Electronics for Analog Signal Processing - II
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Lecture - 35
AGC/AVC (Continued)
Amplitude Stabilization of Oscillators & Multiplier Applications

In the last class, we discussed about A G C and A V C and also started mentioning the fact that the same system can be utilized in amplitude stabilization of oscillators. We have shown how that can be indicated by adjusting the loop gain to be exactly equal to 1, when the phase shift is... the required value, zero.

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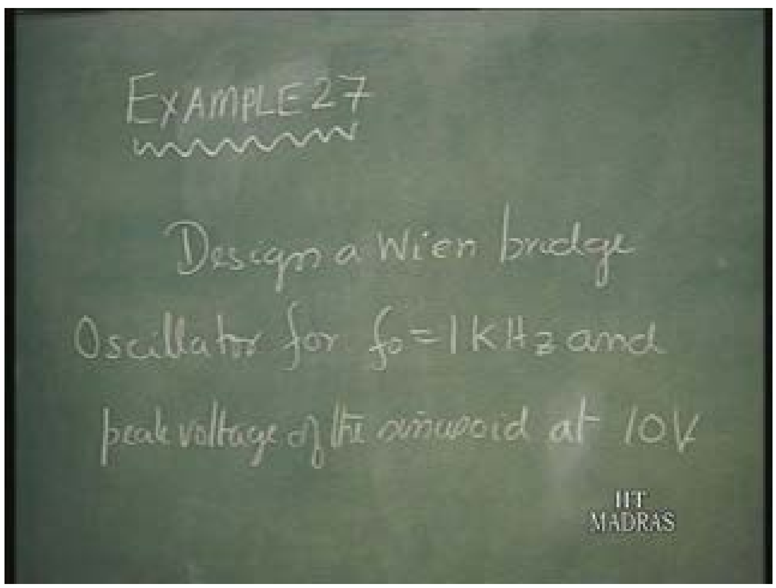

Now, a problem illustrates how this can be achieved in a wien bridge oscillator for oscillating at a frequency of 1 Kilo hertz with a peak voltage of the sinusoid at 10 volts. So, the basic configuration let us draw.

Wien bridge oscillator uses an R C network for fixing up the frequency. R, C, R, C. And that is used in the feedback path; and we have to have a gain fixed at 3 and that is, let us say being done by a multiplier put in the feedback path. So, the Beta of the network is determined by the multiplier as...in fact, if this is V naught, this is going to be V naught into V c by 10. So, the gain of this is going to depend upon the Beta factor which is V c by 10.

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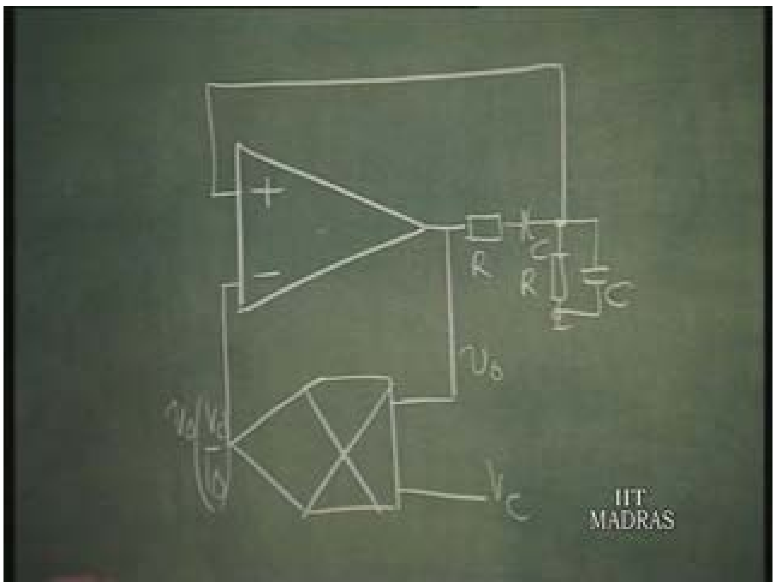

And therefore, since the gain of this amplifier is 1 over Beta, the gain of the amplifier is 10 by V c. This should be exactly equal to 3 for the amplitude to be stabilized at exactly equal to 10 volts. So, at 10 volts, the gain should be 3; or V c should be equal to 10 by 3 or 3 point 33, so on...volts. But prior to that, most probably it was not oscillating when it was switched on. It should build up. That means the gain should be greater than...gain...gain of the amplifier. So, this should be greater than this 3 point 33.

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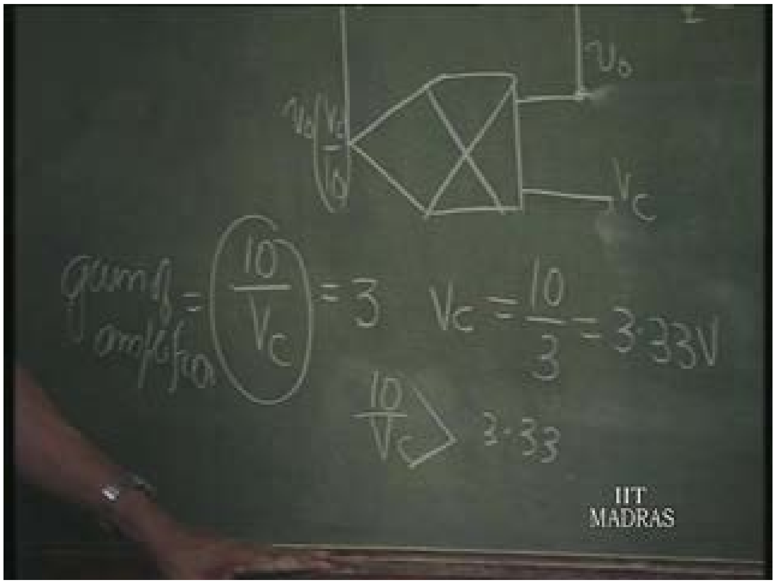

That is, the gain should be greater than 3. Let us say therefore, V c should be less than 3 point 33 volts. Gain should be greater than 3 and therefore V c should be less than 3 point 33 volts.

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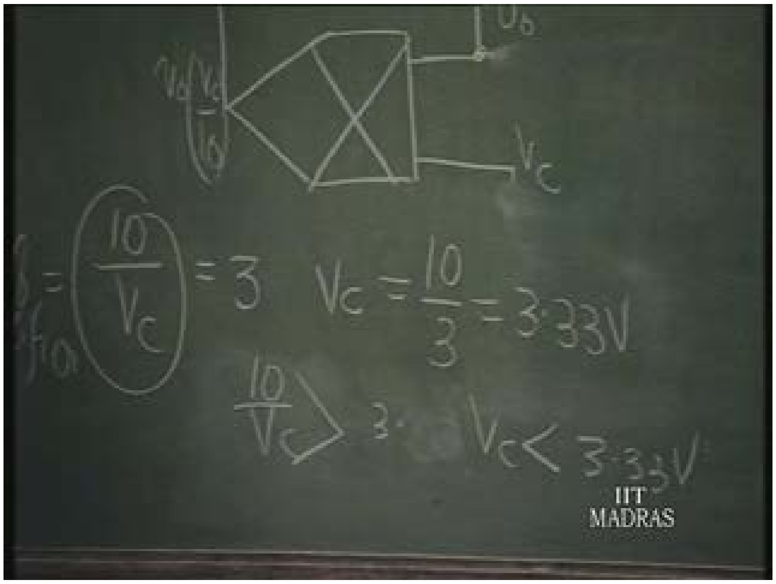

So, let us say it should start at 3 volts or so. We can now put our A G C, A V C system here such that to start with, this voltage is somewhere around 3 volts let us say; and then it goes on to 3 point 33. So, we can have an arrangement where V c starts with, let us say 3. V c initial is 3 and V c final is 3 point 33, let us say. So, we must have an arrangement like that. This is necessary for us to start the oscillation.

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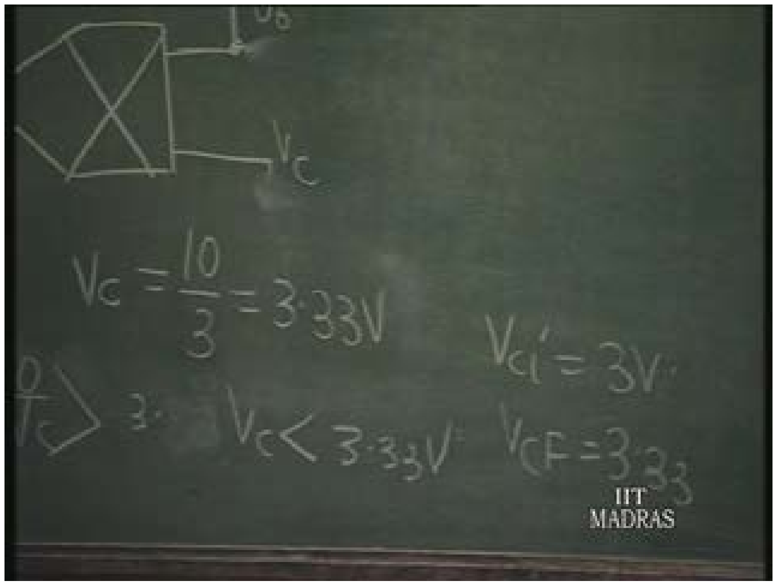

So, let us therefore put our usual A G C scheme where we have put a precision rectifier. So, it will rectify the half wave here. So, we get negative going half wave here. If this is, let us say R dash, this should be R dash. So, if this is a sinusoid like this with peak like this, V peak naught, this will be the negative half wave, wave like this, minus V o p here.

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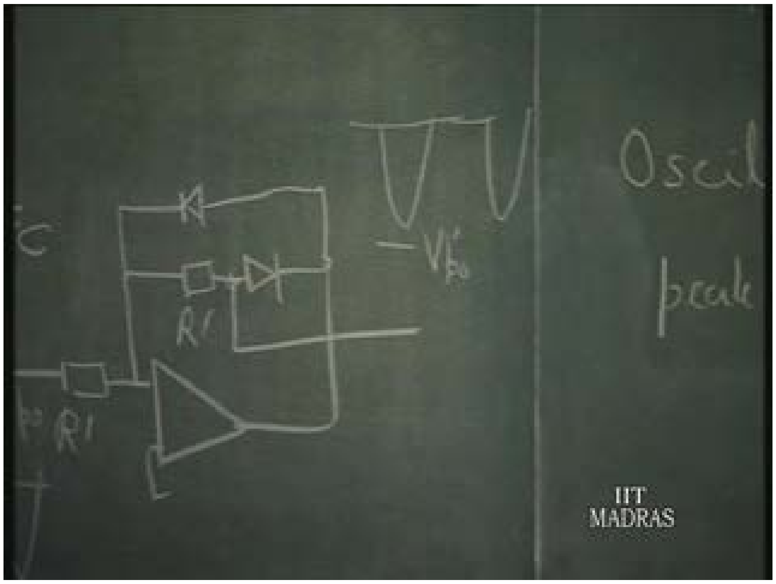

And then we put the low pass filter which is now converted into an integrator. We have seen this, the Miller effect and all comes into picture; R double dash. And we will put a voltage reference here. Since this is negative, it will give a negative average; voltage reference should be positive. So, at the time of starting, this has no voltage here; amplitude has not built up. So, there is V reference which is positive. This will be driven to negative saturation.

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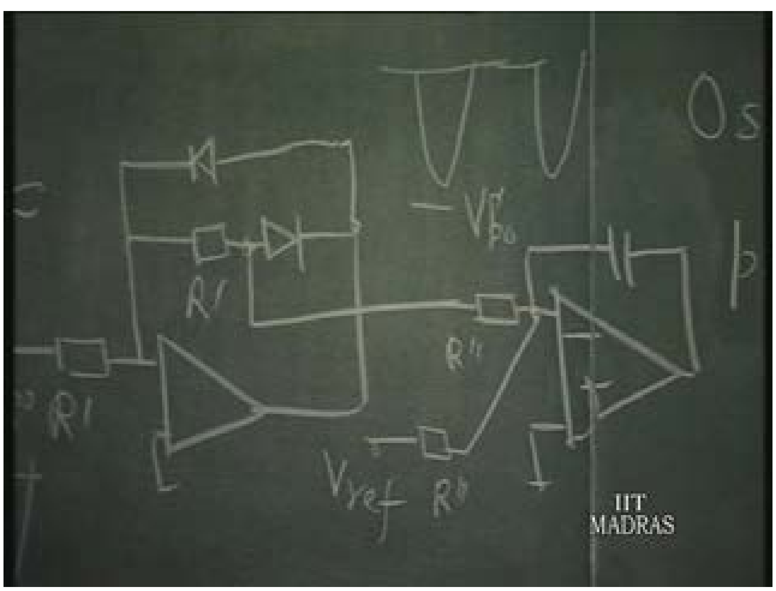

Let us say, the supply voltage is plus 15, minus 15 for this op-amp. So, it will go to minus 15 volts here. So, this minus 15 volts has to be converted into something suitable so that V c becomes equal to your 3 volts so that it can start oscillating. So, we will put an attenuator here. So, we will connect here plus 15 volts let us say. So, this voltage becomes 3 volts initially. That means this Alpha R, this is 1 minus Alpha times R, an attenuator.

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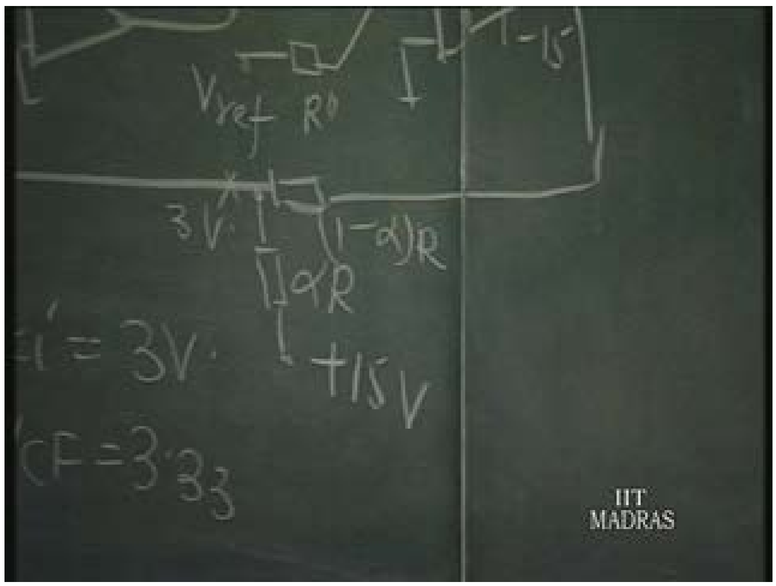

So, the voltage here is minus 15 into Alpha plus 1 minus Alpha into 15. Minus 15 into Alpha comes here. Due to this plus 15, we have 1 minus Alpha times that. That should be equal to 3 volts. So...which is nothing but 1 minus 2 Alpha into 15 is equal to 3 volts; or, 1 minus 2 Alpha is 3 by 15; so, which is 1 by 5. So, 2 Alpha is equal to 1 minus 1 by 5 which is 4 by 5. Therefore Alpha is equal to 4 by 10 which is point 4.

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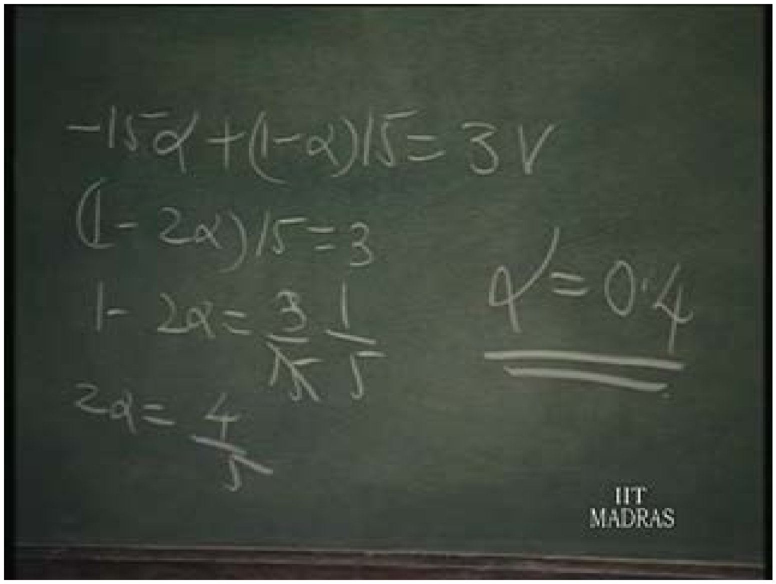

So, if Alpha is point 4, the voltage here is going to be at 3 volts. Now what happens? The amplitude starts building here from zero. This negative voltage keeps increasing; and this negative voltage keeps increasing means it is not applied to minus. So, this will become more positive. So, from 3 volts it will keep increasing. So, it becomes more positive. So, it might become 3 point 1. Amplitude is still increasing. 3 point 2, 3 point... Ultimately, it will go to 3 point 33 at which point, once when this becomes 3 point 33 automatically, what happens is the gain is exactly equal to 3 for this stage.

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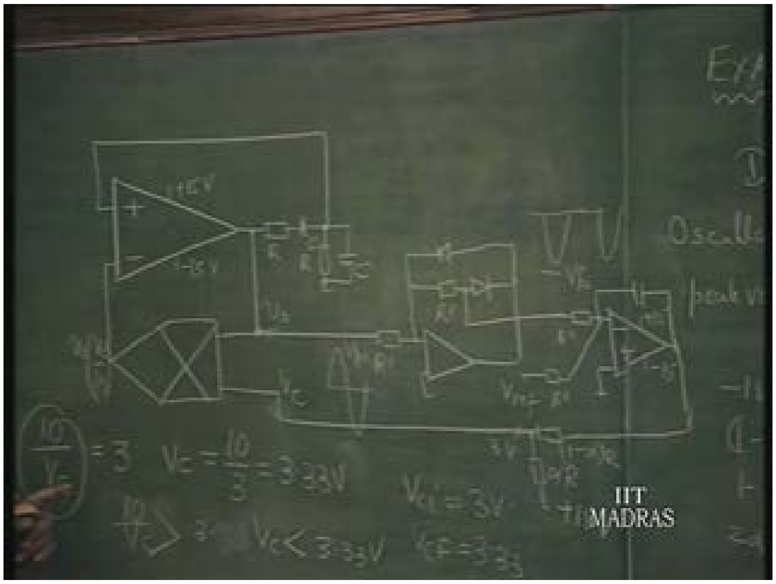

Further amplitude build-up will not occur because now the amplitude is going to be such that V reference is going to be equal to V p naught by pi for this kind of relationship. And therefore, if we want output voltage peak amplitude of 10 volts; that divided by pi should be the voltage reference that you have to connect here. 10 by pi here. This is one answer. What is that equal to? About 3 point... 3 point 18 volt.

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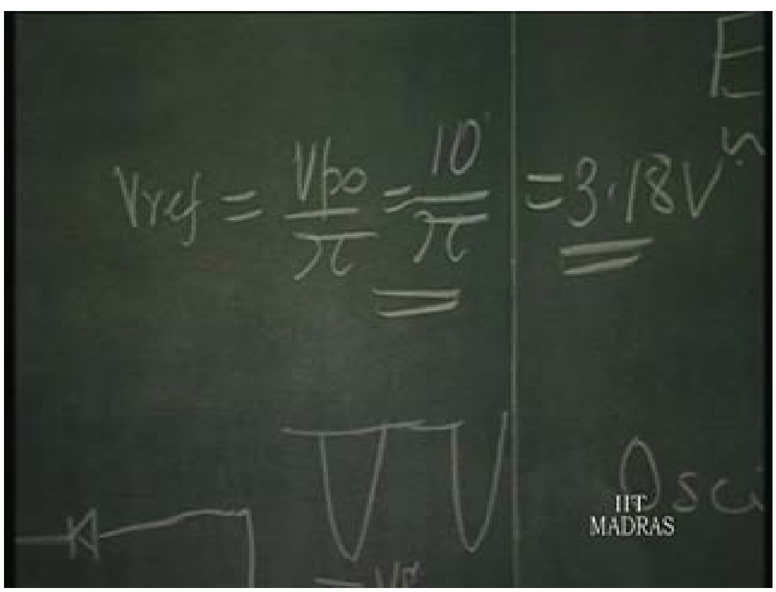

So, if you apply that voltage here, then the amplitude is automatically going to be adjusted to exactly 10 volts peak. Now, one...only one thing is left out. The frequency f naught is equal to 1 by 2 pi R c. That is required to be 1 Kilo hertz. So, 10 to power 3 hertz. So, R c is going to be equal to 1 over 2 pi into 10 to power 3.

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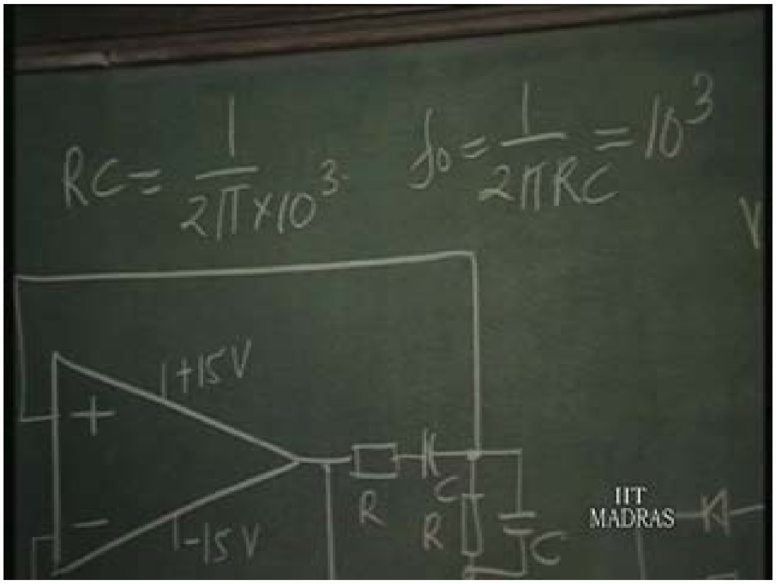

Let us select R as 10 K.

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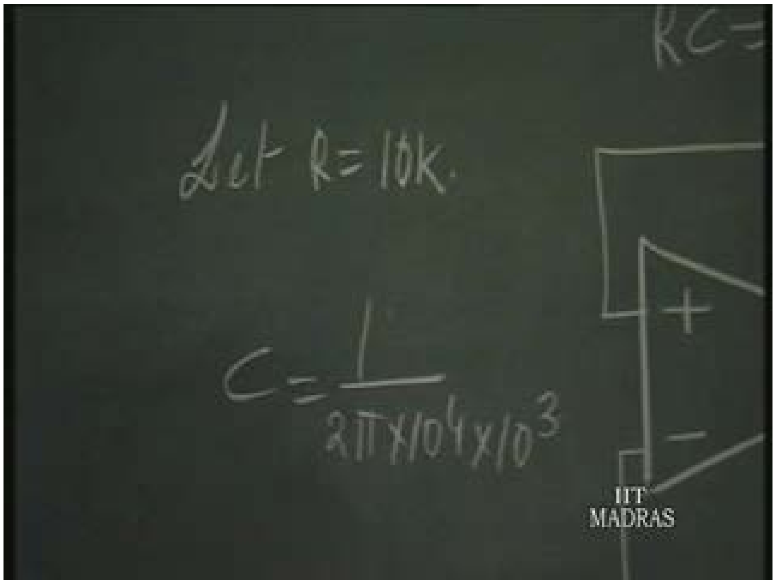

So, C is going to be...let R be equal to 10 K. Then C is equal to 2 pi into 10 to power 4 into 10 to power 3, which is equal to...this is nanofarad. So, let us say, 100 by 2 pi nanofarads which is equal to 1, 5, 15 point 9 nanofarad. Is it correct?

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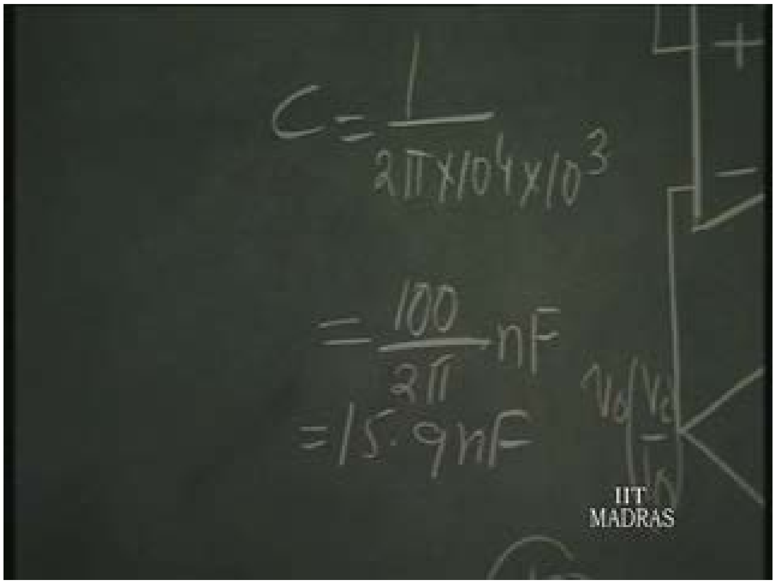

So, we will now discuss what is called as voltage controlled oscillator. It is an important circuit which is basically used for F M generation. We had seen earlier how multiplier can be used for A M generation, for example. In fact, the circuit that we have just now discussed in example...earlier example itself can be used for A M generation because we know that we are able to build sort of an oscillator to oscillate at a certain frequency. In that example, it was 1 Kilo hertz.

Let us suppose that is the carrier frequency and you want to modulate the amplitude of the carrier. So, you simply vary the V reference based on the modulating frequency. So, now you will get at the output an amplitude modulated sort of carrier at 1 Kilo hertz. So, this is very easy to generate, A M, using such amplitude stabilized oscillator. So, you just simply vary the V reference by a modulating frequency. Automatically, you will have an amplitude which is controlled by the modulating frequency; so it will become an A M.

If you want an F M to be generated on the other hand, you have to have control over frequency and this can be done by using the following circuit. We had earlier discussed circuits which can generate voltage controlled oscillators by using multiplier. You can actually use double integrator loop oscillator, quadrature oscillator and triplage each integrator with multiplier integrator combination and obtain a voltage controlled oscillator.

For example, if an integrator is being used, R, C, and I put a multiplier along with it, this is V c, this is V i, this is V naught. We know that V naught over V i is equal to minus V c by 10 scR. This we had earlier itself indicated and we discussed filters and all that.

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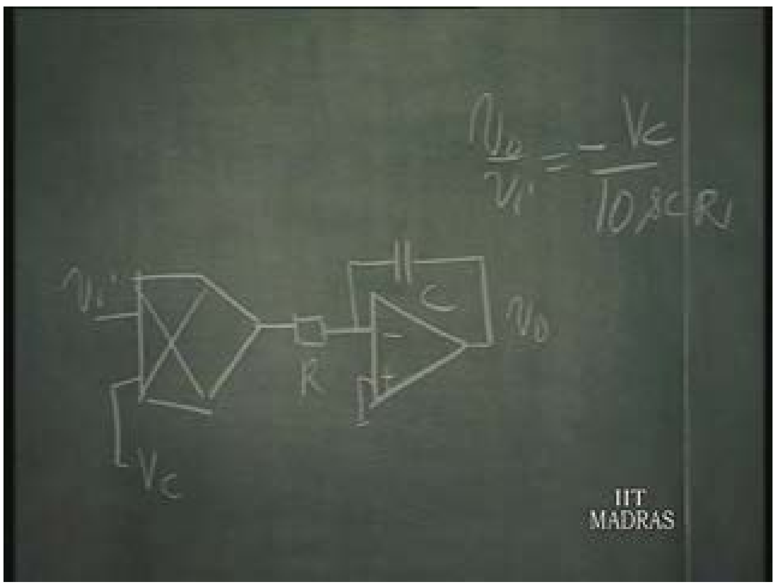

Suppose therefore, we use another integrator like this and give it to the same V c and put this integrator in the loop. So, we give the feedback now. This ideally speaking, should go into oscillation because minus V c by 10 scR, if you start from here...so, that into V i and that again squared...if you further integrate; and then with a negative sign, minus 1 inverter, is going to be equal to V i. So, this into V i is equal to V i.

This can happen only at a certain frequency because Omega C R square will give you this with a negative sign because S square is going to be J Omega C R square. So, J square is minus 1. That gets cancelled. So, that happens at Omega naught equal to 1 over C R into V c by 10.

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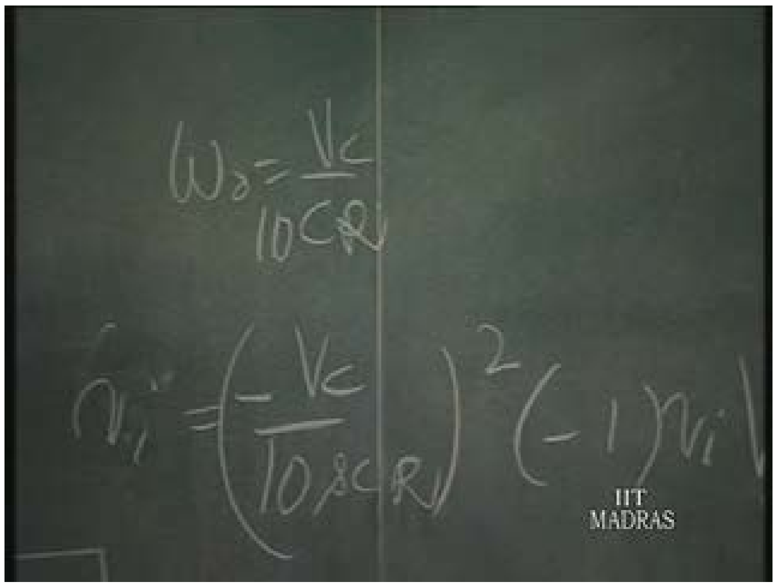

So, if you build an oscillator like this, it is a voltage controlled oscillator. It is linearly proportional to the control voltage. The frequency is linearly proportional to the control voltage.

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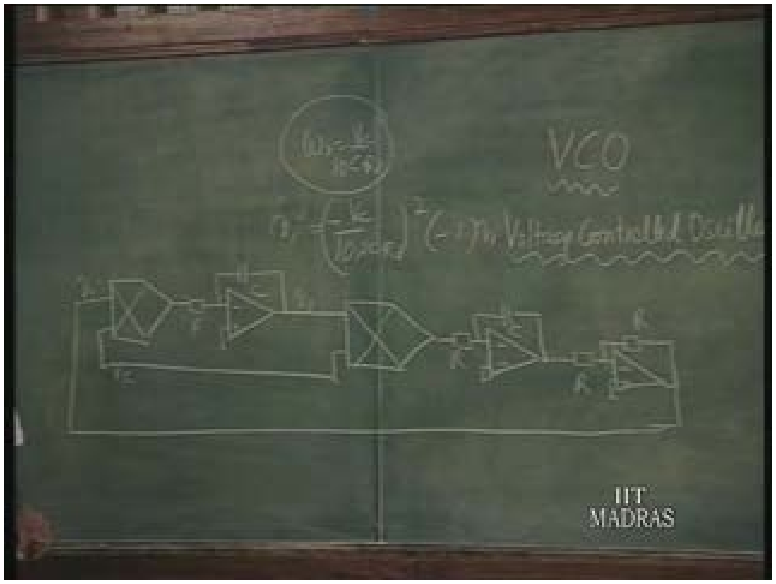

Only thing is this may not oscillate because of the non-ideality of the op-amp. So, what it means is there is certain amount of, let us say negative feedback here which might have to be countered by positive feedback from this side. So, you might have to give a positive feedback in order to make this go into oscillation; and you can bring about again the amplitude stabilization loop such that the positive feedback is there only when the amplitude is zero and the positive feedback gets compensated by the negative feedback exactly at the required amplitude.

All that can be done by using again a multiplier from here; we can put a multiplier here and then...So, this gives you negative feedback here. This one...this has given you fixed positive feedback so that initially this positive feedback only dominates. There is no negative feedback here.

So, the control voltage is zero. That means this output is zero and only positive feedback exists and then this output builds up. V c becomes positive and some portion of this is fed back here so that the negative feedback comes into picture. So, this is a voltage controlled oscillator with amplitude stabilization scheme possible. How do you stabilize amplitude once?

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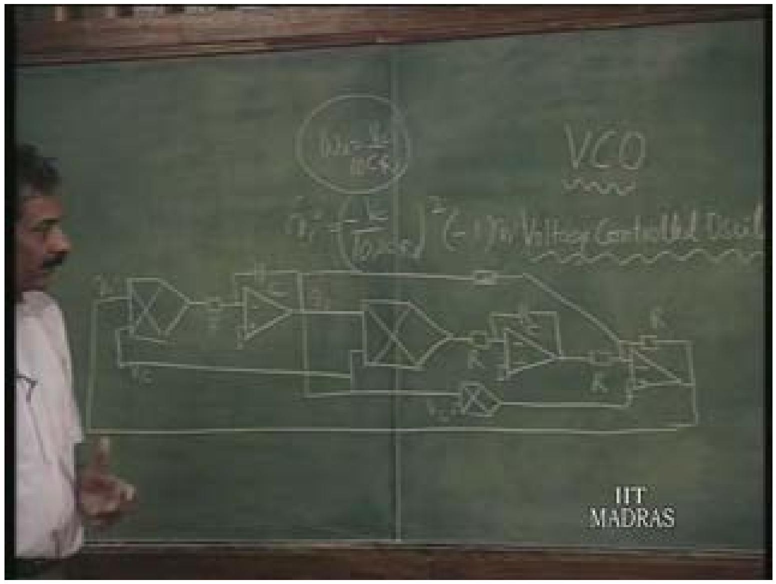

In this particular circuit, you... if this is V p sin Omega T, this output is going to be V p cos Omega T because this is integrator; and if this is V p sin Omega T, this is going to be V p cos Omega T and therefore we can square these using multipliers and simply add. Therefore, the way to build this circuit is you just take these outputs, square these and add. Adding can be done by using just a resistive network like this.

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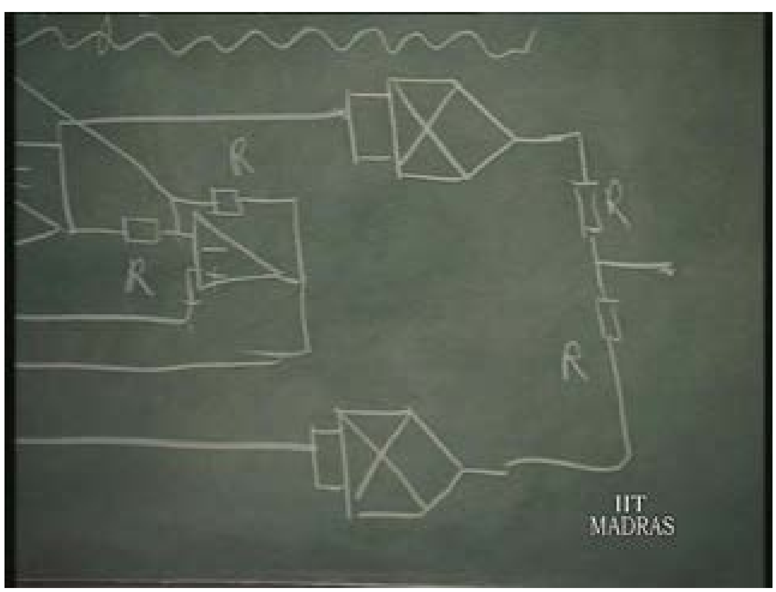

If this is done, this is V p sine Omega T. This is V p cos Omega T. So, what will be getting here will be V p squared by 10 divided by half, because of this resistive attenuator, into sine squared Omega T plus cos squared Omega T, which is constant.

So, you get a D C voltage which is V p squared by 20 here straightaway without really using any rectifier. This is the uniqueness of this circuit. This is why it is called quadrature oscillator. These two outputs are at quadrature. That is, a phase shift of 90 degrees.

So, that can be exploited in getting an amplitude which is D C dependent upon the amplitude, V p square by 20; and this can be therefore compared by means of this comparator. And we can actually... V reference we can put; and this can be used to control the...

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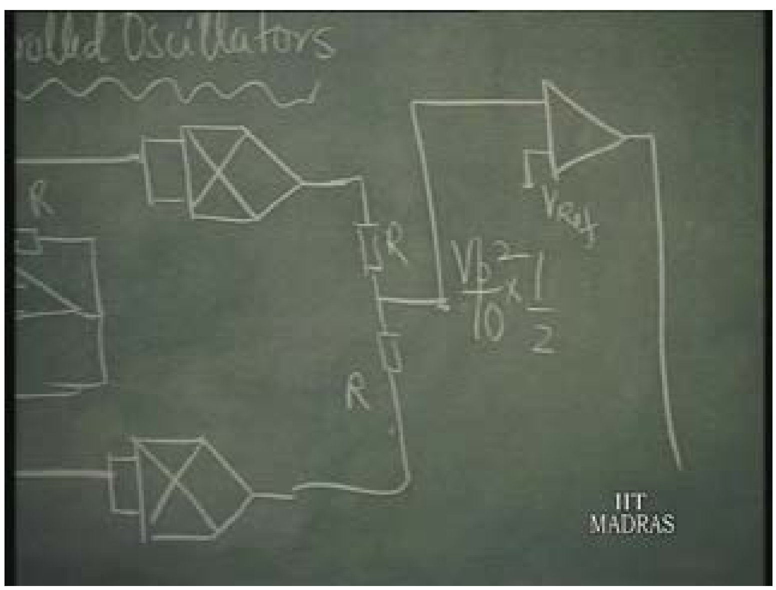

You can see so many multipliers being freely used. These two multipliers are used in order to make the frequency become directly proportional to the control voltage. This, let us say, V c dash is primarily for amplitude control. So, this is something that will control the amplitude. Amplitude therefore is going to be V reference. When that becomes equal to V p square divided by 20.... So, V p is 20 into V reference under the root.

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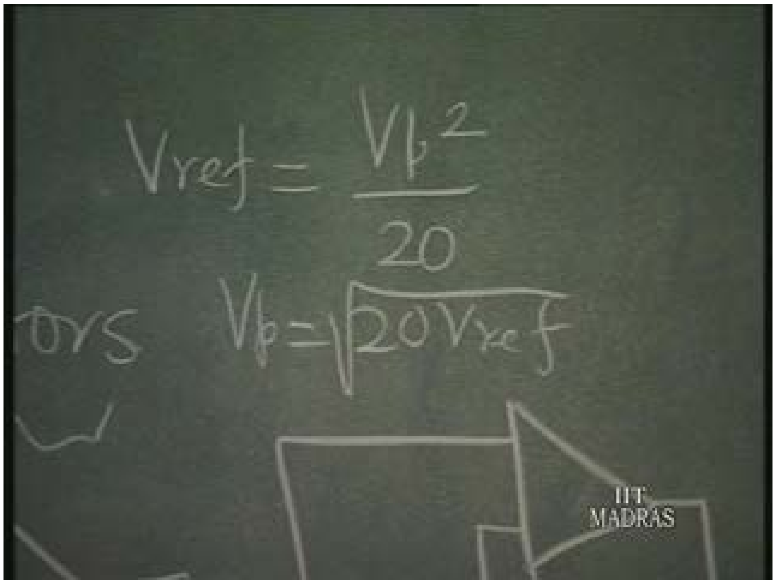

So, you can see that in order to build a good voltage controlled oscillator using this circuit, I have to use two multipliers in order to make it a linear voltage controlled oscillator and then must also stabilize the amplitude. This circuit therefore is not very popular. Only thing is it gives you a sine wave with linear voltage dependence of frequency.

You just now saw the complexity of the linear voltage controlled oscillator, if that has to be a sine wave, because it has to have a voltage amplitude stabilization scheme and the frequency should be directly proportional to voltage. Normally, the VCOs that are abundantly used are not sinusoidal. The reason being that it is pretty complicated to get VCOs which have stable amplitude and linear frequency control.

What is done is you use an integrator along with a Schmitt trigger. This we had already discussed in...we discussed a stable multivibrator; use of Schmitt trigger in generating wave forms.

So, what we can do is put an integrator and then let this integrator have a multiplier so that the time constant of the integrator is again controlled by the multiplier. So this is R, this is C. So, if this is V i, this is going to be V i by R 10 R C into V c with a negative sign into S, integration.

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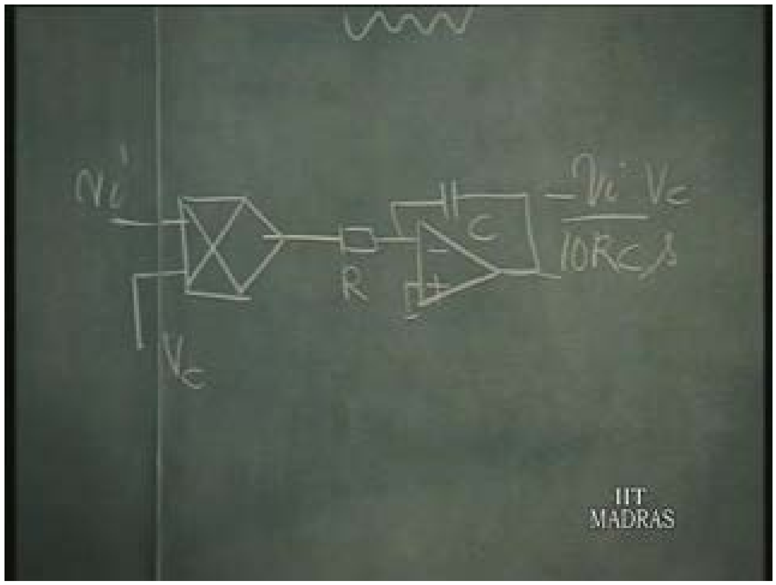

So, what it really does is that it will do integration d t. So, this is equal to minus V c by 10 R C into integral V i d t.

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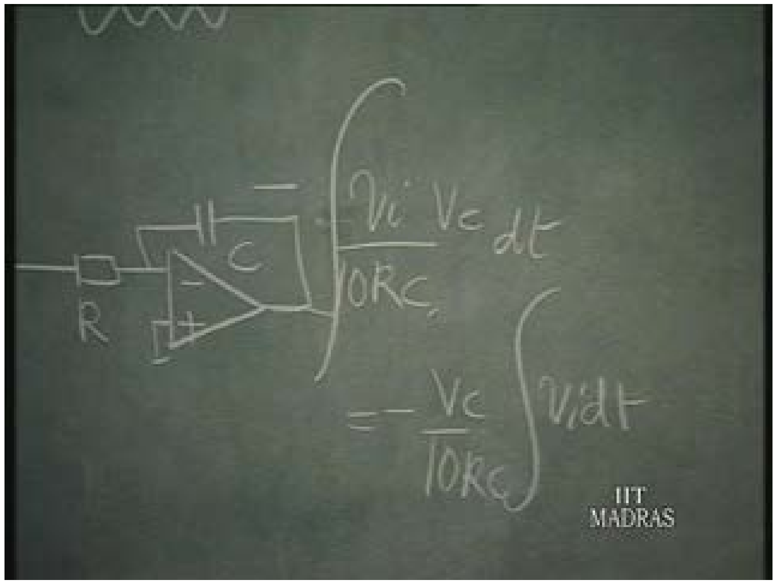

So now, we will do the time domain analysis rather than Laplace because this is going to be connected to a Schmitt trigger which is going to be a regenerative negative feedback circuit that we have discussed earlier. Let us say, this is now plus, positive feedback, local positive feedback is there; and therefore this is R. This is, let us say R and then this is now connected to the input. Let us see what happens?

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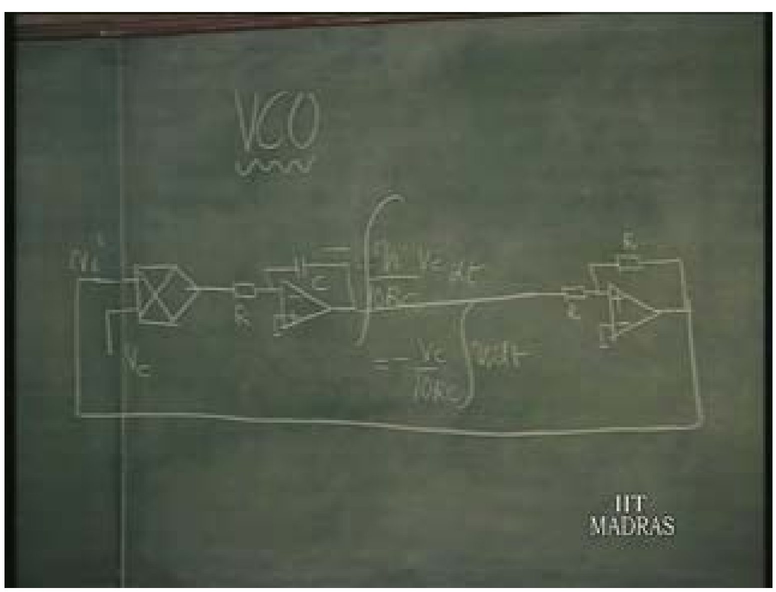

So, because there is regenerative positive feedback here, output has got to be either at plus V supply... Let us say this is plus V supply and this is minus V supply. Either plus V supply or minus V supply. It cannot be at any intermediate point because of the regenerative positive feedback. This is the Schmitt trigger.

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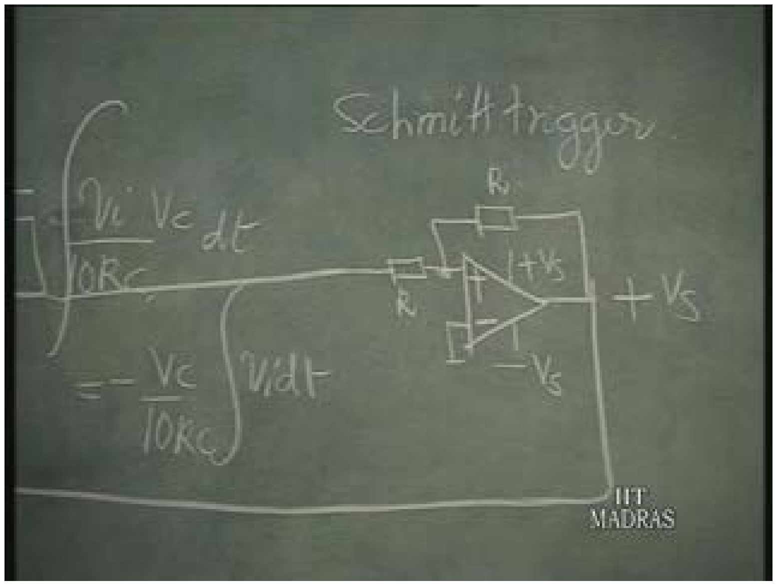

So, if this is at V s, this voltage is V s. So, this particular thing is a constant voltage V s. So, it will integrate that. So, this is V s. So, it will be coming out of it and this will be simply T. That means this will be directly proportional to time; the voltage will be decreasing.

So, if this is V s, let us plot that. Let us call this V naught 1. Then, this is V naught 2. This is V naught 1 and V naught 2 is going to be decreasing like this, linearly. What will be the rate at which it is decreasing? It will be minus V c by 10 R c, minus V c by 10 R c into t. This is the way it is going to decrease.

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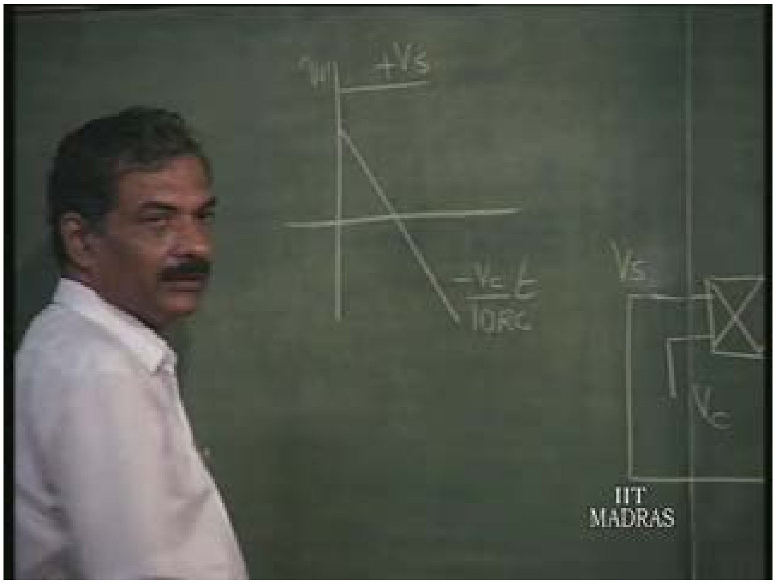

So, this is going on decreasing. This voltage is plus V s. As soon as this reaches minus V s, this voltage is going to become zero. That is the state in which this Schmitt trigger is going to change state from minus to plus. So, it will go to minus...plus to minus here. So, this has gone to minus. So, this will go from plus to minus at that point.

So this, as soon as it reaches minus V s, this change, this particular thing will change state from plus V s to minus V s. So, this has gone to minus V s. The moment this goes to minus V s, this is minus V s now. So this slope here will become for this wave form – plus; and it will be plus V c by 10 R C into t.

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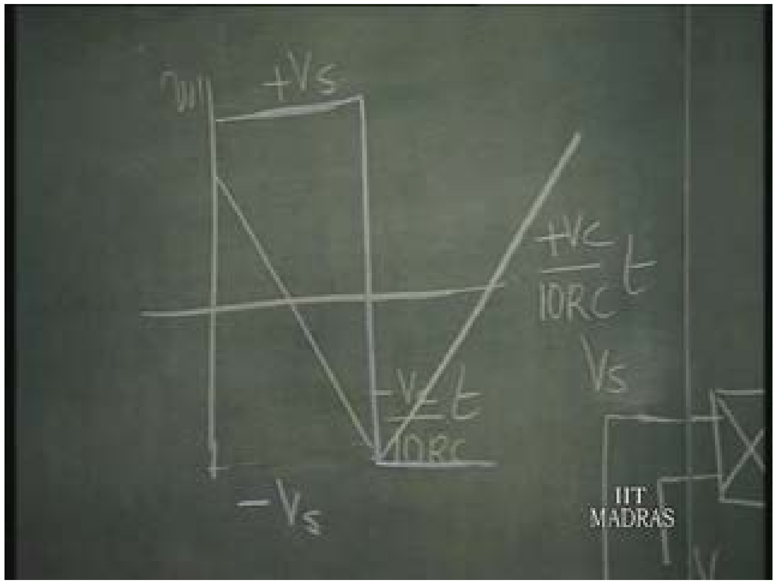

So, it will go on like this. This is already at minus V s. So, this is going on increasing... The moment this voltage becomes plus V s, this voltage will become zero. It will again change from minus to plus.

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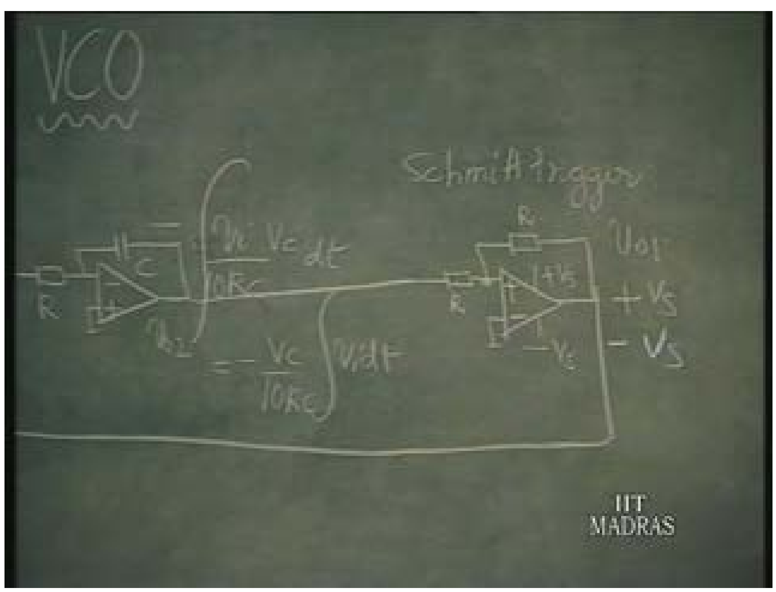

So, this will keep happening for ever. So, the moment this is this thing, it will go to plus V s and this will go down. So, this will be kept at that until this goes to minus. Again it changes state. So, you will get triangle wave form here at this point and square wave form here. The time period can easily computed. This is T by 2 because this whole thing is T.

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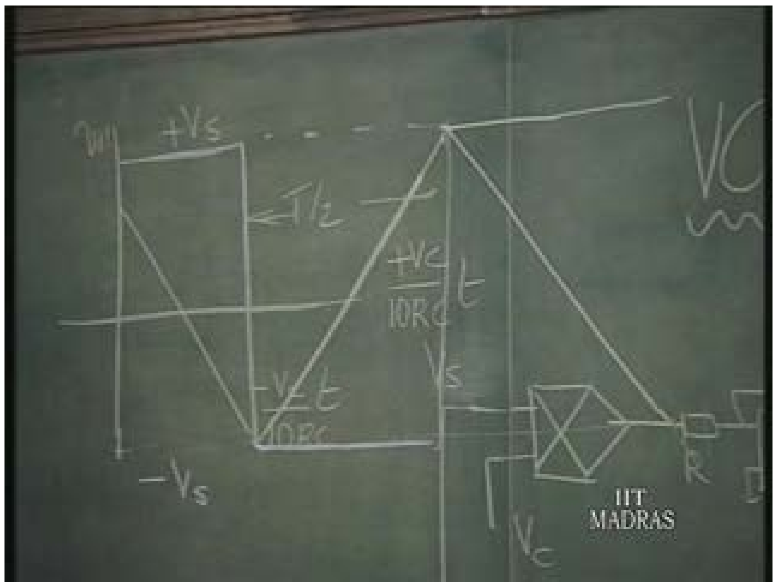

So, T by 2 into V c by 10 R C. This is the rate at which it goes. V c by 10 R C into T by 2. It acquires a voltage of twice V s. This minus V s to plus V s, it goes.

So, V c sort of...sorry, this V c is going to be there. This particular thing into V s. This particular thing into V s... Please remember that this particular thing into V s is all the time there because this is V s, constant. So, this V s gets cancelled with this V s.

So, T is equal to 40 R C or f naught is equal to 1 over T. This 40 R C by V c; 1 over T is V c by 40 R C.

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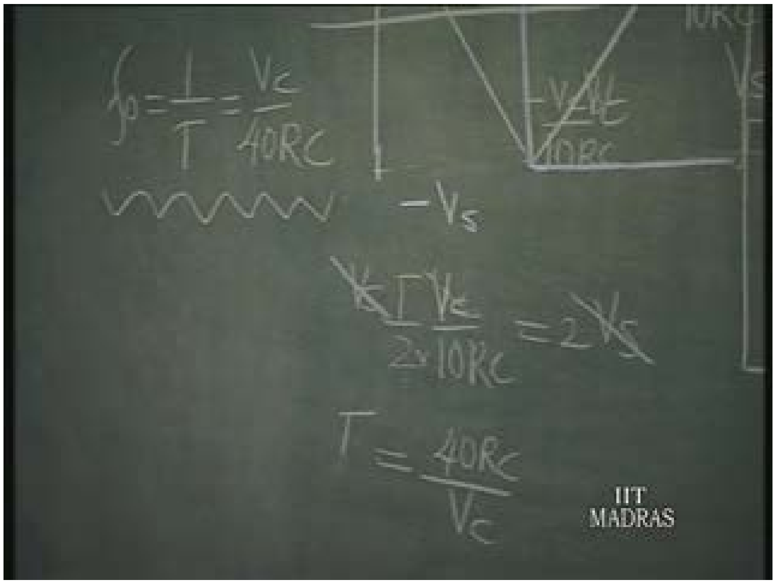

So, this particular thing is a nice voltage controlled oscillator, linear, but it uses only one multiplier. It does not require any amplitude stabilization scheme because already the amplitude gets neatly stabilized at plus V s and minus V s and this rate of rise and rate of fall become same; equal to minus V c V s by 10 R C and plus V c V s by 10 R C, respectively.

Therefore, this is a very popular circuit for generating F M as I told you; and because here...we give the modulating frequency here. So automatically, we can now have the carrier getting modulated by this particular frequency here, voltage here, and this frequency will start changing according to this controls here, linearly.

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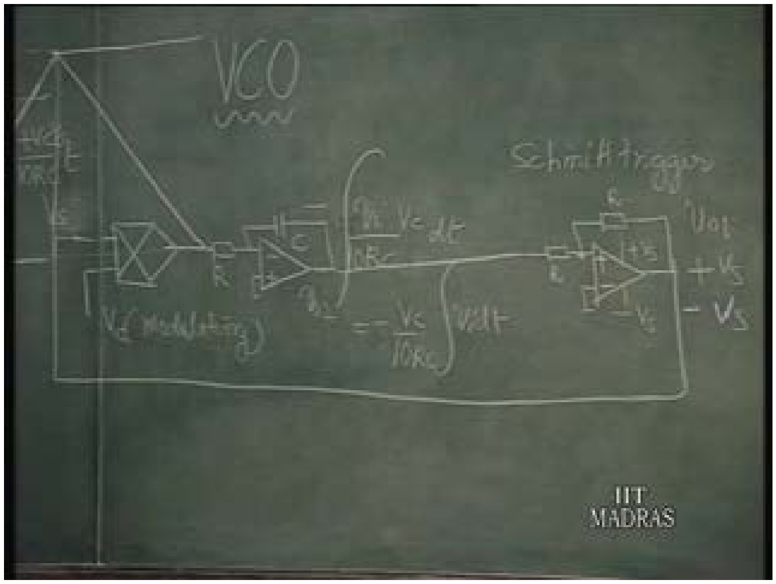

So, this circuit can be also converted into its transistor counterpart wherein this portion is going to be replaced by a voltage controlled integrator. That means you will have a voltage controlled current source driving a capacitor. That is all. And a transistor I Schmitt trigger; but the basic circuit is essentially this.

And it is this VCO which is very popular and this entire circuit is normally called a function generation circuit because it is giving you a square wave, a triangular wave and also, if we just put a function generator, in the sense, diode function generator to convert this triangular wave form into sin wave....that we have done long ago in the first part of our lecture, we can convert this sine wave, the triangular wave into sine wave. You get all the three important wave forms: sine, square and triangle, with voltage control of frequency. This chip is available as a function generator I C chip.

Now we will consider an important control loop which is called Phase Locked Loop or P L L it is called. This has become very popular because of the fact that such a phase locked loop is available as an integrator circuit and it can achieve a lot number of communication as well as control systems like speed control, frequency synthesis, FM detection, AM detection, etcetera.

Therefore, let us see the basic principle of what is called phase locked loop. Before we go to phase locked loop, I would like you to understand the basic principle of negative feedback as taught to you in control system. If X i is the input and X f is the feedback factor coming from the output which is X naught, this is called error detector. In control system, this is called error detector. This will give you an output which is X i; this is put here plus, minus, saying that it will give X i minus X f as the error; and this is called the error amplifier.

Therefore X naught is going to be equal to the gain G times X i minus the feedback factor X f. This is how you have been writing your control loop equations where X is any variable. So, this particular feedback factor, if it is H, this is the way this signal gets transmitted. Output is fed back to the input. So, X f is equal to X naught into H. Then, this is equal to G into X i minus X naught into H.

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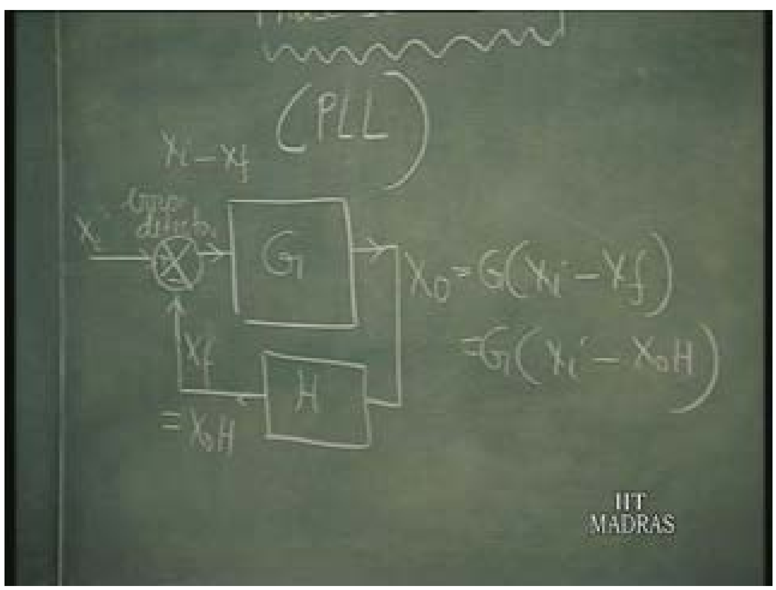

So now, from that we get X naught by X i is equal to G divided by 1 plus G H. This is an important control system equation which tells us that if G H is...this is called loop gain. In our control R circuits, we have been calling this as loop gain.

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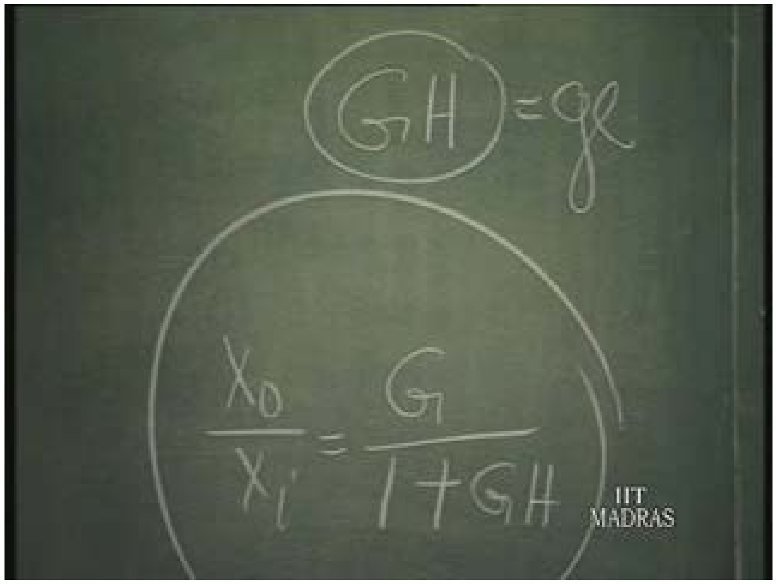

This particular loop gain in this... In this case, it is negative feedback. Actually therefore, the loop gain if you really consider the loop, is negative. So, this is a negative feedback configuration. If this loop gain is much greater than 1, then we can show that this is approximately equal to 1 over H. It becomes independent of G, the amplifier. It becomes only dependent upon the feedback factor H; and if H is 1, if H is 1, this is equal to 1. That means X naught will follow X i. X naught is going to be following X i.

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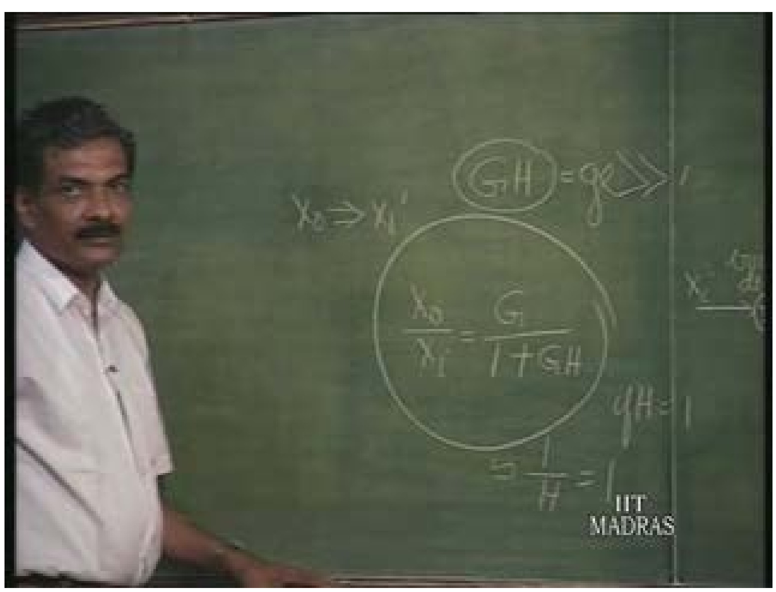

This particular thing...if X i is voltage, you can call this...V naught is going to follow V i. V i is going to be narrow (Refer Slide Time: 34:30) amplifier which is nothing but a differential amplifier. So, plus, minus. So, this entire thing is nothing but a differential amplifier. This error detector with G; and if I give feedback fully, V naught follows V i. This is therefore called a voltage follower. This we have discussed again in the first part of our series of lectures, voltage follower.

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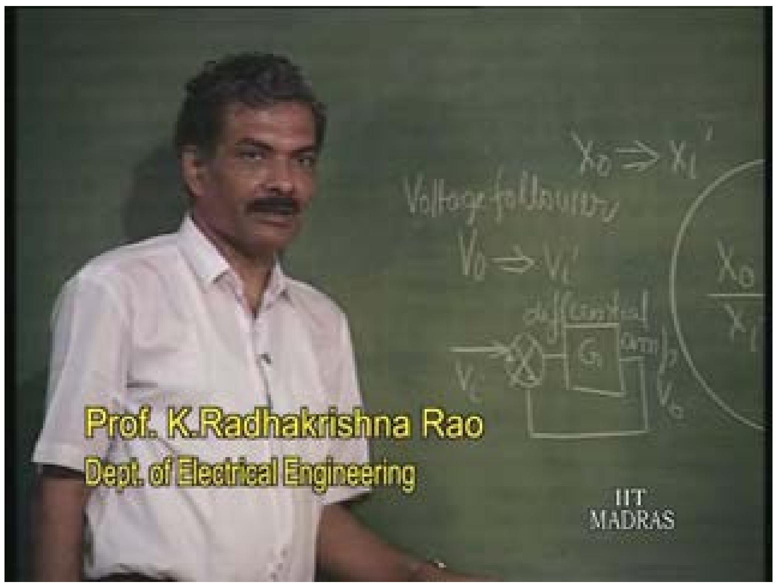

Again, if I say this is I i and this is I naught and this is a current amplifier...this also we have done in what we call as a transistor connected as a diode. This error detector in fact can be very easily done by just merging this into a node because then this particular thing is going to be...in fact, if the direction is changed, it will just give you I i minus I naught as the error output.

So, if you change the direction of the current here, the error detector becomes just a node. This is a current amplifier and therefore I naught is going to be very nearly equal to I i. It is therefore called a current follower.

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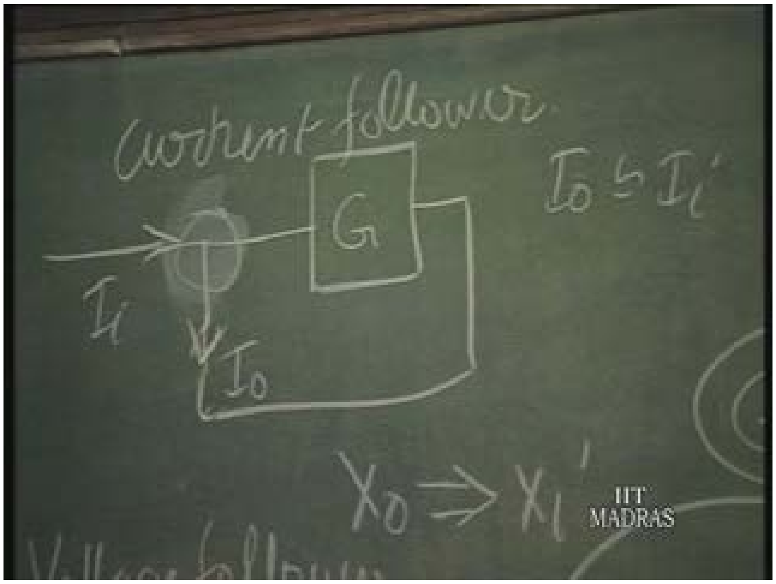

So, that in fact is nothing but a current amplifier. Like common emitter amplifier, when entire collected current is fed back to the input, it becomes a common base amplifier and the current gain becomes very nearly equal to unity. So, you have understood long ago that I can design such control system equivalents in circuits by using voltage as the parameter, current as the parameter, etcetera. Now, when we go to phase locked loop, neither voltage or current is going to be the considered input here.

What is going to be the considered input here is nothing but phase; and this is going to be... let us say we will put this whole thing H equal to 1. This is not going to be error detector. It will be called...this is phi i and phi naught. This is going to be therefore called phase detector.

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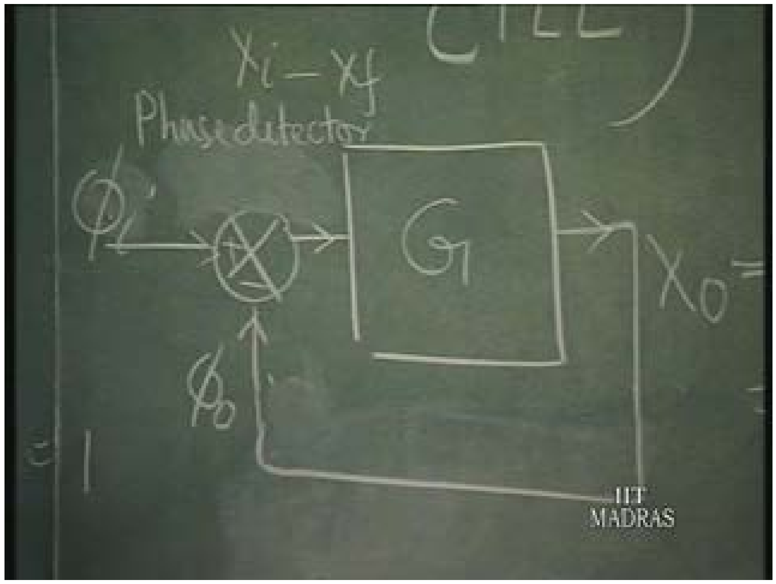

That means, a phase detector is something that...when phase is given as the input, phase difference is given as the input, it will give a D C output corresponding to the phase difference. This D C output is amplified and this output of the amplifier has to be converted again into phase.

So, what is that that converts a D C voltage into phase? That is nothing but a VCO because when I apply voltage, D C voltage here, you get a frequency. What is the relationship between frequency and phase? I know that if phase is phi, the frequency f is nothing but d phi by d t. Frequency and phase, they are linearly related.

The frequency phi f or actually speaking, this is equal to Omega in radiance per second is nothing but d phi by...this is radiant frequency; this is nothing but d phi by d t, rate of change of phase. If you now put Laplace transform, Omega is equal to s times phi or Omega by s is equal to phi.

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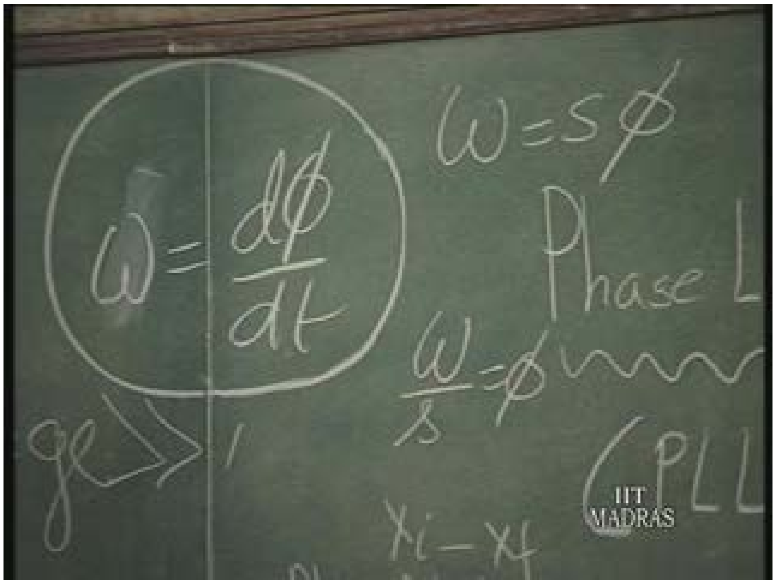

So, if I have frequency, I can say that if the frequency output is given to a phase detector, it will respond to phase change. Therefore, the basic building blocks of a phase locked loop will be a phase detector, a VCO and an amplifier; and it should respond to only average here because D C, I said. So, amplifier with a low pass filter.

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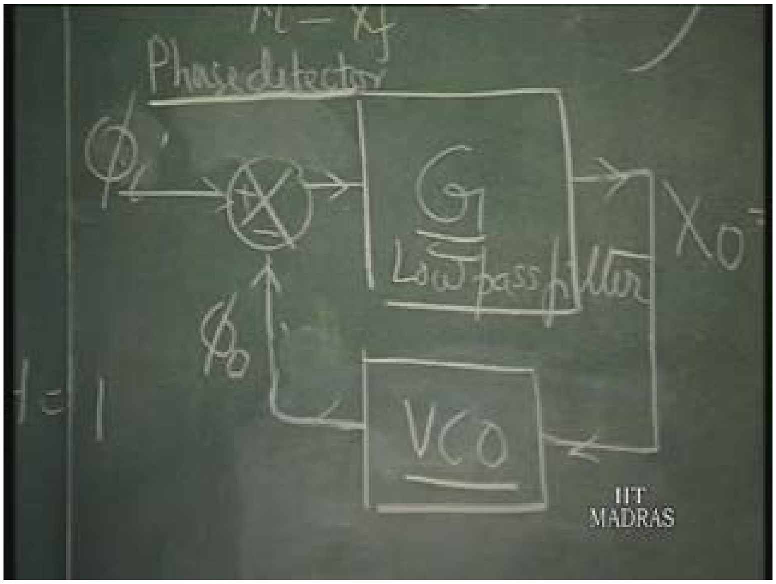

So, let us now list out the basic building block phase detector, amplifier, plus low pass filter. Then 3 - voltage controlled oscillator.

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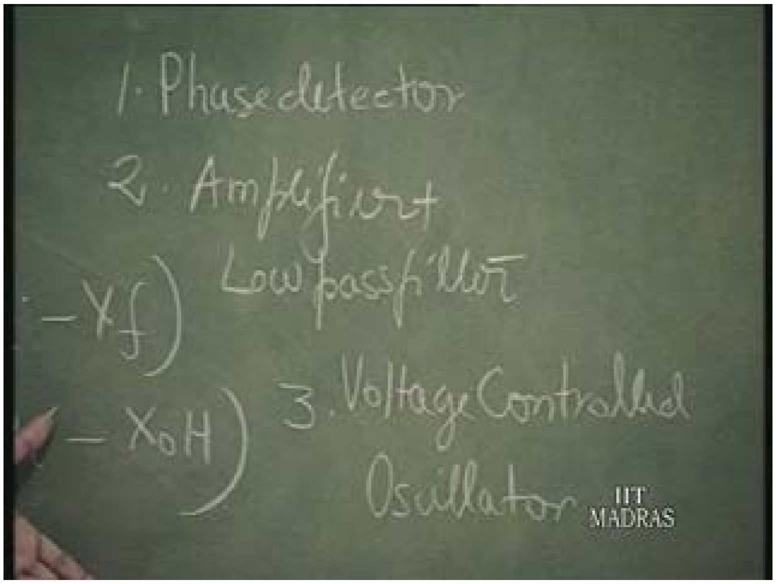

In fact, we had discussed all these three building blocks just earlier. Voltage controlled oscillator has just been discussed; amplifiers and low pass filters were also earlier discussed. How to design amplifiers and how to design low pass filters. Phase detector was discussed when we discussed multipliers.

So, all these basic building blocks of the phase lock loop have been earlier discussed. Their characteristics, we have obtained. What is the phase detector characteristic? It will give you an average output corresponding to some, let us say Kpd into phi i minus phi naught.

This particular Kpd is called the phase detector sensitivity. Amplifier sensitivity is called gain. So, amplifier gain is called A naught. V c gain. Low pass filter has a cut-off frequency. So, that low pass filter characteristic will be looking like this: 1 by 1 plus S by Omega low pass; first order low pass, this also we have discussed earlier. That is Omega L p is the cut-off frequency of the low pass filter.

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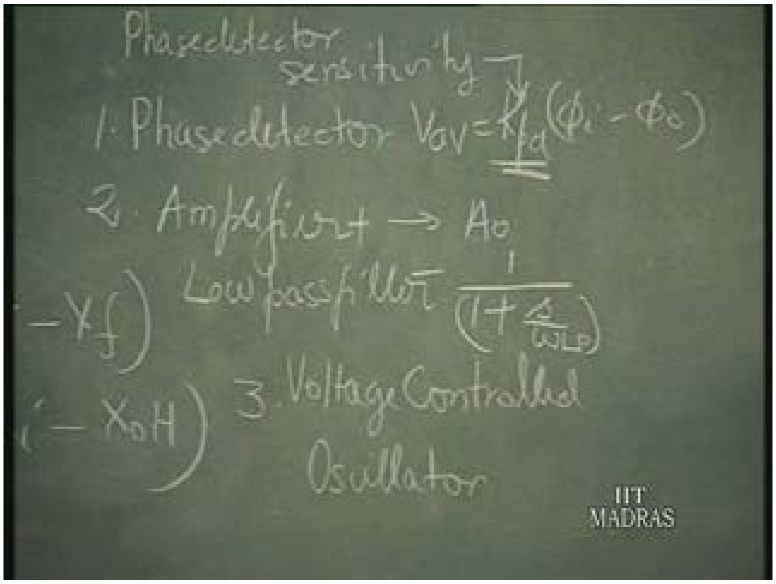

Voltage controlled filter. Voltage controlled oscillator also has a sensitivity. What is it? - frequency Omega is dependent upon control voltage. If it is linear, it will be directly proportional to the control voltage. So, this is called Kvco. This VCO sensitivity, Omega is equal to Kvco times V c.

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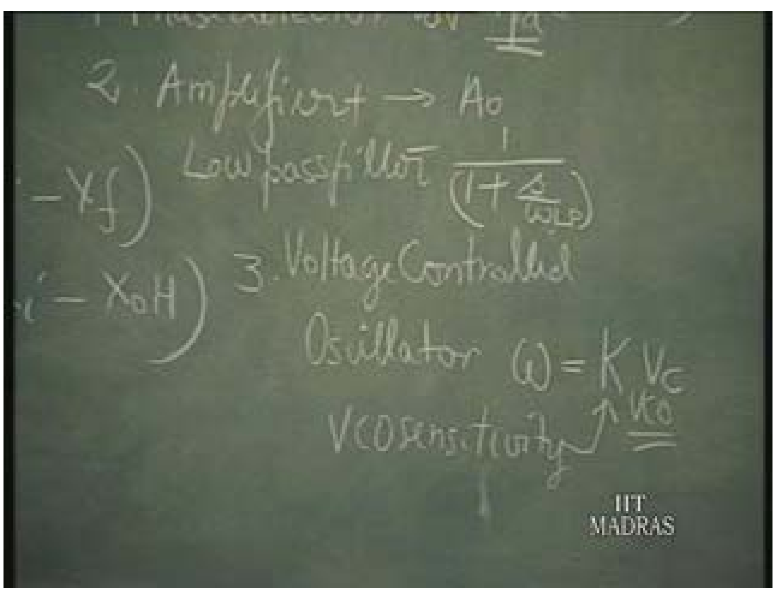

So, the basic parameters associated with these building blocks will be phase detector. If it is linear phase detector, it has a sensitivity factor, amplifier - gain A naught, low pass filter - cut-off frequency Omega L p, voltage controlled oscillator has its sensitivity factor Kvco. So, if we now try to analyze this for the phase, what will we get?

If phi i changes and phi naught will follow it, phi i by phi naught should be equal to 1 because that is what we have been all throughout telling. It is immaterial what the variables are. In this case, phi i by...phi naught by phi i or phi i...phi naught by phi i, in fact, is equal to 1.

So, we can call this as a phase follower; or as it is popularly called, we can call it as phase locked loop. The phase follower action is going to be considered as phase locked loop.

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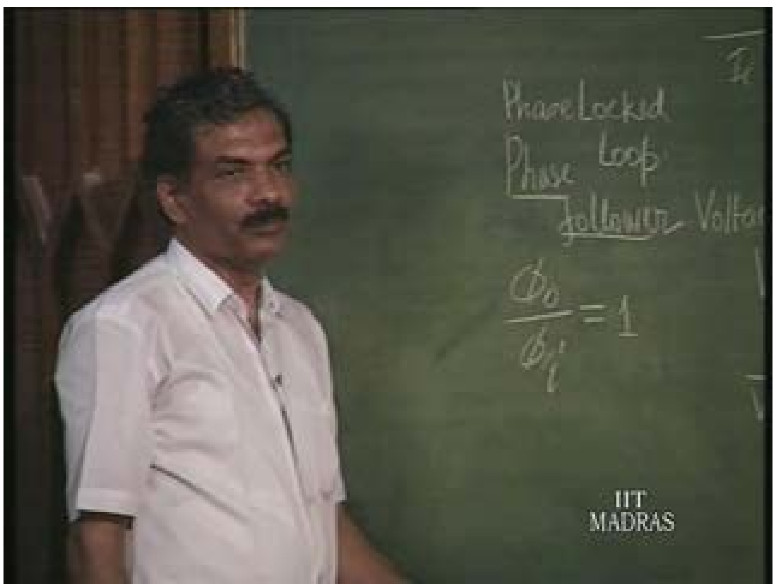

So, what it means is d phi by...d phi naught by d phi - change in phase is going to be followed at the output, if there is a change in phase at the input.

We have just now seen how the phase locked loop comprises of three basic building blocks. A phase detector whose phase sensitivity is Kpd, amplifier with low pass filter; it is necessary so that the output of the phase detector which is really...this is actually multiplier. So, it will comprise of both high frequency and low frequency component; it is the low frequency component, the average component to which output should respond.

So, we have put an amplifier with low pass filter here and then this D C or the low frequency input is controlling the VCO frequency. So, output is going to be a frequency.

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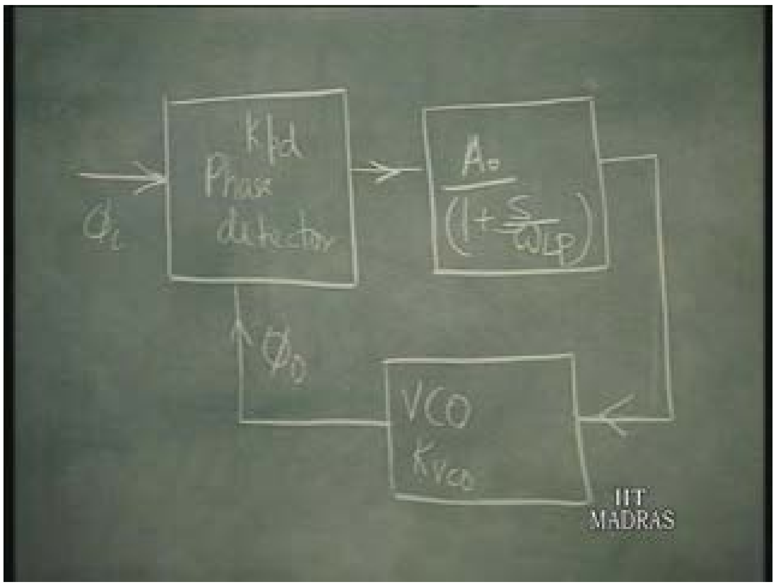

But just now I said the phase and frequency they are related. Omega is d phi by dt, change of phase. That means when I am using phase here in the analysis, this frequency Omega should be converted into phase. That is done by dividing by s because this Omega is equal to phi into s. Laplace transform. Differentiation means multiplication by s. So, phi is equal to Omega by S. So, Kvco by s is the transfer function of the VCO here, which will indicate that it is the phase that is of interest for the phase detector. If that is the case now, we can do the analysis. Assumption is that only the phase is varied.

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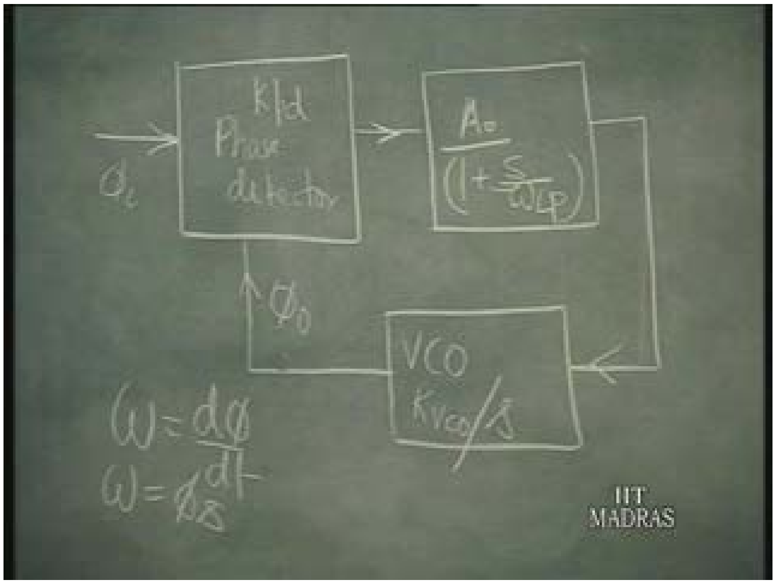

Let us now see how this is going to respond. phi i minus phi naught is the phase difference and Kpd into that is the D C voltage here or low frequency voltage here and that is getting amplified by A naught divided by 1 plus S by Omega L p.

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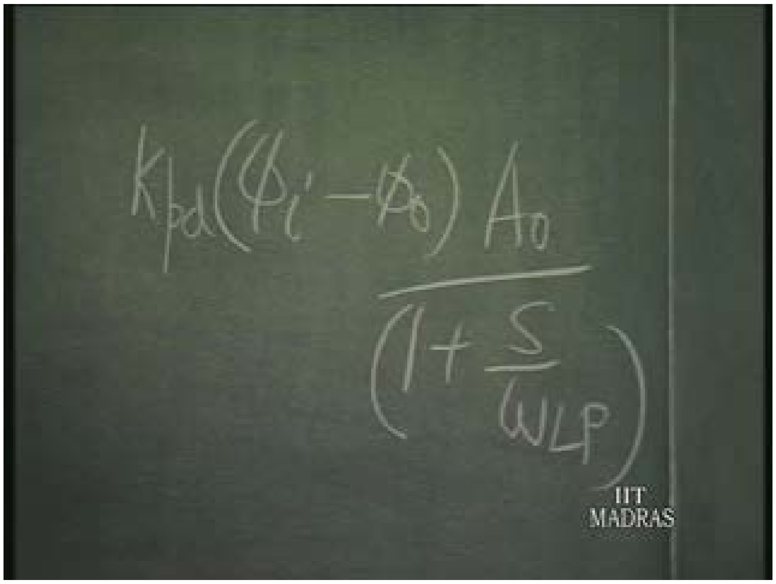

That is the D C voltage appearing here and Kvco by S is the phase conversion factor here. So, Kvco by S and that should be equal to pi naught itself. So, this is exactly similar to our writing X naught is equal to X i minus X naught into G.

This whole thing is going to be called as deep gain or the loop gain. So, we will call this G into phi i minus phi naught.

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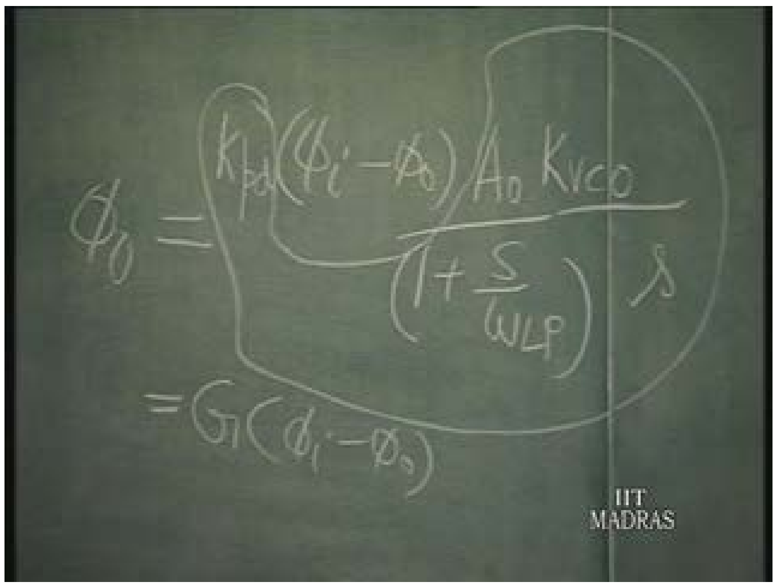

So, what do we get? We get phi naught by phi i equal to G by 1 plus G. If this loop gain is very high, this is going to be very nearly equal to 1. So, that is why we call this a phase follower. phi naught is going to be followed; change in phase at the input is going to be followed at the output.

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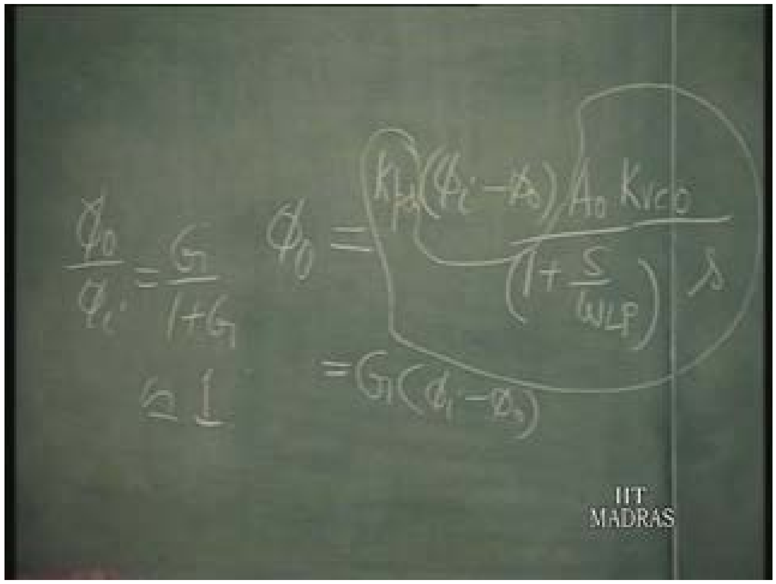

Now, what is G? The loop gain here is nothing but Kpd Kvco into A naught. So, that divided by S into 1 plus S by Omega Lp. This factor, which is independent of frequency, is called the D C loop gain of the...this K l, which is nothing but...you go through this...Kpd, A naught, Kvco, all the sensitivity factor products. You call this as D C loop gain. So, this is going to be equal to K l divided by s into 1 plus by s by Omega L p.

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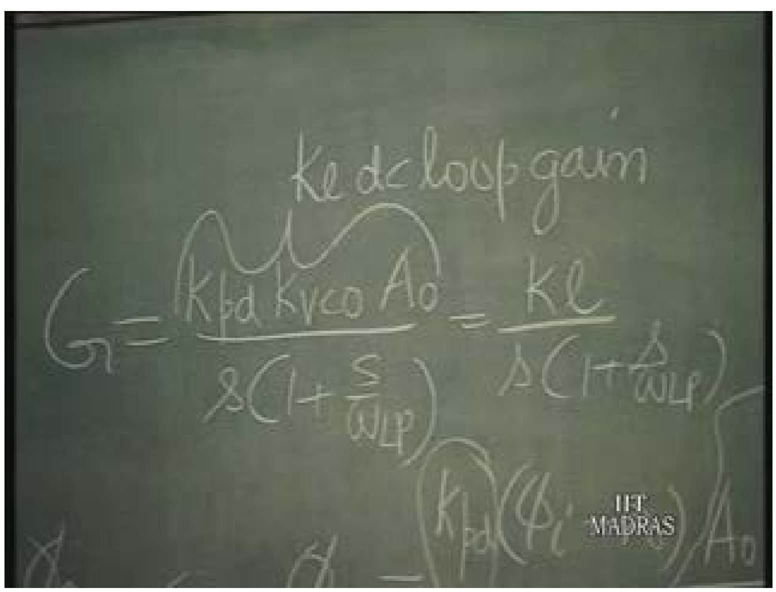

If you write therefore, this equals 1 by 1 plus 1 over G, this is going to be...1 by 1 plus...G is... here, 1 over G, s by K l plus s square by K l into Omega L p. This is going to be equal to phi naught over phi i.

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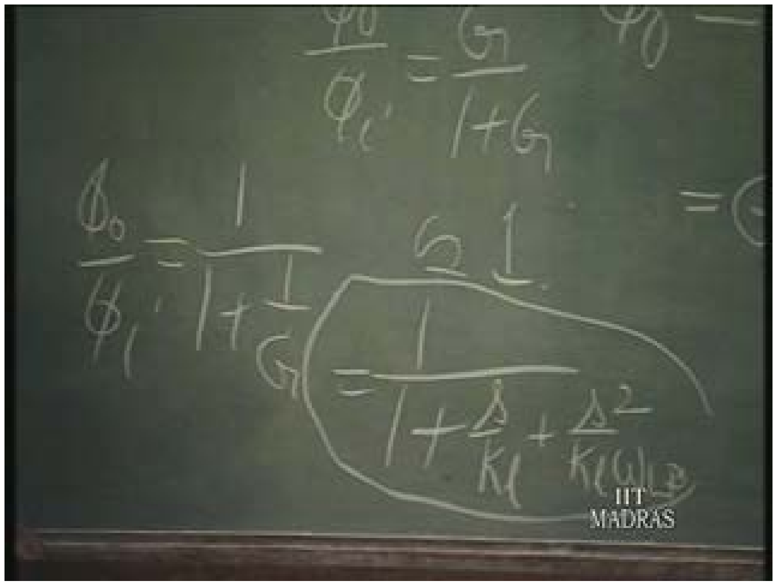

If all these factors can be ignored, if K l is very large, this is going to be equal to 1 so that we have also shown that Omega naught...here, phi into s is equal to Omega. So, Omega naught into s is equal to phi naught; Omega i into s is equal phi i. So, this gets cancelled. So, if it becomes a phase follower, it will also have frequency following action. Output frequency is going to be same as input frequency.

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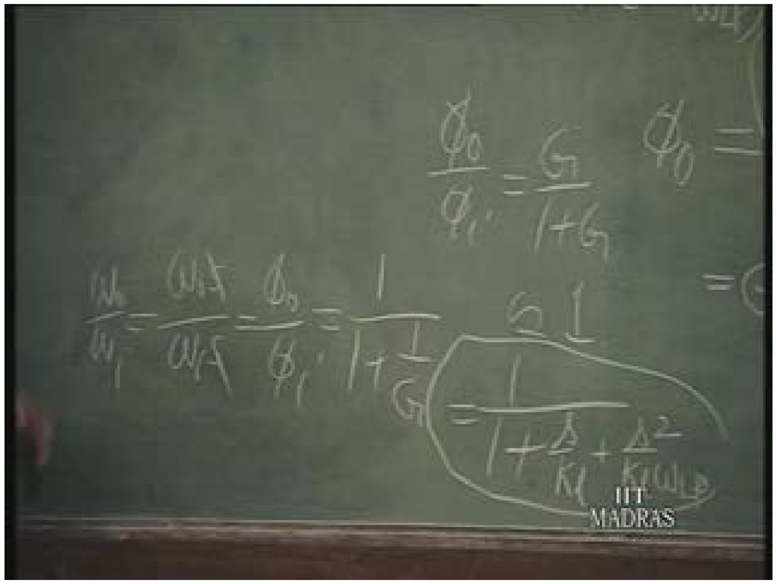

This is an important property of phase lock loop; output frequency will be exactly equal to input frequency.