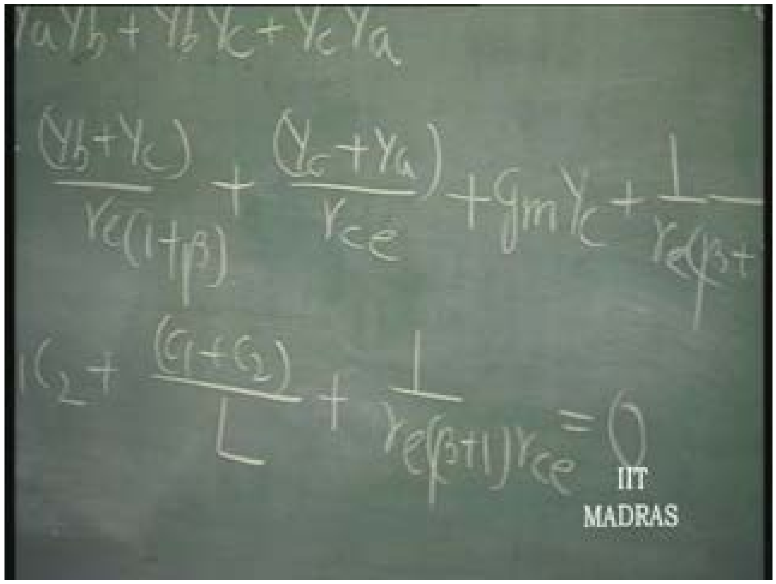

Or, Omega naught square which is the frequency of oscillation; we will take that, that side, is going to be equal to C 1 plus C 2 by L C 1 C 2. This is the first part; plus, what about this non-ideality is? Because, 1 over r c e can be equal to zero. So then, this will vanish. It will be purely dependent upon passive. Otherwise, it will depend upon the active parameter there. So, 1 over r e into Beta plus 1 r c e divided by C 1 C 2. That is the non-ideality. So, Omega naught therefore is root of this.

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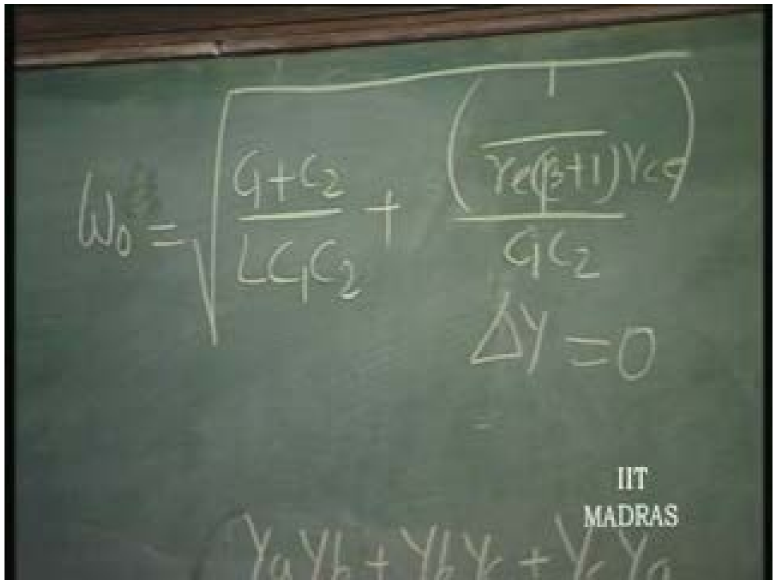

It is going to be approximately equal to root of 1 by L into C 1 C 2 C 1 plus C 2. So, this is the frequency of oscillation.

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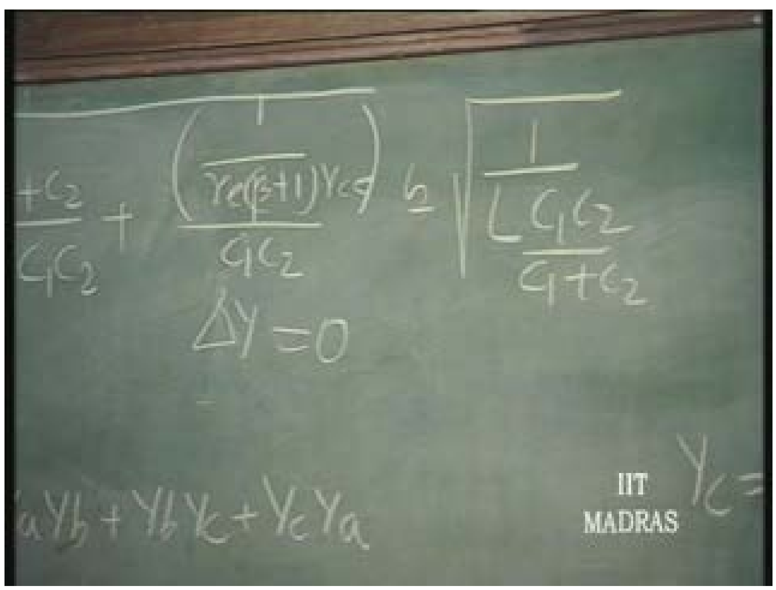

That takes care of completely the real part. This is gone. Now, the imaginary part is going to be due to these three.

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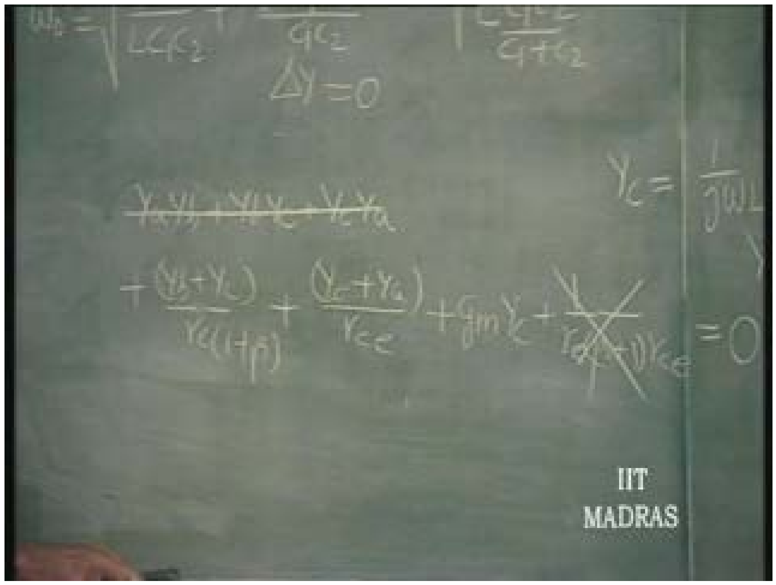

So g m into Y c will result in g m by Omega L minus j. Then, other things... plus Y b plus Y c, Y b plus Y c. So, j Omega C 2 plus 1 over minus j Omega L divided by r e into Beta plus 1, plus Y c plus Y a again. Or, Y a is j Omega C 1 minus j by Omega L divided by r c e. This is equal to zero.

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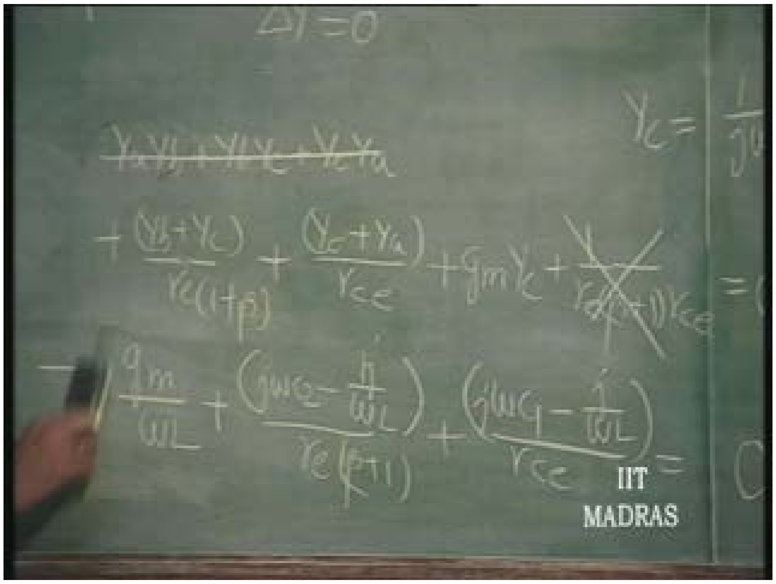

So basically, we can see here - this is only the imaginary part. So, all these things become 1 and this can be made equal to zero.

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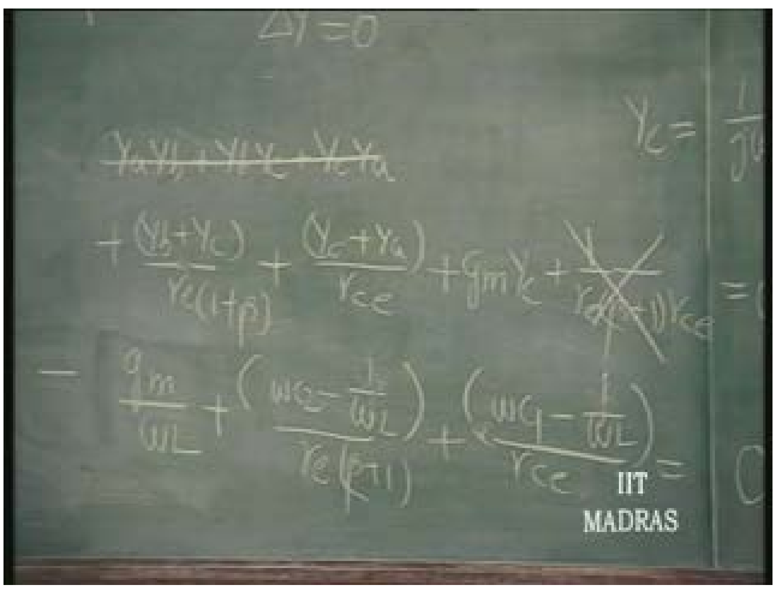

So essentially, we can see that we can collect the co-efficient of 1 over Omega on the other side. So, 1 over Omega into g m by L. This will go to the other side. All of them are negative. So, when they go to the other side, they become positive. 1 over Omega L can be taken out. g m plus 1 over r e into Beta plus 1. Still, this can be ignored because g m is 1 over r e; that divided by Beta plus...you can just compare; plus 1 over r c e, because of this.

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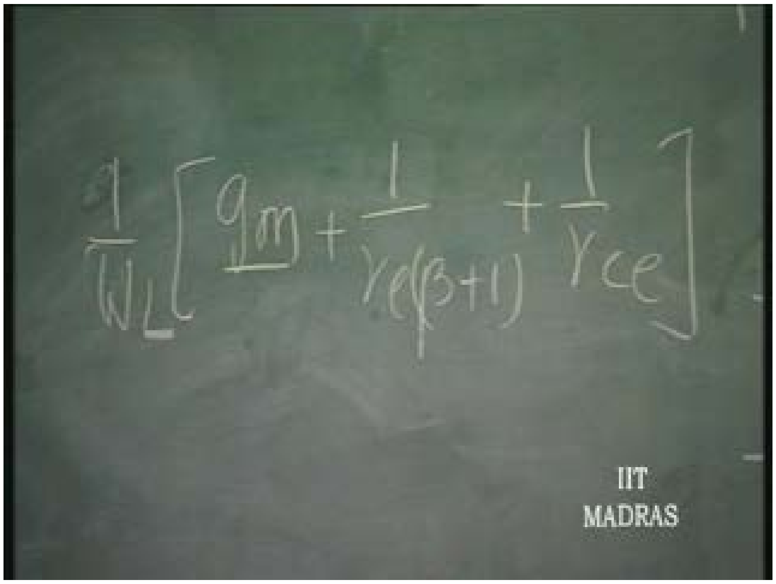

So, this is taken care of; this is taken care of; and so essentially in this, the quantity of interest is only g m. These become negligibly small.

So, that is equal to this and that, Omega into C 2 divided by r e into Beta plus 1 plus C 1 by r c e. So, this is the condition for oscillation.

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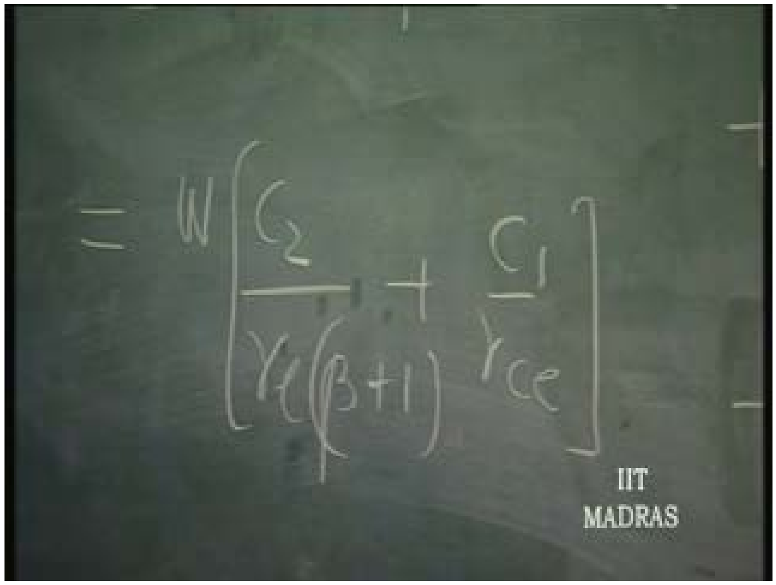

So, this Omega can go here. This will become Omega squared. So, 1 over Omega squared is equal to... Omega naught squared actually. This, we will say, this Omega naught and that Omega naught should be the same.

1 over Omega naught square should be equal to L C 1 C 2 by C 1 plus C 2; L C 1 C 2 by C 1 plus C 2; and therefore, you see that L gets cancelled and essentially this is negligible. g m into C 1 C 2 by C 1 plus C 2 should be equal to C 2 by r e Beta plus 1 C 1 by r c e.

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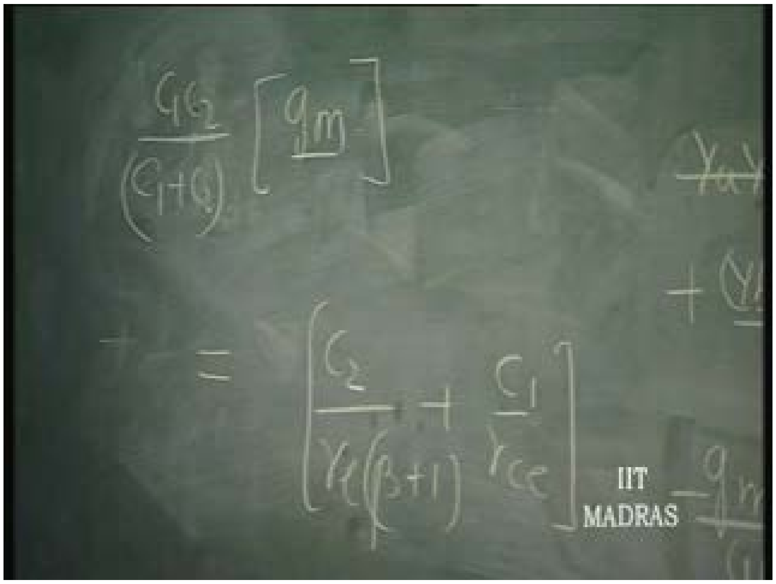

Essentially, this can be ignored compared to this, normally. Or, you can take that also into consideration. So, g m into C 1 by C 1 plus C 2 - this is the condition to be satisfied. Now, g m can be taken...g m into r e is very nearly 1. g m is equal to 1 over r e. So, this divided by g m into r c e. So, 1 over Beta plus 1 should be equal to C 1 by C 1 plus C 2.

C 1 C 1 plus C 2 is always a quantity less than 1 and that can be easily satisfied by 1 making it equal to 1 over Beta plus 1 plus C 1 by C 2 g m into r c e. So, this is the equation; condition for oscillation.

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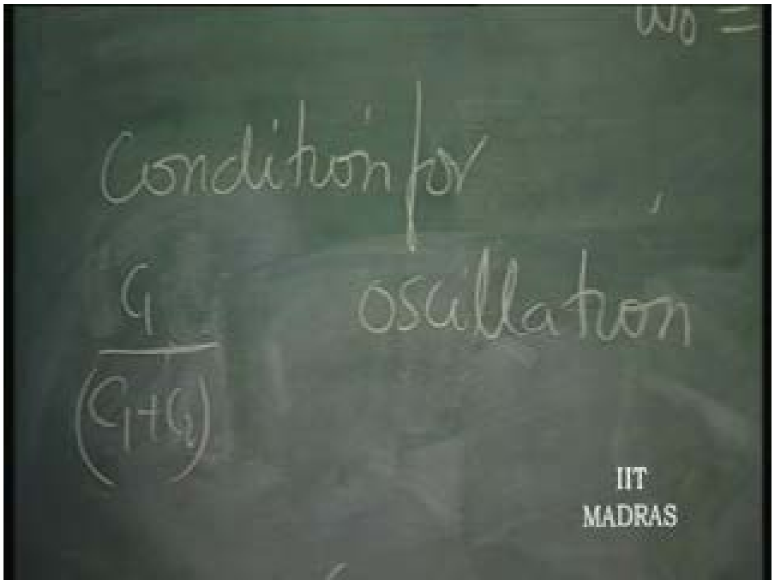

If r c e is infinity, then this also goes. The frequency of oscillation becomes exactly this. The condition for oscillation becomes very simple. Beta plus 1 becomes equal to 1 plus C 2 over C 1. So, 1, 1 get cancelled. So, Beta becomes equal to C 2 over C 1. Or, C 2 over C 1 has to be chosen to be equal to Beta. That is the condition for oscillation.

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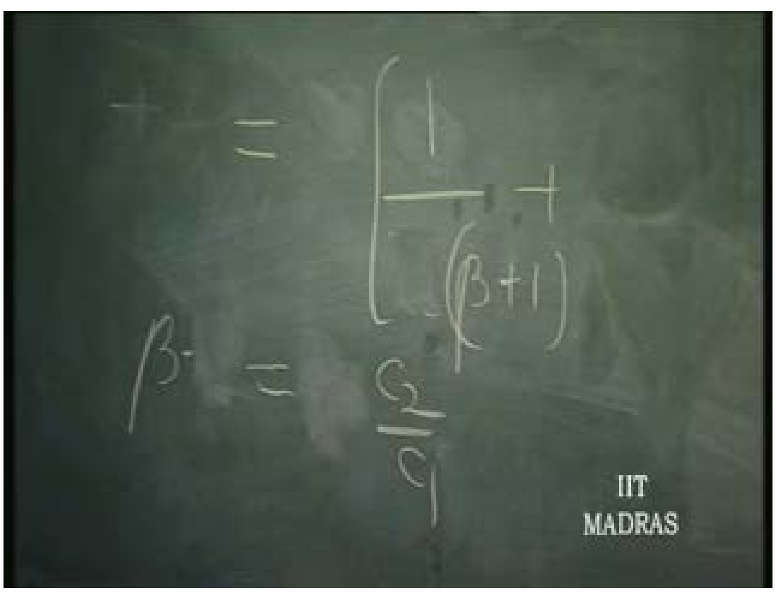

I would like you to work out as a problem when Y c is j Omega C and Y a is 1 over j Omega L 1 and Y b is 1 over j Omega L 2. The frequency of oscillation can be shown to be Omega naught. Show that Omega naught is equal to 1 over root of L into C 1 plus...sorry. L 1 plus L 2 into C.

And, condition for oscillation is now governed by...here it was C 2 over C 1. There it will be L 1 over L 2 becoming equal to Beta. That is the only difference. So, condition L 1 over L 2 - how it is related to Beta.

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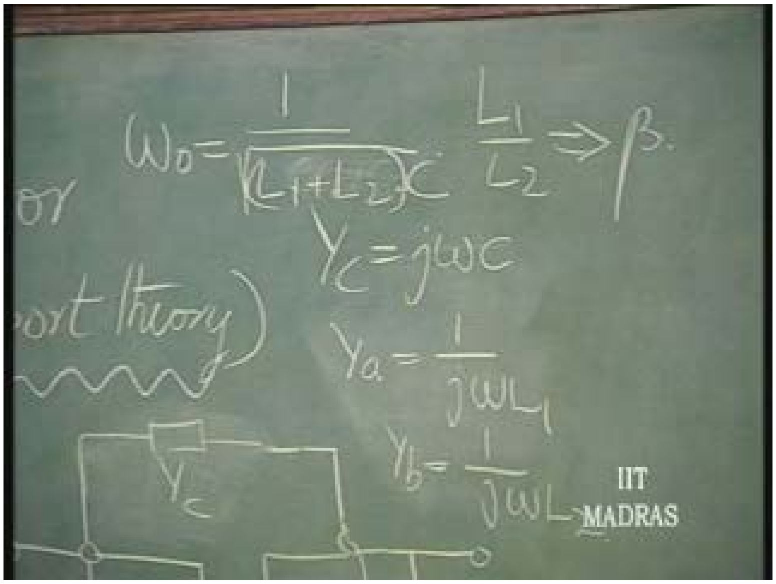

This can be determined by replacing Y c by j Omega C, Y a by 1 over j Omega L 1, 2 Y b by 1 over j Omega L 2. So, please work this out as a problem. So, let me now give you the complete problem.

So, in the circuit shown, let Y c equal to j Omega C, Y b equal to... Y a equal to 1 over j Omega L 1, Y b equal to 1 over j Omega L 2.

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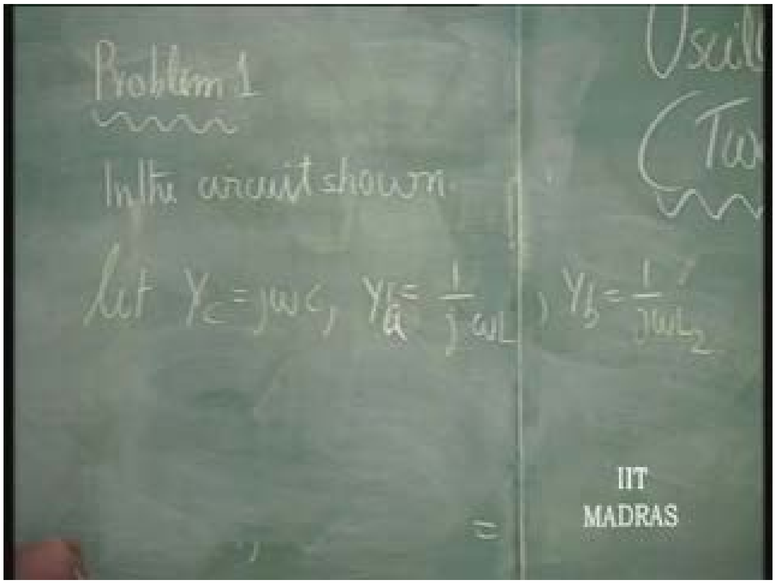

Show that the frequency of oscillation Omega naught is very nearly equal to 1 over root L 1 plus L 2 into C.

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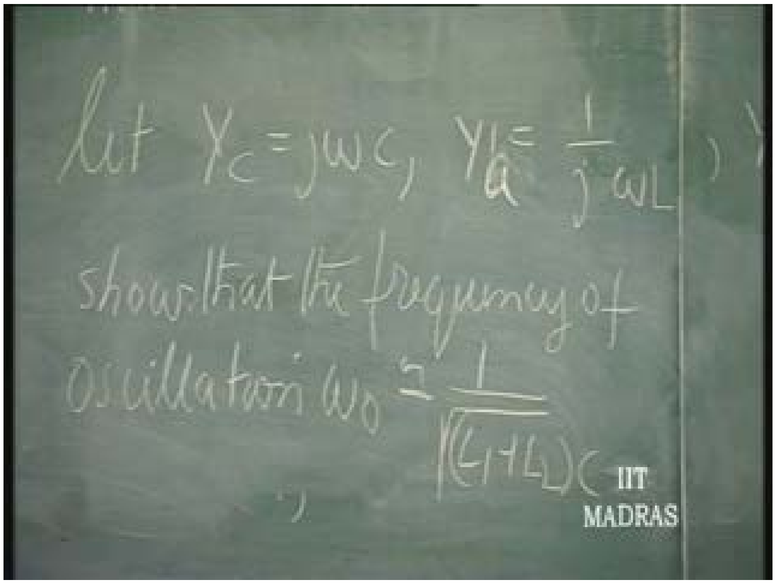

Determine the relationship...determine the condition, for oscillation in terms of L 1 by L 2 and Beta.

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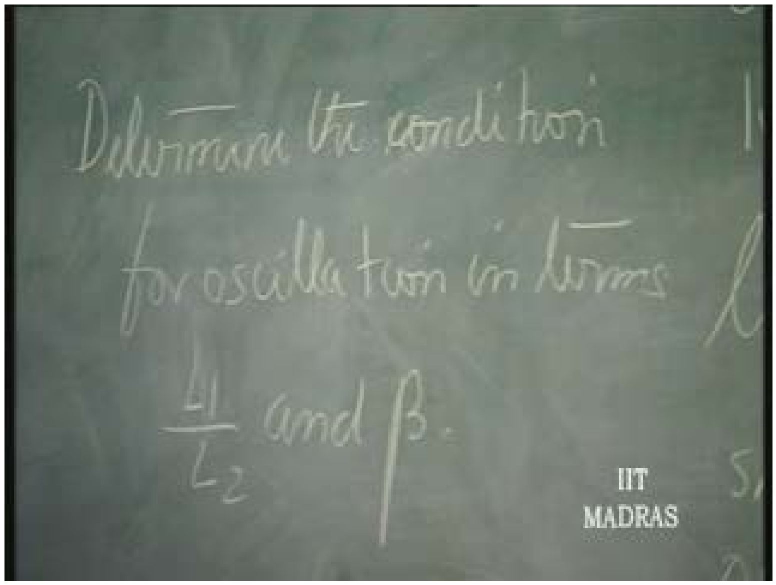

So, these are two of the most popular L C oscillator, transistor, or FET oscillator; we can replace. The same analysis is valid for transistor as well as FET, except that r e into Beta plus 1 is replaced by open circuit and rest of the thing remain same. This is g m. This is going to be replaced by r d s. Except for that, rest of the circuitry remains the same; and therefore, the same analysis can be adopted for the field effect transistors, oscillator also.

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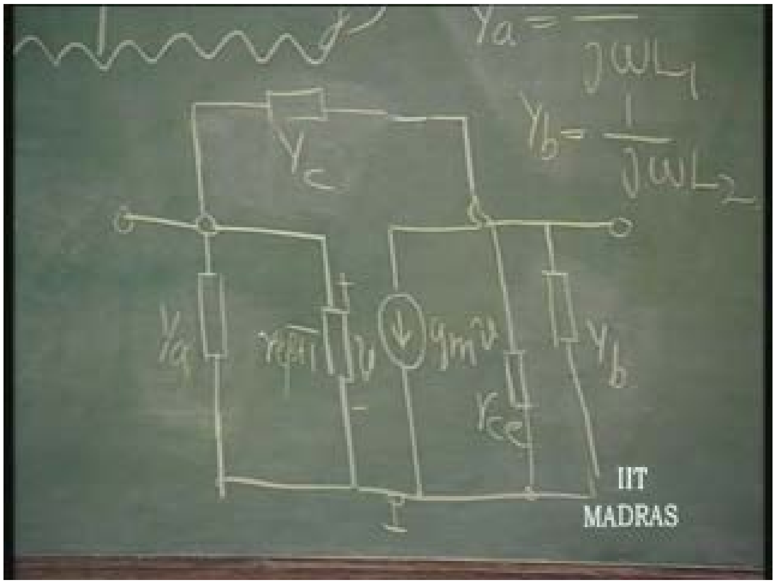

These are respectively called Hartley and Colpitts oscillators. These are the most popular L C oscillators existing today.

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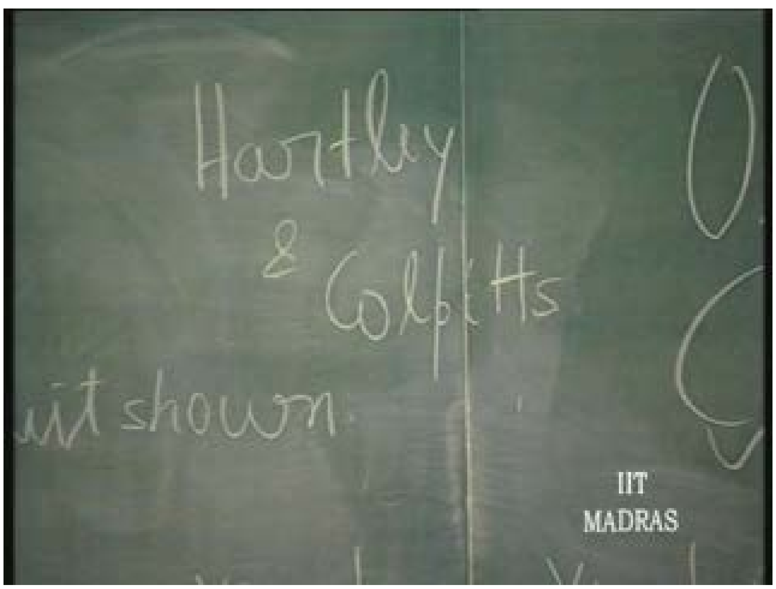

Apart from that, you have tuned, let us say, collector and the transformer coupled base type of oscillators also available; but again, the same type of analysis is valid there also.

The coupling between output and input is a transformer coupling. So, it is a tuned collector transformer coupled base which is used as an oscillator.

Then we have crystal itself being used as an L C. Lock crystal can be used both for series resonance as well as parallel resonance. It is nothing...Equivalent of a crystal is...that means it has both series capacitor as well as parallel capacitor. So, it can resonate with this capacitor in terms of series resonance and the parallel resonance frequencies, very close to series resonance.

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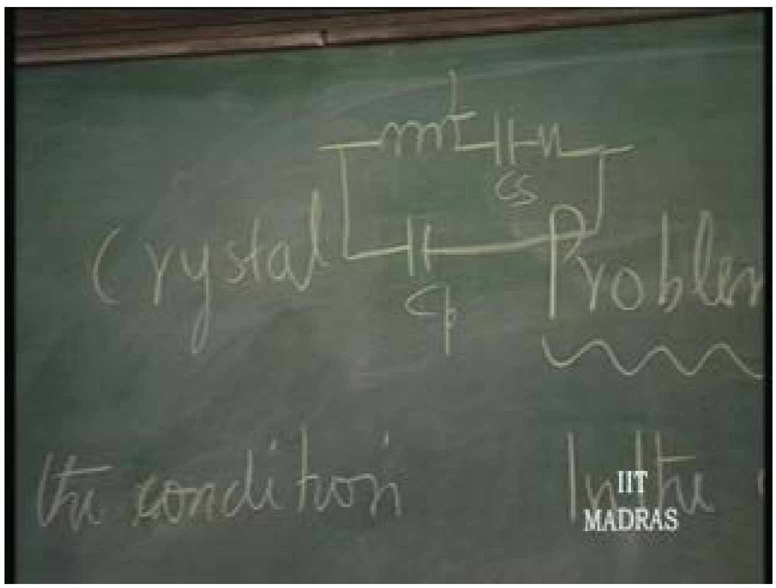

And therefore, it is going to result in either a short circuit or an open circuit. That means impedance variation can be drastic and phase variation also can be drastic, around the resonance frequency. And therefore, such a circuit can be used as a feedback structure where it can take on inductive or capacitive reactance at the frequency of resonance; and therefore, it will always, invariably, oscillate at the crystal frequency.