Electronics for Analog Signal Processing - II

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Lecture - 10
Experimental Demonstration

Today, we are going to demonstrate negative feedback and positive feedback using operational amplifier circuits. This demonstration is going to be done with the help of the experimental kit there.

Ms. Devaki is sitting in front of the kit wherein we have the op amps, multipliers, transistors, differential amplifiers, etcetera; and the connection that is needed can be made. There is a signal generator. Please point out that. Yes. And then, there is the oscilloscope for you to see the wave forms at different points.

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Now we will see what kind of experiment is going to be set up.

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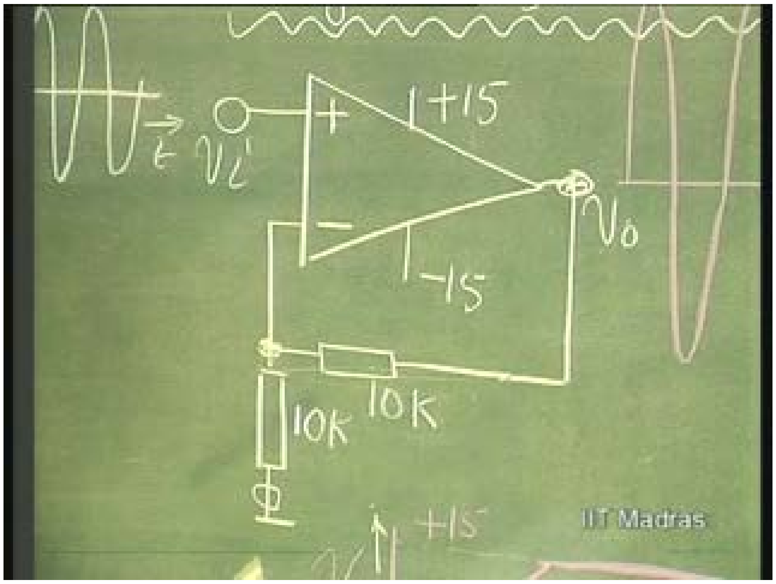

Therefore, here we have a circuit which we have learnt in our earlier class for negative feedback. Output is taken and part of the output can be fed back. It can be 10 K, 10 K. Therefore, it is either V by 2 or if I short this, the full output is fed back. If the full output is fed back when this is shorted, output gain is going to be equal to... output by input is going to be 1.

If it is half the output that is fed back to the negative terminal, negative feedback, then the gain is going to be 2; you know. So, we will see that the gain changes as...demonstration is done, when this is shorted, gain is going to be 1; when this is opened, gain is going to be 2; and this demonstration can be now seen.

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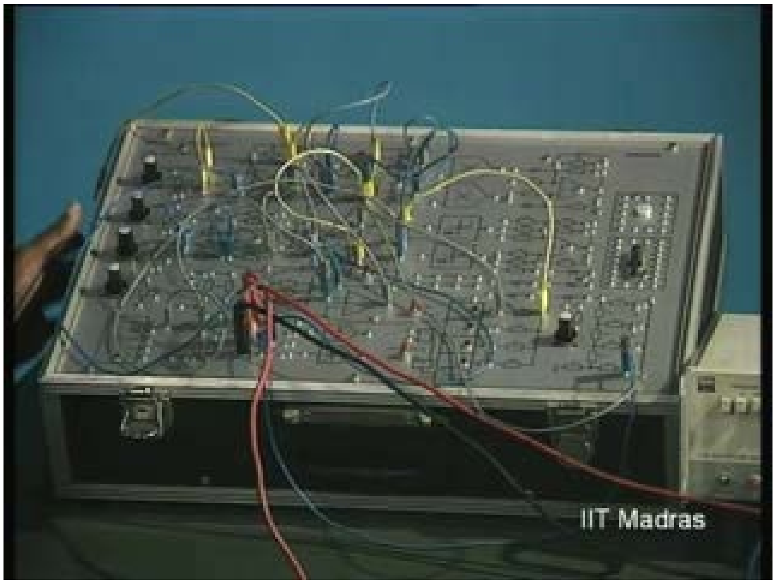

She has fed an input signal and this signal is going to be amplified by unity gain on the oscilloscope, you can see.

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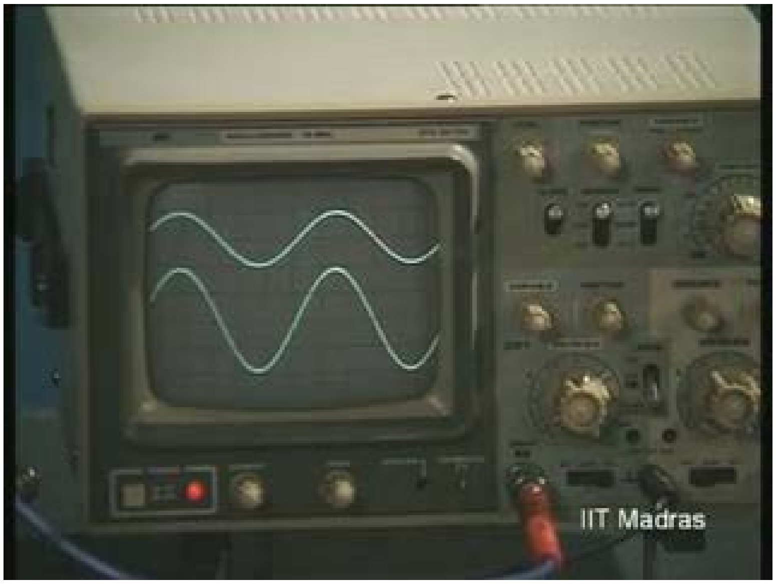

Yes. Output. Now it is amplified by factor of 2. You can see... it is... both the wave forms are on the same scale and therefore the output is lower one and the input is the upper one.

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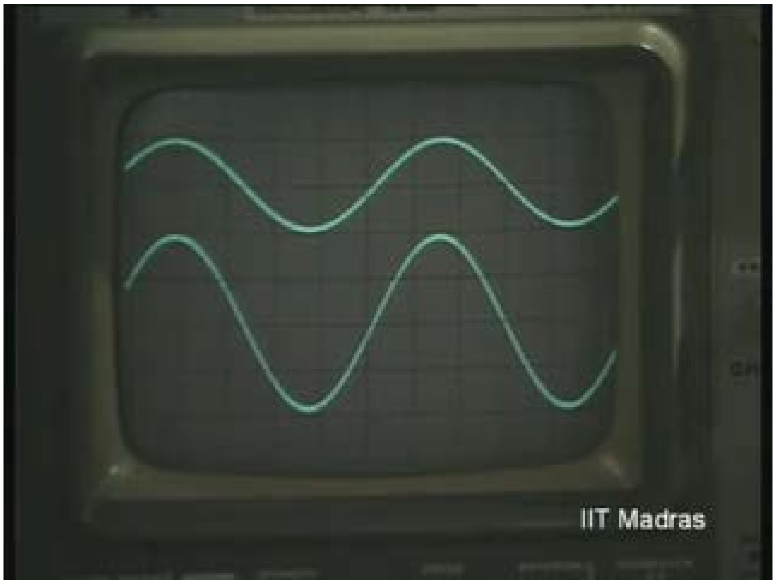

And, you can see the amplification by a factor of 2. Now, she will short the 10 K so that output is going to be equal to input; because the feedback factor is 1. See, though the gain is equal to 1 here and in the other case gain was equal to 2. By changing the feedback factor from one to half, gain is changed to from 1 to 2. Now, she will apply a larger input voltage; input voltage is going to increase and you can see the distortion appearing.

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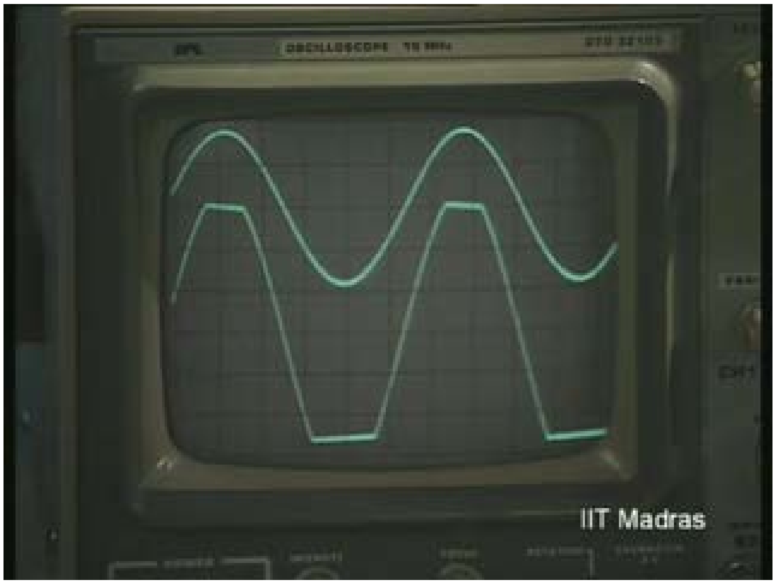

So, see the supply voltage is plus 15, minus 15; and therefore, the distortion has started appearing at the top as well as bottom. So, this is because of the supply voltage limitation. The input is increased and output is getting limited to plus supply voltage. That is 15 volts on the top and minus supply voltage at the bottom.

If you see the scales, you can see that it is now peak-to-peak value of about 30 volts; and therefore, this is called saturation non-linearity. Now she will reduce, so that the signal is not distorted. Now she will apply a square wave as the input; square wave as the input and we can see that the same thing is happening. Input is having some voltage and the output is double value of input voltage.

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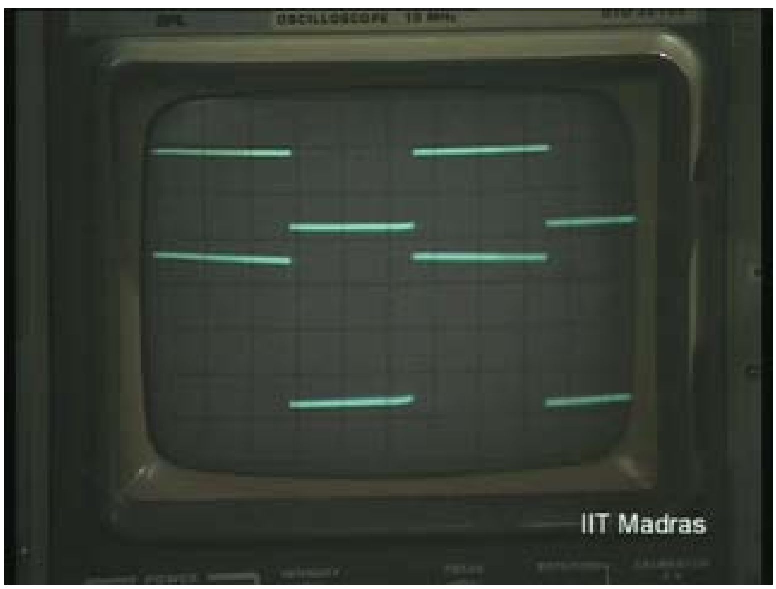

And now, the square wave frequency is going to be changed. This is low frequency. You can see that the output is going to be distorted further.

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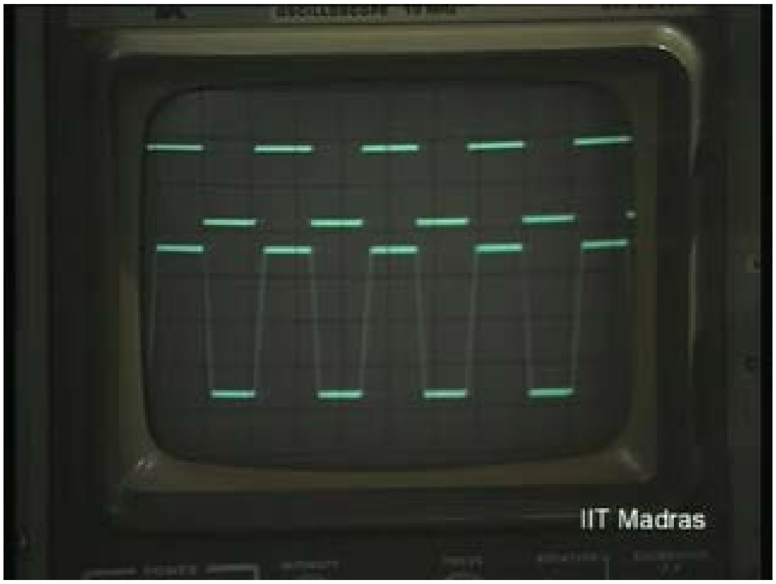

Input is remaining a square wave.

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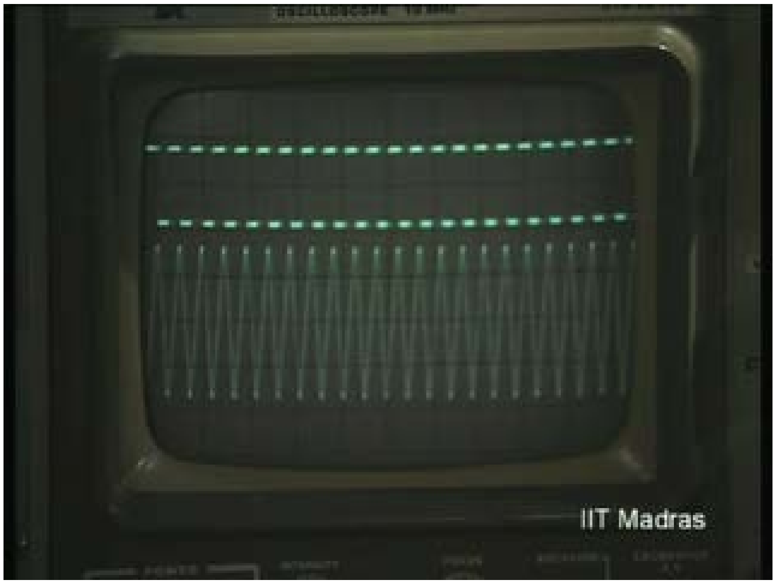

Now, she is changing the scale of the oscilloscope and you can see that the output is going to be distorted. You can see the screen.

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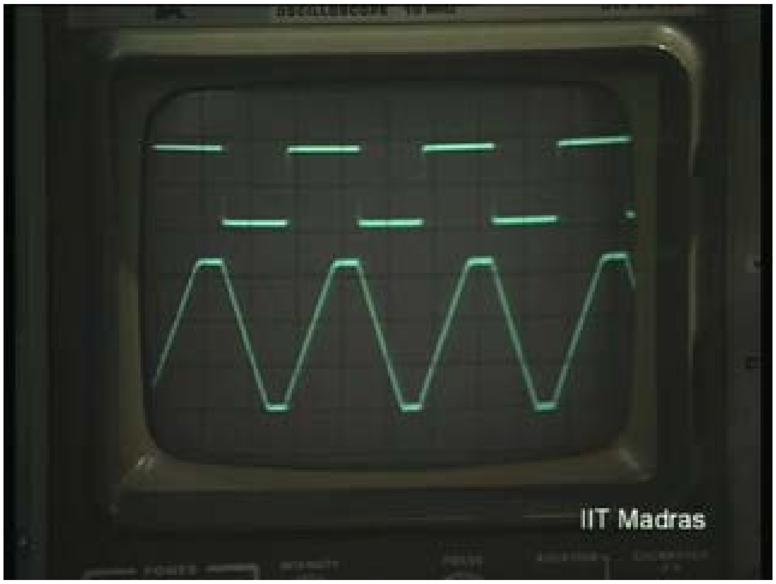

See. The input is a square wave; output has started becoming a triangular wave, trapezoid.

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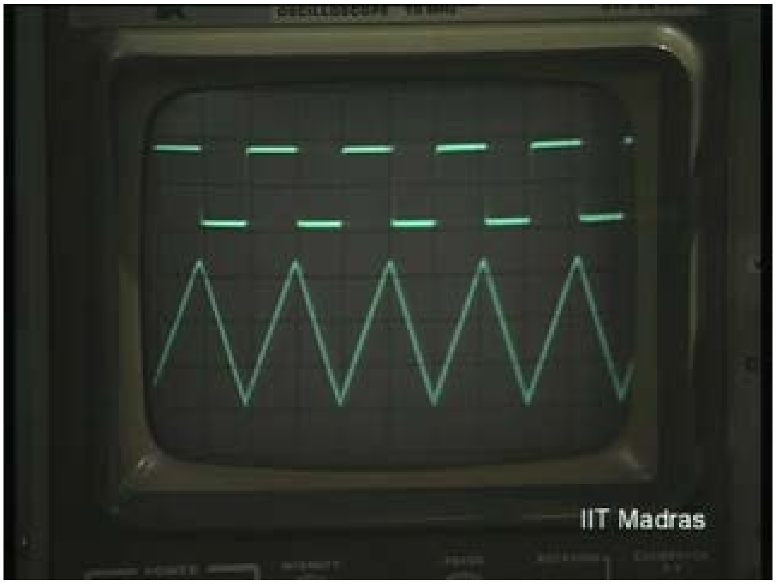

And, you can see... now, further increase in voltage will make it almost triangular. So, this triangle indicates that the output of the op amp is not able to rise as fast as the input. That is because of what is called as the slow rate limitation of the op amp. So, output is only rising at a constant rate. After a certain point is reached, output is rising at a constant rate; and therefore, when the input is square wave, output should have been a square wave and this is the distortion that is set in by the limitation of the operational amplifier and this demonstrates clearly that the op amp cannot be used for very high frequencies.

Now you can see here. As the input was a sine wave, output was an amplified version of the sine wave; that you saw. And the... when this is a square wave, this also became an amplified version of the square wave. This also you saw.

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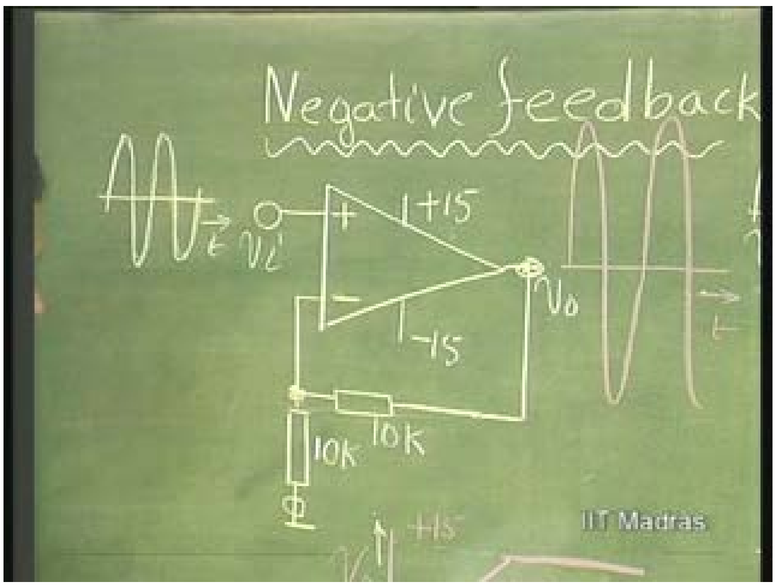

And we can actually now see the output versus input characteristics, which will be like this.

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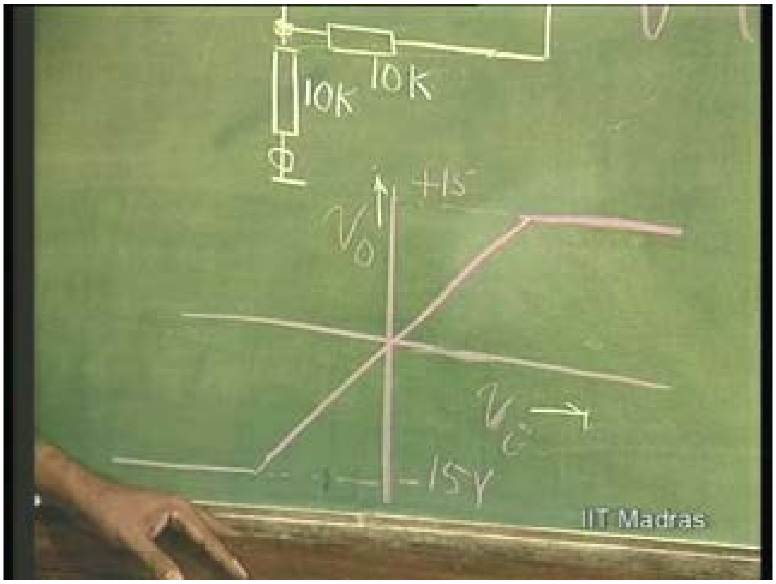

If output versus input is plotted, then it will be linear because it is going to be a factor of 2 gain or 1 depending upon the feedback. So, this slope will be constant and it will be linear; and after it reaches 15, that is, if it is unity gain after V i reaches 15 volts, saturation is reached. If it is gain of 2 after V i reaches 7 point 5 volts, output reaches saturation.

That is what you saw. This wave form became like this. At plus 15 and minus 15, it got saturated. Further increase was not possible at all. So, this is depicted as a transfer function, V naught versus V i in the following fashion. Linear here and saturating non-linearity here.

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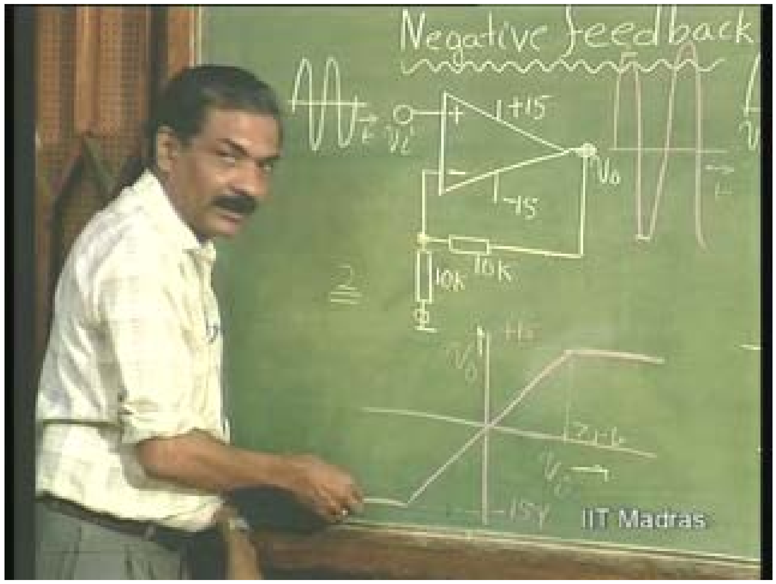

This is going to be demonstrated there on the screen also. You can see. With the help of the oscilloscope, we have plotted V naught versus V i; and we can see that it is absolutely linear, as I have plotted it on the board.

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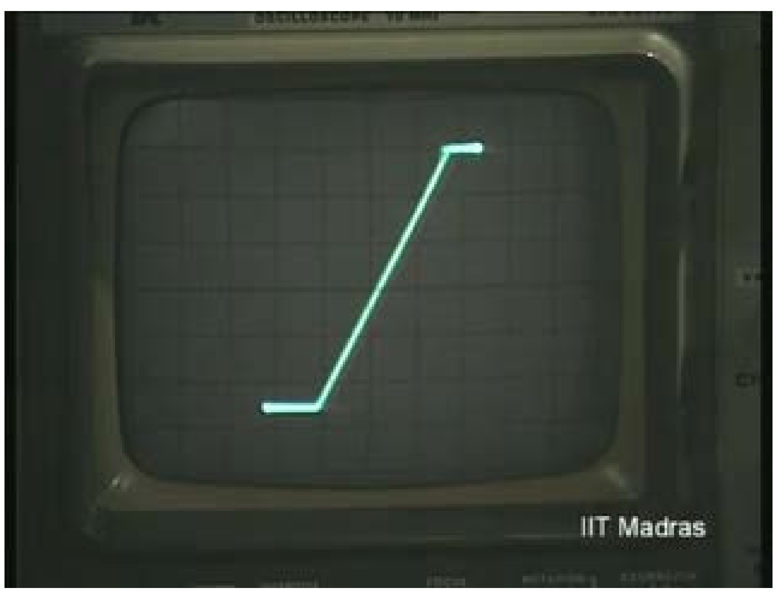

So, you can see that it has reached the saturation at 7 point 5 volts input in both; and saturation value is plus 15 on positive side and minus 15 on negative side. This plot has been obtained by just plotting V naught of the output of the op amp versus V i.

You have just now seen a nice demonstration of negative feedback. The circuit was this. I wanted to retain the same circuit configuration except that I am now changing plus and minus of terminals of the op amp. The same circuit configuration; but plus, minus, only is interchanged.

You just see here. This and this you see. But it is a vast difference in performance. This is what is called regenerative positive feedback circuit or Schmitt trigger, which has been discussed earlier; and here, output can remain either at plus or at minus; it cannot remain at intermediate point at all.

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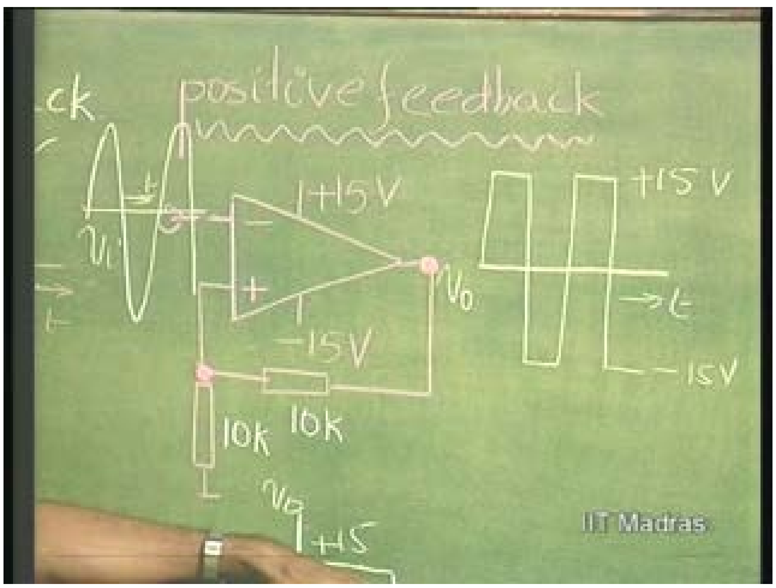

So, it can either remain at plus or at minus; and if the input is a sine wave corresponding to a voltage here, which if this has gone to plus 15; let us say, in this case at 7 point 5 volts, regenerative feedback sets in. And if the input is increasing, at 7 point 5 volts, it changes state. So, from let us say, minus to plus or plus to minus, in this case. Originally, we had estimated it to be plus. So, from plus to minus it will change state; and at 7 point 5 volts; and again when the voltage is decreasing, nothing happens.

And at this particular point, when the voltage is again coming back at minus 7 point 5 volts, it will change state. So, because this has gone over to minus V s, this becomes minus 7 point 5 volts. So, the input when it reaches minus 7 point 5 volts again, it changes state. So, output is going to be a square wave for an input which is a sine wave. At plus 7 point 5, change of state occurs; and at minus 7 point 5, change of state occurs; and you get a square wave.

The input necessarily has to cross 7 point 5 in order to obtain the square wave. If it is less than 7 point 5, then there is no change of state at all occurring. You will see that output will remain at saturation; either plus V s or minus V s. The moment input rises above 7 point 5, it will suddenly become a square wave. This is the characteristics of the Schmitt trigger. In fact, if you see this demonstration now, you can see...

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The circuit connected this way... She has only changed the plus minus terminal of the circuit. And now, the demonstration. You will see clearly the input sine wave being given and output is a square wave.

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See. And you can also note the fact that change of state occurs from minus to plus at minus 7 point 5; plus to minus at plus 7 point 5. Please decrease the voltage, input voltage. Decrease. If the input voltage is decreased below 7 point 5, output just goes to saturation.

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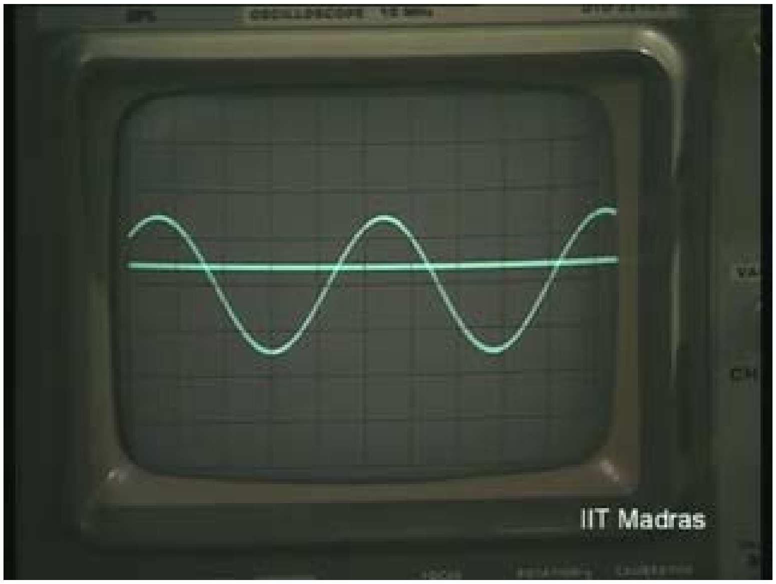

Slowly increase. Yes. So, slowly increase; it has gone to square wave. Again, please concentrate on the screen alone.

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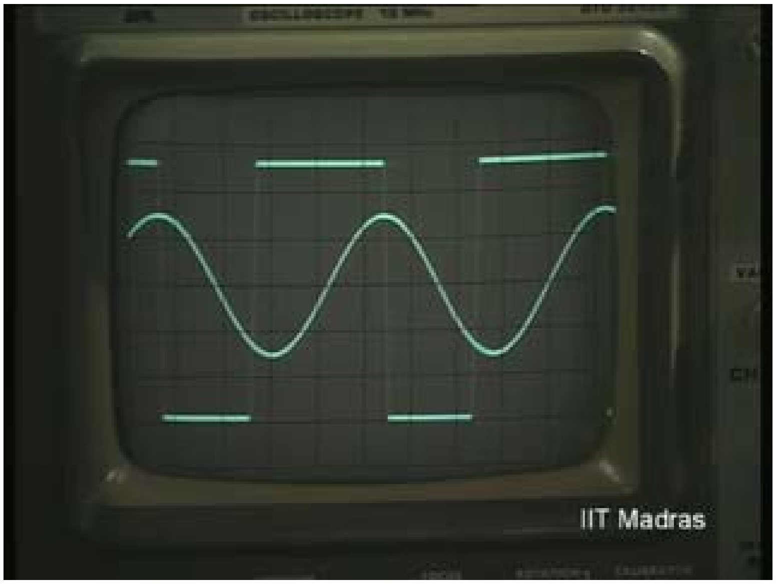

Now decrease the voltage. See. Increase the voltage. See. So, if the input crosses 7 point 5 volts, immediately, output becomes a square wave. Now, let us come back to the theory behind this.

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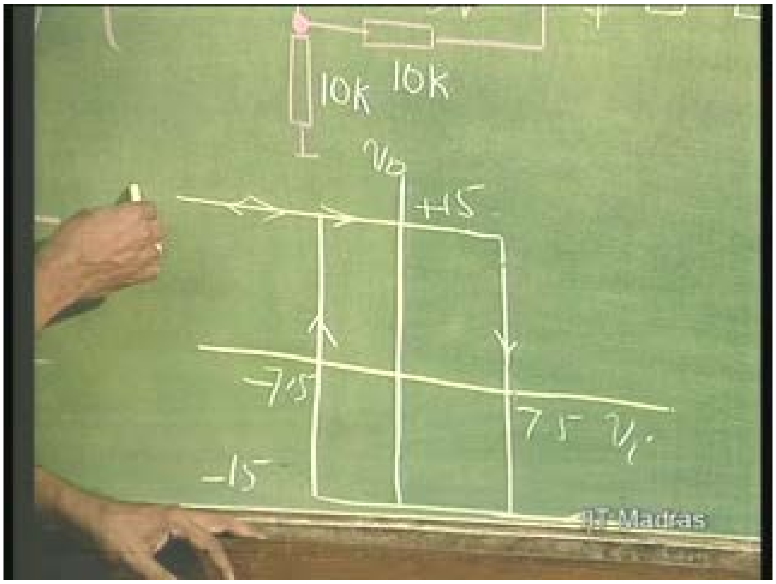

V naught versus V i... if you say, suppose V naught is at plus 15, this is a plus 15, and V i is going to be large negative, it is going to get plus 15 and then this is plus 15; this is going to be at plus 7 point 5 volts.

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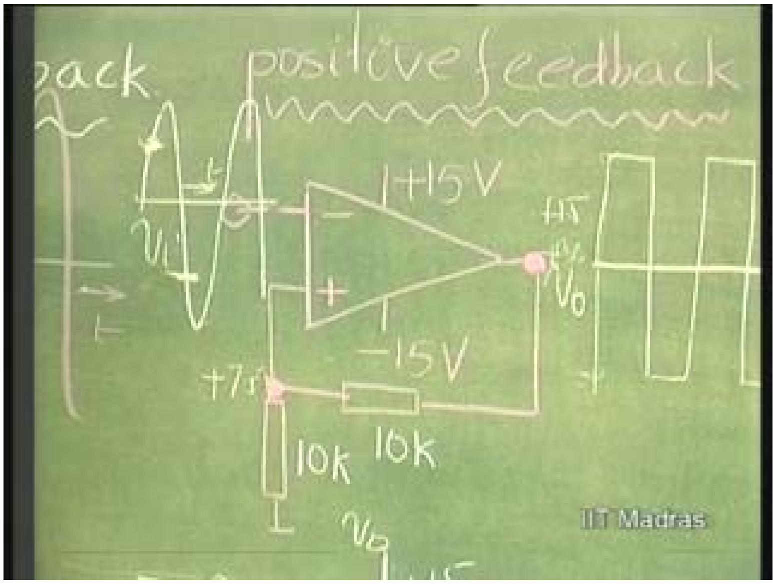

So, only when input reaches plus 7 point 5 volts, the change of state occurs from plus to minus. So, this is the characteristic; and then the input further decreases...since it has already reached minus 15 here, this will be minus 7 point 5 volts. At minus 7 point 5 volts, it changes state. This is what is called as hysteresis. This characteristic, V naught versus V i is again going to be shown to you on the screen.

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You can see. She has now plotted V naught versus V i. Earlier with amplifier, we saw that to be a nice linear relationship. Now you can see the hysteresis. And, if you decrease the input, please decrease the input.

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Yes. The hysteresis will go because the input may... see it has gone to only one saturation.

Now, increase the input. It exactly... Increase it further. You can see that stretching further... that stretches further, the saturation portion; but the hysteresis remains the same. Hysteresis is now going to be from plus 7 point 5 to minus 7 point 5.

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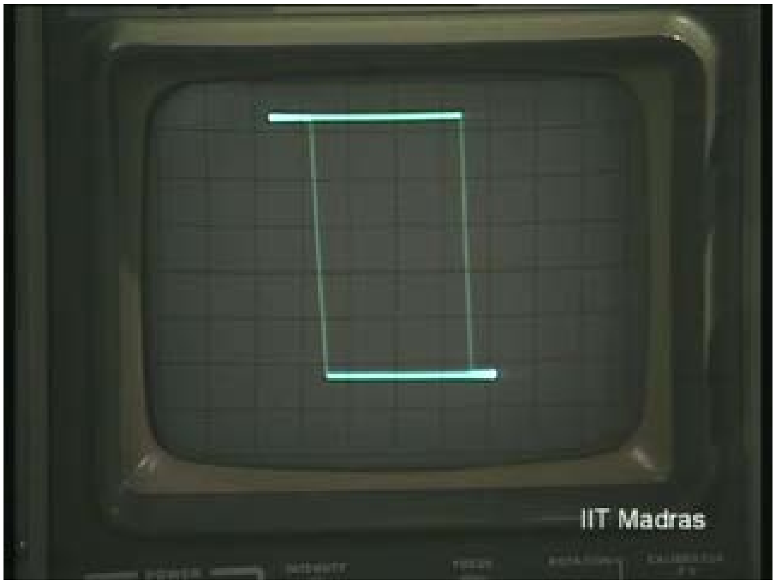

This is an important circuit called Schmitt trigger and it is having this kind of property – that, any periodic wave form given like this can be converted into a very nice square wave.

The rate at which output changes is determined by only the op amp; and once again we can see the rate. She will expand this in terms of time; and you will see that the rate at which it rises is going to be, obviously, will be the maximum rate possible for the op amp and that corresponds to slow rate.

So, this particular rate if you expand here, that is the property of the device; and this is going to be slew rate. What is slow rate? The slow rate is the maximum rate at which the op amp is capable of changing, independent of the input. That rate is called the slew rate; typically of the order of volts per microseconds it is.

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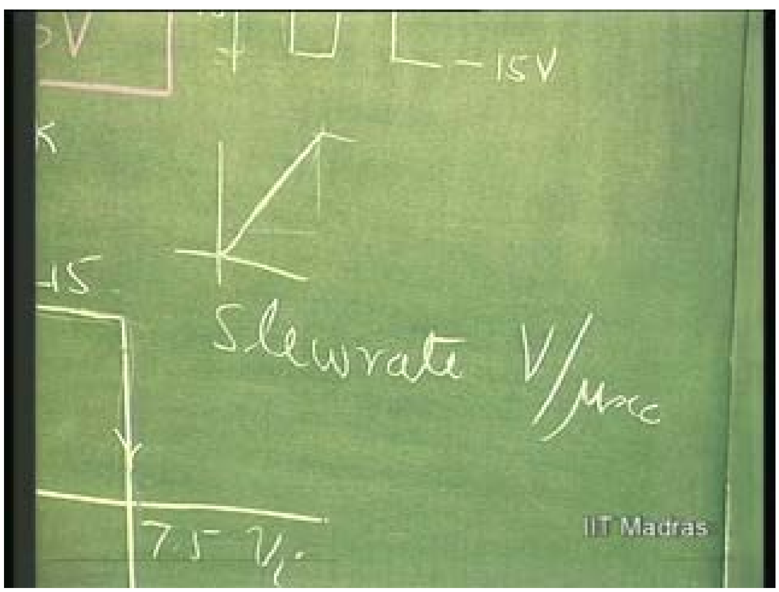

So, this is slew rate. It is going to be typically of the order of volts per microseconds. If therefore, she expands the time scale, you can see clearly the slew rate effect. Please see the screen. Yes screen. Yes.

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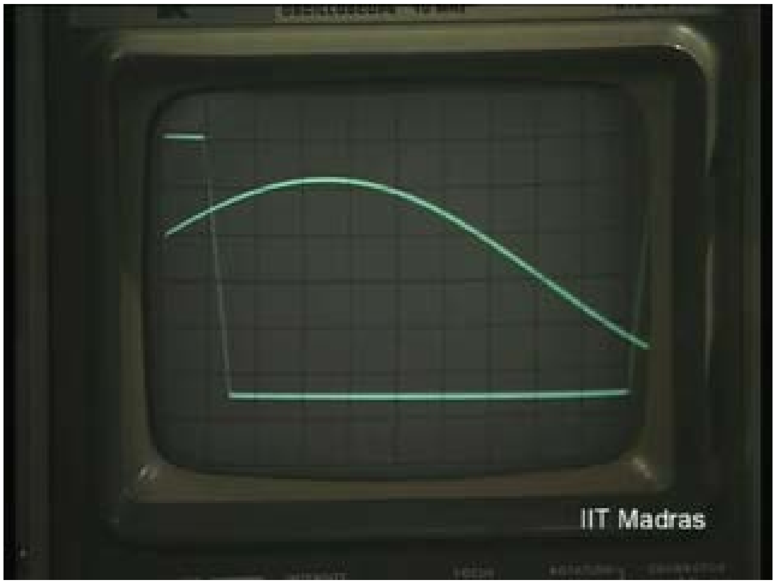

You can see that the sine...input wave form is a sine wave. Where the transition is occurring, it is not abrupt. There is a rate of fall which is determined by the slew rate. Now, there you can show with your finger; you please show that portion of transition. Yes. You please see - that rate of fall is going to be the slew rate.

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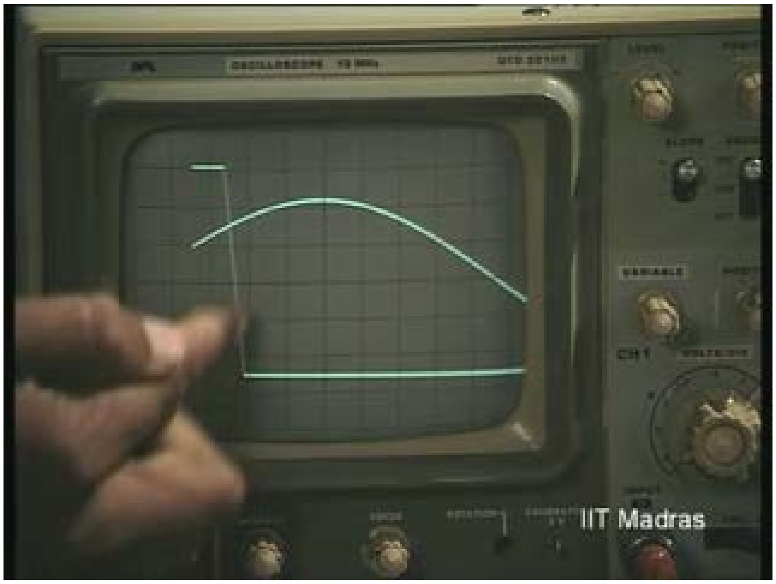

So, this is the fundamental limitation of the op amp. Apart from the gain bandwidth product, if there is a sine wave, that sine wave is going to be reduced in amplitude compared to the low frequency because of gain bandwidth product; but slew rate is essentially a large signal property where the rate of change of output gets limited to a fixed value.

Now we will use this Schmitt trigger that you have just seen working in an application called Astable multivibrator. It is a very simple circuit which comprises the same Schmitt trigger 10 K, 10 K. Therefore, change of state will only occur at 7 point 5; plus 7 point 5 or minus 7 point 5. That we have seen. And therefore, I put an R and C network here. So, if it is plus 7 point 5, plus 15 volts like this, this capacitor will start charging exponentially. So, this voltage here will keep rising.

As soon as it reaches 7 point 5, change of state should occur. So, it will go from plus 15 to minus 15. So, it will go to minus 15. So, this is time axis. As soon as it goes to minus 15, this capacitor will start charging up to minus 15 with the same time constant R C. This is time constant R C. This is time constant R C.

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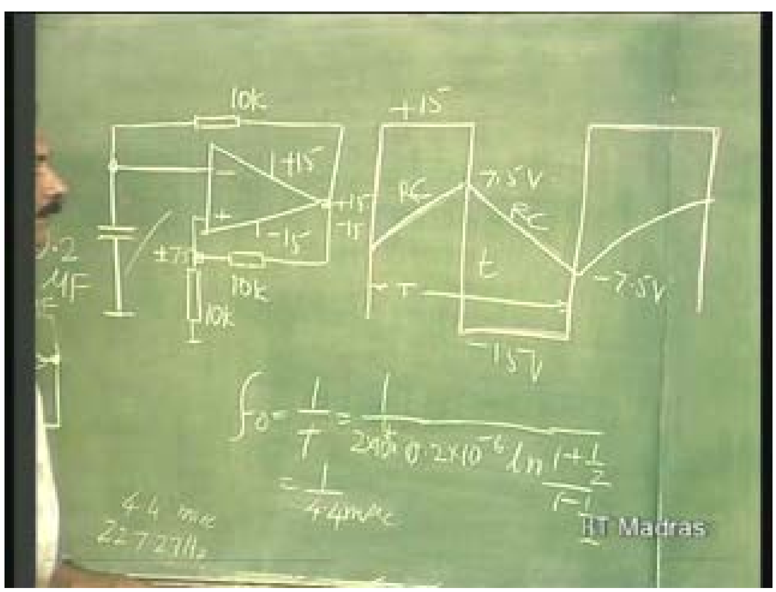

So, with the same time constant R C, it will discharge now. As soon as it reaches minus 7 point 5, again, change of state should occur. So, it will go back to plus 15. So again, capacitor will start charging. This will go on forever. That means this is automatically generating a square wave at this point and almost a triangular wave or exponential wave at this point across the capacitor; and frequency is equal to 1 over T. If this is the time period, this is T by 2 and this is also T by 2. This, we had derived in the class; and therefore, this is going to be... T by 2 is going to be equal to R C log 1 plus Beta divided by 1 minus Beta. Beta is this factor: 10 K by 10 K plus 10 K is Beta, which is half here.

So, T is equal to 2 R C; R is 10 K; C is point 2 microfarads. Log of 1 plus Beta, Beta, is half, divided by 1 minus Beta, 1 minus half, which is actually log of 3. So, this entire thing comes out as 4 point 4 milliseconds. T comes out as 4 point 4 milliseconds. That is the time period.

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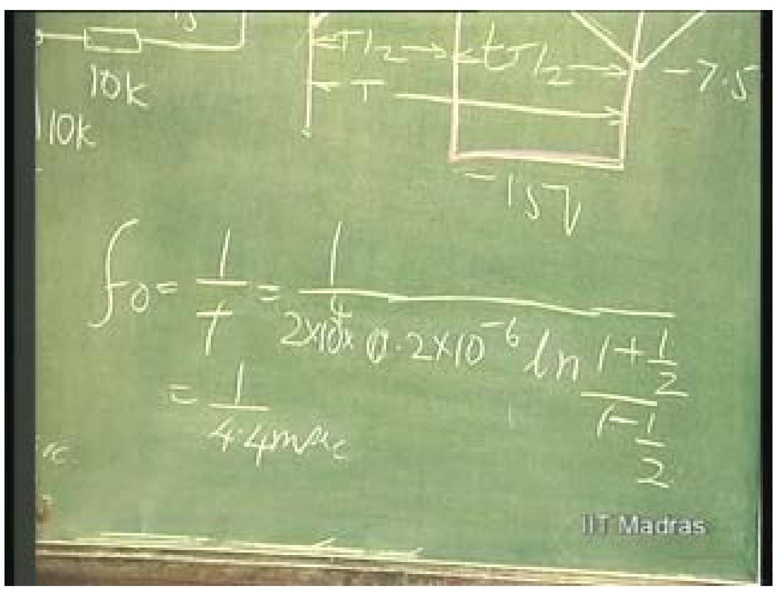

And therefore, if you measure the time period of the square wave, you should be exactly 4 point 4 milliseconds.

1 by 4 point 4 milliseconds corresponds to the frequency. So, this kind of circuit can be built very easily; and it has been built and demonstrated there. On the screen now, the circuit has been built and with R equal to 10 K and C is equal to point 2 microfarads and you can see the wave form on the screen.

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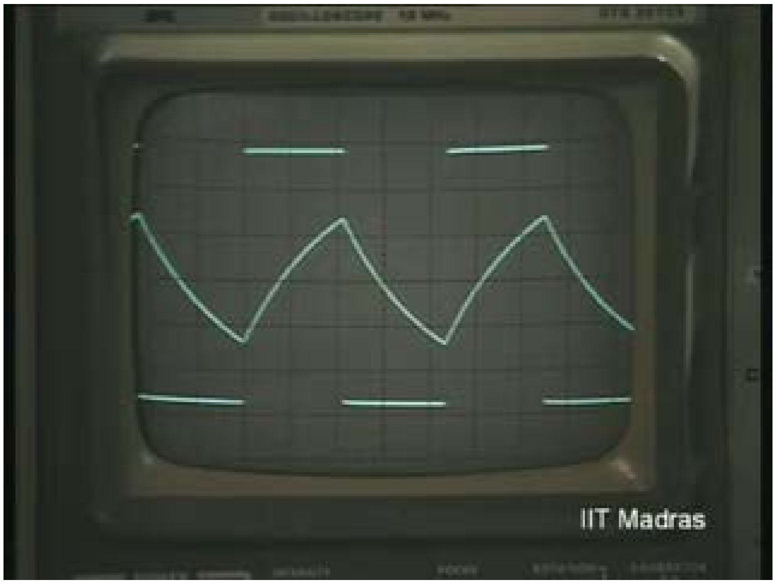

Now, see the wave form; exactly as depicted on the board. The V naught has gone to plus 15 and minus 15; and you can see... the peak to peak value of the exponential wave form is going to be plus 7 point 5 and minus 7 point 5. You are right. Exactly at half the point.

The rate of rise is the same as rate of fall; R C time constant. You can see exponential rise and exponential fall. And, if you can note the scale; Devaki, how much is the time period now? Measure time period. 4 point 4 milliseconds. Exactly that we had calculated is going to be what you get; and therefore, this circuit is popularly used as a function generator circuit.

Now that you have seen one application of the Schmitt trigger, another application of the Schmitt trigger also can be demonstrated clearly.

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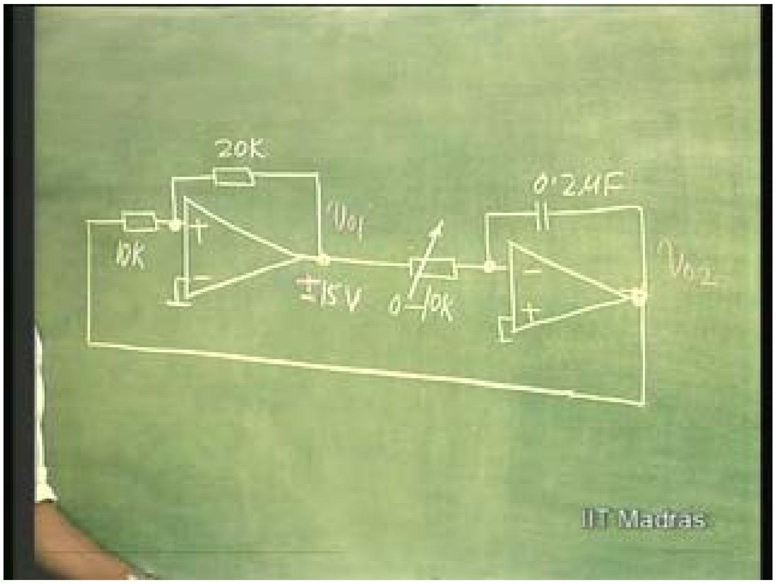

Here, you can see. This is the Schmitt trigger. You can see the regenerative feedback. Output is fed back to the plus terminal. Only thing is this is 10 K and this is 20 K. That means the Beta factor actually, the 10 K divided by 10 K plus 20 K or 1 by 3 instead of 1 by 2, earlier.

So, 10 K by 10 K plus 20 K - 1 by 3. That means, one-fifth of this voltage; this...one-third of this voltage. That is 5 volts. Plus 15 if it is, at 5 volts; that is, when this is minus 5 volts, this point will become... this point will become zero. If this is minus 15 when this reaches plus 5 volts, this point will become equal to zero.

Once again, let us say... if this is plus 15, if this is plus 15, this should reach minus 5 volts for this point to reach zero. That is when change of state will occur. If this is minus 15, this should reach plus 5 volts, for this to go to zero. So, then again, change of state will occur.

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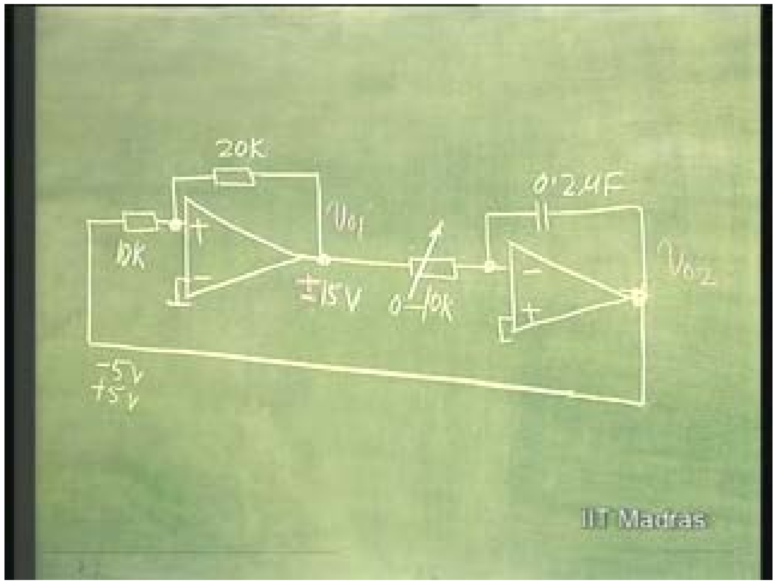

So, this is another Schmitt trigger. Unlike the earlier Schmitt trigger, where the hysteresis was coming like this, the hysteresis here is going to be the other way about. That, it is going to be starting from this negative, going up to this, and then changing like this, changing like this.

So, when this is supposed to be V i because this has been grounded, when this reaches zero volts, change of state will occur. That means, if you consider this as V i, and this as V naught, then this is plus 15 volts, output is plus 15 volts, only when input goes to minus 5 volts, input goes to minus 5 volts; change of state will occur.

When the output is plus 15 volts, only when the input goes to minus 5 volts, change of state will occur, from plus 15 to minus 15. Again, when it is at minus 15 volts, only when the input goes to plus 15...plus 5 volts that the change of state will occur.

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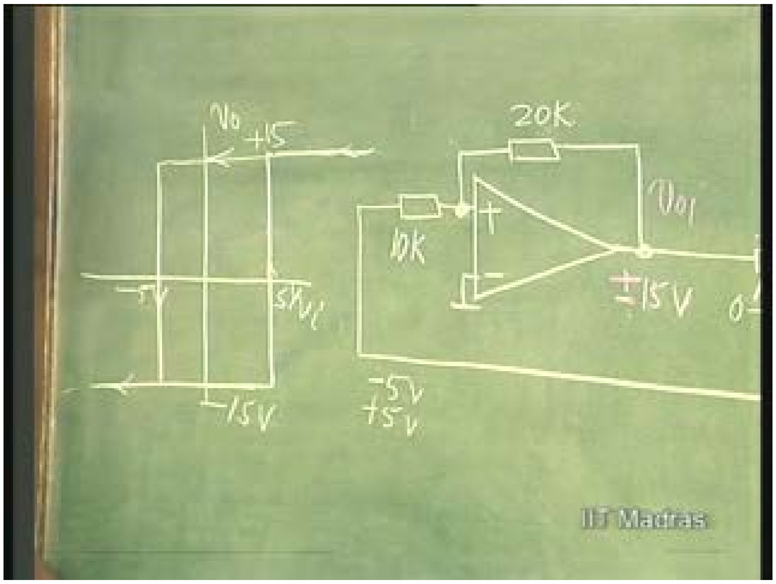

So, this characteristic is different from the earlier characteristics because the input is being fed here at this end and this has been grounded. So, that is all the difference; but it is basically a Schmitt trigger with hysteresis.

Now, let us see how this works with an integrator. Now, this is an integrator. This also we know. In our negative feedback now, this has become ground. That means this is virtual ground. So, if this is at plus 15, let us say, if this is at plus 15, the current will be going like this.

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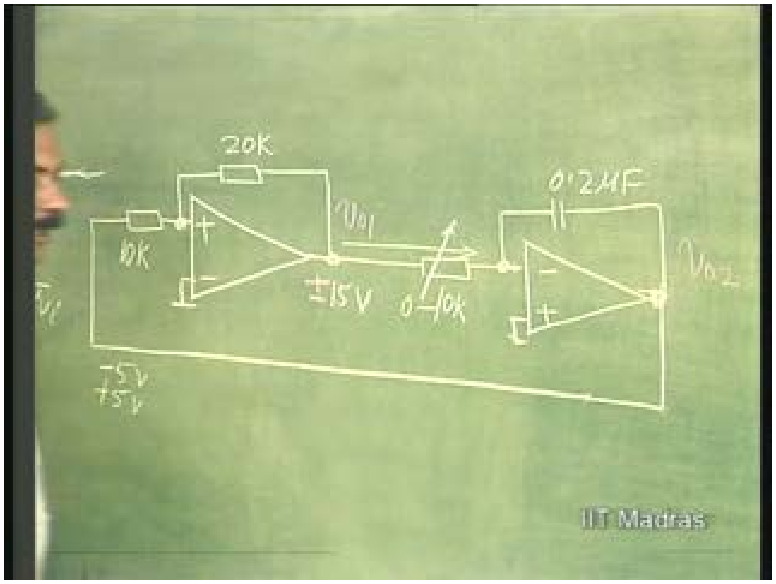

And this same current has to be pumped into the capacitor. So, this voltage will be plus 15 divided by R. If this is R, 15 by R. This divided by C into t; and this will be plus here and minus. That means this will be decreasing. This will be decreasing linearly. So, if this is plus 15, V naught 1 is plus 15, the voltage here, V naught 2 is going to be decreasing linearly. That is clear; because of this integrator.

So, this is a constant current being injected into the capacitor and that current will be going through the capacitor and developing a voltage which is minus 15 by R C into t; and output voltage is same as the voltage across the capacitor. So, it is going at minus 15 by R C into t; linearly, perfectly linear. As soon as it reaches minus 5 volts, the change of state has to occur from plus to minus here. This has to change to, from plus to minus.
Then, this will go linearly in this direction. Same rate; only direction is going to be different. So, it is going positive now with the same rate. Then, this will be plus 15 by R C into t. So, at that point of time, this will go like this, not like this; as soon as this become minus 15.

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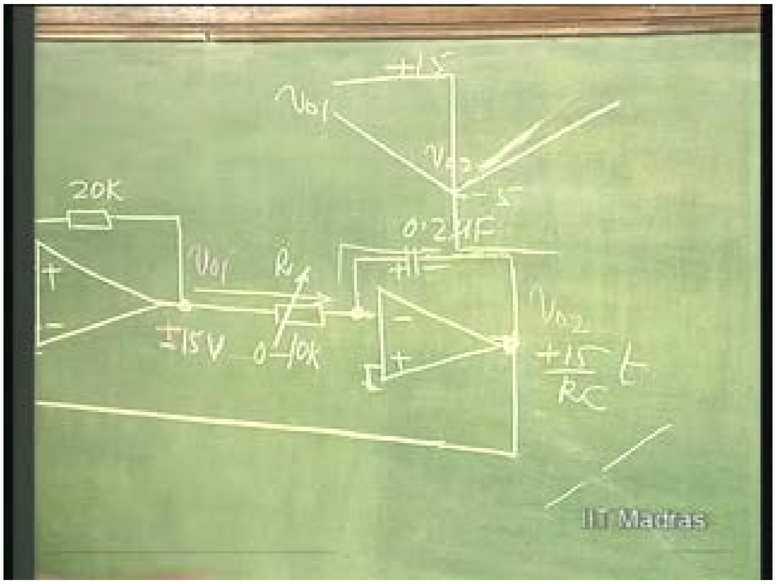

So, as soon as it reaches plus 5 volts, again, change of state will occur. It will go to plus 15. Then this will change again. So, it will go on like this. As soon as it reaches again minus 5 volts, change of state will occur. This will keep on repeating.

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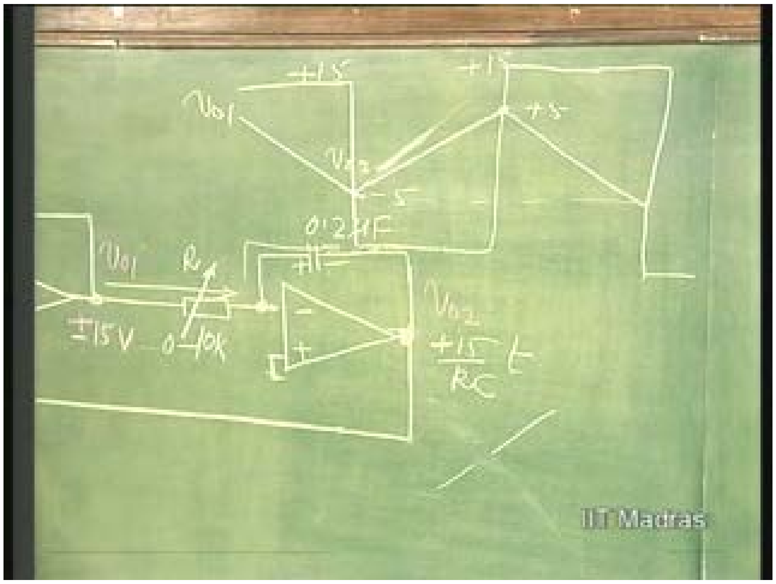

So, once again we get triangular wave form and square wave form, instead of exponent. This is a perfect triangular wave form and a square wave form. This is called function generator. It generates two functions; one is triangle; another is square wave. This time can be easily evaluated. This is T by 2. So, this is obtained by equating 15 by R C into T by 2 to whatever voltage it has changed. Within this time interval, it has changed from plus 5 to minus 5. See, the voltage acquired is plus 10; plus 5 to minus 5, within the time interval T by 2; and it was changing at this rate.

So, you can now evaluate the T as nothing but 20 R C by 15. 20 R C by 15 is the T, time period of this wave form. So simple and so direct.

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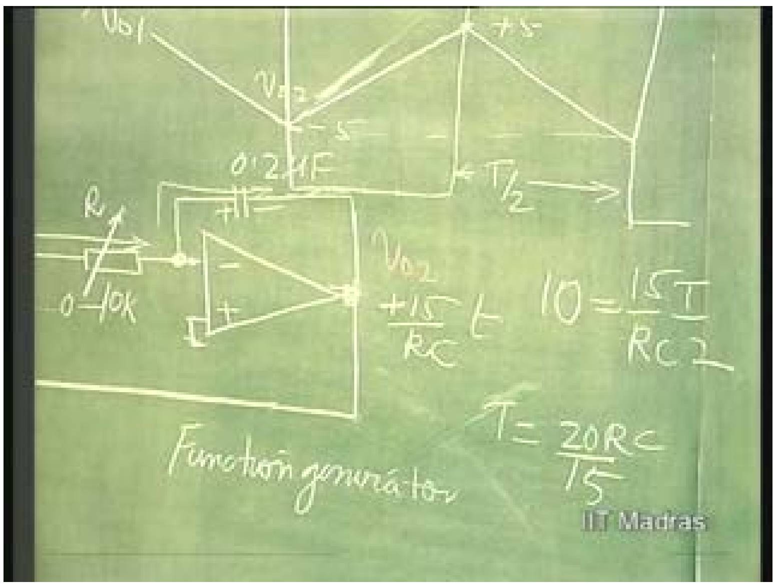

Obviously, if I make R different, it will keep changing. So, we will see this demonstration wherein this R is changed continuously and the time period of the wave form is changed continuously; and f is equal to 1 over T.

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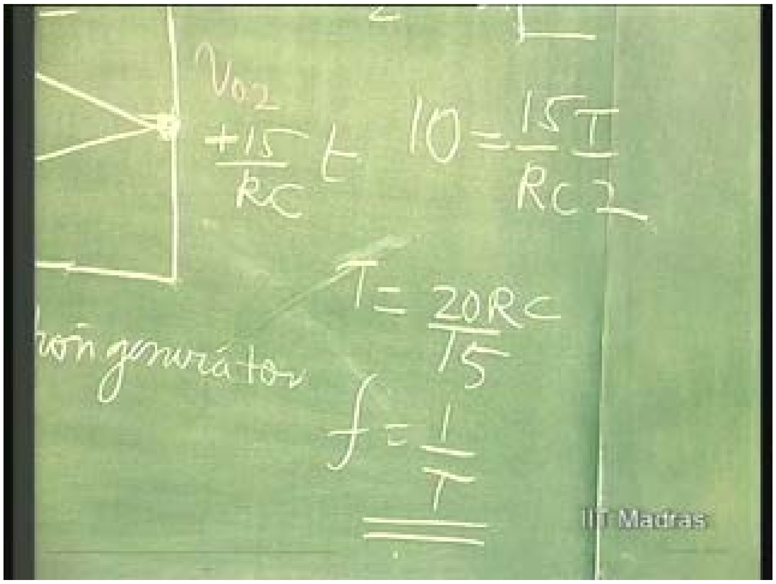

So, this is normally used in all test oscillators these days because this is a very cheap circuit and you can vary the frequency continuously by varying R or C; this is demonstrated now once again.

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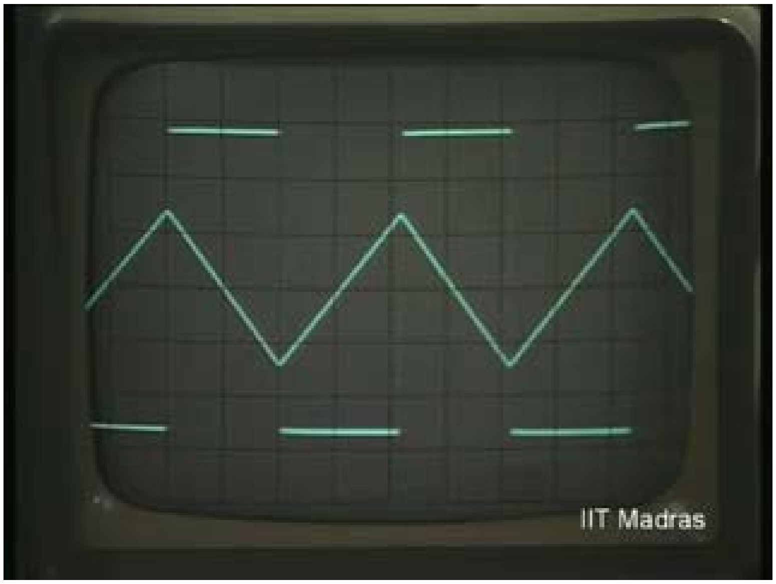

You can see this wave form. See the square wave. When it is negative, yes, when it is negative, it is linearly increasing and it is positive, it is linearly decreasing; and the rate of increase is same as rate of decrease. And it is a square wave. Now, she will vary the resistance R continuously. The frequency is changing continuously. See. Resistance is changed continuously and the frequency is changed continuously. See, yes.

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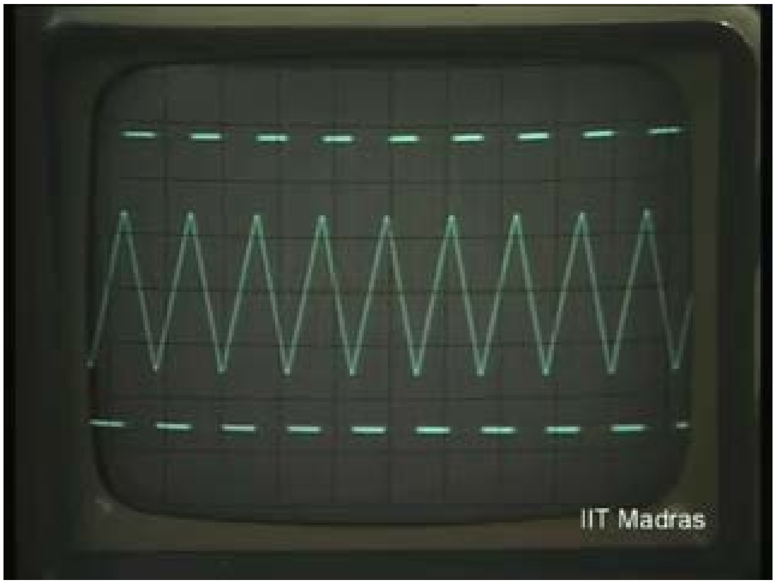

So, this is one of the popular circuits in electronics; and this is later going to be used also for voltage controlled oscillators.

We have just seen experimental demonstration of positive feedback concepts and negative feedback concepts, using operational amplifiers. Now, we would like to demonstrate similar experiment using differential amplifier, which is the most popular wide band amplified structure ever to be used in circuits. Therefore, lets us understand the basic principle of functioning of this.

I have now setup a differential amplifier with collector loads being 10 K each and it is being biased by means of a current source here; and the current source has 10 K, 1 K biasing. So, the voltage across this 1 K is going to be...15 volts is the total voltage. 15 by 11 K is the current in this; that into 1 K, that is, 1 point 36 volts is the voltage across this and about point 6 volts is going to be dropped here.

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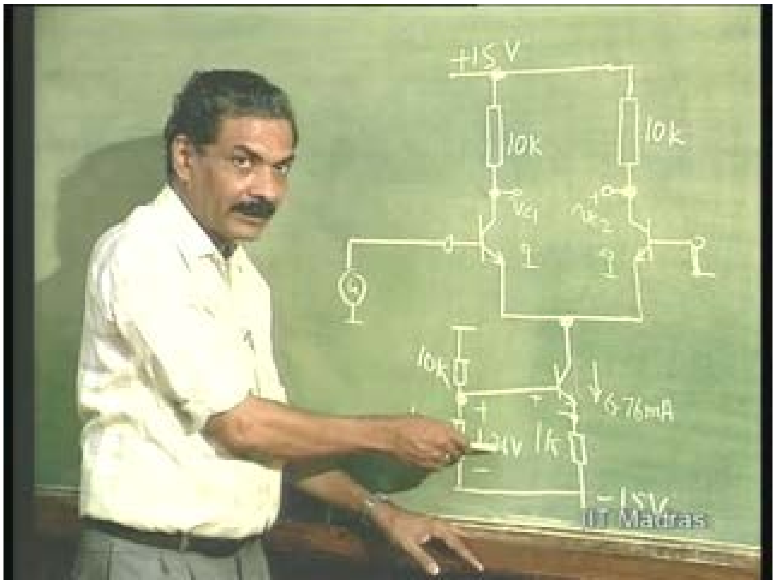

And therefore, this is going to be point 76 volts and that divided by 1 K is point 76 amperes. So, the current, source current is point 76 ampere. Half of this will flow through this if this is grounded. This will be a symmetric circuit. So, half of this, that means point 38 milliamperes each will flow through this and therefore the voltage across the 10 K, quiescent voltage drop will be 3 point 8 volts; very nearly 4 volts.

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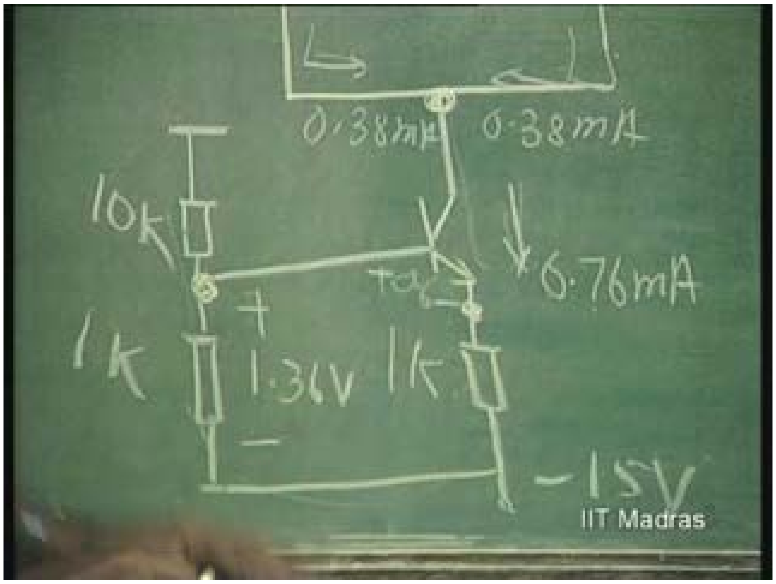

Therefore, this 15 minus 4 volts. Therefore, this will be 11. If it is 3 point 8, 11 point 2 volts, this also will be 11 point 2 volts. That is the quiescent state; that is a D C of 11 point 2 volts. If you take the differential voltage, it will be zero for a zero volt input. This is the quiescent state of this entire differential amplifier.

When I apply a signal here, this signal V i is going to be amplified to an extent which is g m into R C, if it is differential output; that we have learnt. It is g m R C by 2, if it is single ended output. From here to here, there will be a phase shift of 180 degree. This will be minus and that will be plus. From here to here, there will be a phase shift of zero. So, these 2 voltages will be in phase; these 2 voltages will be out of phase by 180 degree.

So, this is g m R C by 2. Gain is from here to here, single ended gain. g m R C by 2. g m is equal to I naught...if this is I naught, this is I naught by 2 divided by V T. This is the g m. In this case, it is going to be point 38 milliamperes divided by 25 millivolts.

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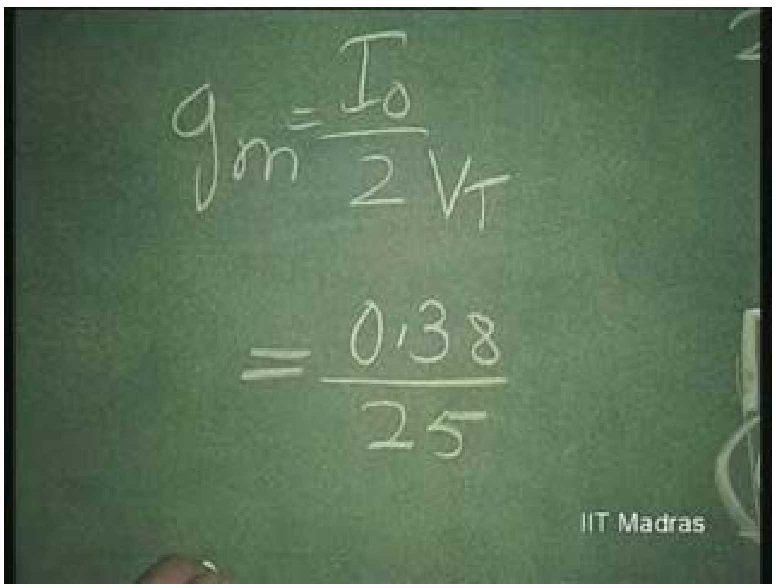

So, 25 millivolts; point 38 milliamperes. So many Siemens. That is the g m of the transistor. That into R C; that is, 10 K is the gain. So, the gain is going to be point 38 divided by 25 into 10 K; so, which is really speaking, equal to 38 into 100 by 25. Now, this is 4; it is about 152.

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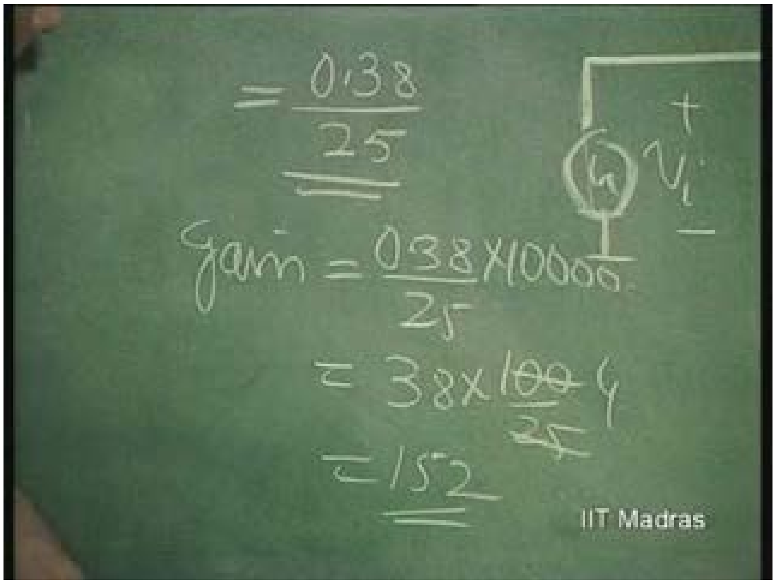

So, this is the kind of gain that you get if it is g m into R C. This is the differential gain. We want g m R C divided by 2. Therefore, that is single ended gain, is half of this - 76.

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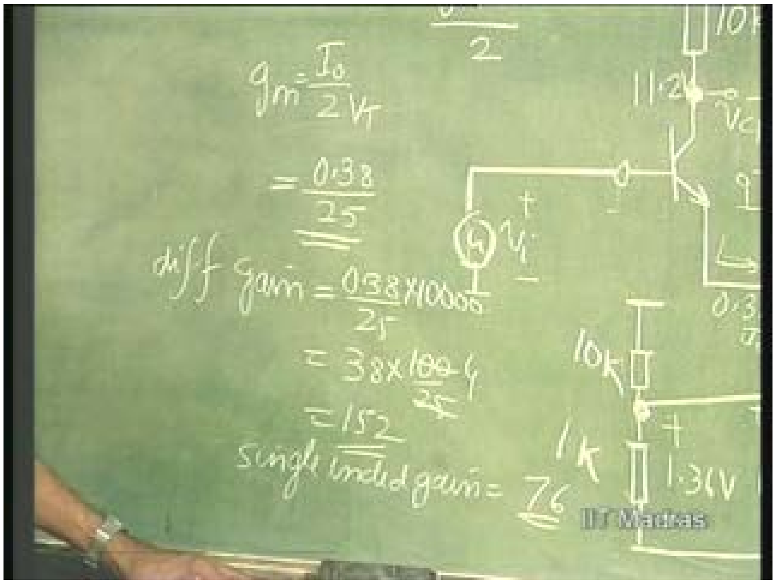

So, let us therefore now see the demonstration there. She has applied input voltage at this point. One of the base. You can see the input and output on the screen - these are now different scales. Please remember. Output is an amplified version of the input. So, these two are in different scales; but you can see the fish shape. The input and the output are out of phase by 180 degree.

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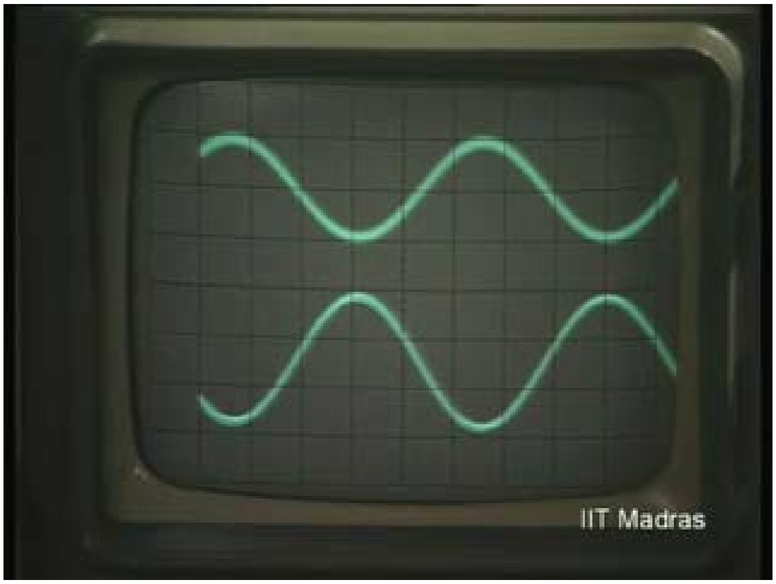

When the input is peaking, the output is minimum, going down. When the input is increasing, output is decreasing; so, indicating the phase shift very clearly. And what is the gain?

So, the gain is going to be... input is 20 millivolts peak to peak; input is millivolts peak to peak. Output is 1 point 5 volts. This 20 millivolts means actually very nearly...this is the limiting signal. After this, distortion will start setting in, actually speaking. So, 1500 divided by 20. So, you can say, about 75, which is nearly what we have computed also.

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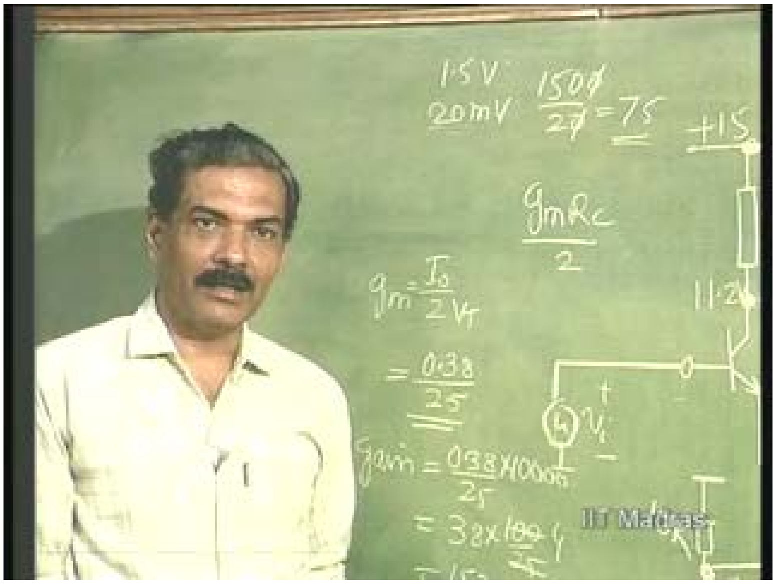

So, this tallies very well with the calculated gain; and you can now see that the signal is going to be increased and you can see the tan hyperbolic distortion, sets in as she increases the signal. Now she is going to another scale in the oscilloscope, because signal level is increased; much more than the original 20 millivolts.

Please increase the signal further. Yes. See. You can see the signal is increased. Now the distortion... This is the tan hyperbolic signal distortion. You can see both the sides. It is almost the same type of distortion that is occurring.

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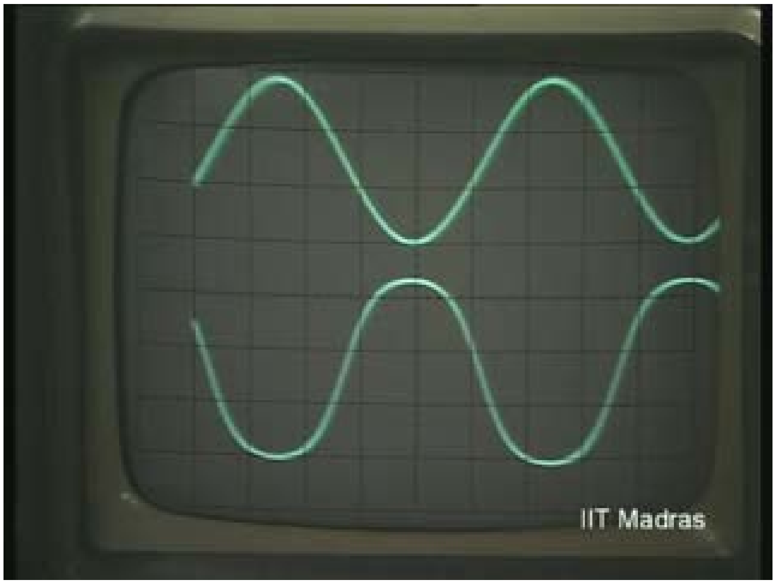

It is going to saturation. Now, further increase will make it almost look like a square wave. See. It is almost like a square wave now.

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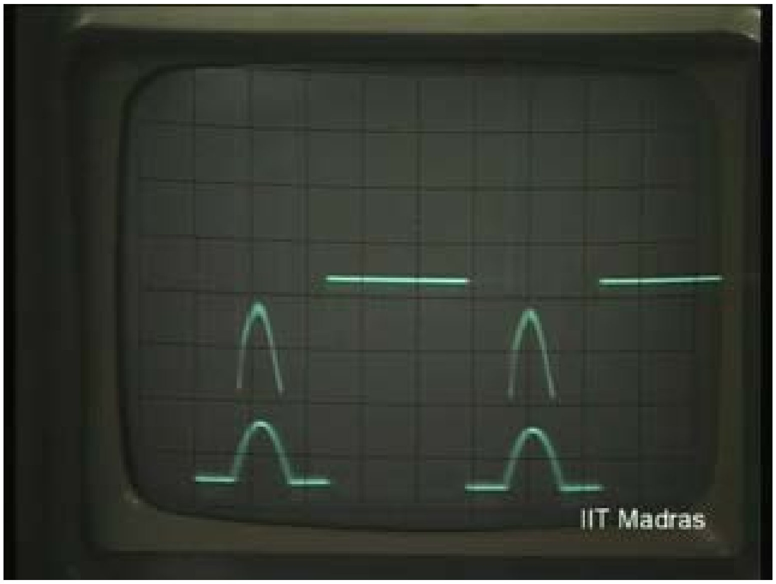

You can see that further she has increased it too much and now the transistor has gone to saturation.

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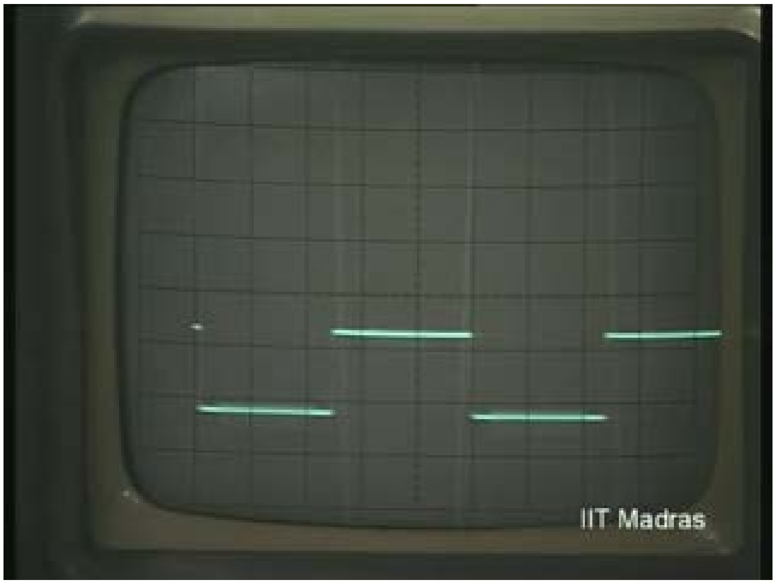

So, this is current switching.

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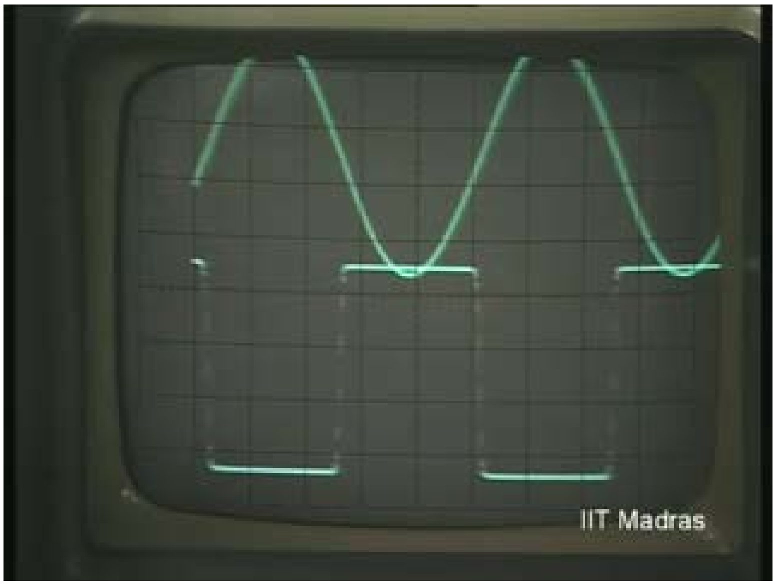

What is taking place is, ultimately, the entire current of point 76 gets switched over to this and this is deprived of any current. So, that is the limitation that comes about; and other side, this current goes to this side and this is deprived of current. So, it goes from V C C to V C C minus I naught R C. That is the limitation that is occurring on the transistor.

That is again seen on the screen. See the square wave. Input is a sine wave; output is very nearly a square wave.

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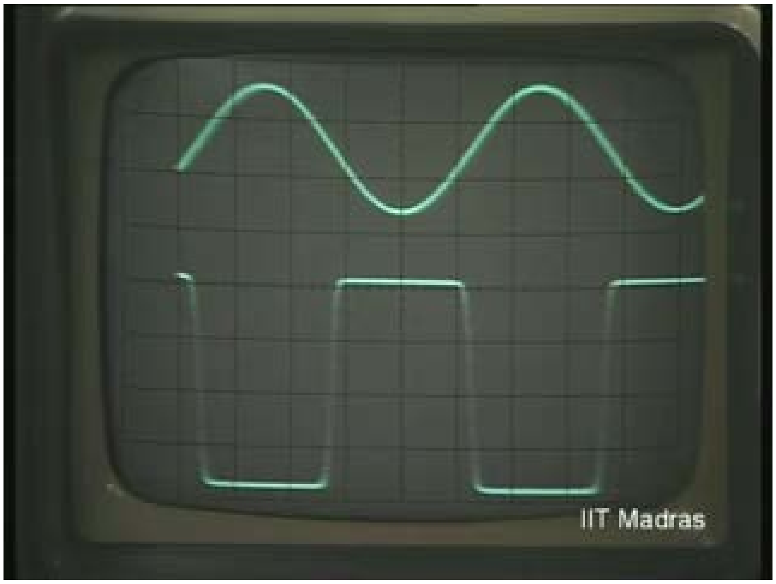

So, this is one another application of amplifiers; input can be converted to output square wave kind of thing using high gain amplifiers like this. This also is that. These are called comparators now, which will convert a sine wave into a square wave.

Next, we will now see that we are going to give the same input to both.

The same input is given to both. That means this is called common mode. Output here should be zero because both inputs are same voltages. Output should be strictly remaining at zero; but because of the non-ideality of the current source, etcetera, we will have some small output, even if the input is very large. So, please see that this method is going to measure the common mode gain. The output, now, divided by the input will give what is called the common mode gain.

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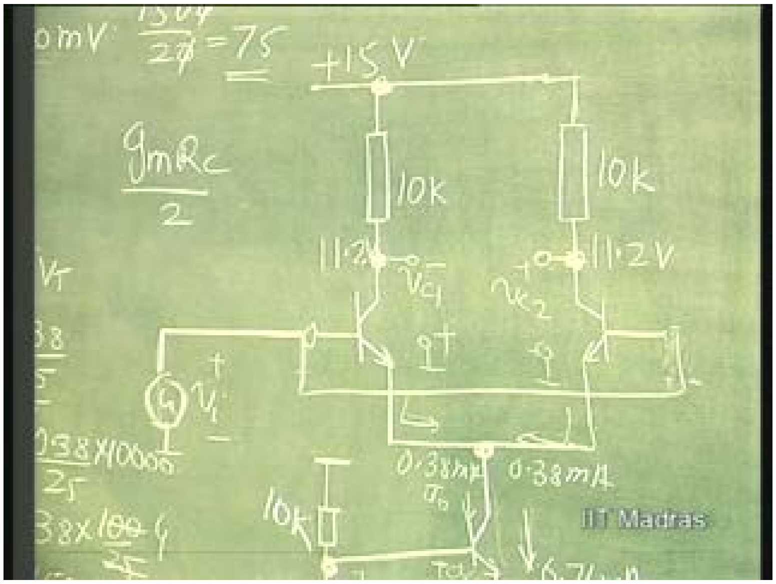

So, please see this demonstration. The input has to become very large. You should go to volts in order to see some output at all. So, output gets attenuated. There you see.

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Input is in what scale, Devaki? Input is in 5 volts scale; 1 centimeter is 5 volts. That means, input is very nearly equal to 1, 2, 3, 4, 5 - 25 volts peak to peak. And output is in what scale? 10 millivolts scale, output. And it is not even reading two divisions, right?

So, the common mode gain now is equal to 20 millivolts divided by 25 volts and that is equal to point 8 into 10 to power minus 3. You can see that common mode gain is very very low.

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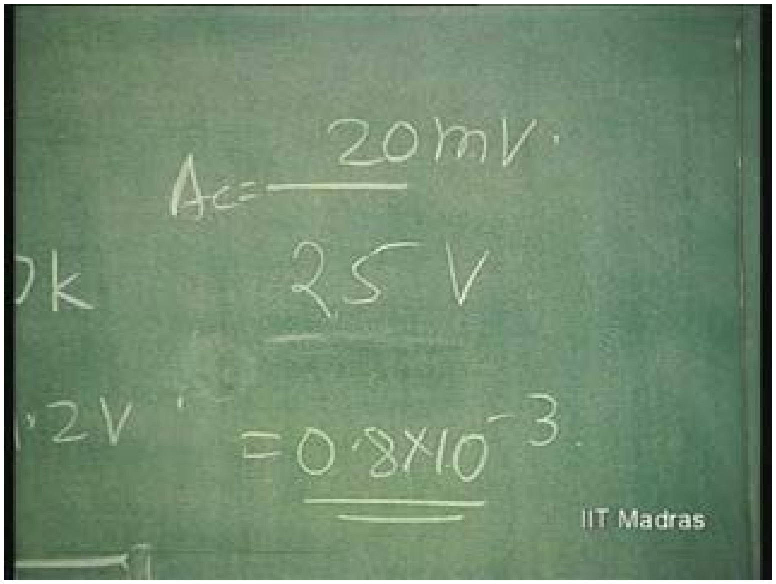

And therefore, A d by A c is this common mode rejection ratio, which is equal to 70... What we calculated was 76, divided by point 8 into 10 to power 3 and 9, 92, 95 – let us say, into 10 to power 3.

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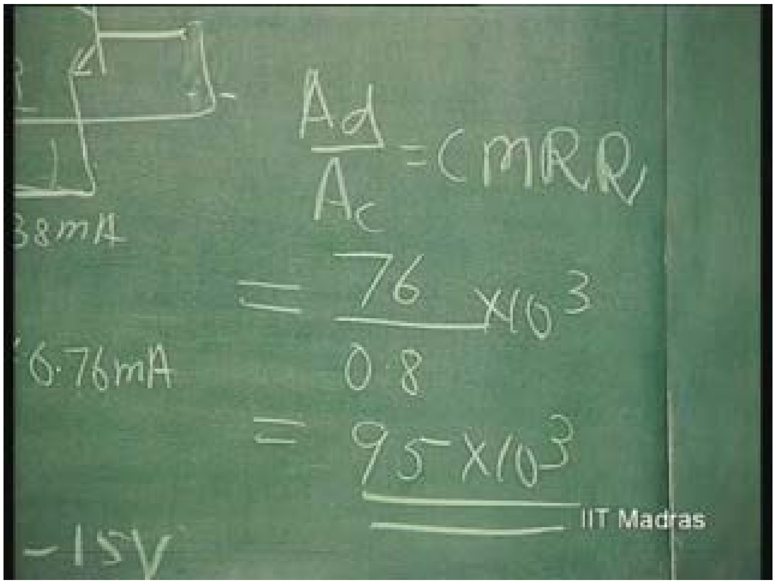

So, this is therefore the common mode rejection ratio. This is a good differential amplifier with very nearly 10 to power 5 as the common mode rejection ratio. A 10 to power 5 means, 20 log 10 to power 5, in terms of decibels. That is hundreds decibels of common mode rejection ratio this has. So, 100 decibels C M R R. It is a good differential amplifier.

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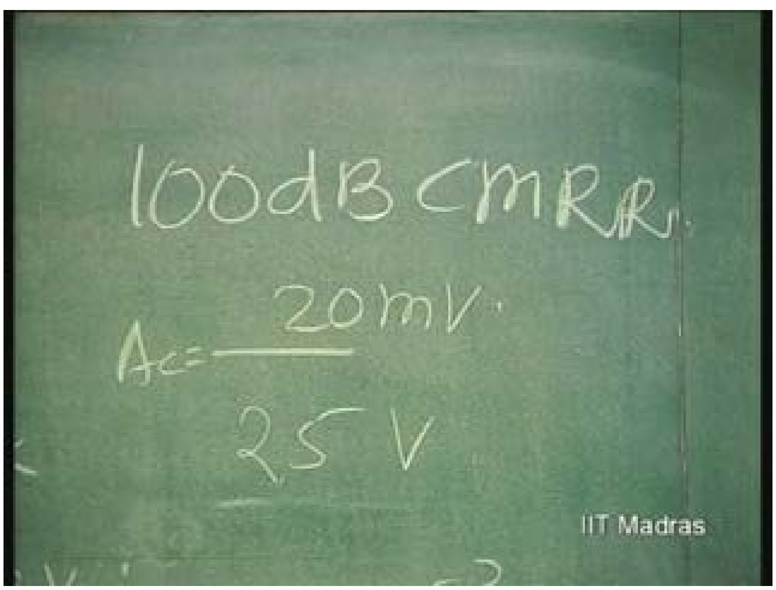

Now, we have modified the differential amplifier here. This is the feedback; emitter regeneration resistance. I have put a 10 K pod with the center tap connected to this current source so that we can adjust this balance here.

If there is some difficulty in making these two currents equal, so that this voltage becomes exactly same as this voltage, so that the output offset is going to be made artificially now equal to zero by adjusting this pod here, not only that this will also introduce negative feedback here, if it is exactly at the center, 5 K will be on this side and 5 K will be on the other side. If 5 K is getting added to other emitter resistance, g m of this is going to be reduced due to this 5 K added.

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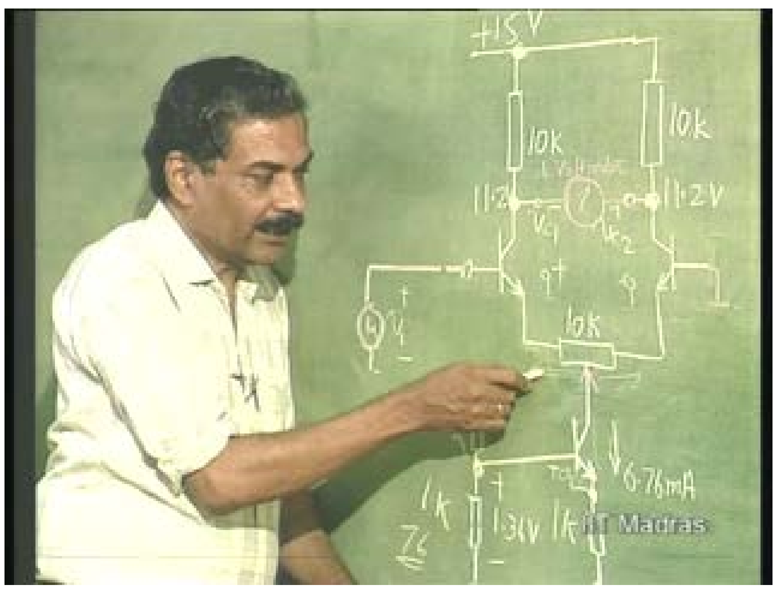

So, this 5 K and this 10 K will result in 10 K by 5 K as the differential mode gain for single ended output. That is, gain will be 2; and differential mode output gain will be 4.

So, we will demonstrate this now. First, you will see that this pod has already been adjusted so that this has been minimized. The offset here has been minimized to pretty close to zero. You can see the arrangement there on the demonstration setup. The pod has been adjusted so that in the volt meter, D C volt meter, the offset voltage is of the order of millivolts.

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So now, the collector volt is 10 K; and because of the adjustment, it will most probably get adjusted, when this is very nearly 5 K on this side and 5 K on the other side.

So, R e of the transistor is going to have 5 K added to it. That means g m is going to be 1 over 5 K and g m R C is going to be 10 K divided by 5 K which is 2. This is the differential mode gain. And therefore, the differential output gain... Single ended gain equal to 1. This is going to be demonstrated now on the demonstration setup.

You can see the output for a specific input. Devaki, what is the input? Point 4. So, the input is point 4 and the output is point 4. So, the gain is equal to 1; and you can see the phase shift of 180 degrees there.

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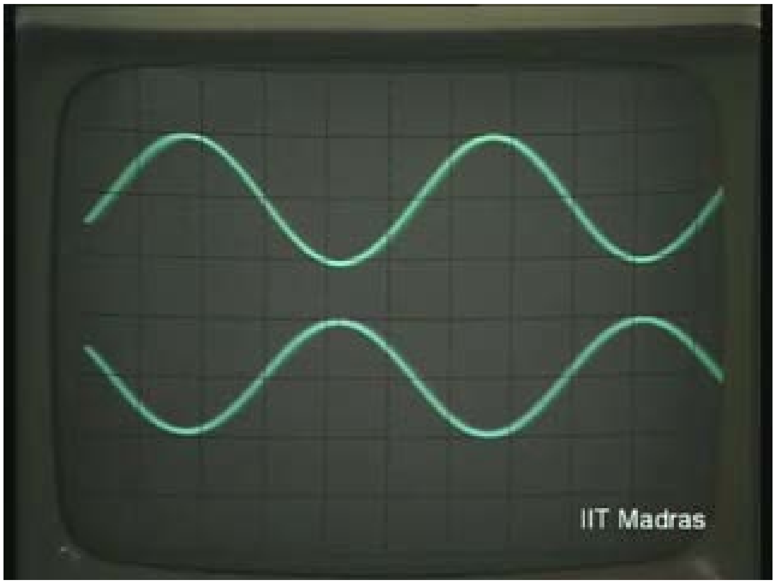

And please see the screen. Now, increase the input; increase further... further... further... Yes. Apply large input now, so that it will go to distortion. Now I can make you see clearly the distortion there. See, distortion has set in on one side; both sides distortion has set in.

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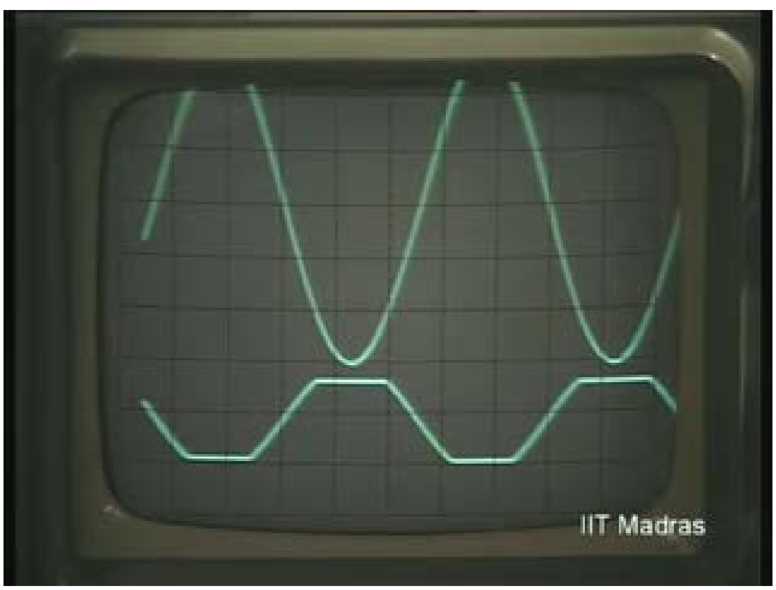

And further increase... You can now see that the transistor has gone to saturation; and on one side it has dropped the input itself. You can see the input peak appearing on the negative side. That is because the transistor has gone to saturation.

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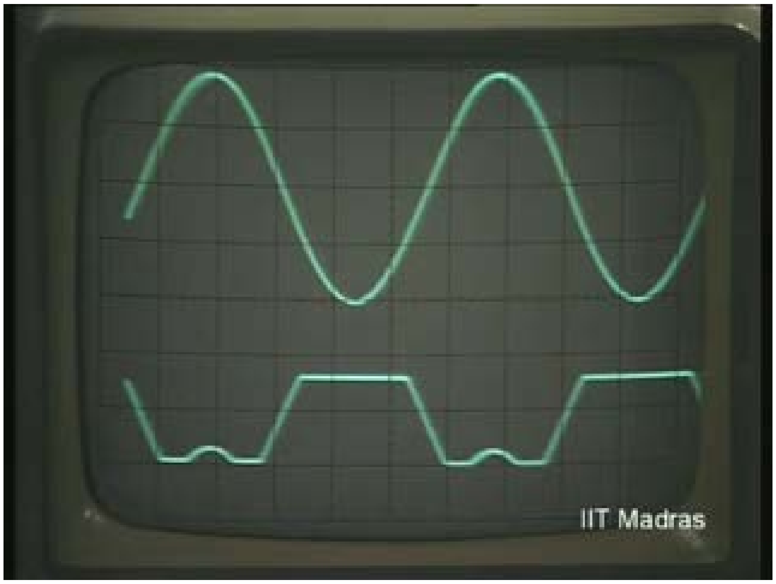

So, output is going to be same as input without the phase shift. So, you can see the input peak rising; on the other side, on the top side, the... the transistor has gone to cut-off; on the other side, the transistor has gone to saturation. There the input has peaked.

You show the peak also; and that peak is appearing. See... Now see... see, the input is now clearly visible. The transistor is not acting as an inverting amplifier at all; and the same input is appearing at the output because the transistor has gone to saturation.

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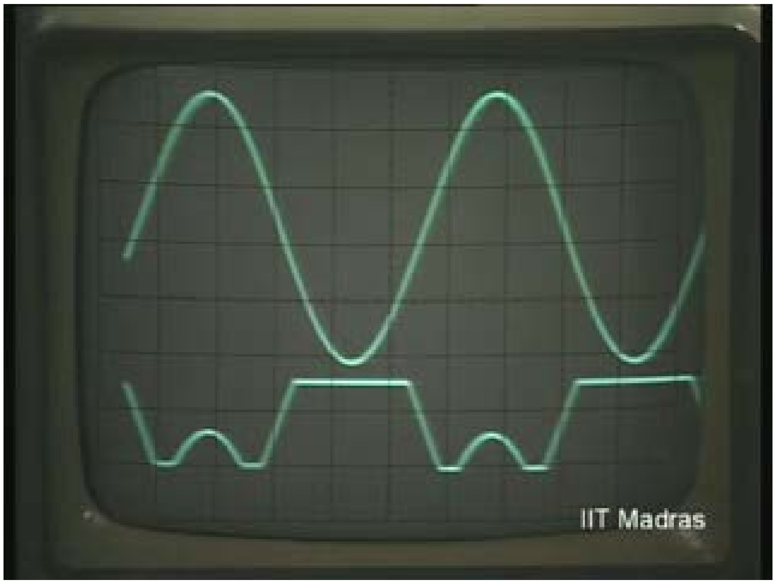

I wanted you to clearly see this kind of effect. How the transistor goes to saturation and it simply... output appears as the input. Now, reduce the input, further... further... So, the transistor has come out of saturation. It is only current switching that has limited. Now, the signal and output is equal to input.

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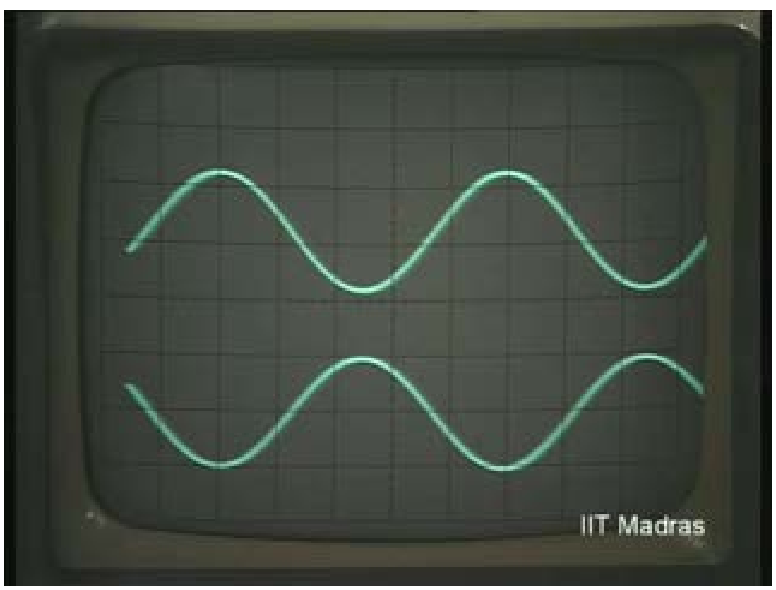

This clearly demonstrates the effect of negative feedback as well as the transistor going to saturation.