Electronics for Analog Signal Processing - II
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Lecture - 36
Experimental Demonstration

In today's experimental setup, we will be learning something about simulation. First, how a second order differential equation can be simulated and how an inductor can be simulated and how a negative resistance can be simulated, etcetera. Let us therefore see the circuit which, with which, we have already become familiar this circuit, which is put within this red dotted line is called the gyrator.

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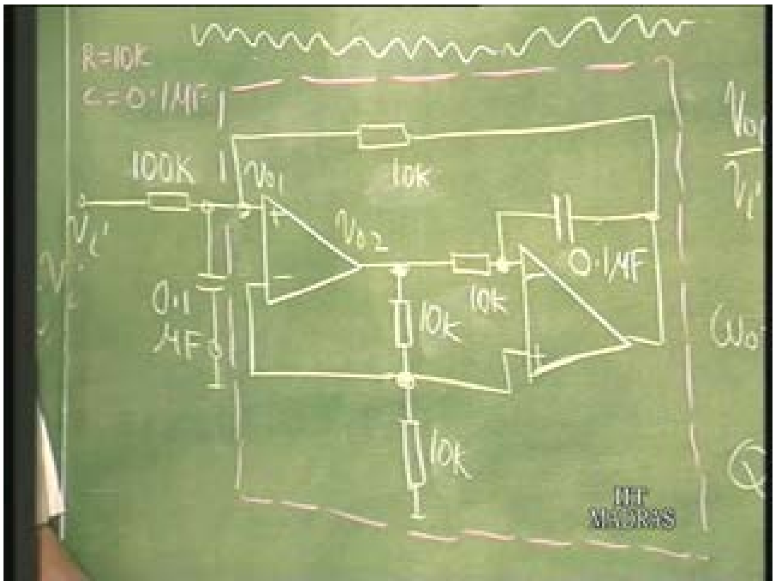

That is, if this is V naught 1 for example, V naught 2 is going to be twice V naught 1; and here, we will get V naught 1 minus V naught 1 by scR. That is what is simulated; and from here to here therefore, the voltage is going to be V naught 1 minus V naught 1. V naught 1 gets cancelled, plus V naught 1 by scR - that is the voltage. V naught 1 by scR. And therefore this will be V naught 1 by scR divided by R, which means it will give you a current of V naught by scR square, which means the current in this is going to be ... by scR square impedance which is nothing but an inductor L equal to CR square.

So, this simulates an inductor L equal to CR square. C in this case is point 1 micro farad and R is equal to 10 K. So, it will now simulate an inductor L equal to 10 to power minus 7 into R square 10 to power 8 which is actually speaking, 10 henries. 10 henries of inductor is simulated from here to ground. That is therefore going to be having a capacitor across it.

So, you have an L which is 10 henries from here to ground and then will put that L that is simulated by this circuit and a C across it. This is called a tank circuit and then if I connect a resistance R times Q, R is the 10 K resistance that has been used here. Here it is Q times R, if I use...this is really a tank circuit with L, C and R.

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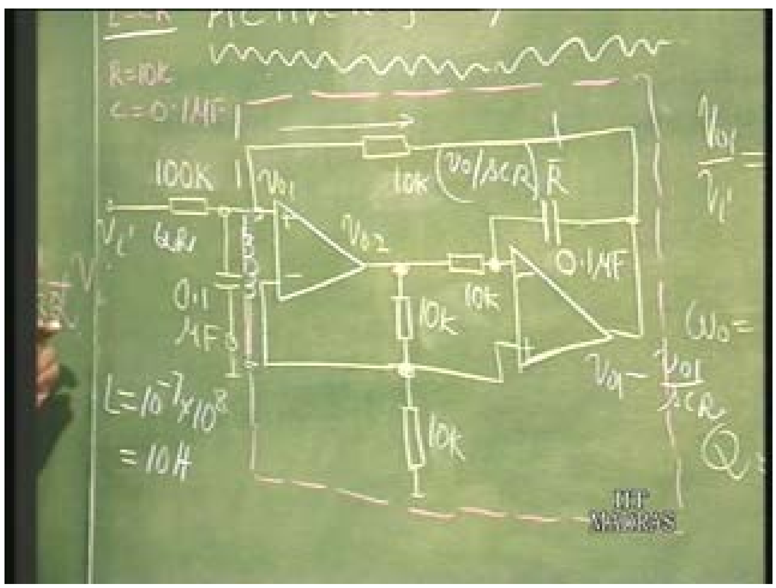

And therefore, its transfer function from V naught 1 by V naught...V i is going to be S by Omega naught Q; that is S square by Omega naught square plus S by Omega naught Q plus 1.

If I take the output at V naught 2, it will be twice V naught 1 and Omega naught is going to be 1 over R which is 10 to power 4 into C which is point 1 microfarad. It is 10 to power 3 radians per second and Q is equal to 10.

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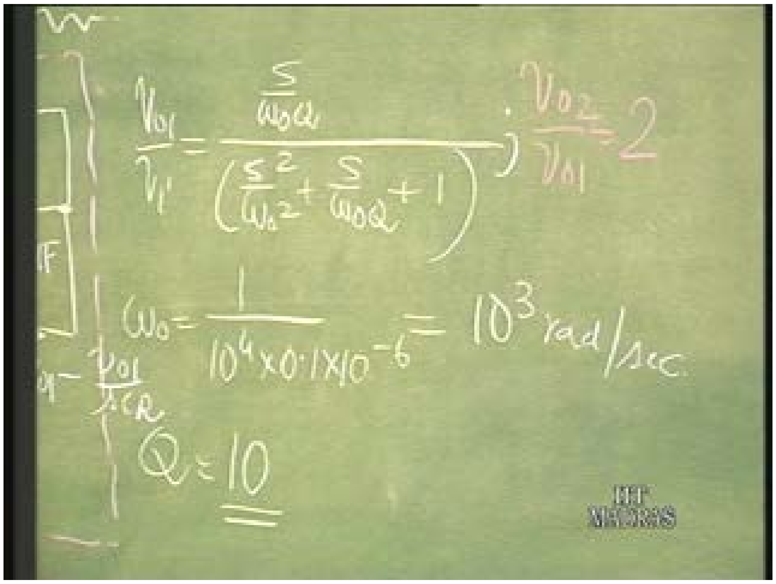

So, this is going to be a band pass filter, band pass filter. Because of S coming in the numerator, at Omega equal to zero, it is zero; at Omega equal to infinity, it is zero, because of the double pole here. So, there is a frequency Omega naught at which it will peak.

So, if you obtain the response of this at Omega naught, it will peak and the band width is going to be Omega naught by Q; in this case, 10. Therefore, Omega naught by 10 is the band width.

This, we will see in the experiment. At at...if I take the output here, the peak gain here is going to be 2 because at band pass, at Omega naught, the gain of V naught 1 by V i is going to be 1 and V naught 2 by V naught 1 is going to be 2. So, this is going to be 2.

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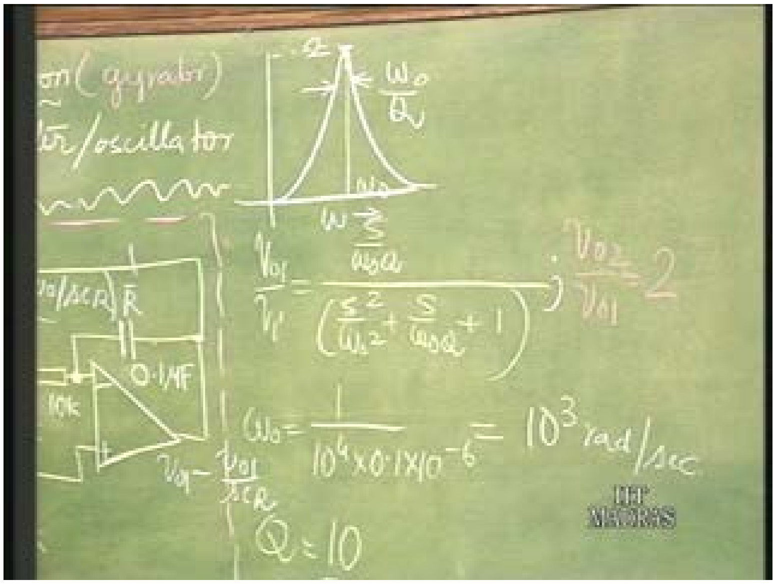

Not only that, if I plot the phase shift, initially, phase shift is due to only S. That means 90 degrees; and then the phase shift is going to become zero at Omega naught and goes to minus 90 degrees at very high frequencies. So, phase shift also is going to zero at Omega naught.

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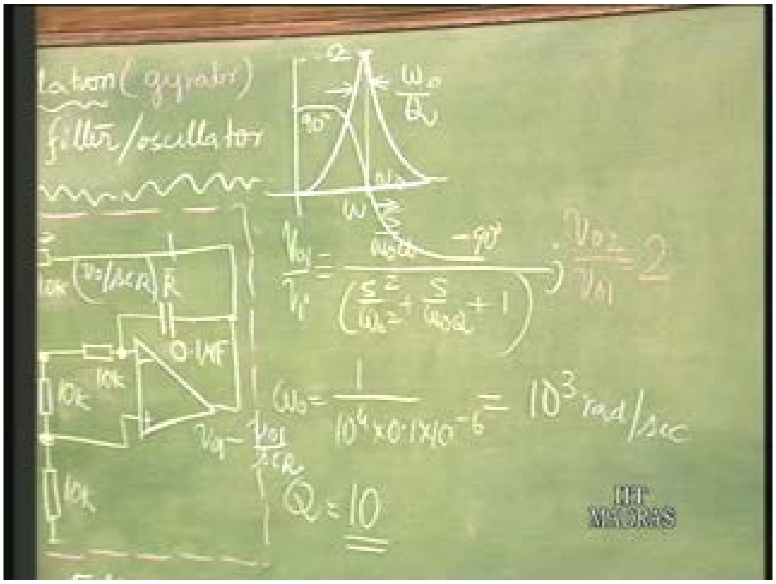

So, this is the characteristic of a band pass filter. Magnitude will peak at this and phase shift will become zero at Omega naught; both of these and phase variation is maximum around Omega naught. So, this particular aspect of the experiment, we are going to see just now. We can see that this circuit has been built there.

And Devaki is going to now demonstrate the fact that the output by input is equal to 2. We can see one, the lower one is the output; upper one is the input. Output by input is equal to 2 exactly at Omega naught, which is roughly 10 to power 3 radians per second or is equal to about 200 hertz.

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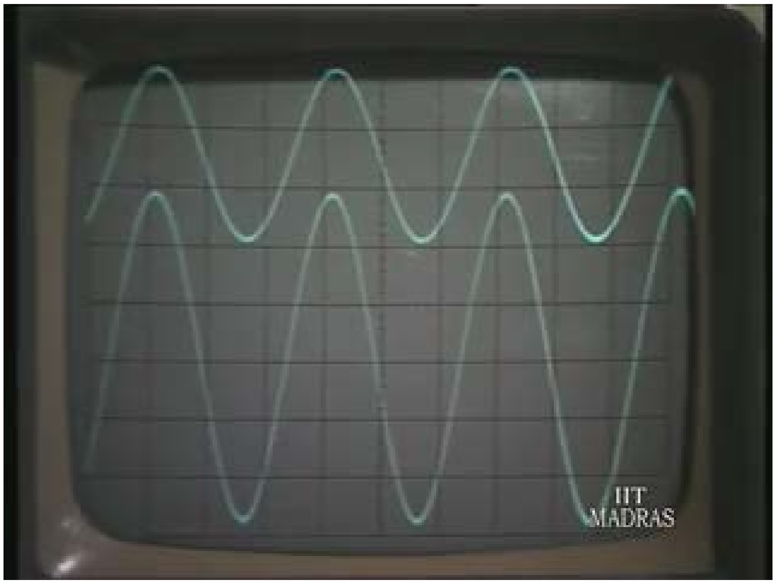

So, you can see this. As I...as she varies the frequency, you can see, on either side of this, it is decreasing; that is why... See...it is decreasing on one side.

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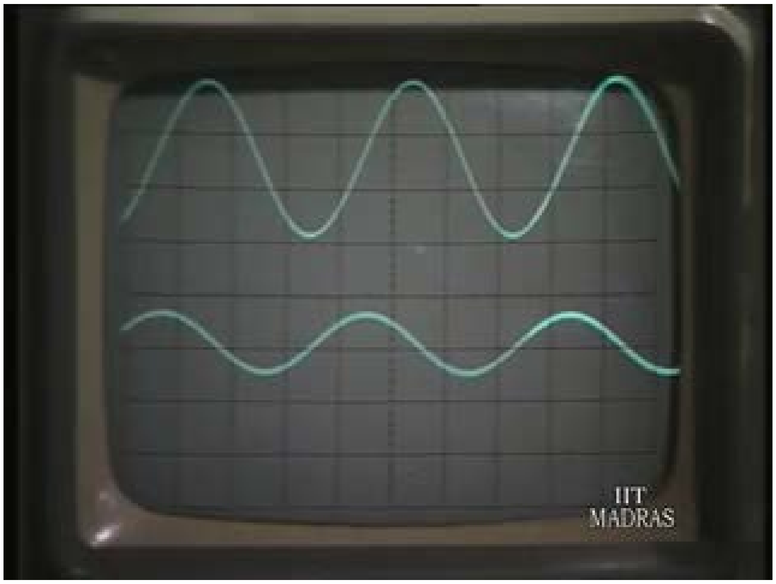

Now you increase. Yes, it is peaking.

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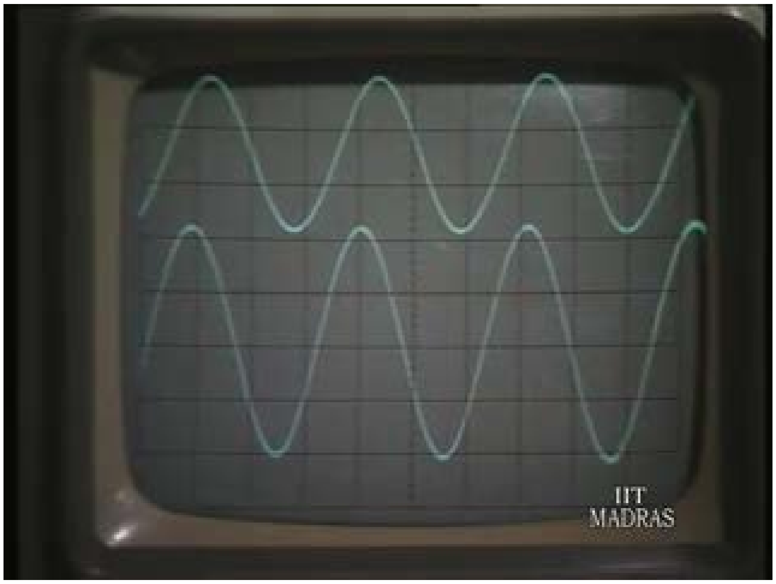

Again, she is changing in the same direction and it is decreasing on the other side also.

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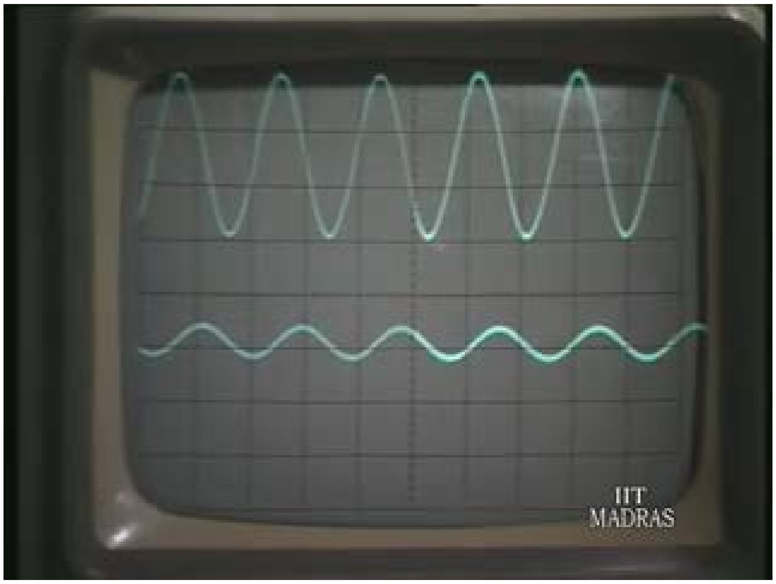

So, that is why it is going to give maximum gain at center frequency.

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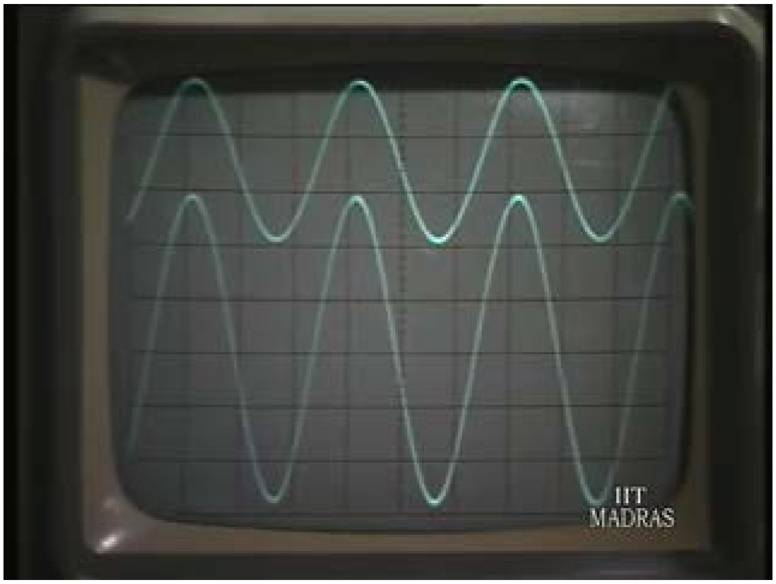

Now, she will also show you V naught versus V i. This is V naught versus time; V naught and V i versus time. Now she will show V naught versus V i which will be giving you the phase shift between output and input. This is...this is an ellipse because of a finite phase shift and phase shift changes.

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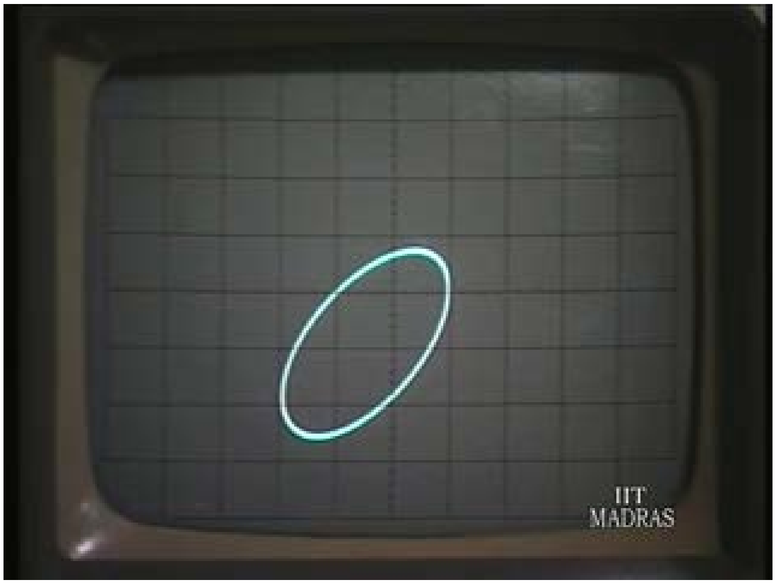

And phase shift becomes equal to zero. Zero...zero means it is a line.

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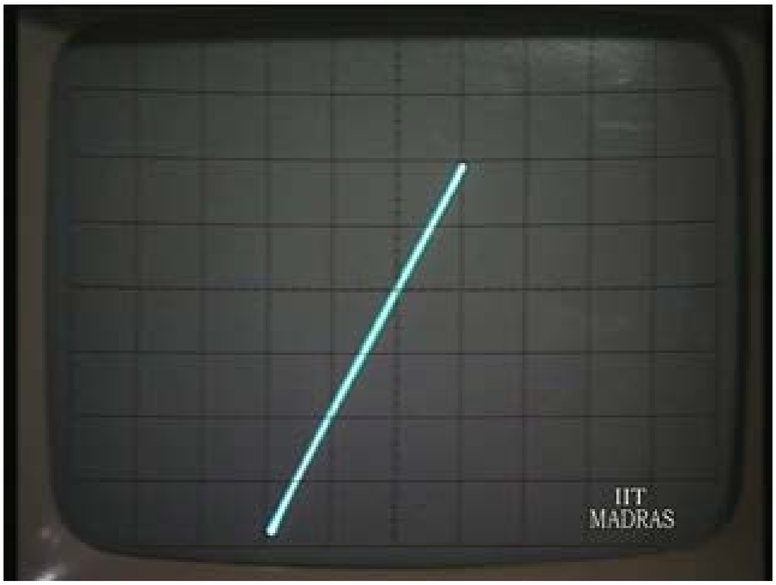

And on either side of center frequency, it will become an ellipse. Now, let it change from...it has become an ellipse on one side.

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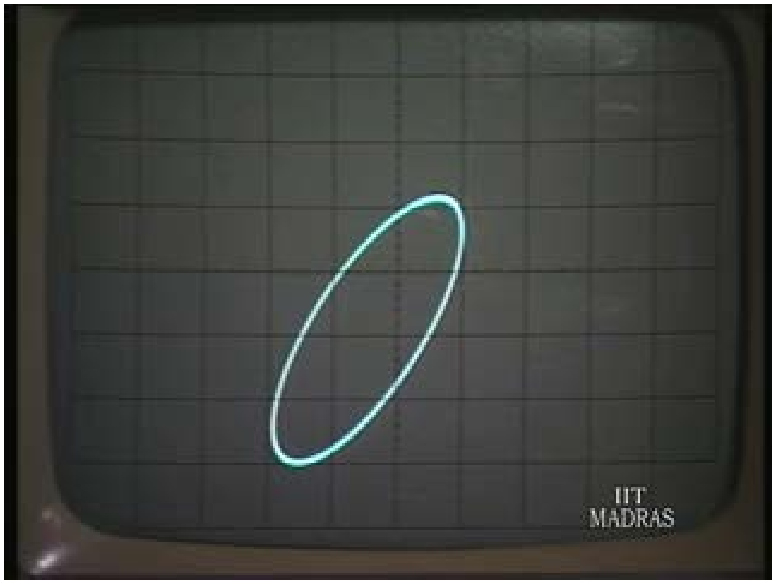

And also has become an ellipse on the other side.

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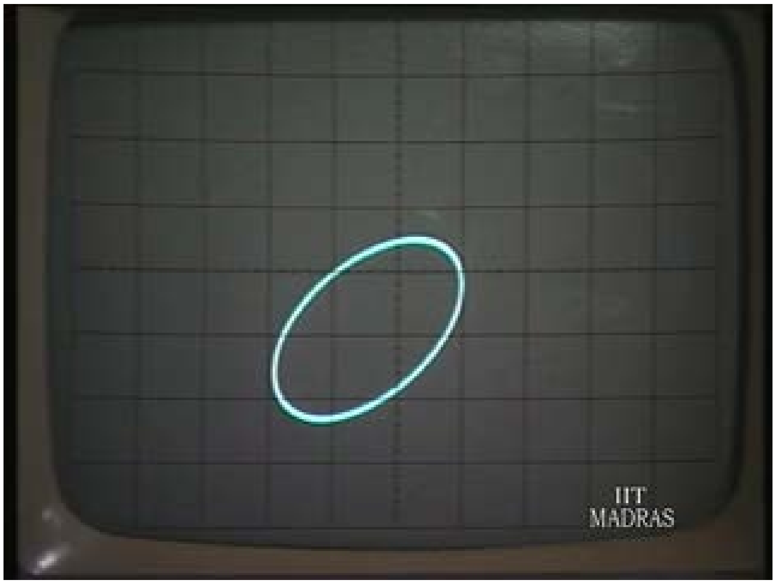

So, there is phase shift which is very nearly going to become equal to 90 degrees.

As it becomes 90 degrees, go for still higher frequency. It will...it will become almost a vertical ellipse. So, this is a very... At infinite frequency only it will become exactly 90. See, so it becomes a vertical ellipse.

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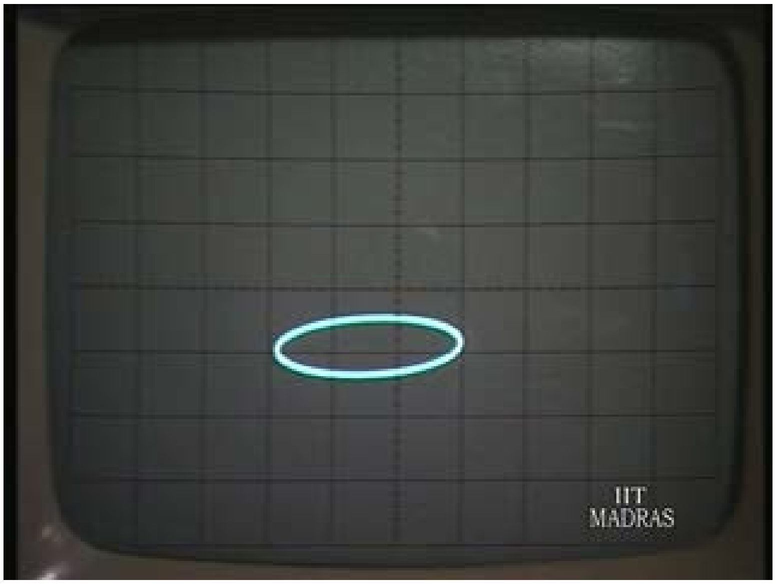

So, this is the characteristics feature of a band pass filter, active R C filter, where inductor has been simulated.

We had just seen how the inductor simulated can be used for a band pass filter. Now we will illustrate how an oscillator can be made out of it. The inductor that is simulated, L is equal to C R square, is obtained from this gyrator. Now if I put a capacitor, it is an L C network. So, it should be possible for me to get oscillation. Omega naught equal to 1 over R C. 1 over root L C which is 1 over root L C. L is equal to C R square. So, it is 1 over R C.

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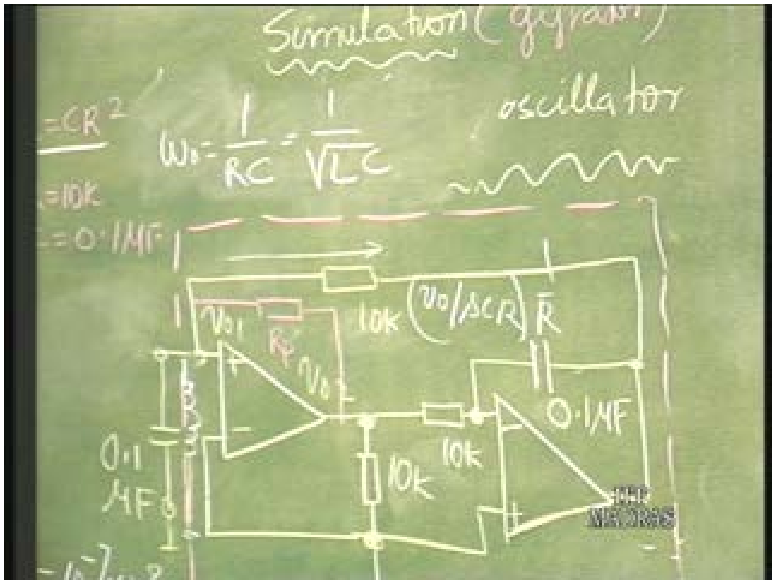

At this frequency, it should oscillate. Now, that is really a 1000 radians per second; so, which is around 185 or 90 hertz. So, but it does not oscillate. Why? That is because the op-amps are not ideal and therefore there is some amount of positive loss; that is, resistance across this. That is why it does not oscillate.

So, I have to simulate a negative resistance across it. How do I simulate a negative resistance? We have V naught 1 here and V naught 2 is equal to twice V naught 1.
So, if I put an R p here, the current will be V naught 1 minus twice V naught 1 by R p. That means from here to ground, we have minus R p getting simulated. Current will be V naught 1 minus twice V naught 1 by R p which is...minus R p is the effective resistance from here to ground.

So, across this inductor, you have a negative resistance that is simulated. We make it variable; start from a very large value; keep on decreasing it such that at a certain value, it equals the lost component across the inductor.

So, this is going to be demonstrated and at that point without anything being connected, suddenly output of this op-amp will have a sine wave generated at this frequency around

200 hertz. So, this is going to be very clearly demonstrated by Devaki now. She has put across this op-amp, first op-amp, a resistance, variable resistance and she will now show you by varying that resistance... So, you can concentrate on the screen. Yes. Now it is oscillating.

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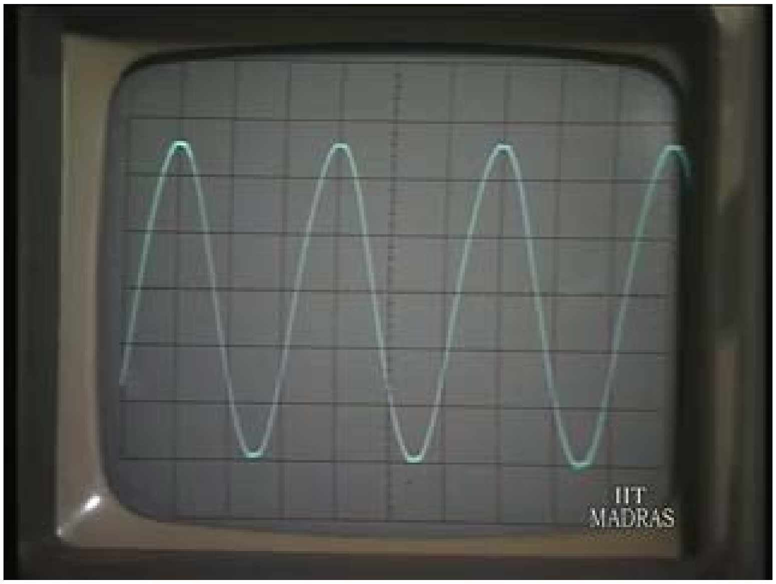

If the resistance is increased further, it stops abruptly oscillating.

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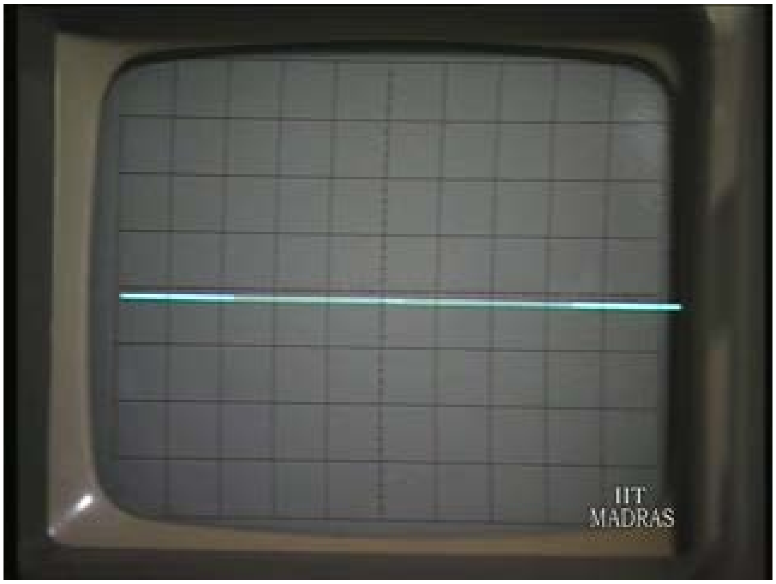

Again, change it. I...if she increases this too much, you will see that it will get saturated.

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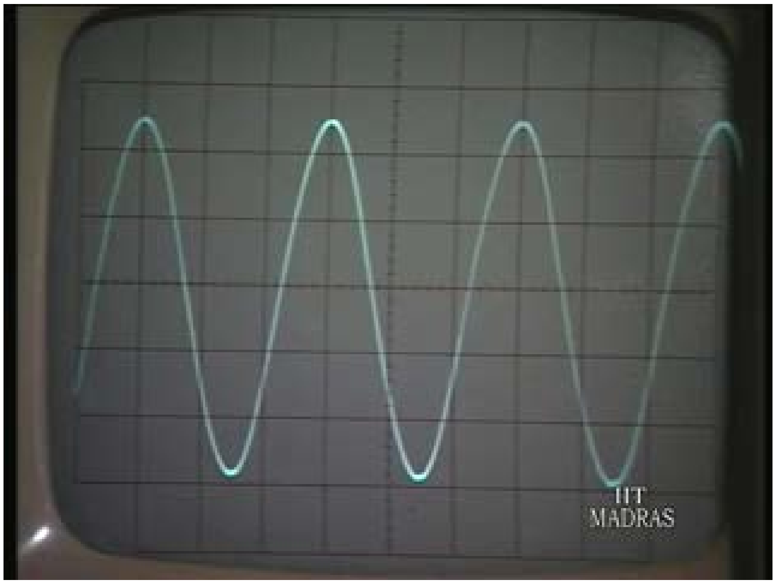

So, the resistance...if value is decreased too much, it is going to get saturated; and now you can see that this frequency can be determined by what is called as a gain plotting. One frequency wave form is applied to x.

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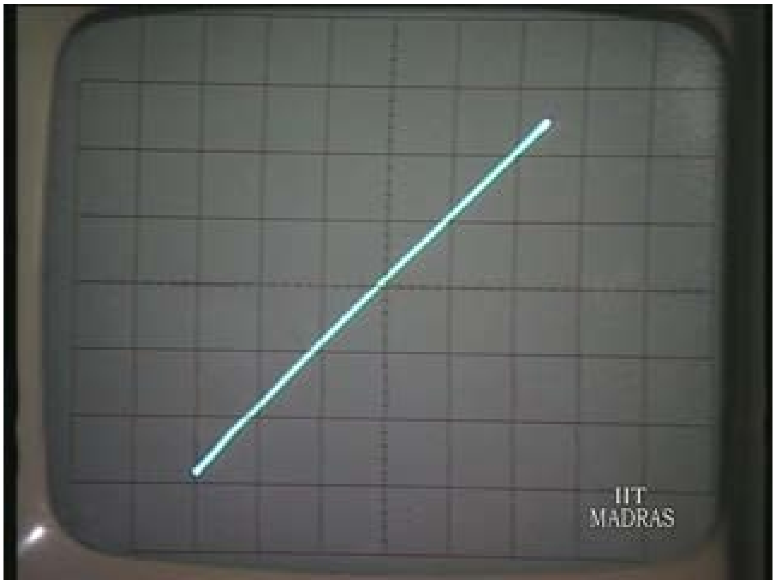

Another frequency wave form is applied to y.

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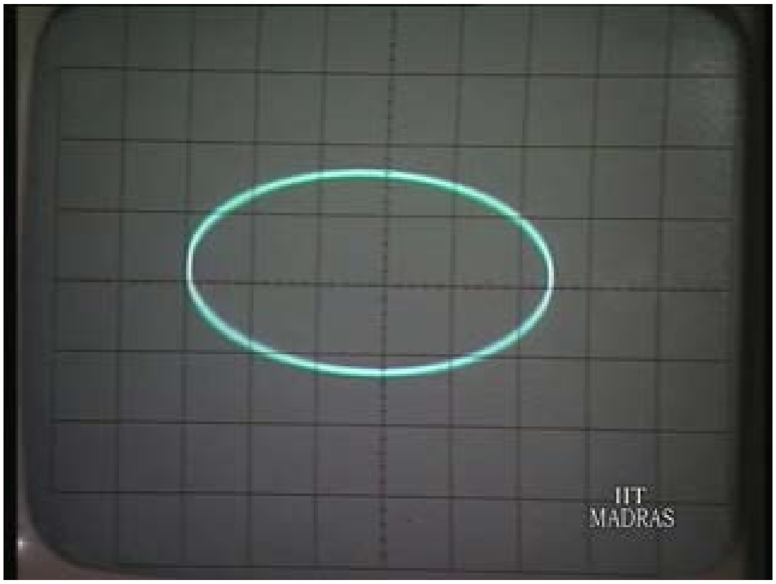

Then you get a lissajous figure. If the two frequencies are one and the same, then it should be an ellipse; and that ellipse is moving like that because we can never make the frequencies exactly same. And therefore there is some phase shift keeping on changing. That is why that ellipse is changing that way.

Devaki, please adjust it so that ellipse becomes at least stable for some moment. There you see... There...there...there...I mean, it is very difficult because both are unstable frequencies and therefore it becomes stable for very short amount of time.

Now she will apply double the frequency and you will see that that figure becomes unstable; and at a certain frequency, you will get a figure of 8; double the frequency means around 360, 360, around that. Please adjust slowly. 360, 390...There...there...there...there. Just...you concentrate...there you are going to get that... There you are... So, figure of 8.

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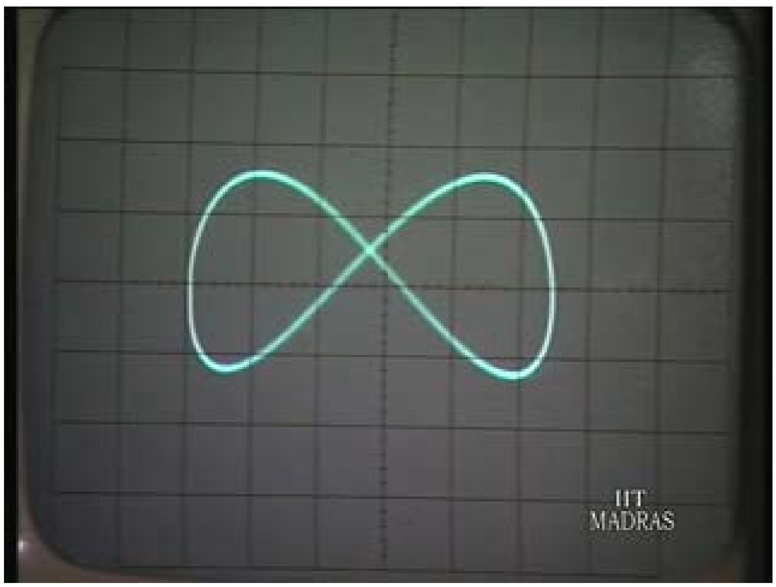

So, that corresponds to double the frequency. At half the frequency, again, you get a figure of 8 in the vertical direction. Half the frequency, ellipse again. This is a technique of measurement of frequency; obtaining this lissajous figure it is called. Given a standard frequency input, you can obtain this kind of lissajous figure and estimate the frequency very accurately.

It is not in that. There you have a vertical figure of 8. There you are. Vertical figure of 8. This is half the frequency... So, you can therefore measure the frequency of oscillation by using this lissajous figure.

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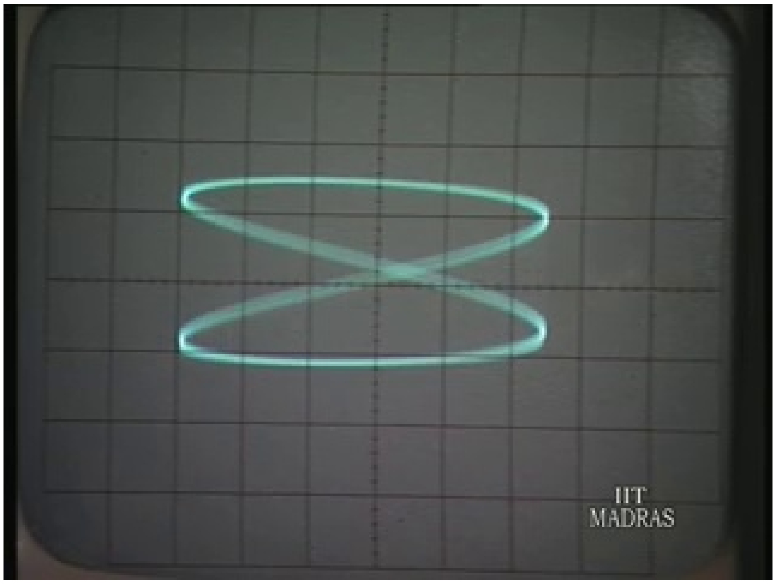

We now go into another filter which is very important which you have also explained as a universal active filter, which uses two integrators in a loop. It is also called double integrator loop or biquad, K H N network, it is called.

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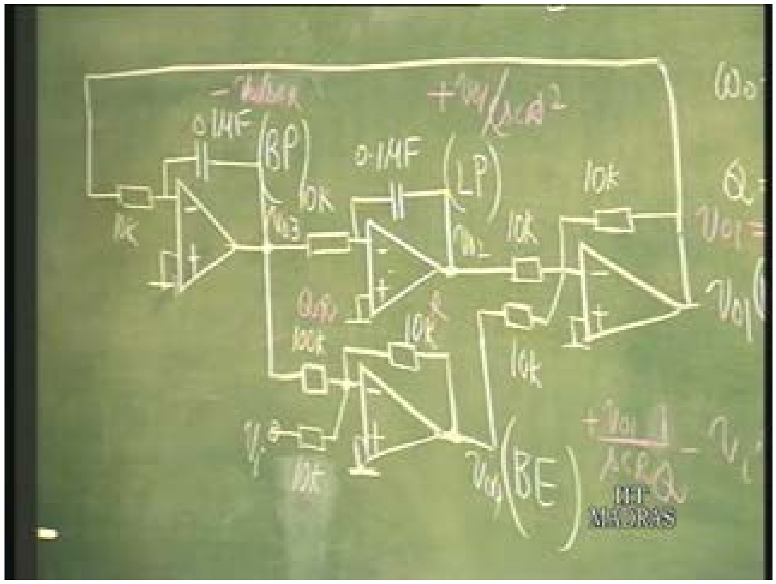

Only difference between K H N network and this circuit that I am demonstrating here is that in our K H N network, we had these two integrators and the inverter and then output from here was directly attenuated and fed to the inverting terminal. Here on the other hand, this output is attenuated of course; but using an op-amp. But since it is getting an inversion here, we can directly use it at the inverting terminal of this, so as to give the required negative feedback. So, instead of an attenuator coming and feeding it to the positive terminal, I am having an inverter with the attenuation of course. You can see 10 K and 100 K.

So, it is attenuation not amplification; and that Q determining network comes as a feedback factor in the negative feedback, but negative terminal. Thereby, I can use only the inverting amplifiers all throughout. So, this modifies the circuit in the following manner. If V naught 1 is this input, this is V naught 1 minus V naught 1 by scR.

Again, this is integrating second time plus V naught 1 by scR square, let us say, 40 amperes. Here, this V naught 1 is going to be amplified by 1 over Q. It is attenuated really into scR with an...minus sign and therefore this becomes plus V naught 1 by scRQ;

and then this V i is coming as minus V i, 10 K 10 K; and therefore, minus V i. So, this is again inverted and is going to appear here as minus V naught 1 scRQ plus V i.

And from here, we have V naught 1 by scR square. So, this is what is going to be equation for deriving the transfer function. So, from this you can note that V naught 1 into 1 plus...V naught 1, 1 plus 1 over scRQ, this one, plus 1 over scR square is equal to V i.

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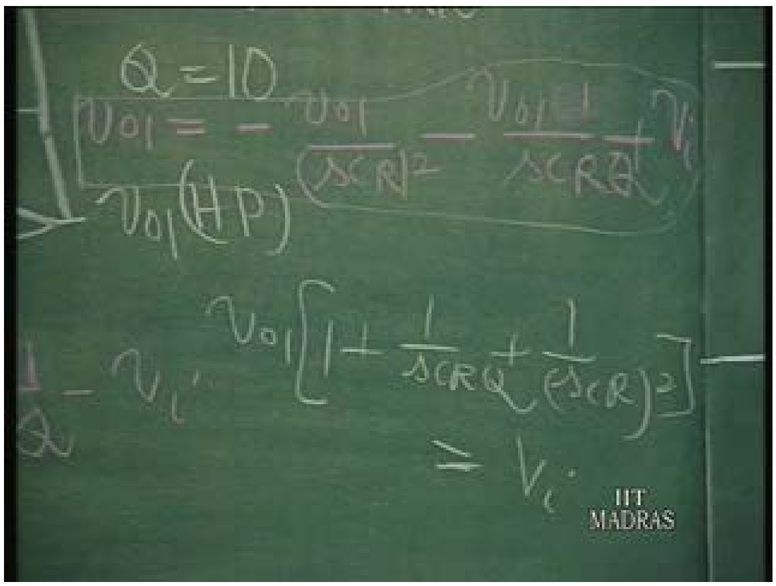

So, V naught 1 by V i, for example, can be written as S square by Omega naught square plus S by Omega naught Q plus 1. In the numerator, we will be having S square by Omega naught square. If it is V naught 1, it will be S square by Omega naught square. You can see that. This actually has been multiplied by S square by Omega naught square throughout. So, it is high pass. This is the high pass output like in the case of K H N network, high pass.

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If I now use this at this point, it will be V naught 2, V naught 3 over V i which is going to be multiplied by minus S by Omega naught. So, this will get cancelled and we will get S by Omega naught. That is band pass at this point. Again, it is going to be multiplied by Omega naught by S minus; and therefore at this point, it will be low pass. This numerator will change to 1 by that. That will be V naught 2 by V i.

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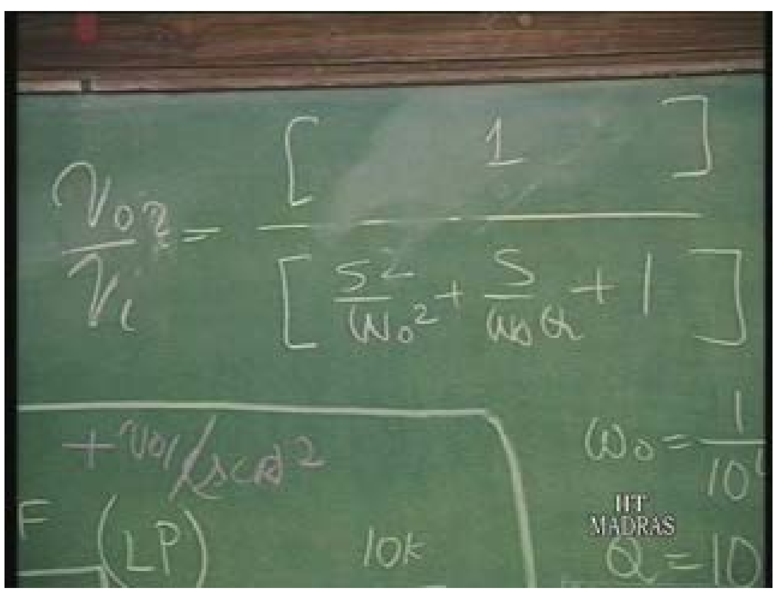

On the other hand, if you take this, this will be a notch output or band elimination output wherein it will be having S square by Omega naught square plus 1 as its function.

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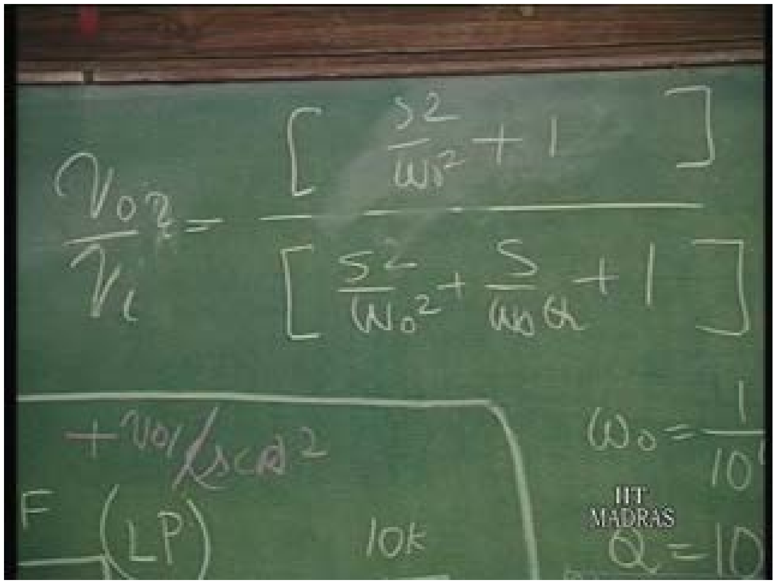

So, this is going to be band elimination at this point, low pass, band pass and high pass here. So, this is able to give all important outputs; very nice demonstration of what exactly happens in this circuit can be given by feeding V i as a square wave.

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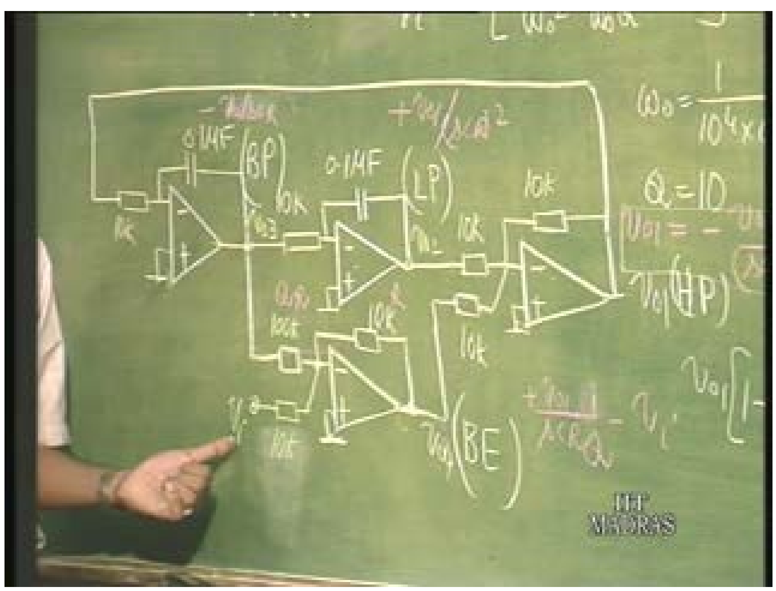

So, that is depicted here in this. This is the square wave at a certain frequency, Omega equal to...determined by the time period here. And if it is exactly tuned to Omega naught, if the incoming frequency is same as Omega naught which is equal to 1 over R C of the filter, then at the band pass output, it should give me the fundamental.

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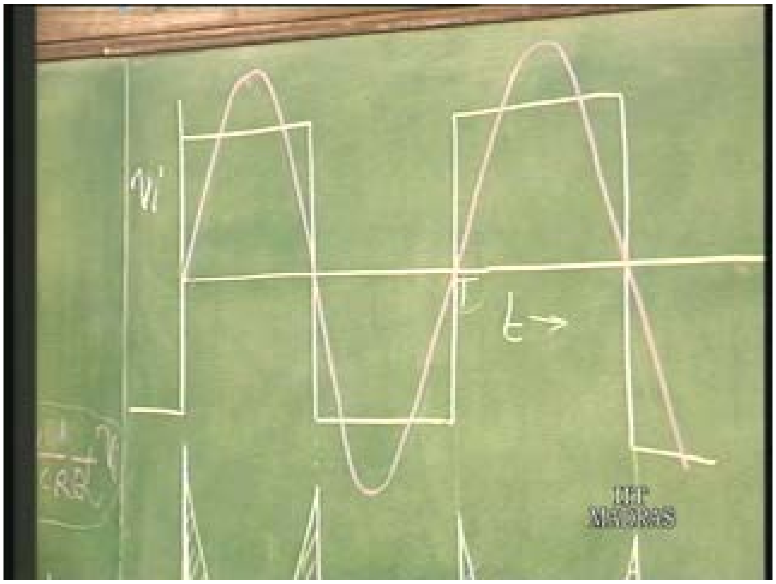

You should select the fundamental and eliminate all the harmonics. So, this may be some kind of fundamental output and it will be almost Q times the input. So, the fundamental amplitude will be very huge. If I apply some value of input signal, Q times that is going to be the fundamental output compared to the fundamental of the input square.

Now if I see the notch output or band elimination output, this fundamental is going to be eliminated from that if it is exactly tuned to Omega naught and you will see that from this square wave, I am removing the fundamental. If you remove this fundamental as this thing, you are subtracting and you will get a wave form which is containing only third harmonics and higher harmonics.

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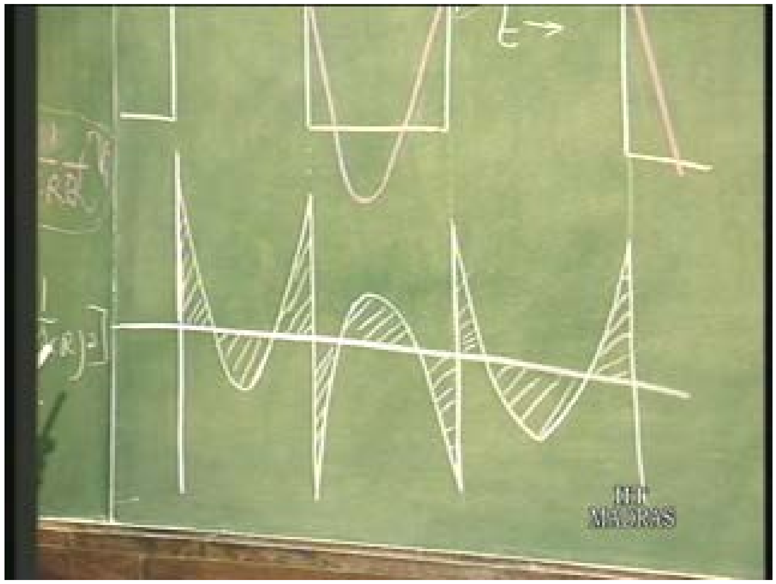

We can see that it is third harmonic because in one time period, you will have 1, 2, 3 and 1, 2, 3. So, it is predominantly third harmonic and higher because these are not exactly same wave; so higher harmonics are also preserved.

This is going to be demonstrated clearly to you. This is a high Q circuit. I have purposely made this Q pretty high here. Instead of using 10 K, if I use, for example, 1 K here, this input is going to be also attenuated by 1 over 10 here; but Q is going to be 100. So, we have designed it for a Q of 100 and therefore here input attenuation is 1 over 10 instead of 1 of earlier situation.

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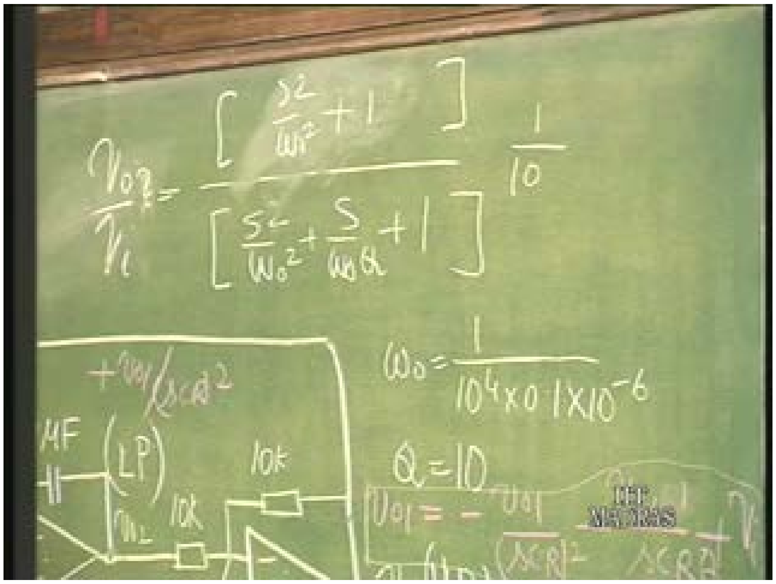

This is going to be demonstrated by Devaki.

She has built this entire circuit and now you are going to see the square wave that is applied at the input. Please... That is the input square wave for which she has shown you the output of the band pass, which is nothing but the fundamental, which is amplified Q times...compared to the fundamental of the square wave.

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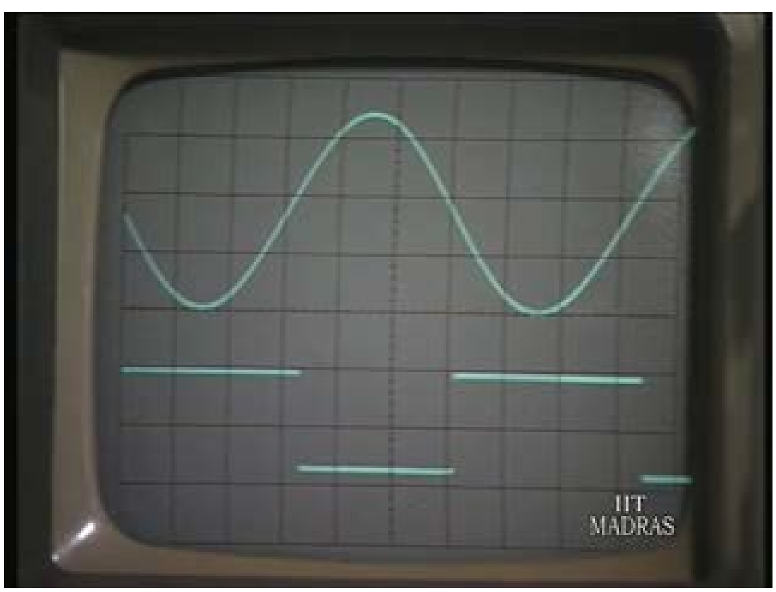

Please do the tuning and see that it rapidly falls. See, see... Yes. Concentrate on the screen; it rapidly falls and again...

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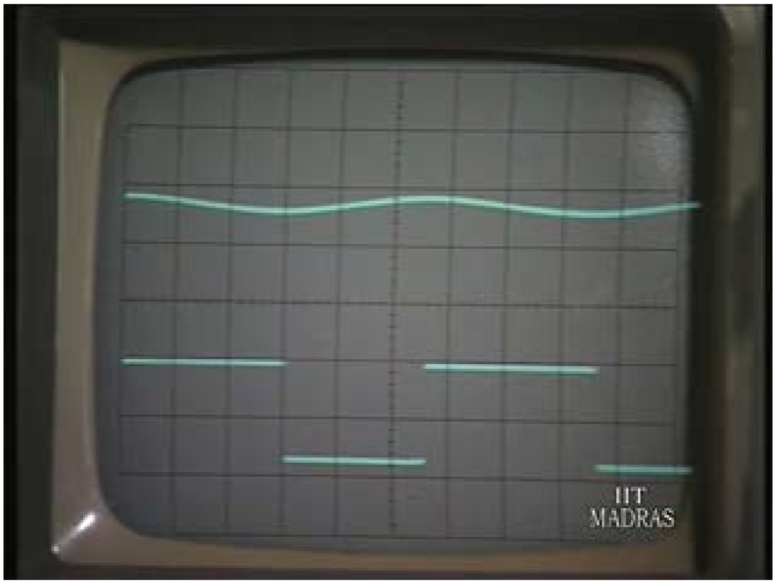

...and...change... This is the center frequency.

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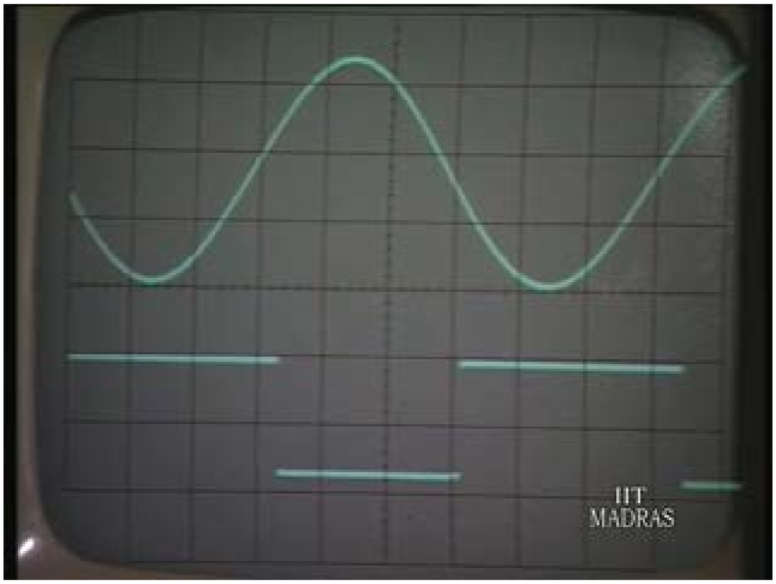

On the other side also it rapidly falls. See, it rapidly falls. Again, tune it please, exactly; tune it exactly to the center frequency so that you get the highest fundamental output.

Now, let her show you the notch output. The fundamental has been eliminated. So, only the harmonic should be there. There, output amplitude should be extremely small and therefore, she is changing the scale so that the small amplitude of the harmonic content can be shown to you at the output of the notch; and we can see that waveform exactly as I had shown you on the board. Now, so please tune the thing so that it is exact... see, tuning... that is what is called tuning exactly because now it clearly tells you how to do the tuning.

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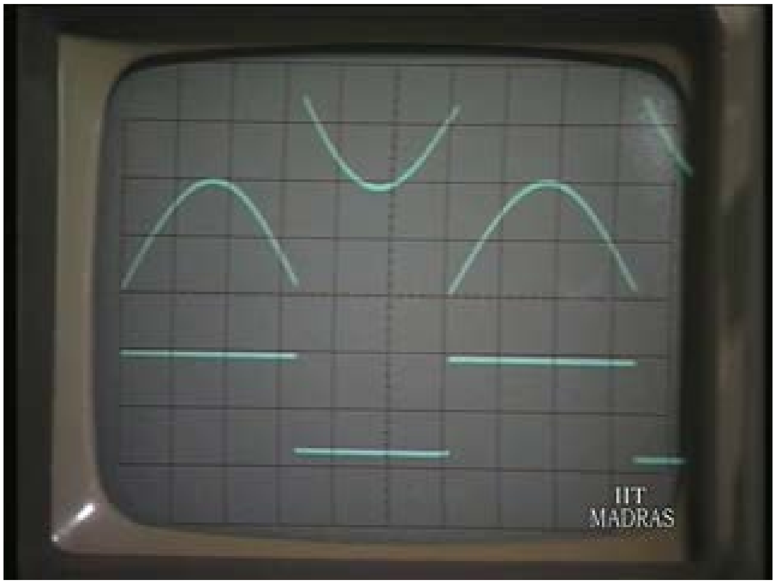

Those two peaks should be symmetric with respect to the center point valley. That is the board waveform and you can see...exactly the same waveform being shown there.

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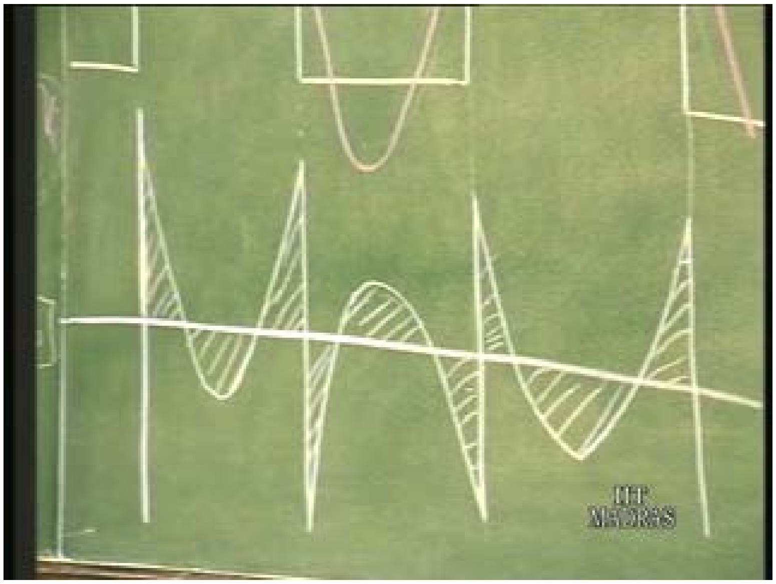

This is the case only if this square waveform is same as the Omega naught. If it is different, you will see that the output is going to be a square wave, if the input is a square wave.

Please show the thing. Change the figure. Now, so the output is simply the square wave on either side of Omega; not output is...output of the notch is a square wave.

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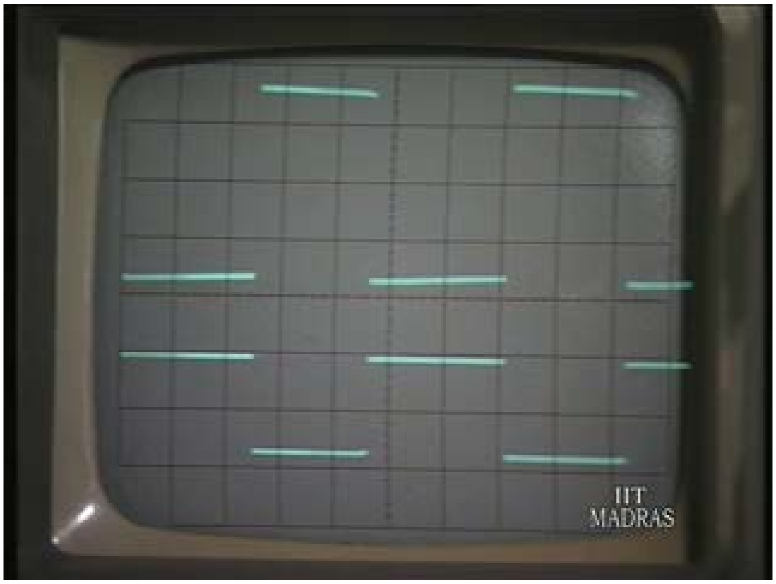

So, it has not eliminated anything at all and therefore output is simply a square wave for an input which is a square wave. This is a notch filter. This is going to be really tuned... only when it is tuned exactly to the Omega naught of the filter, it will remove the fundamental and not otherwise.

This is the use of the... please... tune it exactly Devaki because do not leave it...you can see, she as real difficulty in tuning it exactly because the Q is very high and it...yes...Thank you.

I have to make only one comment. Last time when we saw the notch output, the notch output that we saw on demonstration has a phase inversion of 180 degrees. What I have drawn is without phase inversion. When from the fundamental, from the square wave, fundamental is removed, what is shown is going to be the notch output without phase inversion. So, with phase inversion is what you really saw on the screen of your oscilloscope.

Now, I am demonstrating here another experiment using the same block. We had this part giving negative feedback and Q here has been adjusted to be 10, brought back to 10 from 100, 10 K, 100 K.

So, I put a 100 K variable resistance here so that Q can be made infinity. From here to here, there is negative feedback, if it is fed this way; but from this to this, it is directly getting fed without going through the inverter. That means it is going to introduce positive feedback.

So, if I put a 100 K resistance, around 100 K, it should be capable of changing the Q to infinity because there is a positive Q of 10. This will introduce positive feedback such that the Q can be made equal to infinity. At that point, it will go into oscillation. This is called quadrature oscillator. Why? It is using double integrator and if you take the output from here to here, frequency of oscillation is going to be 1 over R C which is 1000 radians per second, as usual.

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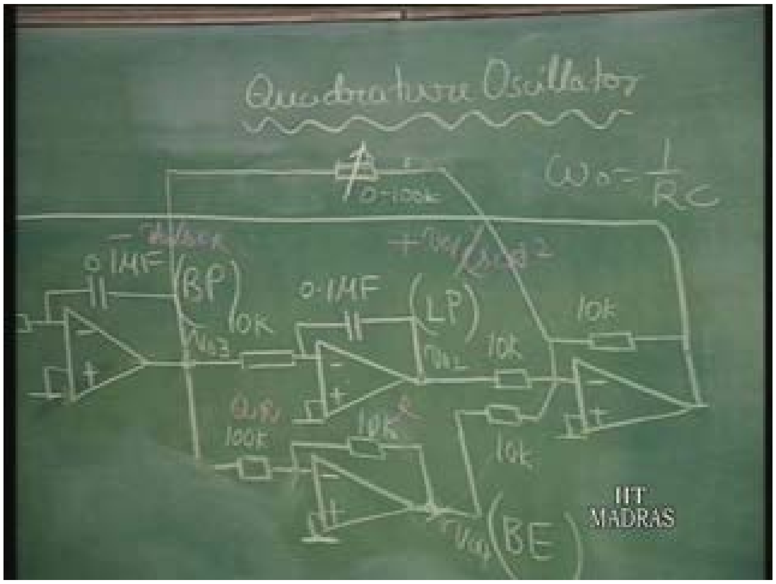

If it oscillates and when it oscillates, this amplitude is going to be same as this amplitude; but phase difference of 90 degree is going to be seen between these two outputs. That is why it is called quadrature oscillator. The phase shift is 90 degrees. So, it is quite useful in communication where you want to generate two outputs in quadrature. This can be seen now.

She has assembled the same circuit now and it is oscillating there...you can see the screen.

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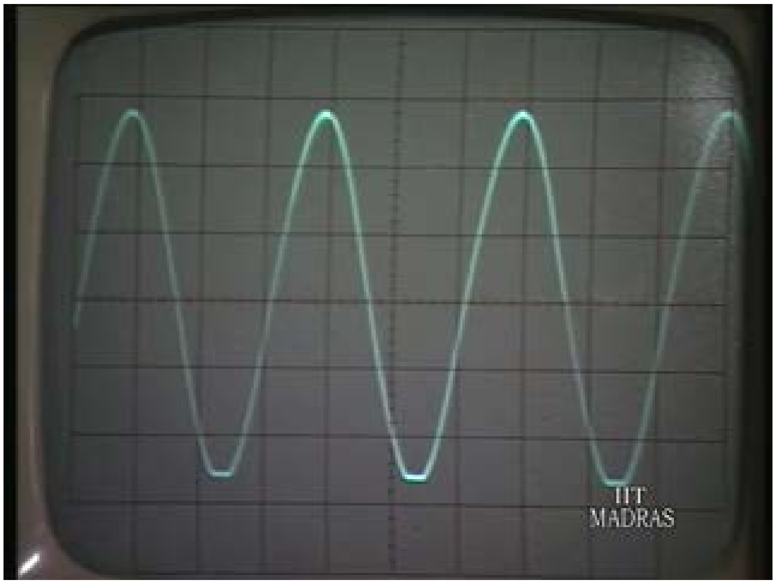

Now, please change the feedback so that it stops oscillating. It stops oscillating because she has introduced more negative feedback than positive feedback.

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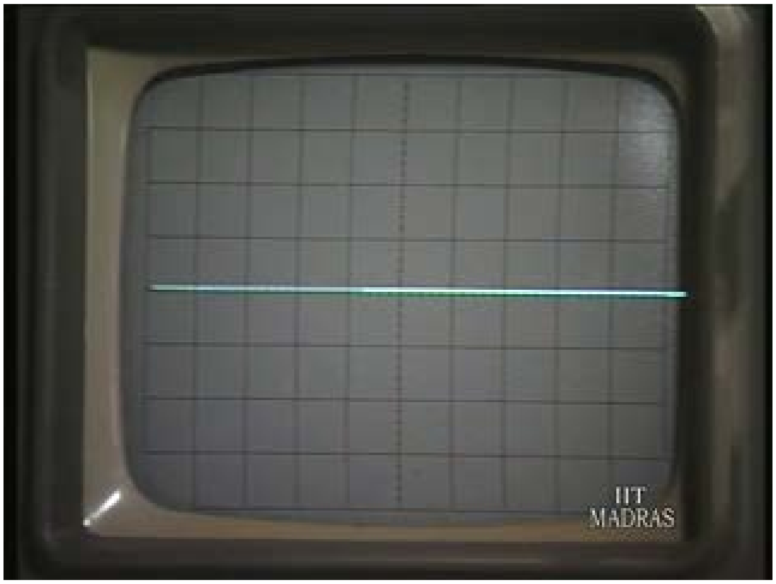

Now, introduce positive feedback, so it starts oscillating. Yes. Now, it is almost going to saturation.

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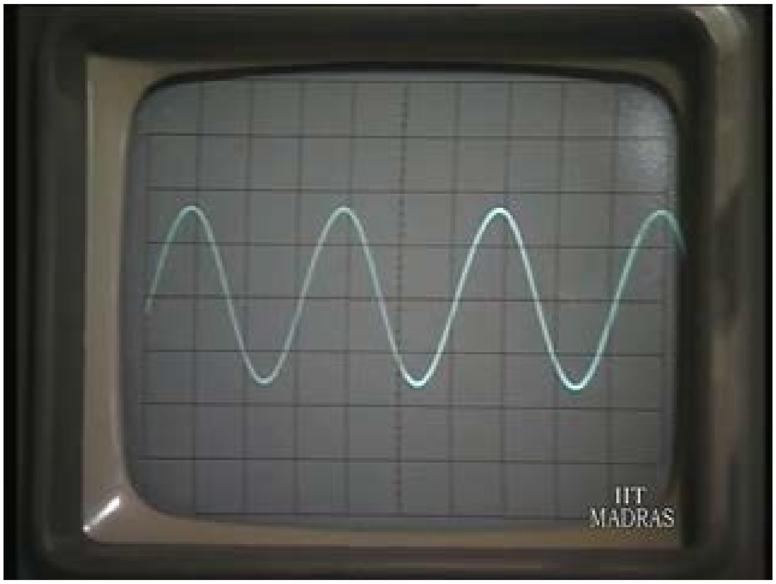

You can see... There is no control over amplitude of oscillation. It will go to almost plus minus supply voltage. You can see... See, this has gone almost up to plus minus.

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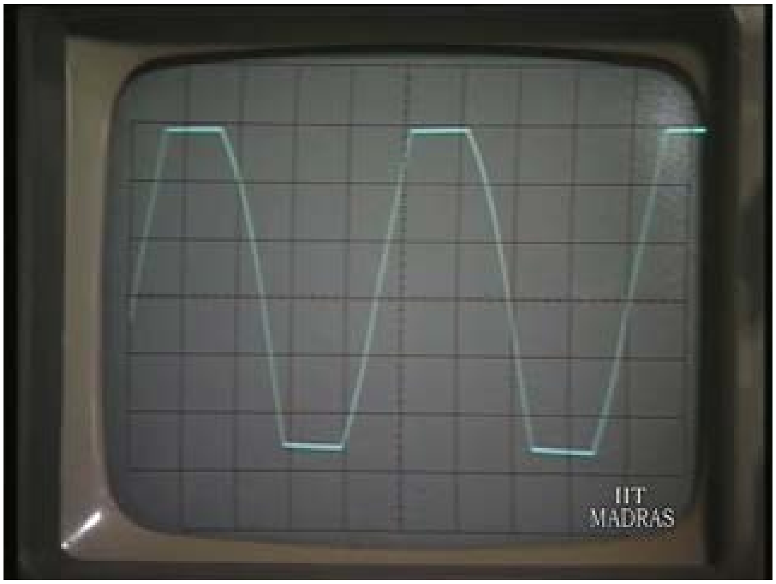

She has introduced too much positive feedback here. Now it has gone to saturation altogether; too much of positive feedback.

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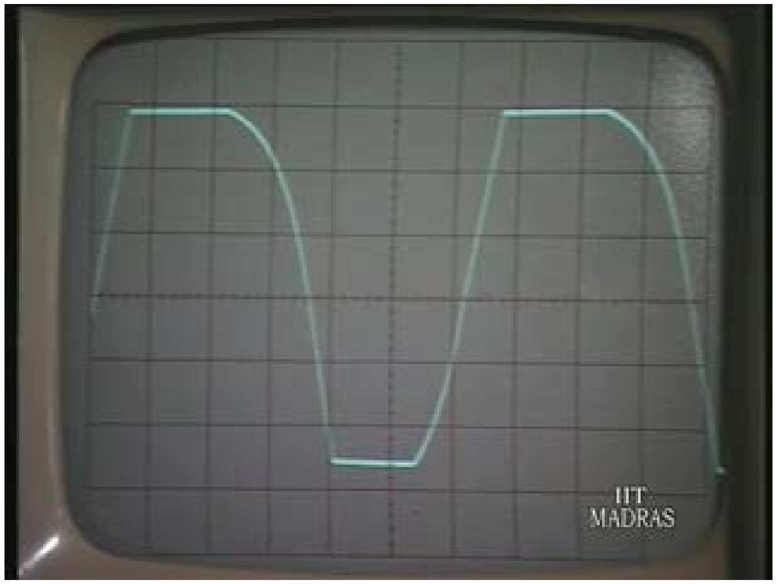

Then...this is clearly demonstrating the effect of too much of positive feedback. You have to just introduce positive feedback in order to get rid of the negative feedback. Then only it will give you a perfect sinusoid. Otherwise, it will be distorted.

Now, the frequency of oscillation is once again around 200 hertz. Now I want you to see the phase difference between one output and the other output. Will you please connect another output so that they can see the phase difference between one output and the other output? She is now connecting another output so that we can see the effect of quadrature, that is, phase shift of 90 degree between the two outputs.

So, this is perfect circle you can see, because amplitudes are same and there is a phase shift of 90 degree and it is a perfect circle. x square plus y square... See...See... She is changing the feedback so the amplitude changes slightly. But it is vanishing; and when it is going, both are going simultaneously; that is perfect quadrature output. This is the beauty of the quadrature oscillator.

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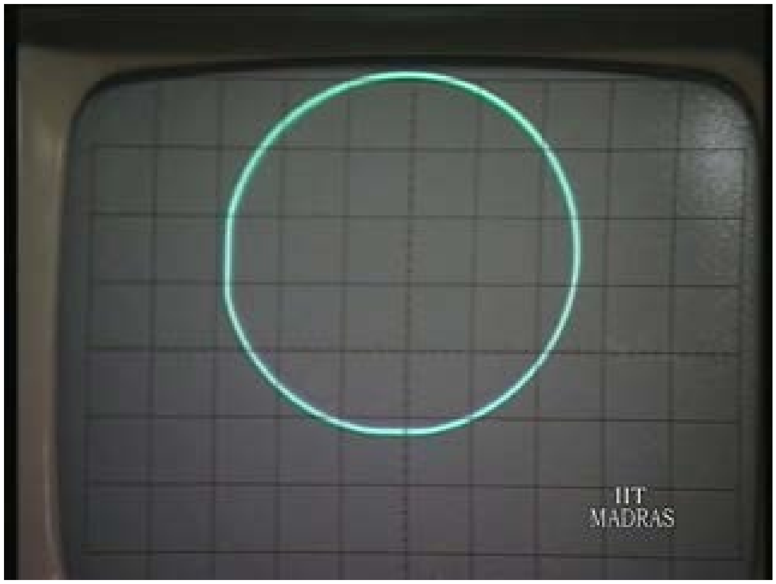

On demonstration of negative feedback and positive feedback effect of these, we have clearly brought out filters, oscillators, etcetera. Now we will see how certain amount of non-linearity can be got rid of by using negative feedback. This is precision rectifier, its application and elimination of crossover distortion in Class B power amplifier. This can be done with the help of negative feedback. How do we do that? Let us see here.

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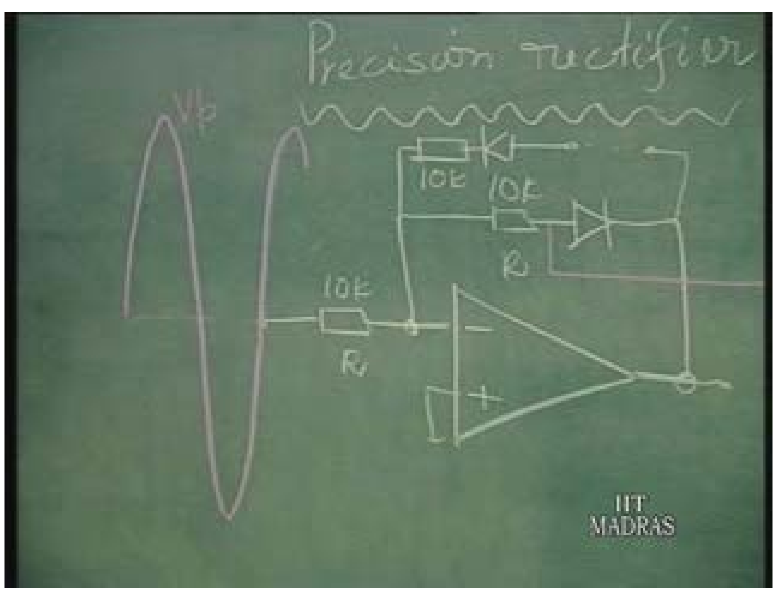

I am explaining about the precision rectifier which we had earlier discussed. This contains the op-amp here and this converts the voltage into current. So, whether it is going positive negative, this is converted into current which is V i by 10 K; and V i by 10 K always flows through this. But on the output side, this V i by 10 K is pumped into this diode when it is going positive; and if we do not have anything else connected, then this is eliminated. This part is eliminated and therefore this current cannot go anywhere.

So, the op-amp is going to behave like a comparator there, where it will be simply magnifying whatever voltage is appearing here at this point. But that is of no use because this positive voltage is going to get converted into negative here and this diode is going to conduct; but when it goes negative this is going to be having open loop.

If you do not have this conducting, this will be open loop and this voltage will appear here and this voltage will appear here as well. So, when it goes negative, this voltage, input voltage, will appear here. When it goes positive, this is going to be inverted; therefore with the resultant effect, you see a wave form like this. When input goes positive, it will be inverted because both resistances are equal. This is plus minus, this is plus minus.

So, this is at ground potential and therefore this is inverted and appears as minus V p; and this appears as such because the op-amp has no feedback at that point. So, you get a full wave rectified wave form; but that is no use because the moment I load this, this voltage wave form is going to change its state.

So, this depends upon the load here. But I want the output to be independent of load. So, what I do is when it goes negative, I will permit a path here so that there is going to be another diode connected to take that negative current. But at that time, this voltage is going to be virtual ground. So, this voltage is transmitted here as virtual ground. So, it will climb to ground potential. So, this output here is going to be a true half wave rectifier only if I connect another diode.

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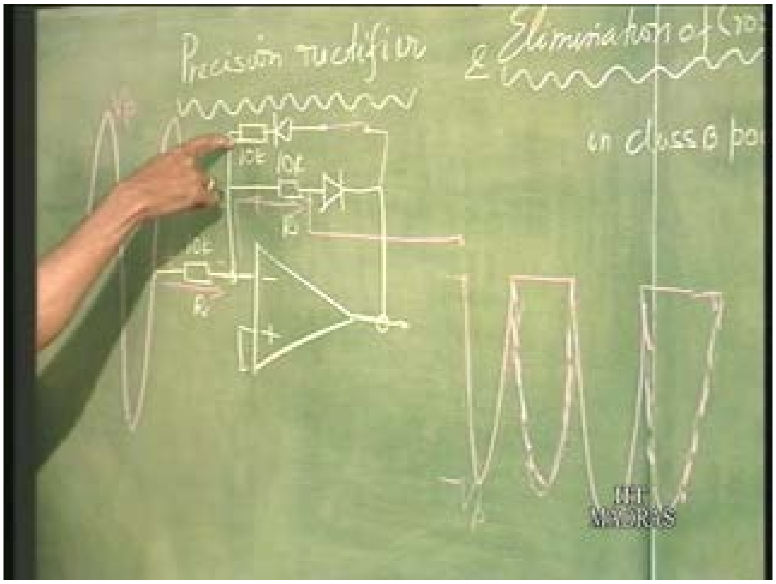

So, we will see the demonstration even if this is not connected purposely to see whether we get this wave form. When you will see that this amplitude is different from this, it depends upon the amount of loading it has and I am connecting an oscilloscope here and all that. Even that make load get to a certain extent like this.

This wave form you see; the moment this is shorted, you will see that this has climbed to zero. This demonstration occurs and this is independent of the cut-in voltage of the diode. As soon as this goes positive, this will try to go to negative saturation. So, the diode conducts as soon as this voltage goes to minus V Gamma.

So, this actually...voltage jumps from plus V Gamma to minus V Gamma. You will see this wave form also. So, the op-amp comes into picture, jumps to plus V Gamma and minus V Gamma respectively so as to make these diodes conduct. That is why the conduction of the diode is independent of its cut-in voltage, as long as the gain of the amplifier is very high. And therefore, we are able to use a practical diode in the negative feedback path and get a rectifier which can rectify even millivolts of peak input voltage.

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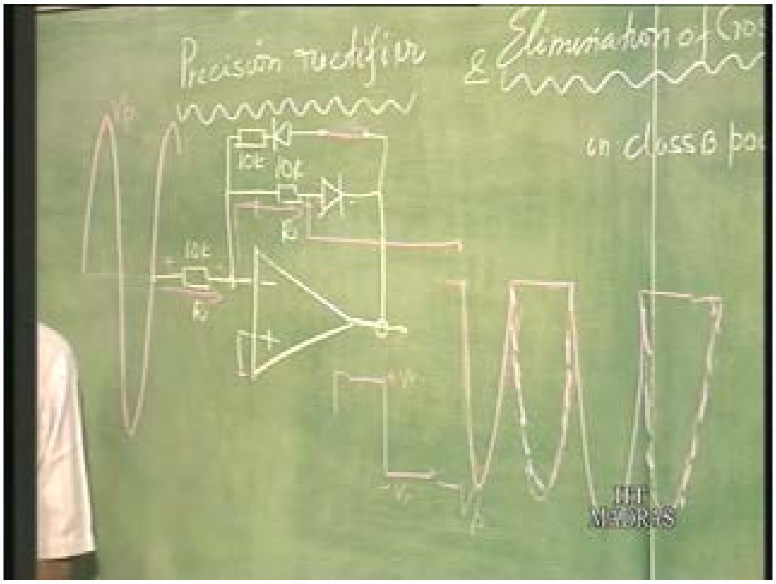

So, this demonstration is going to be done there. You can see, this circuit has been built and constructed; and now what you are going to see on the oscilloscope is a situation where the other diode is not connected. You can see that the wave form is there; but it is showing full wave output instead of the expected half wave.

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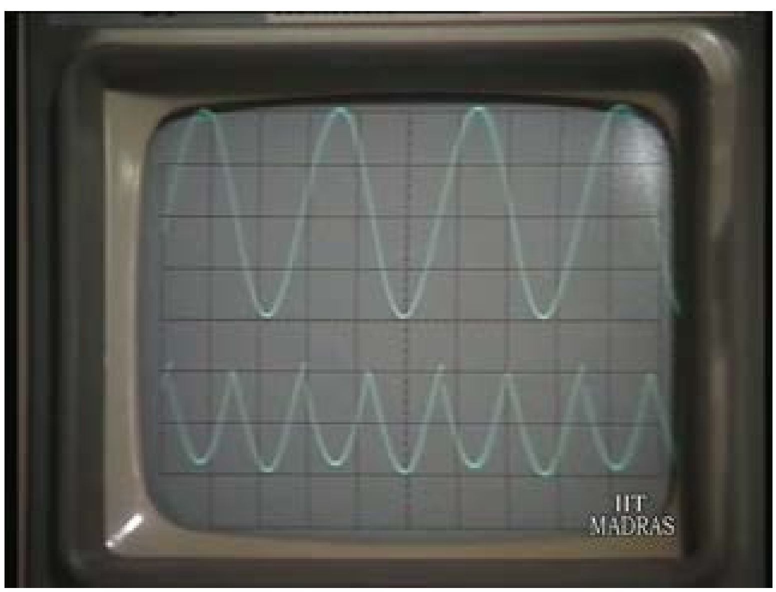

Now she will connect the other diode and you can see that output is going to be climbed to zero when the other diode is not conducting. So, we can see that this is a half wave rectifier wave form.

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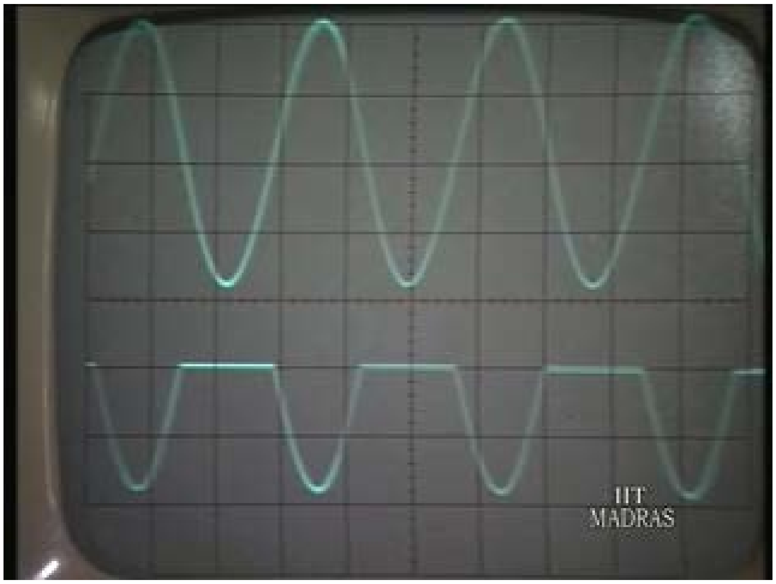

Devaki, you can show the other output also here because that also is the other half wave. Each of these will give you half wave. This is one half wave, this is the other half wave at the end of the other 10 K. So we can see now; this is going positive, other one was going negative. So, you can get two half wave rectifier wave forms here, clearly.

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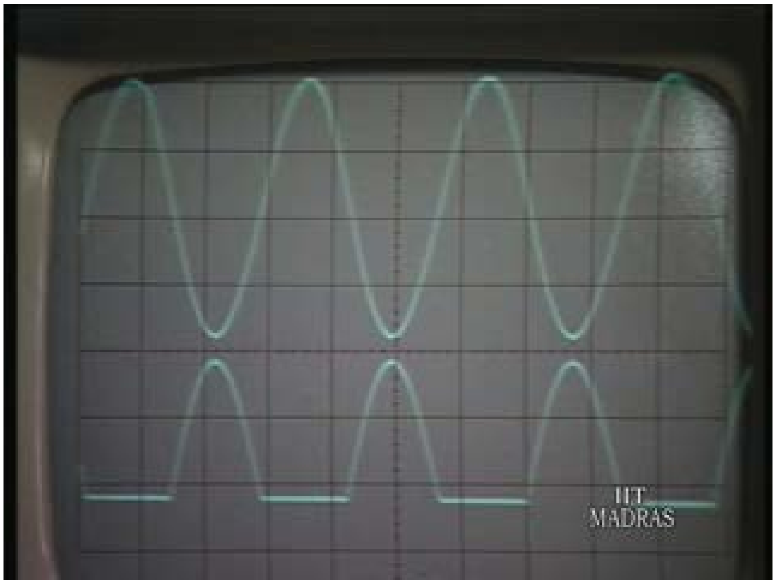

And if you now see the output of the op-amp...please show the output of the op-amp. So, output of the op-amp...you can see, it is jumping and then following the input. So, it is jumping by an extent equal to V Gamma - plus V Gamma and minus V Gamma and trying to follow the input.

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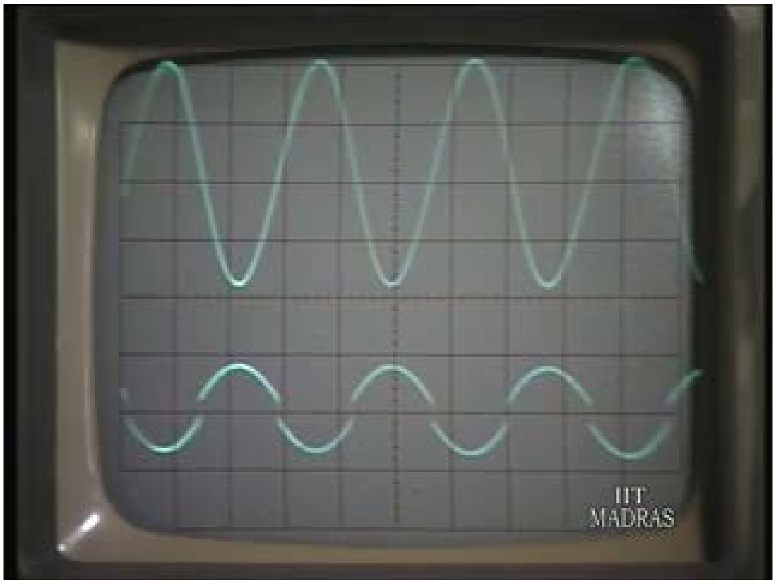

So, even if the input is very low, make the input low, we can see that it is almost becoming a square wave. Increase the triggering...so, input is very low now. It is less than cut-in voltage of the transistor.

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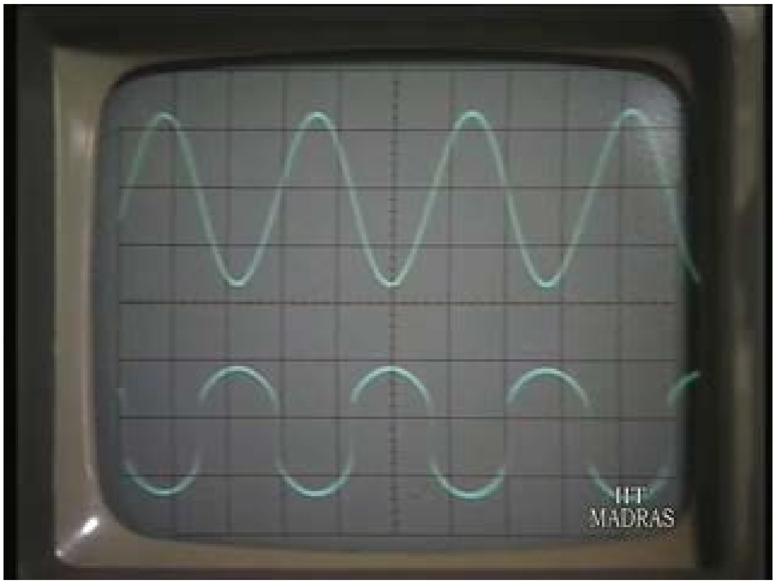

And further reduce the input. Go to the higher range. Yes. No, slightly. You can see here clearly, input is very low and output of the op-amp is almost looking like a square wave; whereas the diode is still rectifying...

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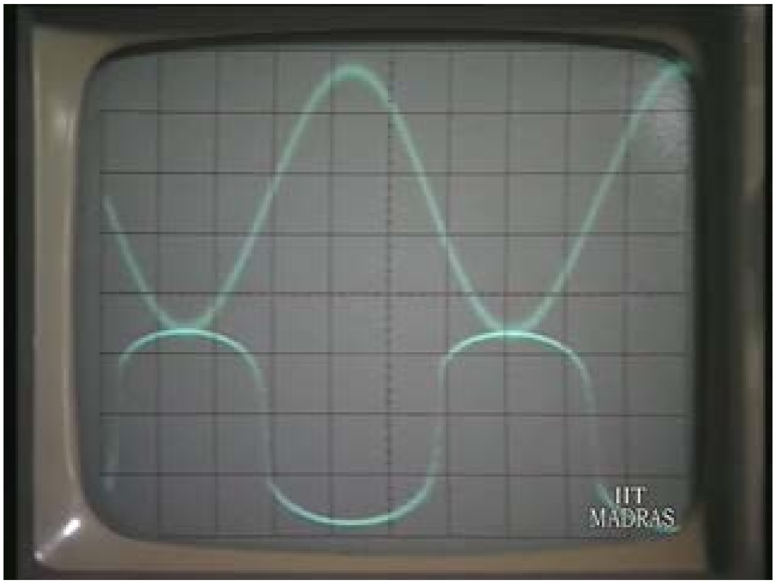

Half wave rectifier output - please show...scale... Yes. See, you can see the thing is still faithfully doing...What is the input level please?

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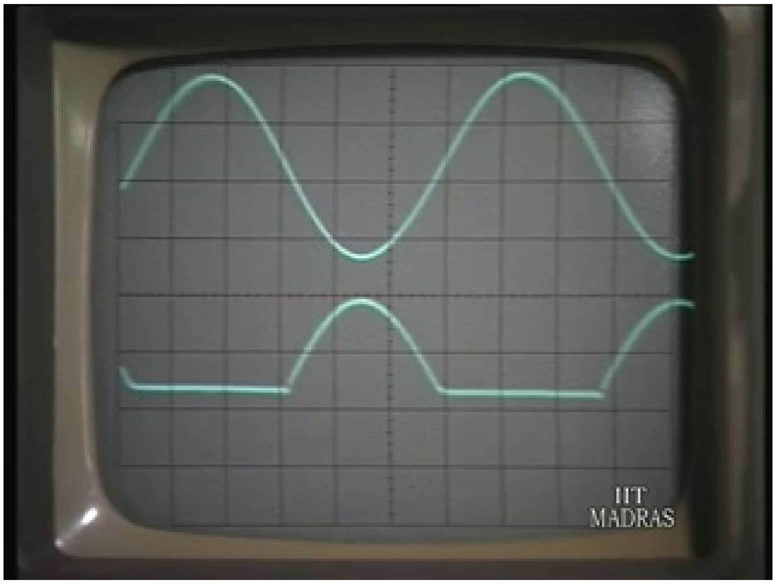

10, 150 millivolts; and even so, output is going to be half wave rectified. So, this is the precision rectifier.

Let us now see the board and in the case of Class B power amplifier, the same scheme is going to work, but it is going to be the power amplifier application. It is the same as that of the diode scheme. So, you can see that this is the Class B power amplifier, 10 K, 10 K we can put; and there is a diode connected like this here and like that there.

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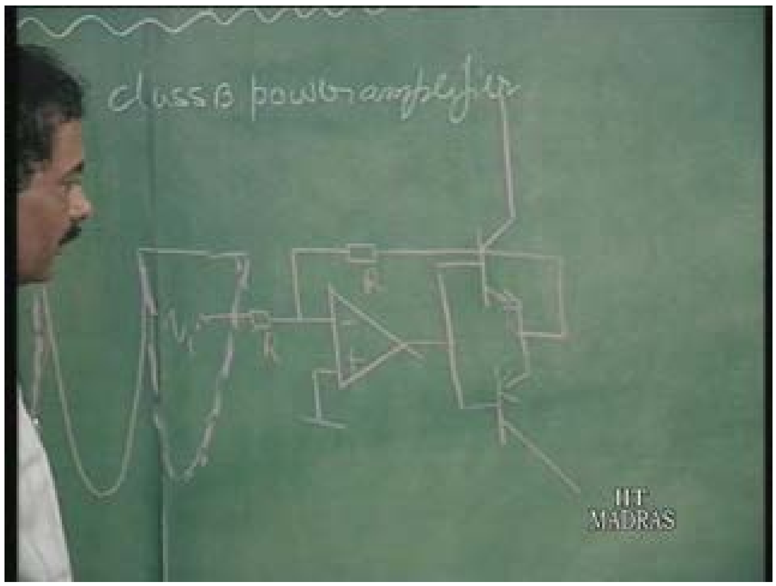

So, as far as the current is concerned, current is always going to flow in this direction. So, when it is showing here like this way, this transistor will take that current. When it is flowing in the opposite direction, it is this transistor which will conduct. So, it is equivalent to the same circuit. Only thing is we have R, R and two diodes connected in parallel; but the current taken is...actually, as far as the op-amp is concerned, it has to feed only the base current in order to retain the transistor in conduction.

So, the basic principle of this structure is exactly similar to what we have just now demonstrated of the precision rectifier. So, if you see the wave form at the output of the op-amp, it will be again square wave like thing and here it will be absolutely a sine wave.

Even if this sine wave amplitude is going to be very small, this is going to be inverted here and going to appear as a perfect sine wave in spite of the diodes conducting, only after cut-in voltage is applied. So, this is clearly demonstrated in the case of precision rectifier as well.

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Now we will demonstrate certain applications of the multiplier which we have also studied in our theory class. If V x is one input and V y is the other input, output is V x V y by 10. In the case of an ideal multiplier, V x and V y, both will have a dynamic range of plus minus 10 volts.

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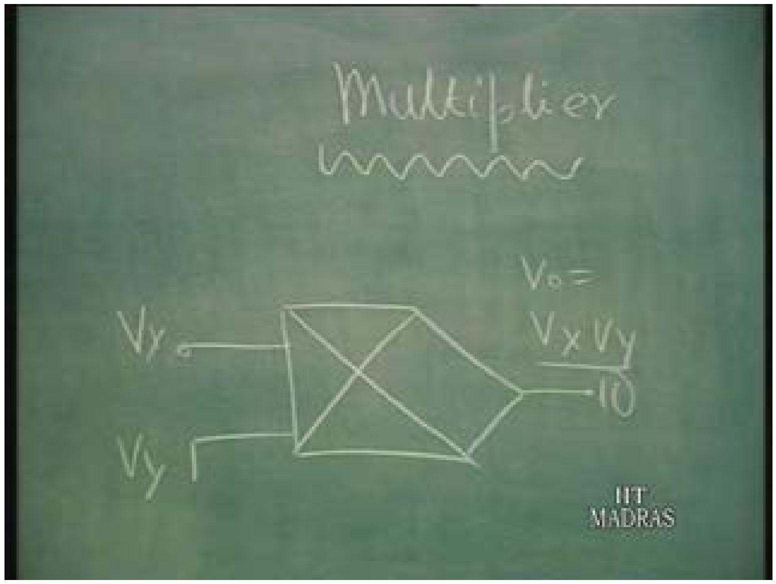

Now if V x is, let us say some frequency input. Let us say...we will say that it is V p sine Omega c t, the carrier and V y is the modulating frequency, Omega m. Let us say Omega c is some 1 Kilo hertz and Omega m is 100 hertz. So, we have this gain being changed by the modulating frequency, gain of this amplifier. In fact, we can see that this is V y by 10. You can consider the lower frequency 1 as the gain. V y by 10 is the gain of this and V x is the amplitude which is V p sine Omega c t.

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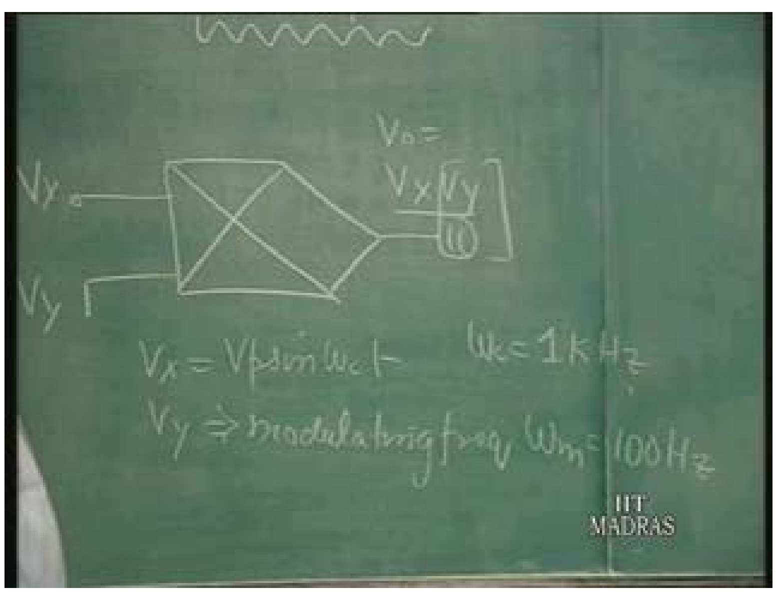

So, V y by 10 - that is, the gain is changed for this V p sine Omega c t. So, when V y is high, the gain is going to be high; when V y is low, almost zero, let us say it goes to...again it is going to be zero. So, this is something like a frequency shift key.

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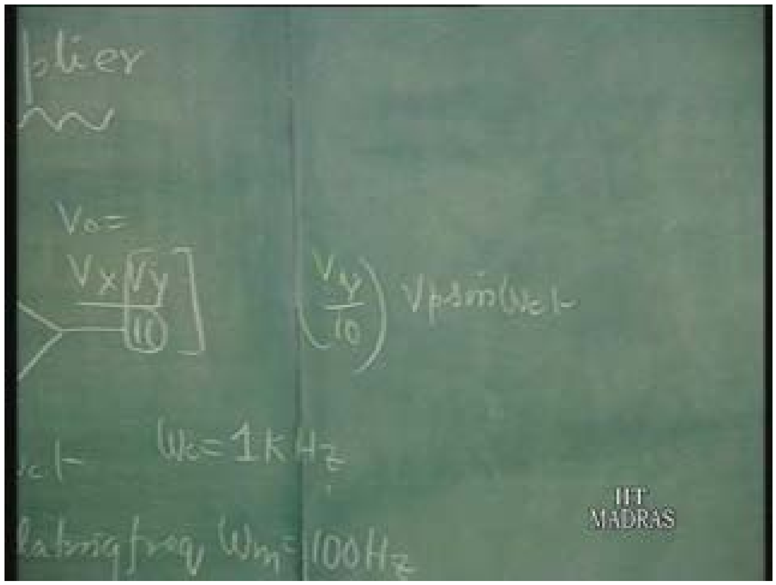

There is going to be the carrier frequency information coming for some time and not coming for some other time. This is going to be demonstrated now by Devaki there.

On the screen you can now see, she has connected a multiplier input. One input corresponds to modulating frequency of 100 hertz; another corresponds to the carrier which can be varied, of course. It is about...kept at about 1 Kilo hertz and you can see: the lower one corresponds to the carrier; the upper one is the output of the multiplier and since these frequencies are not very stable, it can be triggering only one waveform properly. We see that kind of movement there and it is the modulated output.

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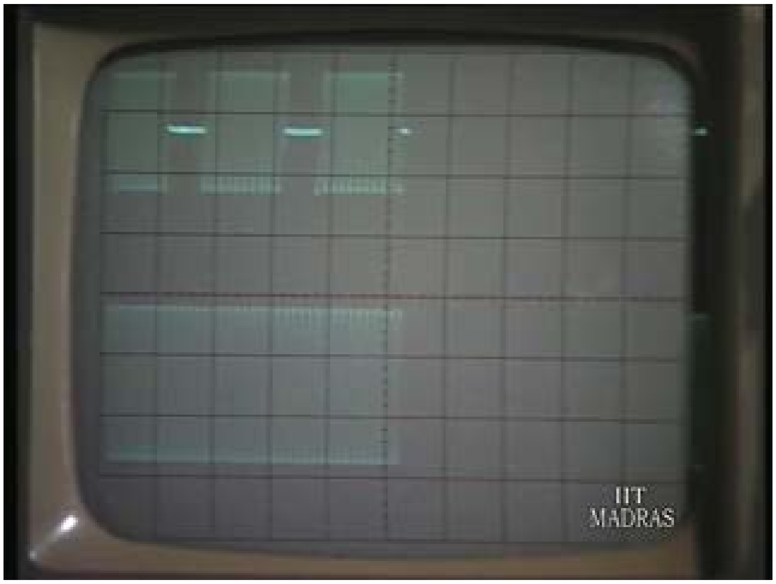

Please vary the modulating frequency now from 100 to 50 or something. So, she has changed the modulating frequency from 100 to 50 hertz and now you can see again the modulated output. See, the frequency is different.

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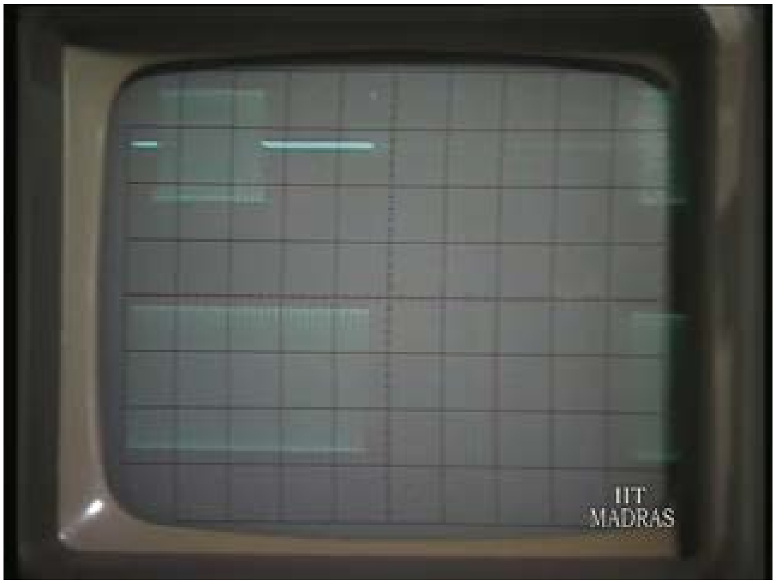

So, again it is made very nearly equal to zero; nothing of the output is visible there and output is fully visible during... So, it is a square wave modulation. So, this is a clear application of multiplier.

In the last demonstration, you saw the gain was varying from zero to 1; zero at some interval and 1. It is called frequency key. Now, if you want to convert this into A M amplitude modulation, you have to make it non-ideal. We want the gain to vary from some value to some other value. That means we have to apply a D C, plus the modulating frequency. The D C will bring the carrier and the modulating frequency will change the amplitude from some value to some other value.

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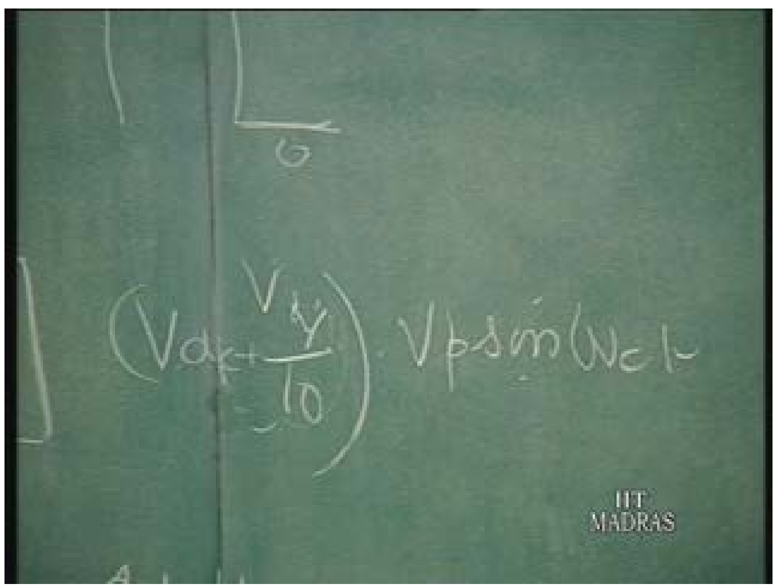

So, we have now an arrangement where we have added the D C and the square wave at 100 hertz so that output is an A M.

Now that is demonstrated to you again by Devaki again clearly, bringing in a D C, and an A M. Now, let us concentrate on the screen. The output of the multiplier corresponds to the amplitude modulated output.

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You can see the amplitude modulated output here. Please go to another...lower frequencies range, please. You can concentrate on the screen meanwhile. So, you can see the amplitude modulation here. It is going from the maximum to minimum abruptly because it is a square wave.

Now, what we are doing is we are doing synchronized detection. The output of the modulator is fed to another multiplier and this is now fed to low, sort of low pass filter so as to eliminate the high frequency component; and you can see this...the output of the multiplier now contains carrier also before filtering. You can see the square wave and then the filtered output, filtered output. This is the filtered output. Increase the scale please for the filtered output.

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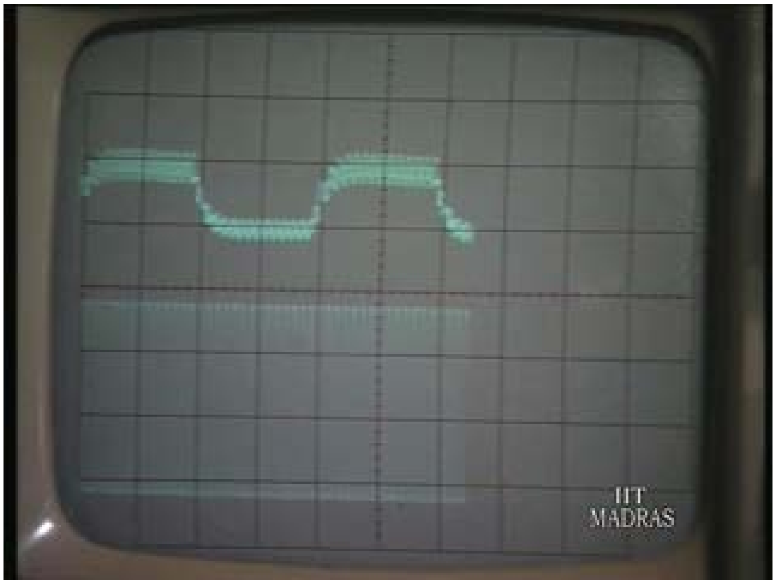

So you can see; still it is only a low pass filter that has been put. So, the carrier is still there. If you want better filtering, you have to put higher order filters so that you can get the square wave back. This is the demodulated output. This demonstrates synchronous demodulation. This is not normally adopted. What is done is envelope detection because it requires the presence of carrier to multiply with the modulated waveform in order to get the output. So, this part of the experiment demonstrates some of the communication applications of the multiplier.

Now we will demonstrate another application of the multiplier wherein same input is fed to both V x and V y. V p sin Omega t, V p sin Omega t. Output will be V p square sine square Omega t divided by 10 which means it will have a D C component and a 2 Omega t component.

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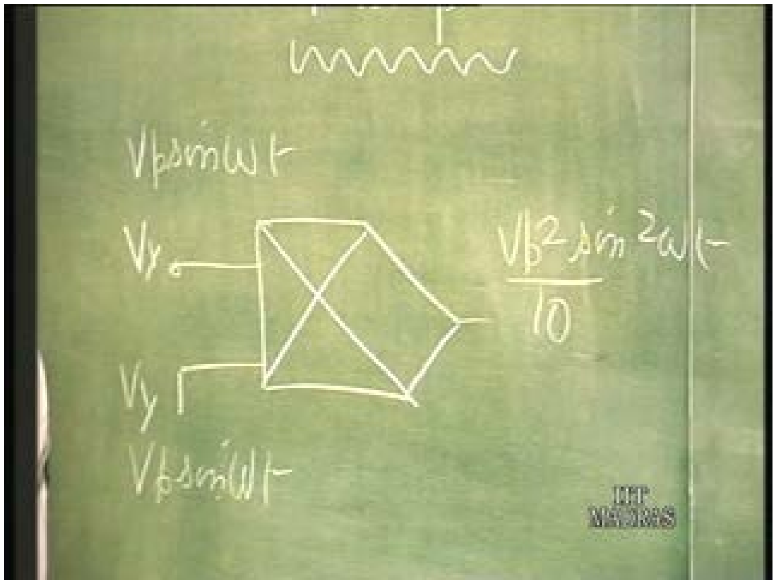

This is going to be therefore its application as frequency multiplier. So, if you feed Omega, you get 2 Omega as the output.

This is demonstrated very clearly now by feeding the two inputs to this multiplier; same input to the multiplier. And you can see here, for one cycle of the input waveform which is shown at the bottom, you have two cycles of the output waveform. You can clearly see that.

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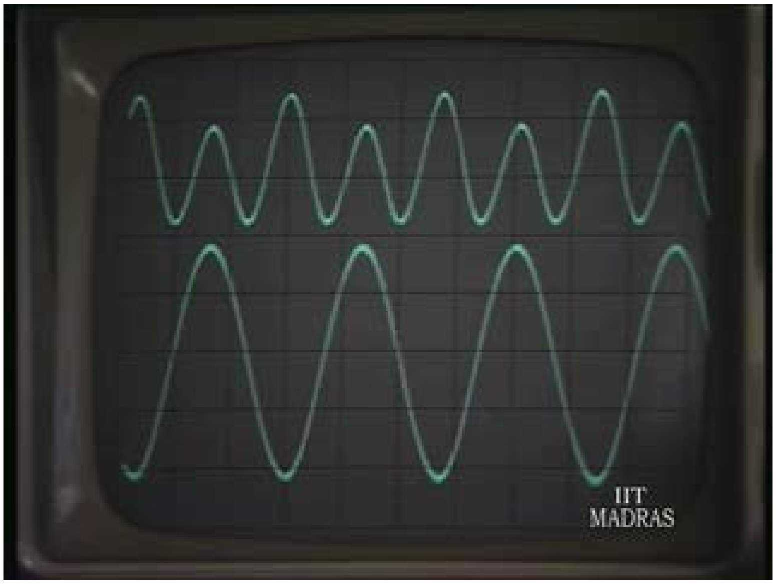

There is a certain amount of feed through component of the fundamental; that is, the Omega component coming, because the multiplier has a certain amount of offsets. So, the feed through components also is coming along with the double the frequency component. So, this can be eliminated by adjusting the D C or applied to one of the inputs so that the feed through component gets cancelled.

So, this gives you frequency doubling effect and we can multiply frequency by using successive multipliers and we can generate a periodic waveform this way.