Electronics for Analog Signal Processing - II

Prof. K. Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology – Madras

Lecture - 39
Experimental Demonstration of Lock Range, Capture Range and FSK and FM Detection Using PLL

We will discuss another application of the multiplier in what we had earlier indicated as A G C or A V C scheme, which is automatic gain control or automatic volume control. This is a control scheme which is quite often applied in radio receivers and television receivers to maintain output constant, output sine wave constant amplitude. So, this is the multiplier whose input is V i; and if control voltage is V c, it will have a gain of V c by 10 into V i; that we have understood.

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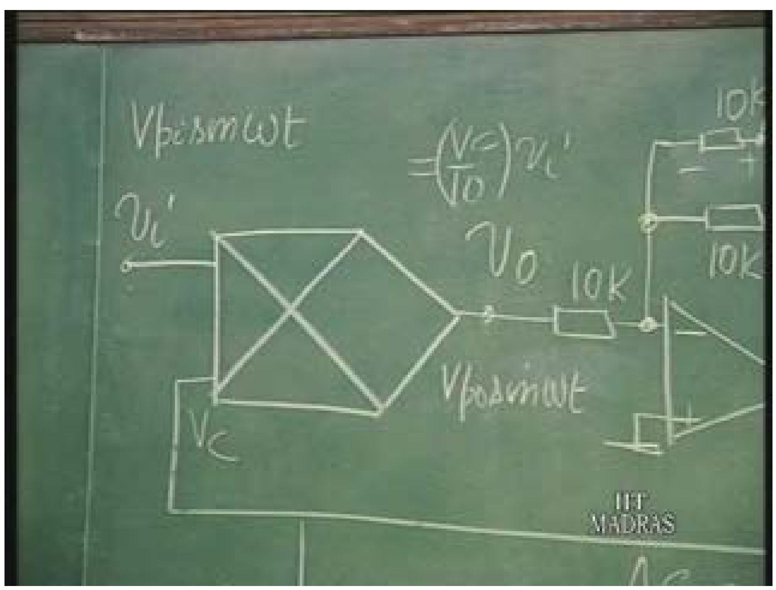

So, what is done is V c is adjusted by this control loop such that V c by 10 into V i remains constant at a specific value. That means V p naught after a certain point remains constant independent of V p i. V p i sine Omega t is the V i and V p naught sine Omega t is the output.

So strictly speaking, if we were to plot V p naught versus V p i, peak output voltage versus peak input voltage in a situation like this, in the multiplier case, if we were to expect an output of, let us say point 1 volt, peak, then until the gain…the gain of this is maximum equal to 1 because V c can utmost go to 10 volts, let us say.

So, until your gain required for adjusting this falls less than 1, it will remain at the maximum. The control loop will be such that V c will remain at the maximum 10 volts and therefore the gain will remain at 1 until this input reaches point 1 volt. Thereafter, since the input is going to be higher than point 1 volt, the multiplier gain can adjust itself to any value less than 1; and therefore, it will come into operation and output will be maintained at point 1 throughout, even up to peak voltage of 10 volts. There is no problem for this to work. This is the dynamic range of operation of A G C here.

So, every A G C will have a limit after which it cannot work. It will work with the maximum gain and thereafter it will come into operation and it will keep the output constant at the given value. Now the output is sensed by this precision rectifier which we have demonstrated in yesterday's class. This is the precision rectifier; so that this sine wave gets rectified here. The positive half cycle appears here with V p naught as the peak voltage and negative half appears here. This we had seen.

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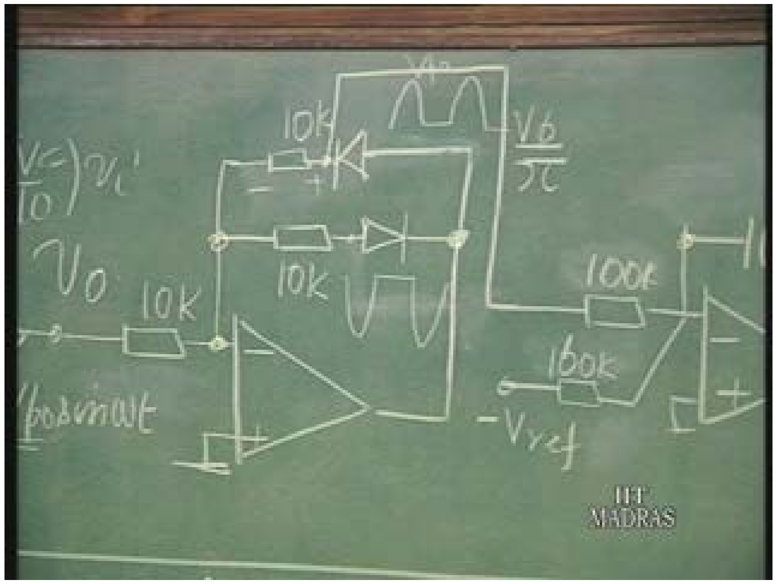

This positive half is filtered and the average of this corresponds to V p naught divided by pi and that is injecting a current in this direction; the same current, D C current is withdrawn here, so that this voltage remains constant at V c. So, that is the required V c in order to maintain the output voltage constant.

So, that means V p naught divided by pi divided by 100 K minus V reference divided by 160 K should be equal to zero; or V p naught should be equal to, let us say V reference by 160 into 100. So, this is the peak voltage at which it will remain constant.

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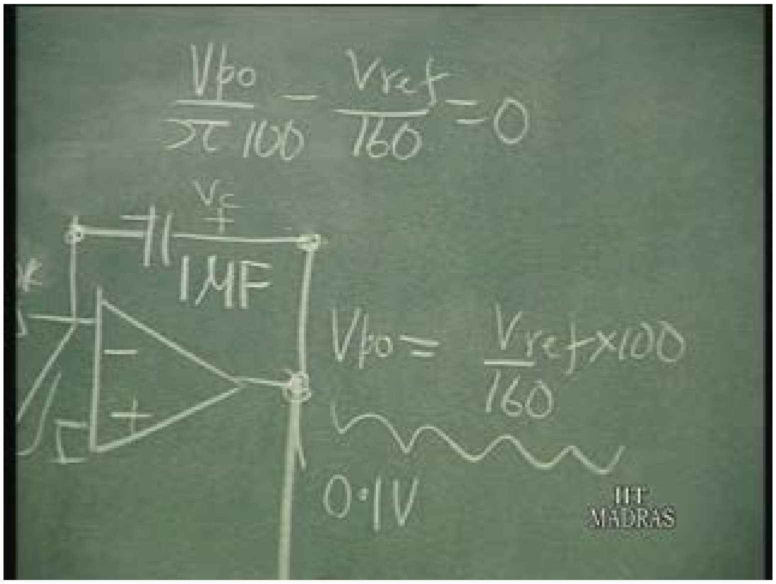

In the demonstration setup we have made V p naught equal to point 1 volt as it has been depicted in this figure. Peak voltage has been maintained. This value has been…V reference has been so chosen that this is point 1 volt, which means actually speaking, V reference required for this is going to be about point 16 volts.

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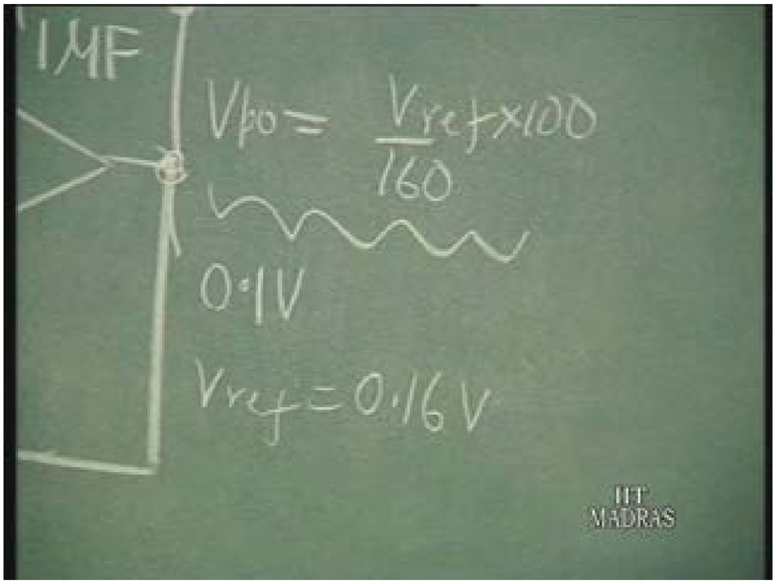

So, after fixing the V reference at point 16 volts, we are now showing to you in the demonstration how, when V i is changed, we are starting from the highest value here and coming down and up to the point when it becomes equal to the point 1 volt, this will remain constant at point 1 volt. You will see that; and thereafter, output will be following the input. So, this demonstration again is going to be shown to you on the screen of the oscilloscope now.

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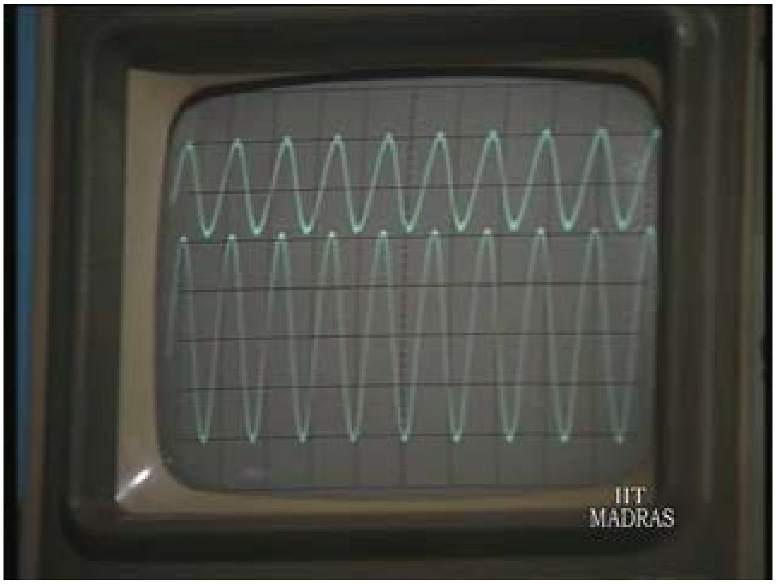

So, you can see the screen here - output is going to be at what value? Output is 200 millivolts peak to peak or point 2 volts peak to peak. Input is 20 volts peak to peak. That means 10 volts peak. Now it is at this value... You can see she is going to almost halve the input…reduce the input.

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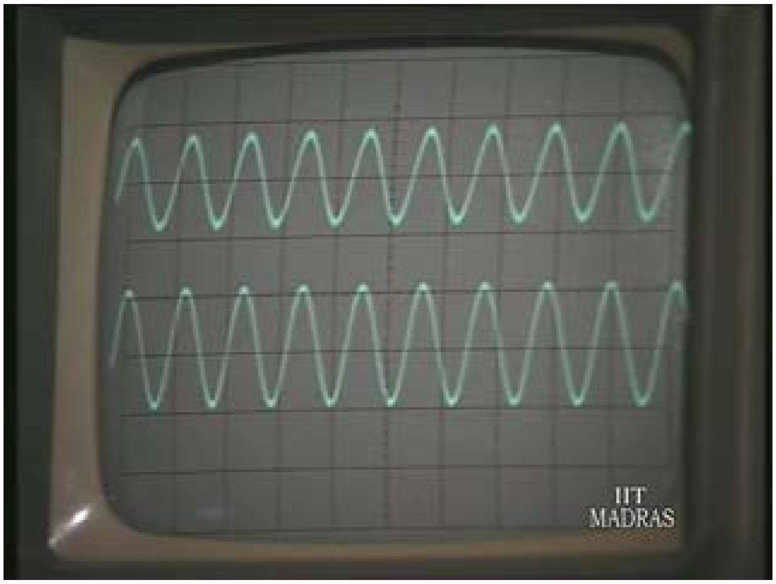

So, she is slowly reducing. You can see…it is...the control thing is coming into action. Slowly reduce and now input is almost half the original value. Output has still remained the same. It has not changed. That means input is now how much? 10 volts peak to peak. Input is 10 volts peak to peak and output is still remaining at point 1 volt peak.

Again now, reduce…go the other scale as far as… So, she is still reducing the input. Output has remained constant. Now see…slowly reduce so that the control loop has some chance to adjust itself.

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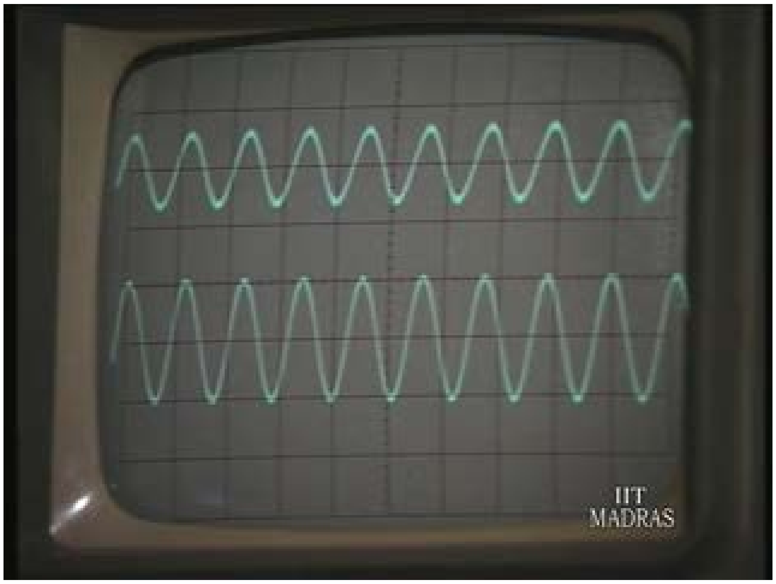

Now what is the input? 4 volts peak to peak. That means 2 volts peak. Even now the output has remained constant, almost.

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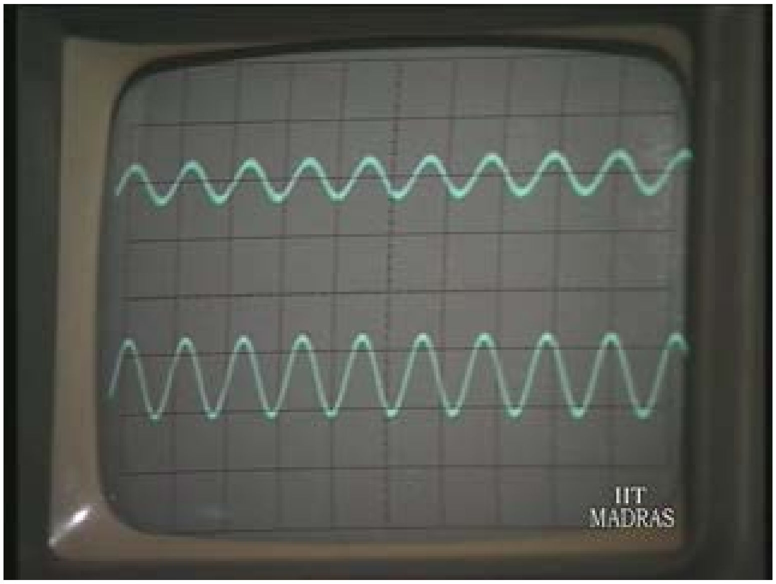

Now reduce. Go to another scale. Reduce. Now you can see some visible effect of input slowly reducing. Yes. Now slowly change the scale of the input. Now input has become almost… So, input and output are changing. So, the A G C scheme has stopped working almost when it becomes very nearly same as the point 1 volt peak that we have adjusted. So, this is the A G C scheme.

Now we will demonstrate the working of phase locked loop which we have already studied. You can see here, the phase detector that we are using is nothing but a multiplier itself; the multiplier with inputs going to saturation; let us say plus V s, minus V s.

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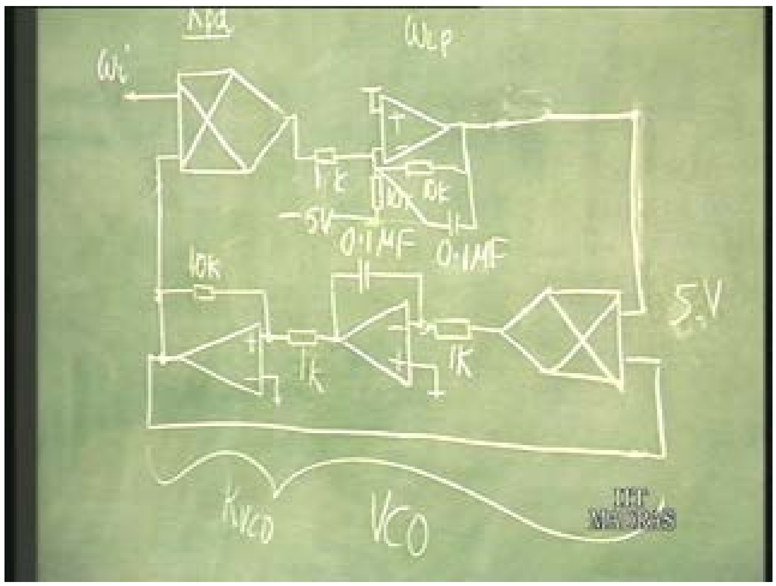

So basically, we have V s squared divided by 10 into what is that? - this thing - 1 minus 2 phi divided by pi. This, we have derived earlier. This is a linear phase detector and therefore this is the V average. So, Delta V average divided by Delta phi is nothing but K p d which is a constant throughout; and that is equal to minus 2 by pi into V s squared divided by 10. So, this is the value of K p d for this block.

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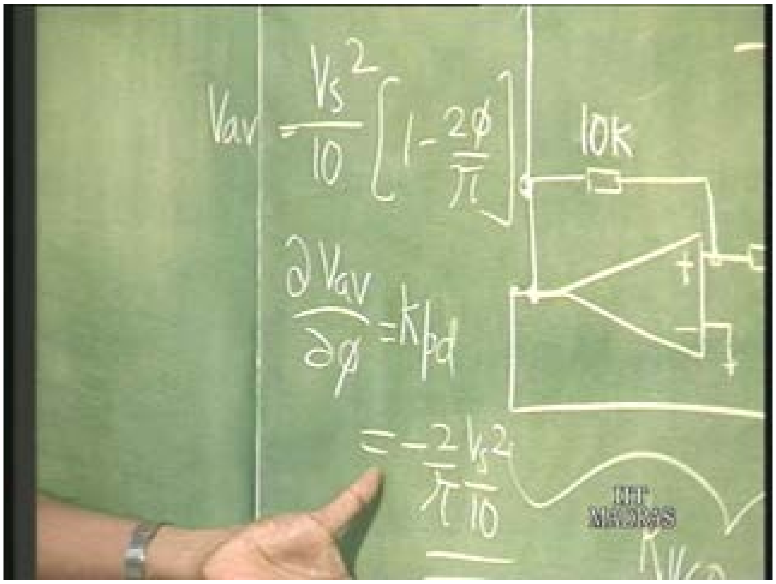

Next, we have an amplifier here whose gain is - inverting amplifier of course - 1 K here and 10 K here. So, the gain, A naught, is equal to 10; of course minus 10. And it also gets an input of minus 5 volts here through 10 K. Therefore this quiescent voltage of 5 volts is maintained here in order to make the P L L free run at a certain frequency.

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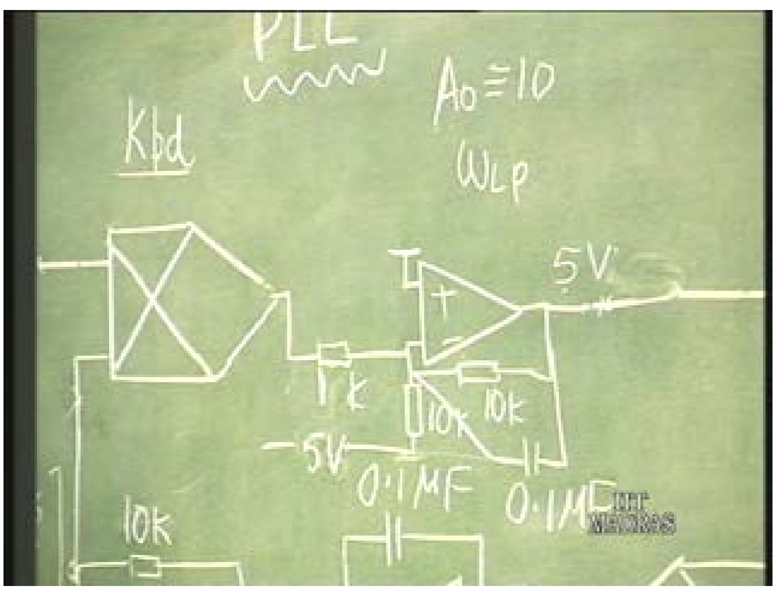

So, the quiescent voltage of this is maintained here at 5 volts and I can tune this, I can vary this and change the quiescent frequency of oscillation of the V C O and thereby the free running frequency of the phase locked loop can be changed and this entire block which we have also discussed earlier as a voltage controlled oscillator which uses an integrator with RC time constant determined by 1 K and point 1 microfarad here and the multiplier….

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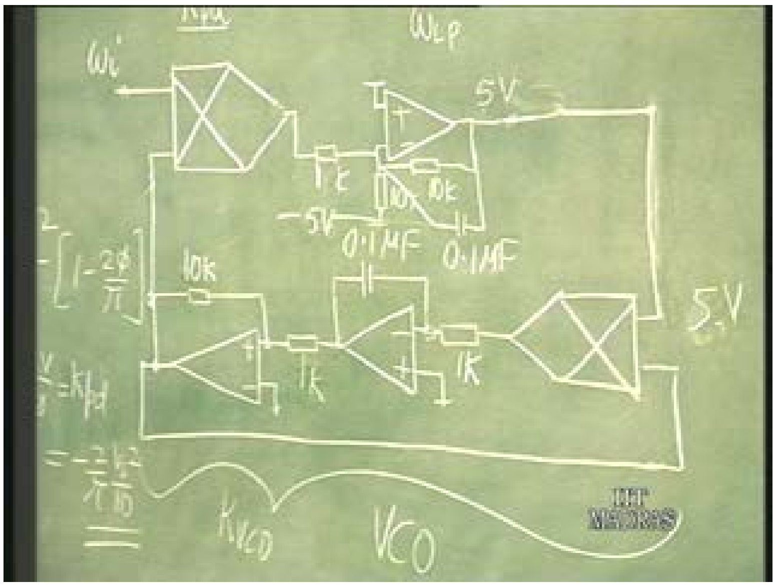

So, V c divided by 10 R C is the kind of time constant associated with this particular thing; and therefore this combined with the Schmitt trigger here…I have purposely put 10 K here, 1 K here, so as to facilitate transfer of the state from taking place. Normally, what happens is this is 10 K and 10 K; theoretically, it should function alright. But this voltage is expected to go all the way up to plus V s or minus V s for change of state to occur; but it may not go because of the op-amp limitation.

So, this may not work with equal resistance there, in practice. So, it is made to go to fairly reasonable low values where the change of state can occur. So, this arrangement has a Schmitt trigger with 10 K and 1 K here; and therefore, V C O frequency is going to be determined by this R c and this V c here and that will determine the K V C O.

What is the K V CO? Omega naught is going to be equal to V c by 40 R c; and therefore...is it correct? So, Omega naught is going to be V c by 40 R C. Delta Omega naught by Delta V c is the K V C O and V c equal quiescent value of phi volts. You can find out Omega naught Q…pardon…This one is t, isn't it? So, it is f naught. Please…it is not Omega naught. Please remember this. That means, K V C O is in terms of hertz per volts; not radiants per second per volts.

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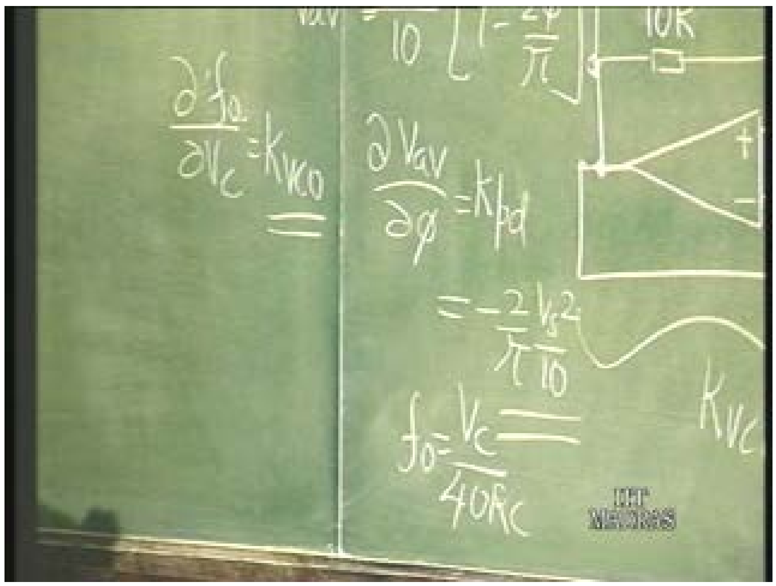

If you want to utilize it in any of the transfer function, you have to convert it into radians per second per volts. That is an important aspect. So, we will initially give no input in the demonstration and see what the free running frequency of the phase locked loop is. Then, give an input very nearly at the free running frequency and see that it locks and see how it goes out of lock, etcetera.

In the oscilloscope, when you see this waveform, the one waveform only triggers the oscilloscope and therefore we have made it such that it gets triggered by the free running frequency. So, the input frequency waveform which is seen in the other…this thing…vertical reflection plate - that is going to be not stable. The moment it gets locked, you will get a stable waveform, both for the input as well as the output.

So, this is the way to recognize that it has got locked. When it goes out of lock, once again it starts moving. So, this is a demonstration of whether it is locked to the input or not. You can also see harmonic locking. On either side of this free running frequency, you can see harmonic locking as well as sub-harmonic locking phenomena.

So now, Devaki will show you some demonstrations of the phase locked loop.

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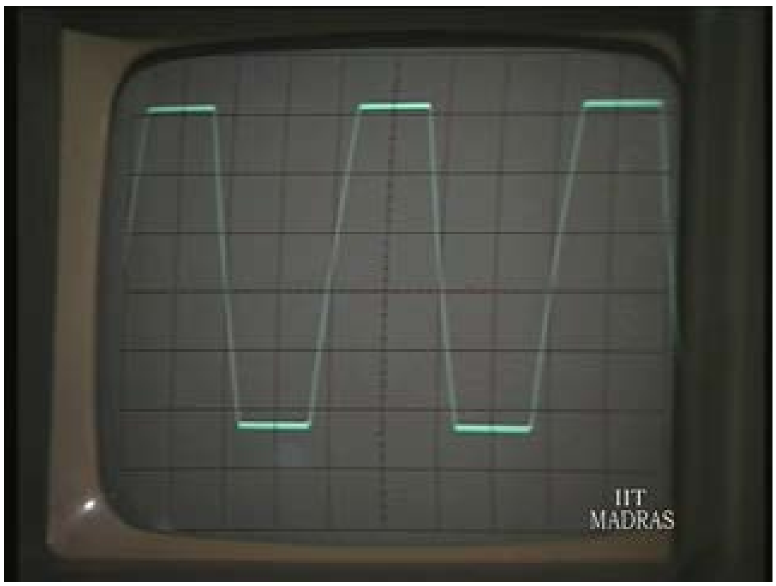

So, concentrate on the screen. So, the free running frequency, free running frequency of this oscillo...I mean oscillator… What is the frequency? - about 4 Kilo hertz. And now, you please show the input also. Input... Free running frequency can be varied by varying the quiescent voltage. That is what she is doing. That is called tuning the phase locked loop.

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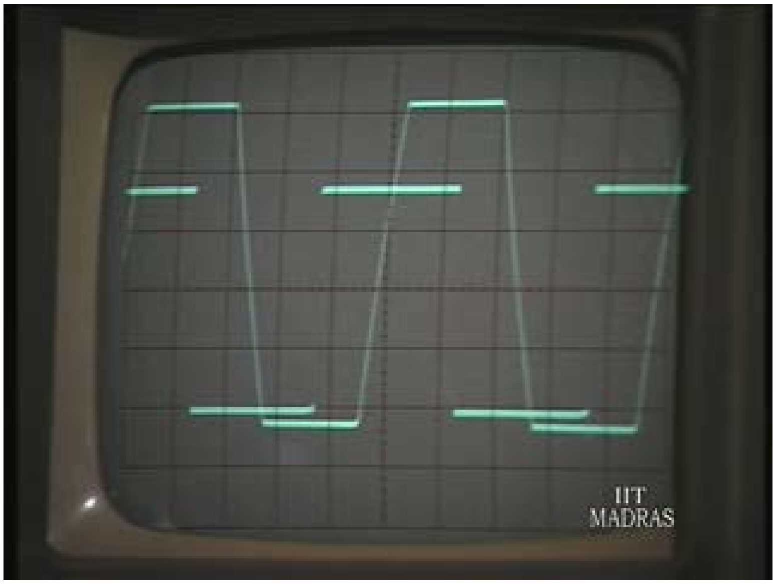

Now she is going to apply the other input and... it is now locked. How do you make out that it is locked? How do you say that it is going to be very nearly Omega naught Q? Because the output and input have a phase shift of 90 degree. You can see that clearly such that the output and the input, they have a phase shift of 90 degree.

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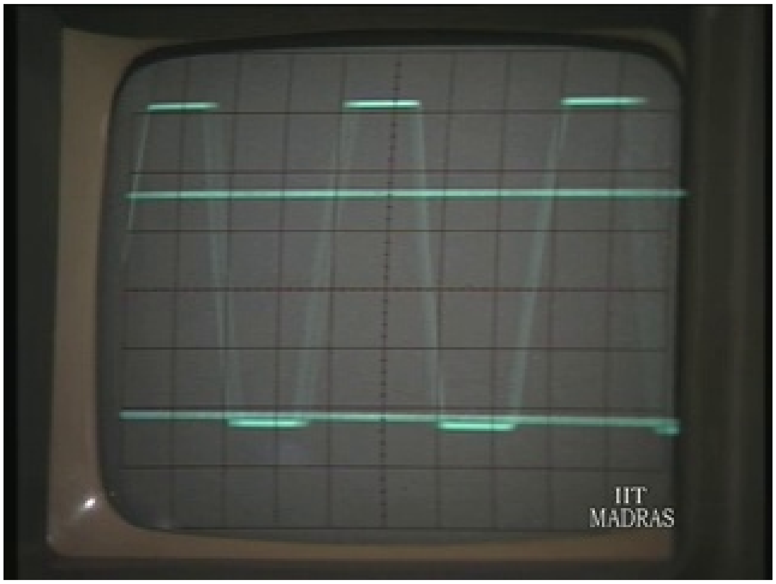

Now change please…slowly change…slowly change. See… It is tracking; and the phase shift is…now it has gone out of lock. Please go to the other side. Yes. And you see, the phase shift changes from 90 degrees also and it is going to become very nearly equal to zero on one side and equal to pi on the other side, at which it will go out of lock. Go further and show them the harmonic locking. Further...Let it go out of lock and then... further…further…you go to the same side.

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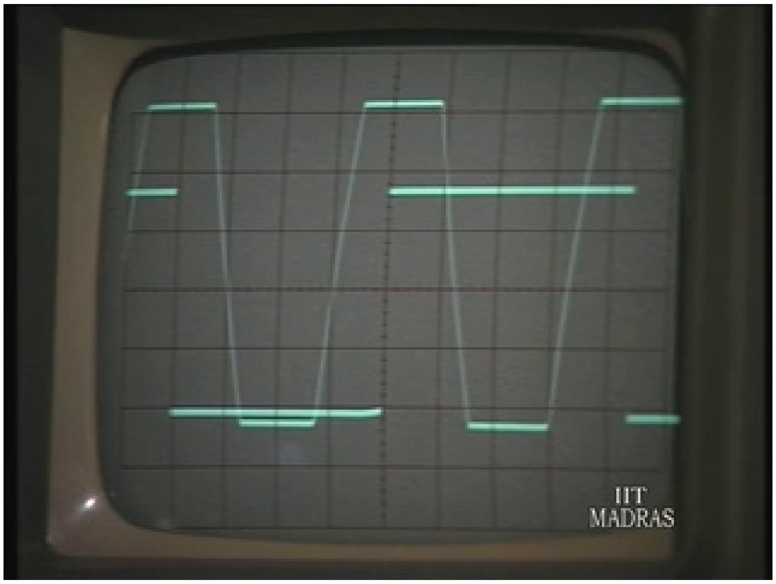

Now it is harmonic locking. For one cycle of this waveform, you have two cycles of the other waveform and it can maintain itself under lock again over a certain range.

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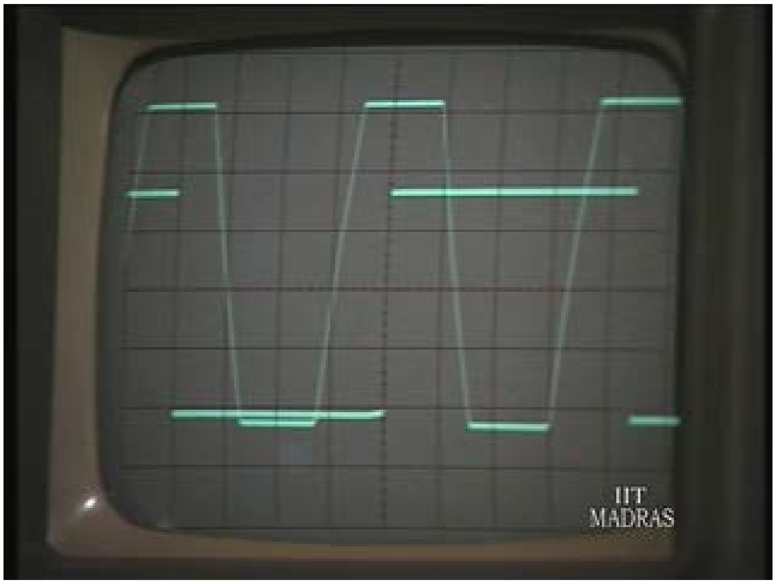

You can slowly change. See…see…it is under lock. Only phase shift is changing; it has gone out of lock. Go further, if it is possible in the same scale. Now it is again harmonic locking. Can you go to the lower scale?

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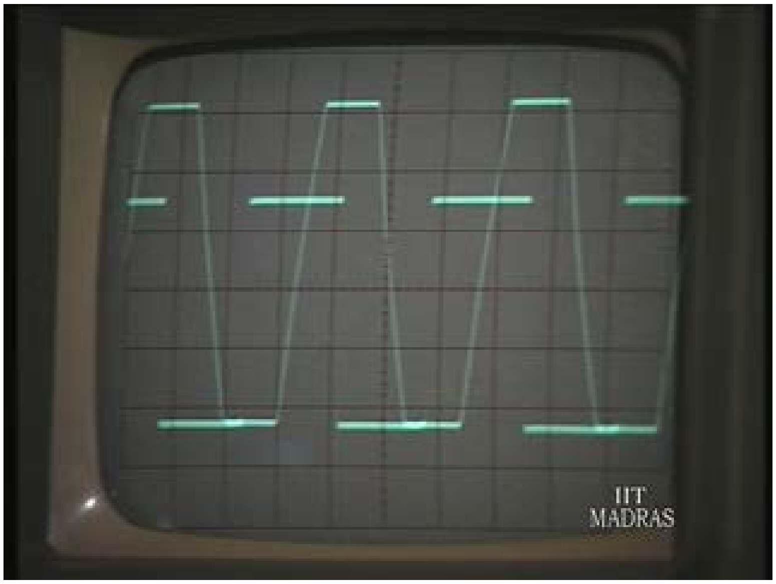

It is out of lock in the lower scale because if she has suddenly changed, slowly…this is the fundamental locking. Change the frequency.

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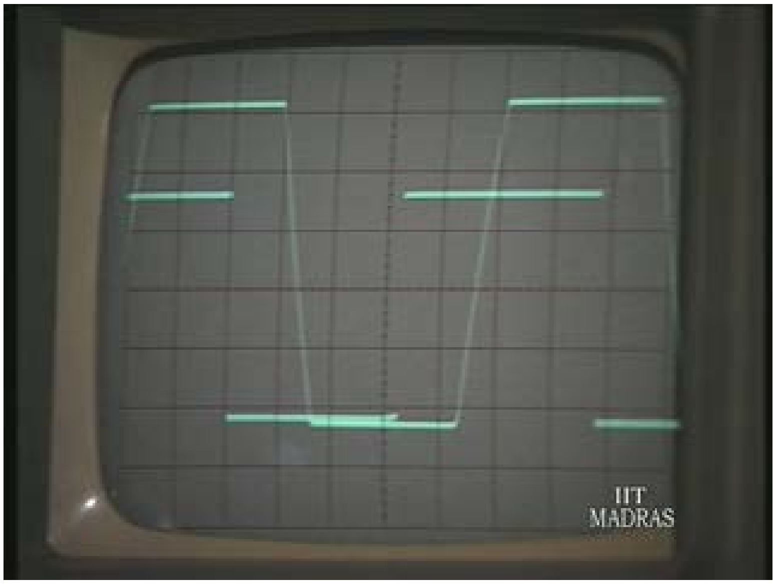

I think we have come back to the original scale; in the other scale, lower scale. It is possible. It is not…slowly if you do or adjust the free running frequency slightly… No, it is not…It did not absolutely stable…

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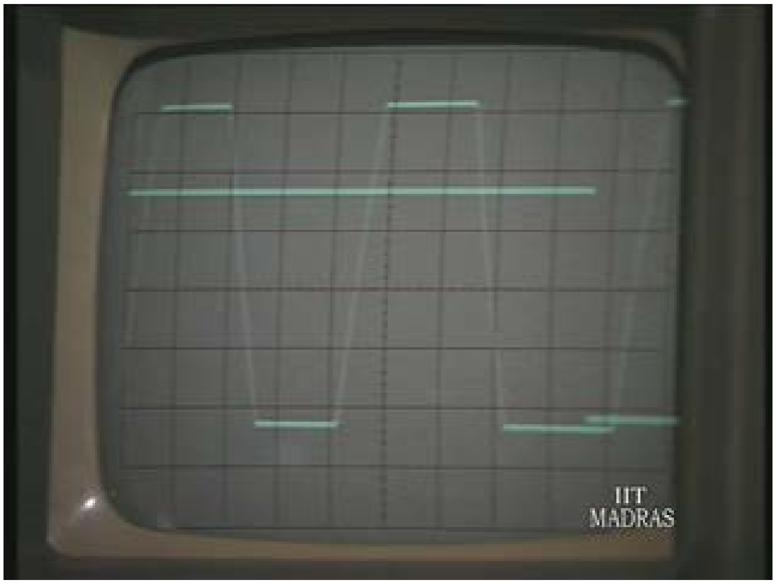

There you are…So, this is sub-harmonic locking; and again slowly change now in incoming frequency…See…it is maintaining itself under lock, beautifully.

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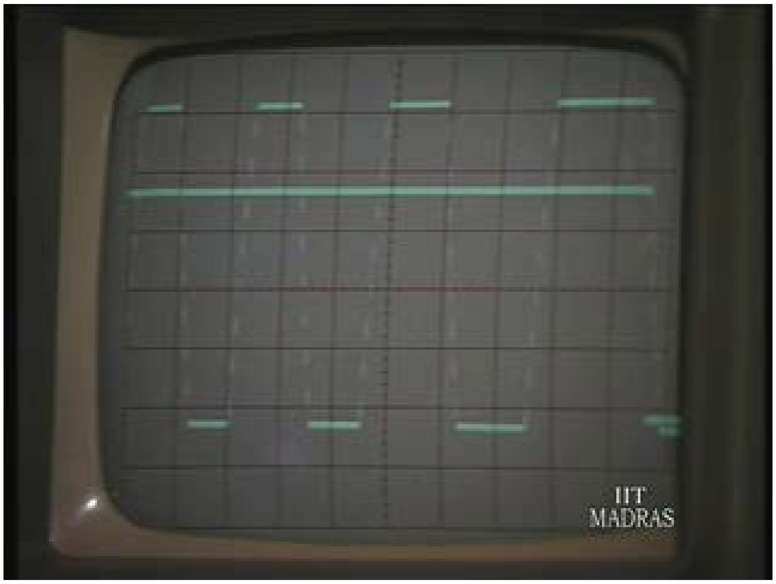

Show the …It is still locked but multiple harmonics…It has gone out of lock. So, this demonstrates clearly the ability of the phase locked loop for harmonic locking.

In the earlier demonstration, we had put for the low pass filter across this 10 K, point 1 microfarad. This low pass filter time constant which is 10 K into point 1 micro farad really fixes up the dynamic performance of the phase locked loop; and it also sort of tells us how fast the frequency can be changed or how slow it should be maintained in order to keep the system under lock.

Now, we are going to remove this capacitor and demonstrate to you that in such a situation, the lock range is very nearly the capture range, even though the amplifier itself is going to have a low pass filter cut-off frequency which is going to be pretty high because its gain is 10. And therefore, if its gain banded product is, for example, 1 megahertz, its cut-off frequency will be 1 megahertz divided by 10, something like that.

So, this particular thing…in fact, it is…gain is 10; but strictly speaking, the ratio of the resistance is 10 and therefore, the non-inverting amplifier gain is 11 and therefore the gain banded product will be 1 megahertz divided by 11, not by 10. This is something that you have to note. This particular situation is depicted now in the demonstration very clearly.

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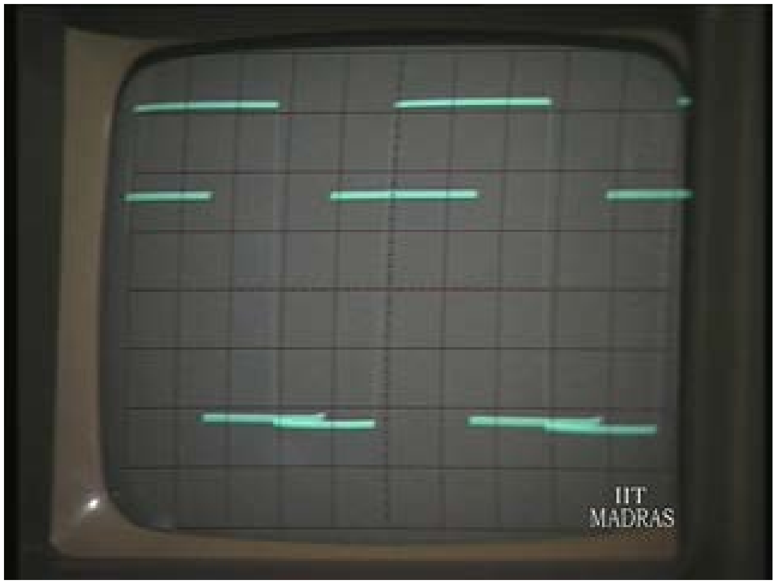

You can see that it is going to keep itself under lock over the entire range of frequencies. Start with 90 degrees. No… Yes…

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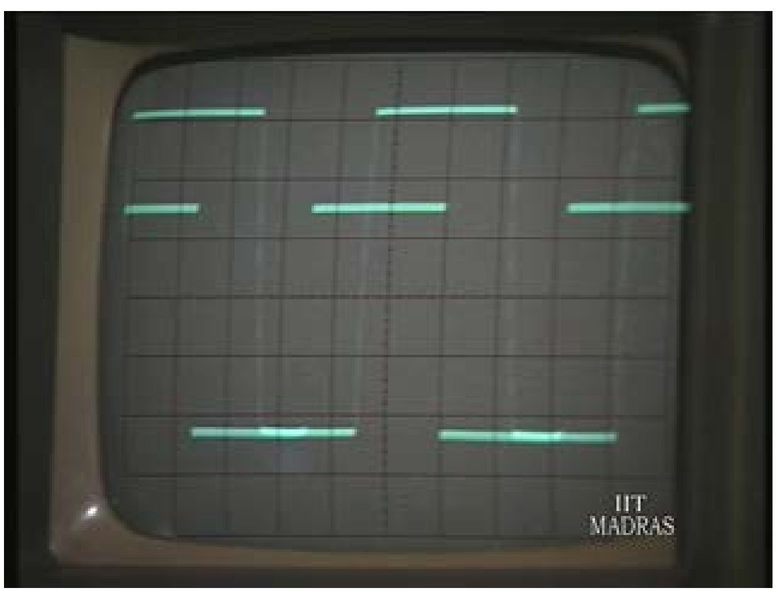

You can see that the phase shift is very nearly 90 degrees now, not exactly. Adjust…which means…no, it is not yet…yes…further keep changing now in one direction only. No, please do not switch the range. Please do not switch the range. In that range itself, let us try to demonstrate.

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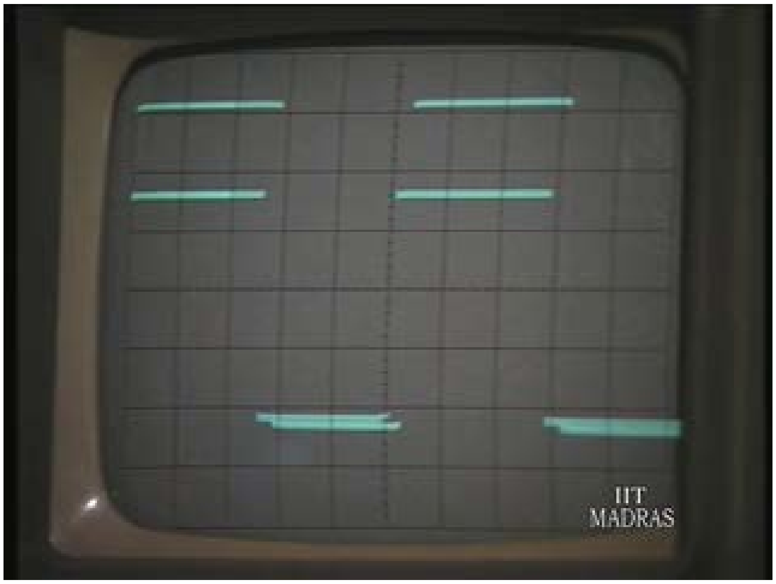

If it is possible to go in one direction, go…keep going only in one direction. If it is…decrease in one direction...; then, if it is not…decrease…decrease…decrease…decrease. See…the phase shift is changing from 90 degrees. That you can change further. Can you further…further…further…Yes. You will see that the phase shift has become very nearly zero. Further…it is now approaching the limit of lock range. It is still maintaining itself under lock. Now, of course…unfortunately, we are not able to demonstrate here because we have to continuously change; if you suddenly change, it can go out of lock.

So, in this entire range of the oscillator, it is keeping itself under lock unlike the previous situation where it…because of the fast changing of the frequency, it has gone out of lock and it has gone beyond the capture range.

You can now go to another range. In the other range also, now it will keep itself under lock.

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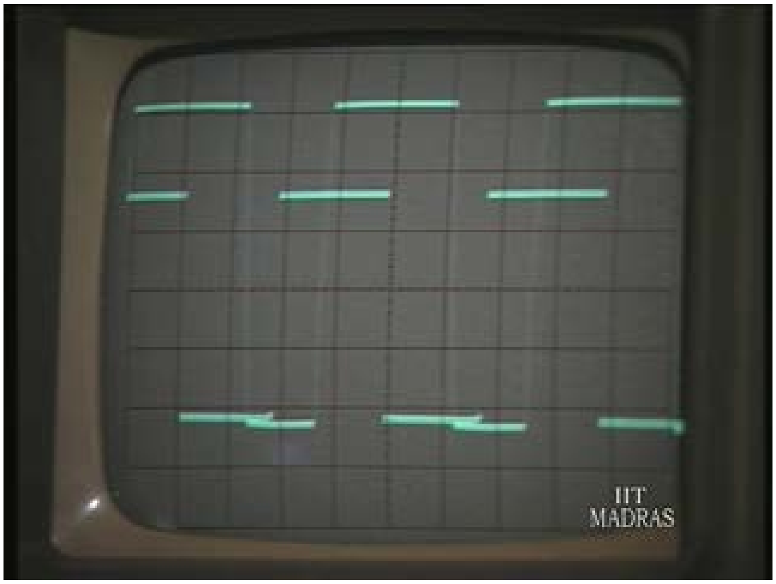

See, this is the other frequency range where it is still maintaining itself under lock, gone out of lock now because here, this is way different from the free running frequency.

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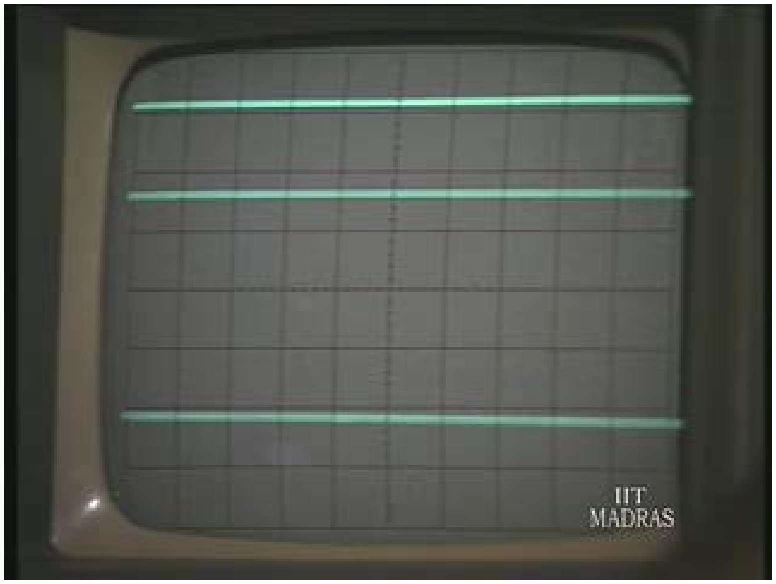

So, still it can go out of lock. Yes, further… Now it is coming…further…further… Is it the limit?

So, this demonstration of the phase locked loop actually tells you mostly about its ease for application in a variety of fields in communication as well as in speed control of motors, etcetera.

Today we will see something more about the phase locked loop. The phase locked loop that I have designed here which is going to be demonstrated is exactly similar to what we did earlier. Only thing is it is oscillating at a lower frequency. Earlier, we had put 10...1 K and point 1 microfarad; now I have put 10 K and point 1 microfarad so that the free running frequency is one order of magnitude reduced, because these op-amps are such that the wave form that you get as a square wave was not good at high frequency.

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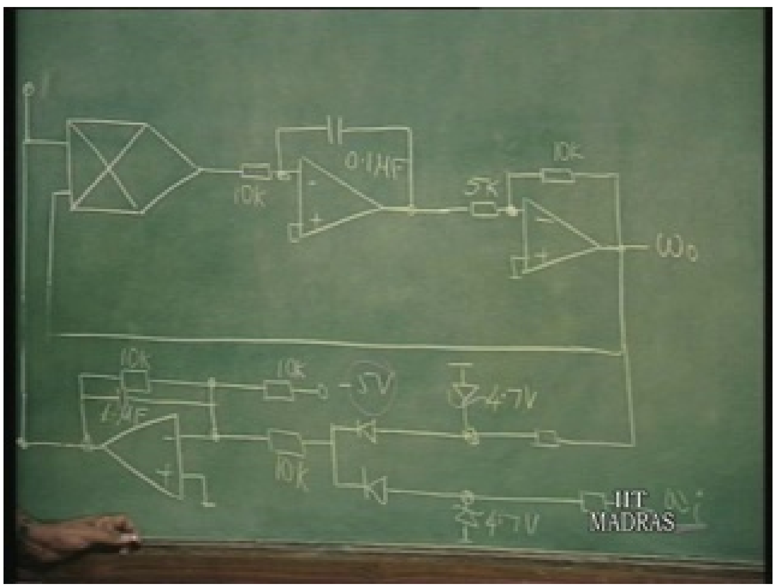

I have made it, operated lower frequency for ease of demonstration. Further, instead of the multiplier, I would… I had also pointed out that we can use an OR gate in order to do the phase detection; that is what has been done. Output of the VCO is ORed with input. This is the amplitude limiting Zener - 4 point 7 volts here and 4 point 7 volts here.

So, you get square waves of 4 point 7 volts magnitude roughly and these square waves are ORed here. 10 K is the load and this is the OR gate and the...obviously, the low pass filtering is going to be done by this op-amp here; and the gain has been fixed at 1 so that the sensitivity is slightly reduced for this. Earlier, the gain was pretty high and actually when the gain was high this DC voltage was also high. The op-amp was going to saturation and we could not see...very clearly see the actual theoretical limitation of the lock range etcetera, earlier.

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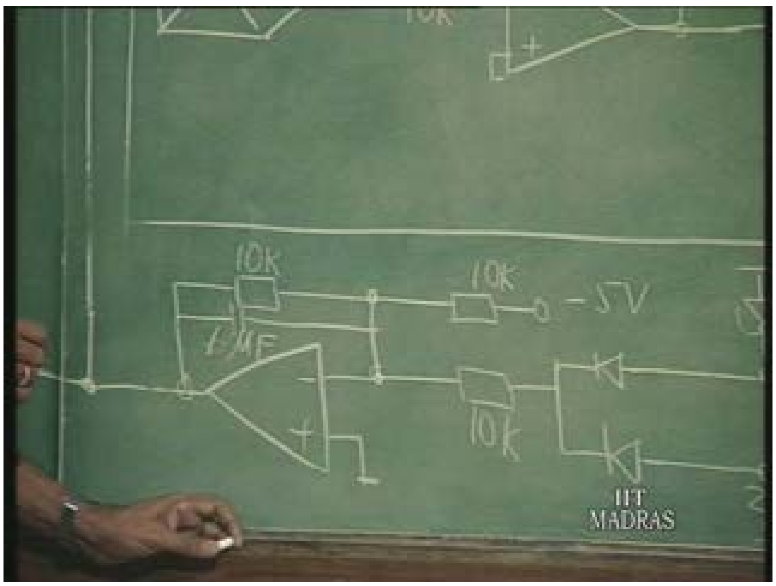

Here, now you can clearly see the lock range and how this phase locked loop will get locked to the incoming frequency which is here; and this is the output frequency. So, we will now show you that Omega i, if it is around let us say 600 hertz or so, which is the free running frequency of this, which can now be obviously be adjusted by varying this quiescent voltage here. This is called tuning of the phase locked loop. It can be made to get locked to the incoming frequency with, let us say which is around 600 hertz or so.

And when the locking occurs, you can clearly see: one wave form, if it is like this, the other wave form is going to be like this, indicating a 90 degree shift between one and the other, in case the incoming frequency is the same as the free running frequency.

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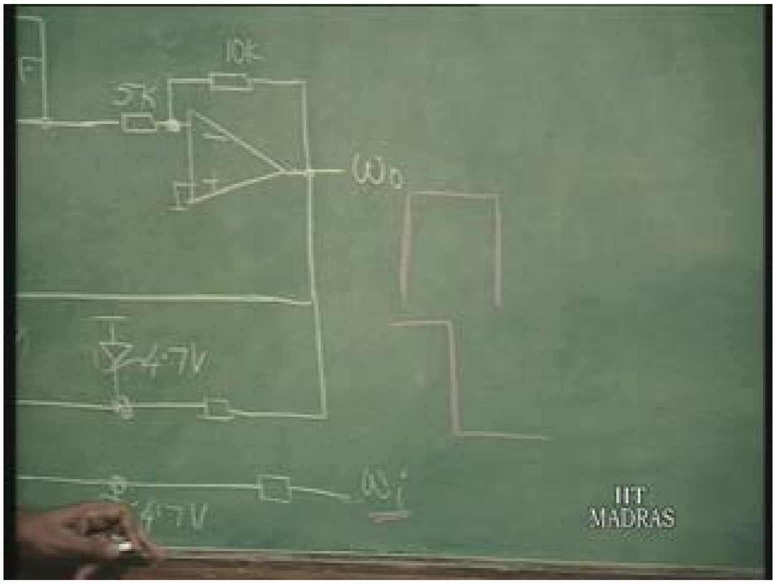

This also we see and we can see that when this incoming frequency further is changed, the phase shift will change around the 90 degrees going towards zero on 180 degrees. This also, you can see. Zero on this side, 180 degree on this side.

So, this demonstration is going to be done first and then we will apply...First, you will manually see that...when this is manually varied, this is going to track. Then, we will make this vary automatically. That means we will apply an FM wave form here. So, around this carrier which is closed free running frequency, we apply a modulating frequency to the carrier. So, we will get an FM which is modulated by a sinusoid. So, then you will see that this is also going to follow this. In the same fashion, you can see the edge tracking and keeping itself under lock all the time; and then as I vary the...there are two frequencies here - one is the frequency deviation...

So, Omega i is going to be Omega c which is close to Omega naught Q, plus Delta Omega sine Omega m t. This is a low frequency, modulating frequency. This is the frequency deviation.

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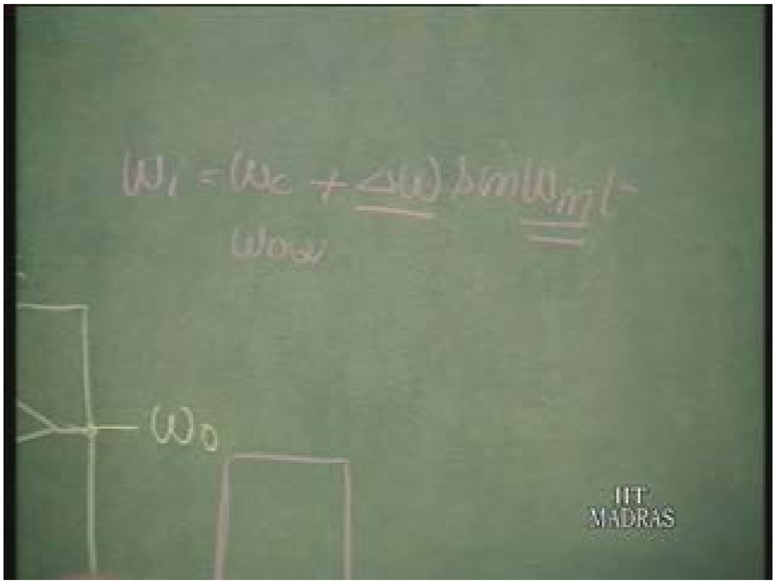

I will change the deviation and show that it is going to track that; and this deviation can be changed faster or slower by changing this frequency. So, this will demonstrate clearly that the FM inputted here is going to result in an FM at the output. All this demonstration will be now done and Devaki will show you the output of the V C O.

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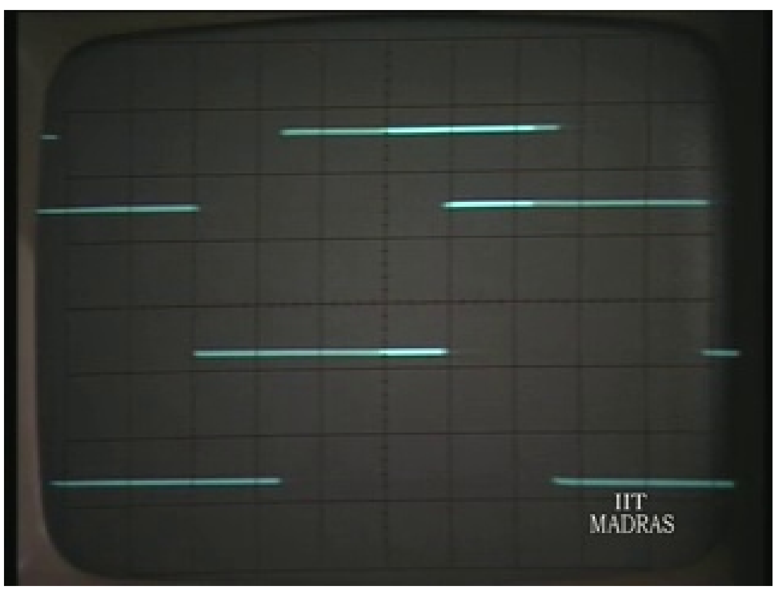

We can see, one is the input wave form, input wave form, and other is the output wave form; and you can see that these are perfectly locked and there is a phase shift of 90 degrees between one and the other.

Now, manually she will change the incoming frequency and you will see that it is tracking, but the phase shift is changing.

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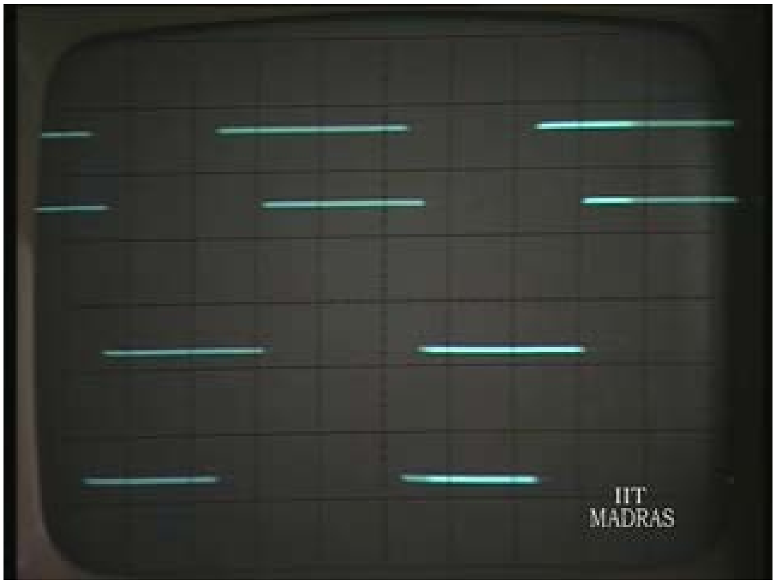

It has gone out of lock on the other side. It is again tracking...phase shift is changing now. It is coming in phase. Further...further... It has gone out of lock. This was not very clear last time, but it is now fairly clear. Again, change...change...change...gone out of lock.

So now, come back to the 90 degree, very nearly 90 degree. Now, slowly change manually around that frequency, incoming frequency; slowly change. Manually she is changing. Increase and decrease like that. Oscillate. So, it is following...You see...it is following. Now this is going to be done automatically. She will put it to FM now. See...it is now following, tracking. The output is exactly tracking the input.

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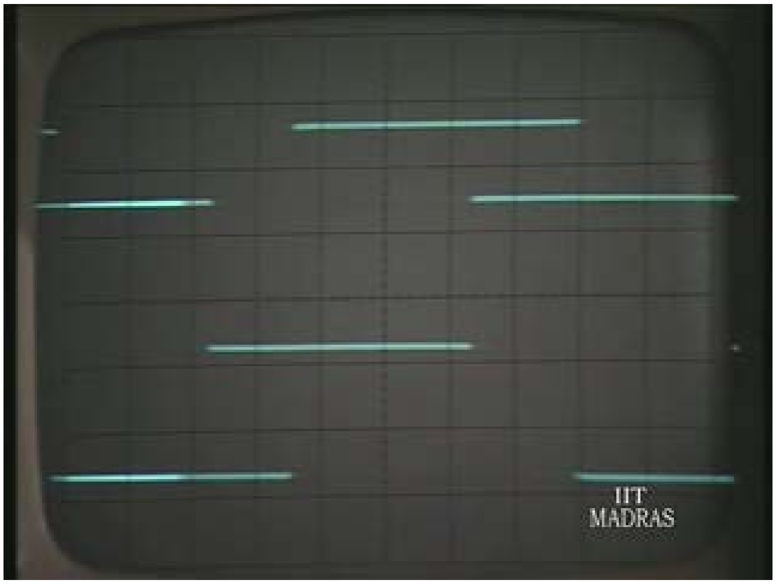

You can see this deviation, extent of deviation. Please decrease the extent of deviation; almost zero. Slowly increase...further increase... See, deviation is very high; but it is tracking. Now, change the frequency of modulation; it is moving faster but still it is keeping itself under track. Slowly reduce the frequency; very low...very...very low... almost zero. You can visibly see that tracking.

This is FM at the output, FM at the input. That means this application demonstrates signal conditioning when there is FM varied in noise at the input, output is free from noise; but it is the same FM and this is called signal conditioning; and this is one of the... and also useful for frequency synchronization. It will track the synchronization pulses coming at the input and produces its own synchronization pulses required for horizontal and vertical synchronization of television signals.

In the earlier demonstration, you had seen signal conditioning effect of the phase locked loop where FM at the input produces FM at the output; FSK at the input will produce FSK at the output of higher signal strength, better signal to noise ratio, etcetera.

Now, its application as FM detector, you will see. Obviously if FM is inputted, FM is outputted at the output of the V C O. Now, what is going to be the modulating frequency? That is straightaway coming at the input of the V C O.

So, if FM is produced at the output, the same...this is going to be FM detected output, if this has done proper filtering. Otherwise, this particular thing...if it is an FM and FM detected output, let us say it is the sinusoid...if this is the sinusoid that is to come out, you will see the high frequency wave form riding over this, if the filtering is not proper.

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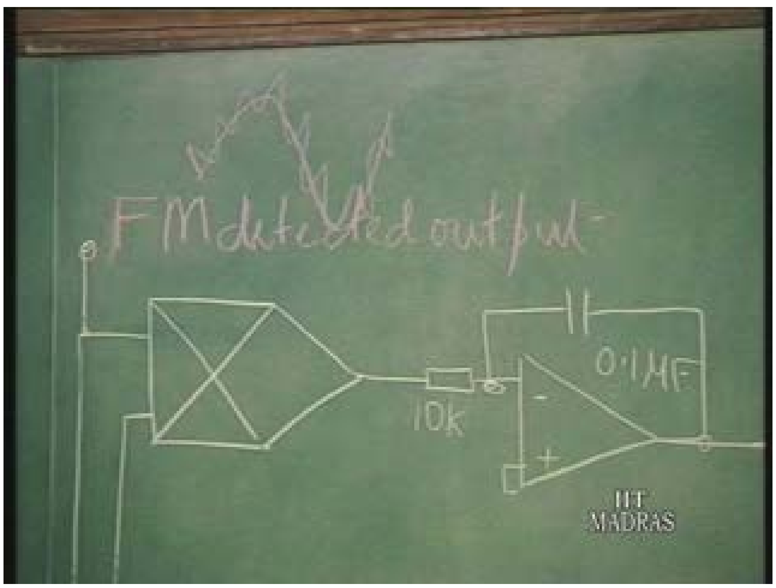

This high frequency corresponds to the carrier. If therefore we have provided some filter here so that at this point the wave form can be better seen without the carrier also, this comes outside the loop. Always, further filtering in FM detection is done after the loop; otherwise, the higher order filters within the loop will become...make the loop become unstable.

So always, only first order filter is put in the phase locked loop within the loop; but other filters can always be put there after after the amplifier, outside the loop... This can be any higher order filter. This can be actually even Butterworth or Ferlic, good filter that is removing all the high frequency very efficiently.

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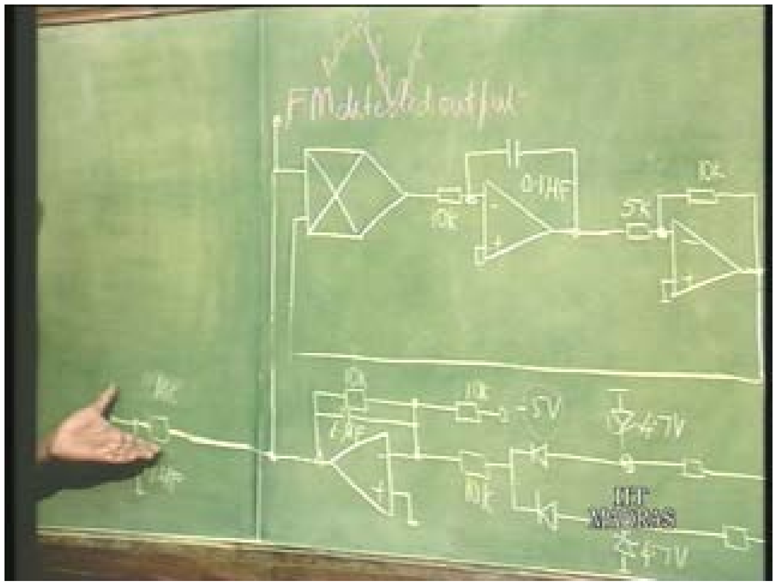

So, Devaki is now going to show you the FM detected output. It is going to be modulated by a sine wave here; and therefore, you should see a sine wave. The amplitude of the sine wave should depend upon the deviation; and she will also show...vary the deviation so that the amplitude correspondingly varies at the output of the FM detected wave. And further, she will vary the frequency of the modulation...modulating this thing, signal, and you will see the frequency of the detected signal also correspondingly changing. This demonstration will be performed just now.

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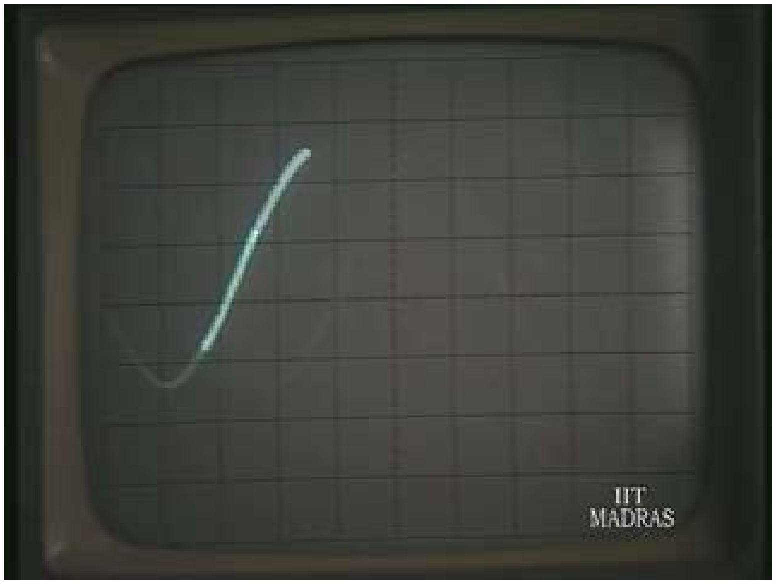

What you are now seeing is the F M detected output at the input of the V C O. This is a sine sine wave, low frequency, because all this…carrier itself is pretty low and therefore this is still lower. That is why you are seeing that kind of sine wave on the oscilloscope. Now she will vary the deviation. Amplitude is reduced, the frequency deviation is reduced, amplitude is reduced. Increase the deviation; amplitude is increased.

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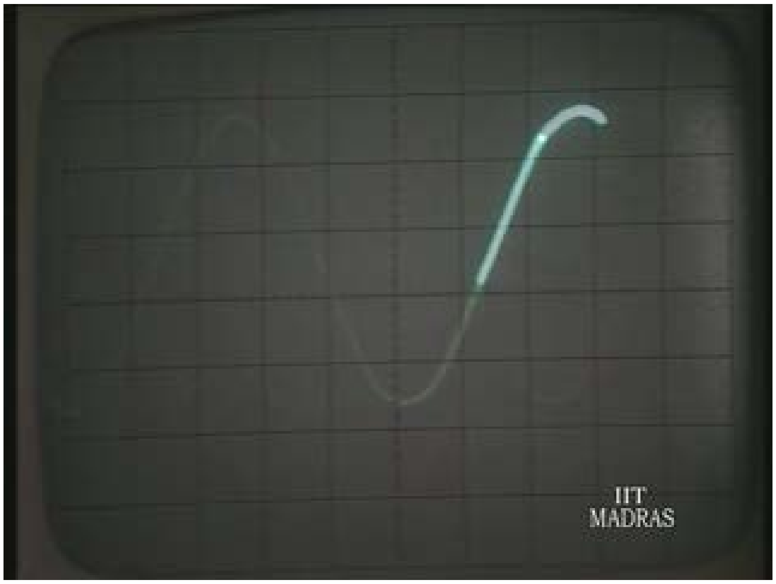

So, this is as far as deviation is concerned; and the deviation produced at the input should be same as that at the output. If it is low frequency modulating signal, deviation produced at the output is going to be same as the deviation produced at the input.

Now she will change the frequency of modulating signal. It is reduced. You can see, the frequency is reduced, very low.

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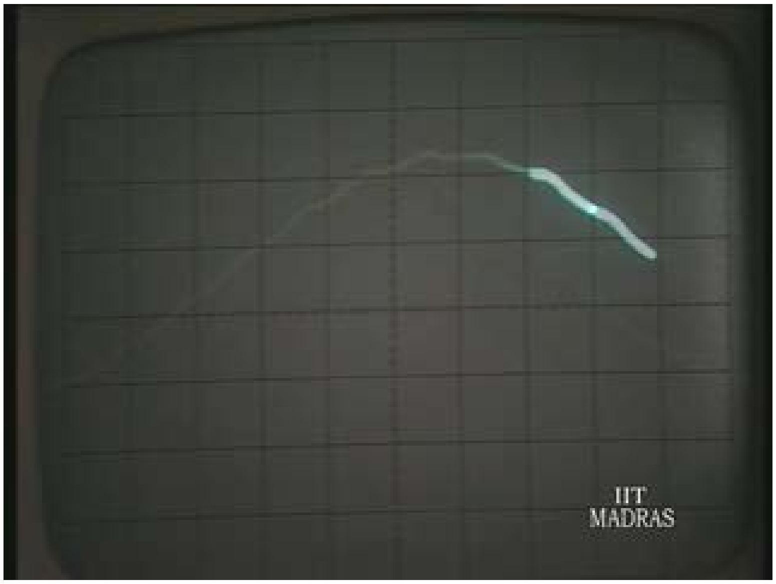

You can see that very low...increase...frequency of modulating signal is increased and this is the FM detected output. This is one of the best FM detectors available to date and most of the data communication systems use this for FM detection. Modem...the so-called modems used in the present day computer communication makes use of this VLL for FM detection purposes. So, these experiments illustrate clearly the application of phase locked loop.

Now we will demonstrate to you the effect of AM detection, synchronous AM detection, using PLL. What is done is that the amplitude modulated input is fed to a limiter so that the modulation is chopped off; only the carrier part is applied to this input of the phase detector.

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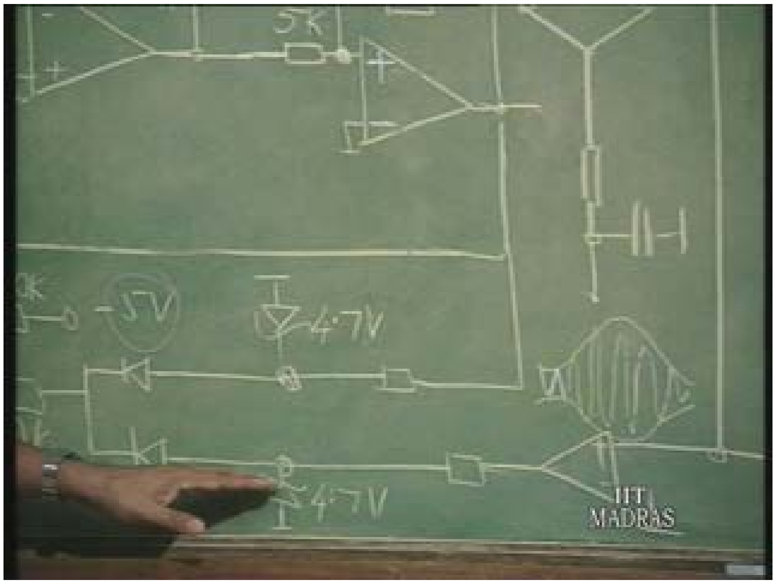

This particular limiter is a high gain amplifier. So, it will simply get saturated at these points. Therefore, waveform here is going to be a square wave without any information about modulation so that this phase locked loop...there is a correction here. In the last this thing, we had marked this minus plus, but it is plus here and minus so that this is a Schmitt trigger. Otherwise, it won't work.

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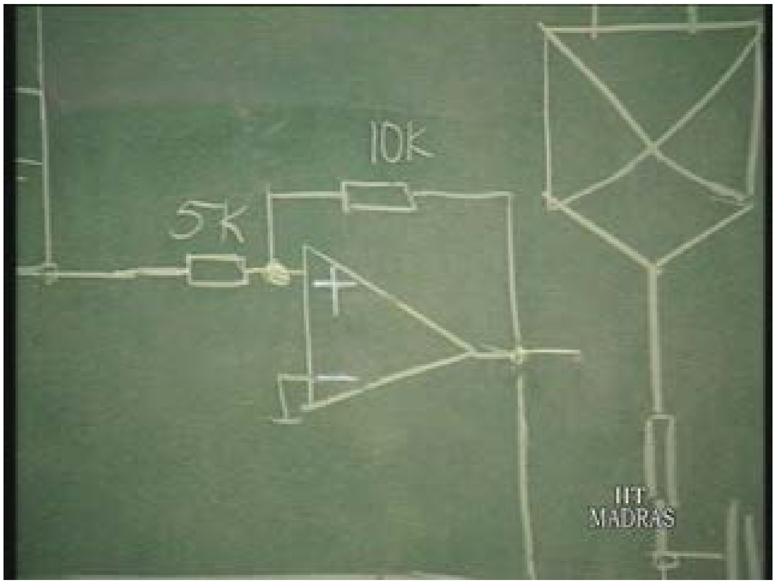

Even though the experimental set up has been connected with plus here and minus here, in the diagram it was marked minus here and plus here. Please make that correction.

Therefore, this phase locked loop gets locked down to this frequency carrier; but since the phase between this and this is going to be 90 degrees, if free running frequency is same as the carrier frequency, there will be a phase shift of 90 degrees between this and this. If we apply this to synchronous detector, one will be having A M coming; another has a 90 degree phase shift. This will be sine Omega c; this will be cos Omega c; average will be zero.

So, we have to shift this waveform by a phase shift of 90 degrees further. That is already done by this V C O here. That is an integrator. If we take the triangular wave output, this will be in phase with the incoming sine wave for this particular carrier. So, this part of the experiment, we will see that if you take the output here, it will be a triangle with the same phase as the incoming carrier.

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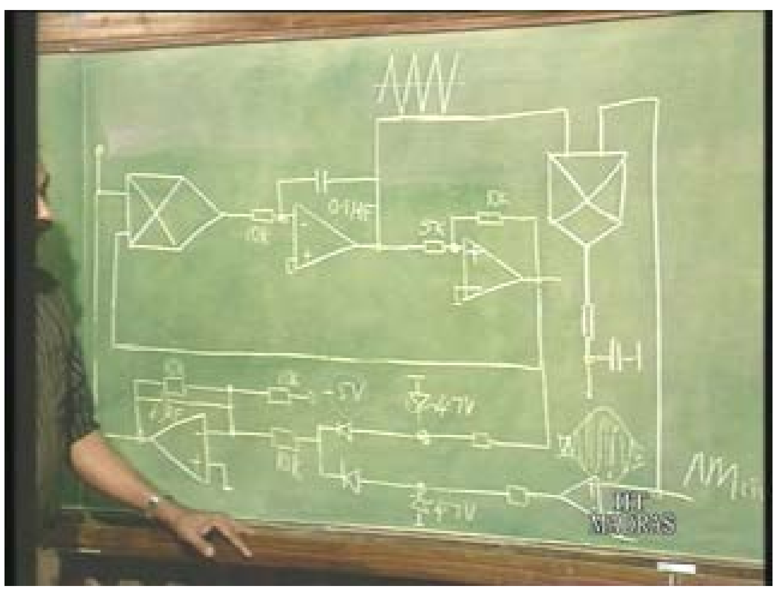

If that is the case, now I multiply this by this multiplier and the carrier…this is sine Omega c t, this is sine...sine Omega c plus or minus Omega m; and output will be Omega...twice Omega c plus or minus Omega m and Omega m; and that can be filtered and seen here.

First, we will see this effect of obtaining a triangle which is in phase with this sine wave carrier here.

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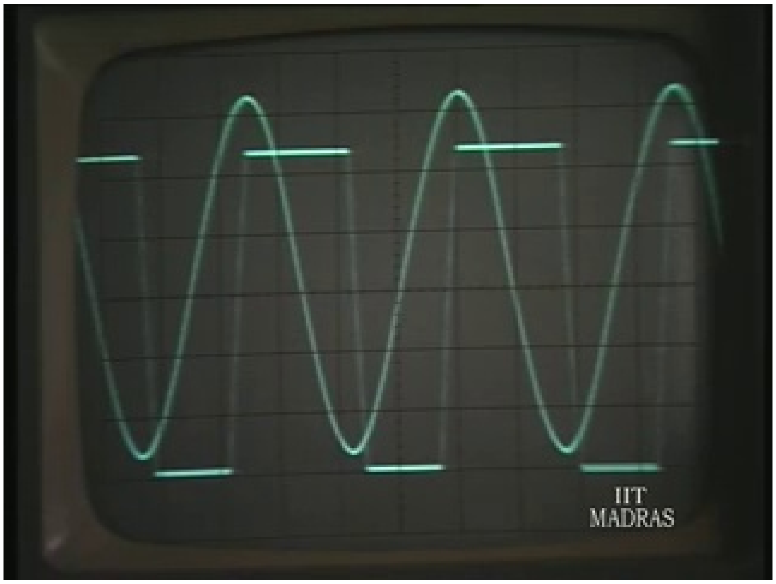

Now you will see on the screen the carrier just being applied without any modulation and the output of the V C O is seen as a square wave; and there is a phase shift of 90 degree between the input carrier and the output of the V C O.

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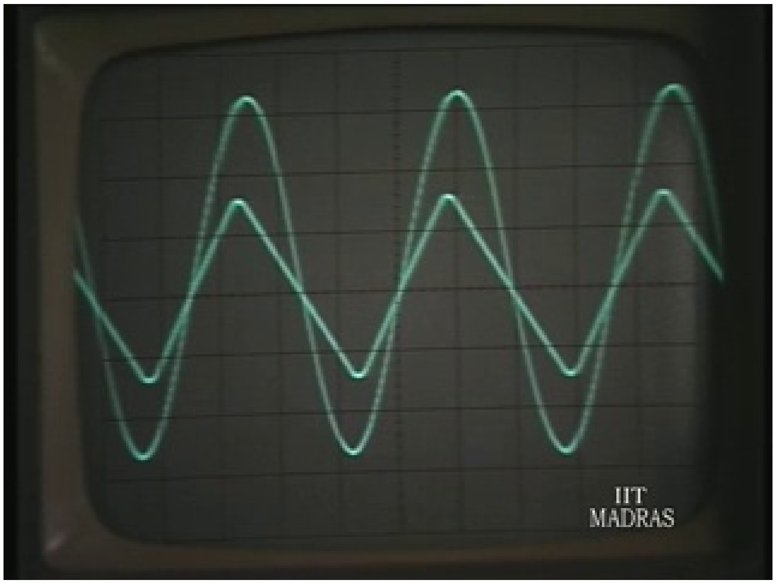

And if…now she will connect the output to a triangular wave which will have…please adjust the frequency slightly so that the phase shift…she will adjust the frequency slightly so that the phase shift is exactly zero. Now, phase shift is zero and now, if this is multiplied with the carrier, this triangle is multiplied with carrier, plus or minus Omega m using another multiplier, output will be containing the modulating frequency and twice Omega c plus or minus Omega m - that portion will be subsequently shown.

Now, without the modulation, you can see the output of the multiplier when the… What is that? Phase locked loop, input as well as the A M input; both are given to the multiplier. You will get Omega c into Omega c; that is twice Omega c - sine Omega c t into sine Omega c t - sine squared Omega c t, which will be containing two Omega c components there.

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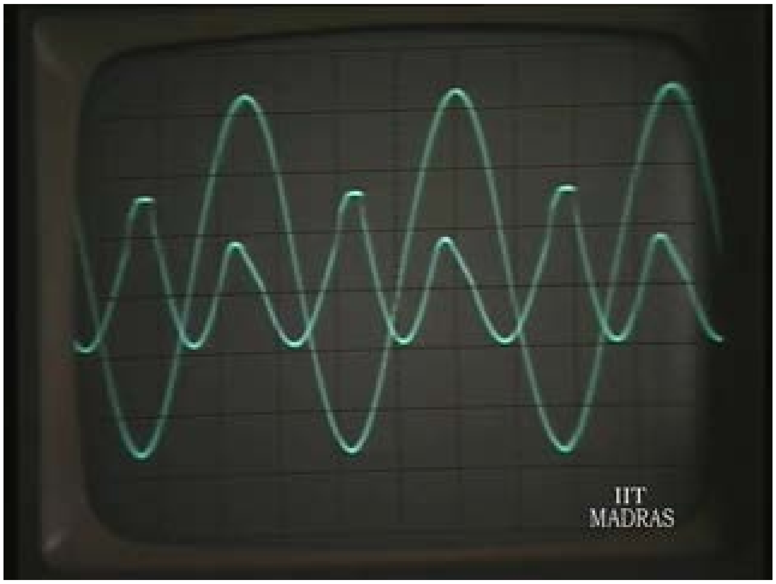

So, there is no modulation now. Now she will apply the modulation. Just apply the modulation. You can see…the low frequency component is already coming. We will later see the FM detected…that is, A M detected output.

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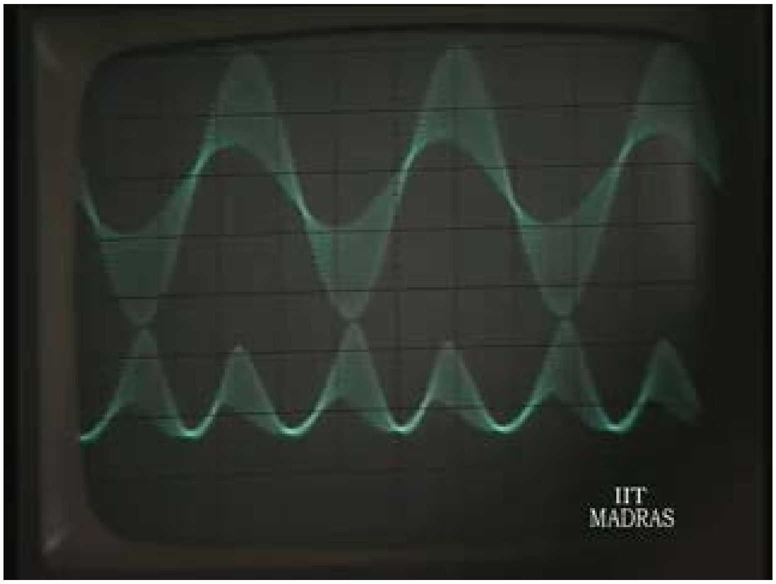

So, now that you have seen that the A M detected output is going to contain...that multiplier output is going to contain 2 Omega c plus or minus Omega m and the Omega m component that is separated by the low pass filter…so, now you are going to see Omega m component on one axis, on one vertical plane and another one is the A M itself.

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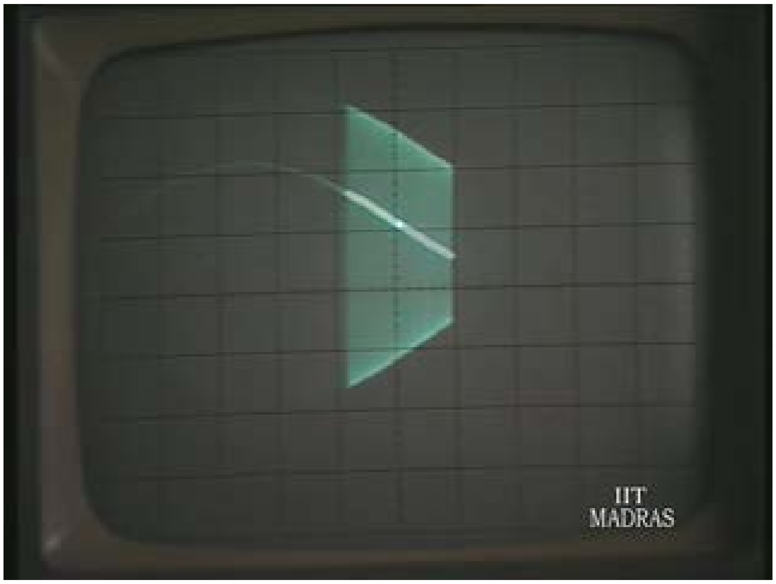

So, we can demonstrate to you how the depth of modulation, when it changes the amplitude of the A M detected output will change; and you can see on the screen now…that, one is the A M wave form; another is A M detected wave form. That is, what is in between that A M wave form is the A M detected wave form. Please change the depth, depth of modulation. She is decreasing, so you can see…the amplitude of the detected output is decreasing…decrease…decrease…almost nothing, let us say.

So, this is it; almost no modulation. Increase... Go up to 100 percent modulation. You just see the…this is almost more than 100 percent…just decrease it. Yes. So, this is almost 100 percent modulation and even so the amplitude is quite alright. Now, change the frequency. So, the frequency is changed; it is tracking the frequency. Now, it is almost 100 percent modulation. Still, it is nicely tracking. Reduce the modulation. Yes. So, go up to the highest frequency…decrease the frequency.

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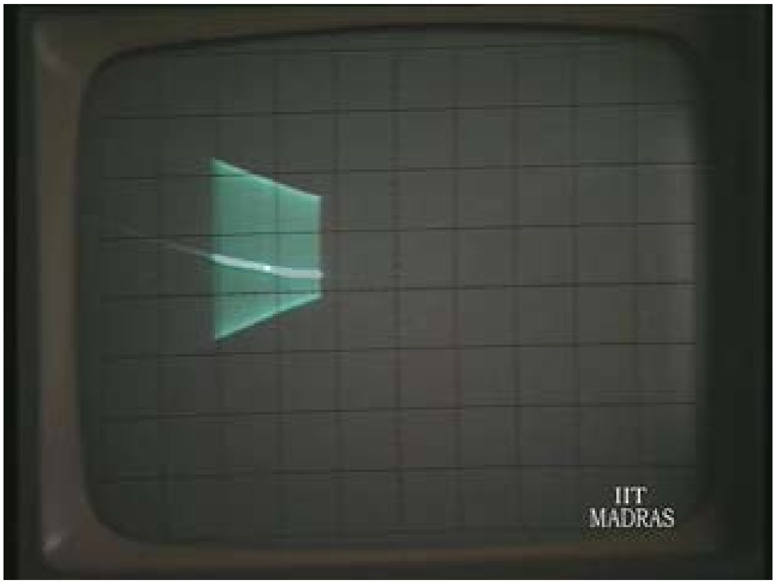

Now, show them only the A M detected output. Switch off to single channel…single channel.

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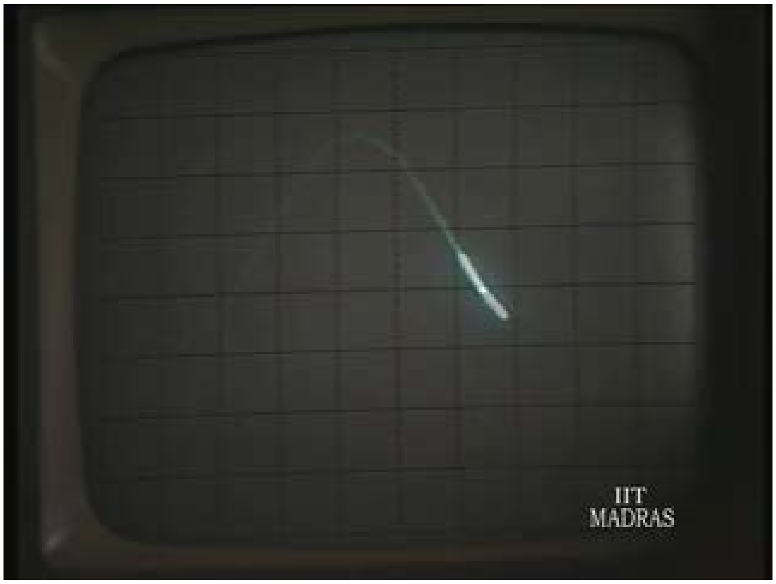

So, this is the A M detected output. That is better. She is changing the depth of modulation now, decreasing…increase it…increase it…Yes. Keep…leave it at that. Change the frequency. Yes, modulating frequency is changed. Yes.

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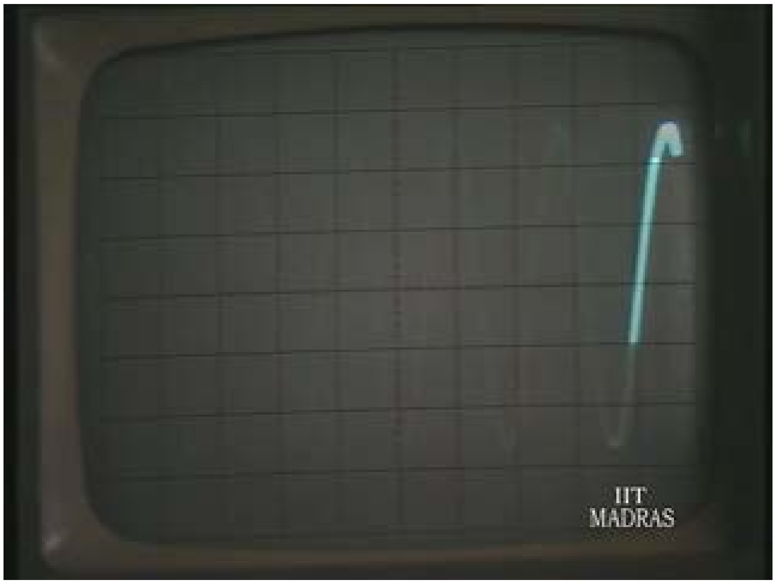

You can see… Change the depth now to the highest frequency. Yes. So, this is A M detection. This we call synchronous A M detection; is in parallel…this is frequency selective.

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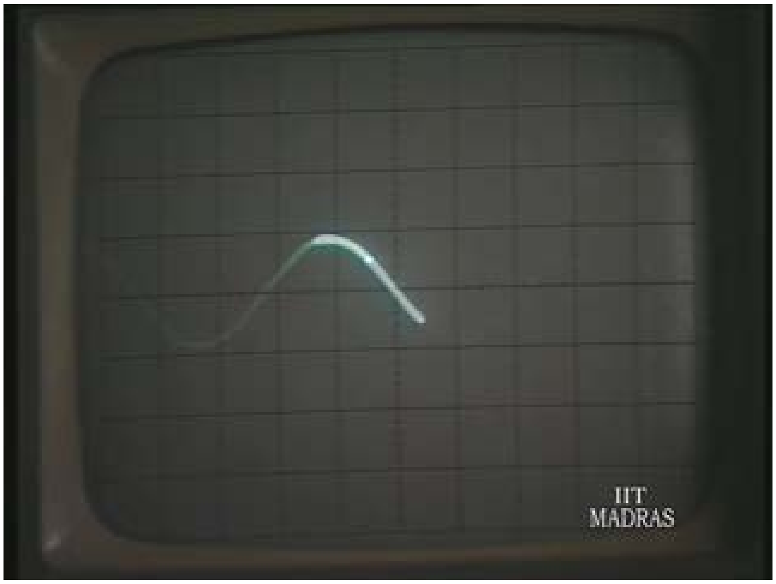

So, this also can be adopted, strictly speaking, for radio receivers; but at the time of radio receiver design, this idea even though was proposed, was rejected because the P L L was very costly during those days and what was selected was the super heterodyne receiver with simple diode as the detector at this giving end.

Thank you.