Basic Electronics
Learning by doing
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Lecture – 32
Non - Linear op Amp Circuits
(Comparators, with zero reference, hysteresis, noise ....)

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. As usual let us first recapitulate whatever we discussed in the previous lecture.

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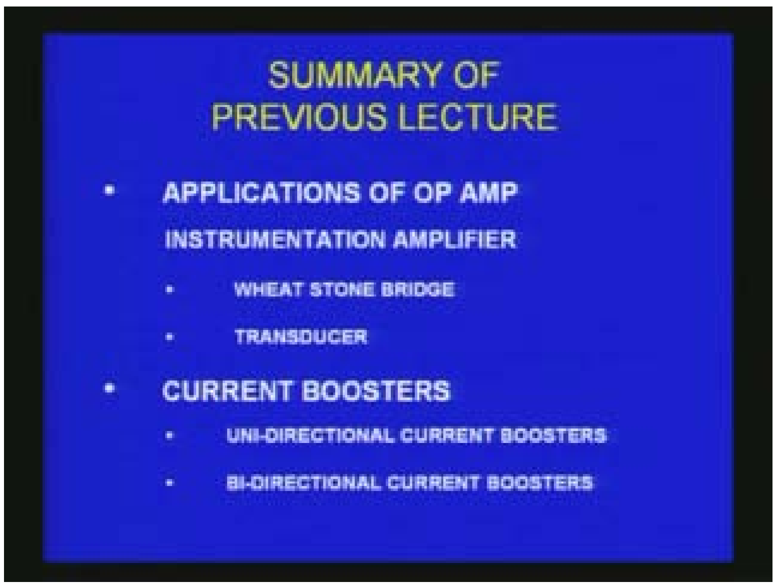

You might recall we discussed about the applications of operational amplifiers especially the instrumentation amplifier configuration how it can be used for amplifying the signal from a Wheat stone's bridge and we also discussed how in a Wheat stone's bridge you can have a transducer or a sensor, resistance sensor connected in the form of a bridge can be used along with the instrumentation amplifier so that you will be able to measure the different parameters like strain or the temperature etc. Then as the second application we also saw the current boosters. The basic capabilities of the operational amplifier are limited in terms of the output current. In order to boost the current much higher values like 1 ampere or even larger we must make use of what are known as pass transistors and we discussed about the various configurations; for example unidirectional current boosters and bidirectional current boosters. Now we let us move on to the next series of applications which will involve non-linear applications of operational amplifier.

Till now we discussed about the applications of operational amplifier where the output and the input had a linear relationship; something like y is equal to mx or V out is equal to A into V_i. The output voltage is V_i, the input voltage multiplied by A the gain of the amplifier. Then it becomes a linear device and the amplifier is basically a linear device. Now what we are going to do is look at some of the applications of operational amplifier in non-linear situations. That means the output and the input are not related by a simple constant factor. V out is equal to A into V_i will no more hold good but the output will have some relationship with the input certainly but it will be of a different kind. Let us see what it is? One of the simplest applications that I can think of is how we can compare two voltages? Which is higher in magnitude or lower in magnitude can be detected.

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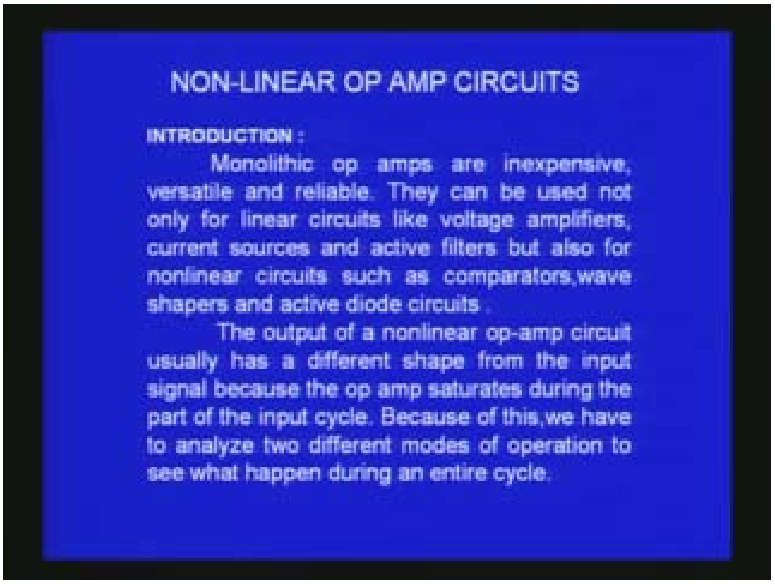

Such application circuits are useful in many situations. We will take up some examples and application of these circuits also at a later time. Because the monolithic op amps are inexpensive, versatile and reliable they can also be used for applications where it involves non-linear output input relationship. One of the simplest examples is a comparator. A comparator basically compares two voltages applied at the two inputs and the output will show which one is larger of the two or which one is the smaller of the two. The output can be completely a different shape with reference to time compared to the input. That is what I want you to realize here because there is no linear relationship. In the case of a normal op amp for example in the amplifier if there is a sinusoidal wave that I give at the input the output will invariably be a sinusoidal output. Whereas in this case if I give a sinusoidal input the output need not be sine. It can also be a square wave. Especially in the case of comparator when I give a sine wave it will become a square wave.

What is the basic principle of this comparator? Let us look at this basic principle. We all know about the operational amplifier.

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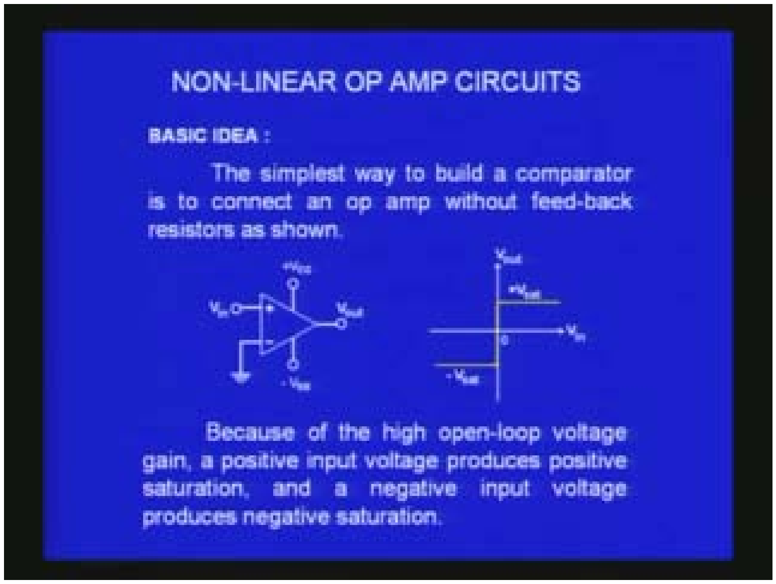

The operational amplifier when you don't use any feedback, when you don’t give any negative or positive feedback it operates under what is known as open loop condition and an open loop condition without any feedback the operational amplifier has got very high gain. The typical gain of one of the operational amplifiers that we keep using 741 is 10 to the power of 5, 100,000 and if I connect to the ground one of the inputs, the inverting input I have connected to the ground and to the non-inverting input I want to give a input voltage. Let us assume I give some dc input. We know the transfer characteristics of the operational amplifier; we have discussed. When I keep increasing this voltage V_{in} starting from zero when I cross even a very small magnitude of the voltage above the zero which is corresponding to the inverting input the output will become $+V_{cc}$ or $-V_{cc}$ as well. In this case when the V input is larger than the inverting input, the output will become plus because the input is coming to the plus input. When it becomes more positive than this the output will become $+V_{cc}$ to be amplified by the open loop and any voltage you cannot get at the output larger than the V_{cc} in principle and the output will saturate at $+V_{cc}$.

If I now make the V_{in} negative by inverting the terminals at the power supply input source and then keep increasing from zero in the negative direction because it is less than the positive inverting input the output will go to $-V_{cc}$ because now in magnitude the input corresponding to the inverting input is larger and the output goes to $-V_{cc}$. You can detect voltages which are larger than some minimum by looking at the output of the operational amplifier. When the output is $+V_{cc}$ you know it is larger than zero volts which is the one of the inputs for the operational amplifier and when the output is $-V_{cc}$ you know the input voltage has gone below in the negative direction with reference to zero and that is why you are getting $-V_{cc}$. That is also seen from the figure that is shown by the side of the circuit. X-axis is input voltage; y-axis is output voltage and this is zero. When I go for input voltages less than zero that is on the negative side the output voltage is $-V_{sat}$ which is actually $-V_{cc}$ almost and when I go on to the positive side of the input voltage it goes to $+V_{cc}$. What you get is almost a vertical line here. But it is in principle not a vertical line.

The slope of this vertical line will be the open loop gain and then this becomes the transfer characteristics which we have already discussed. The positive voltage produces positive saturation, negative voltage produces negative saturation.

What is the minimum voltage above which when it goes above zero then the output will change to $+V_{cc}$?

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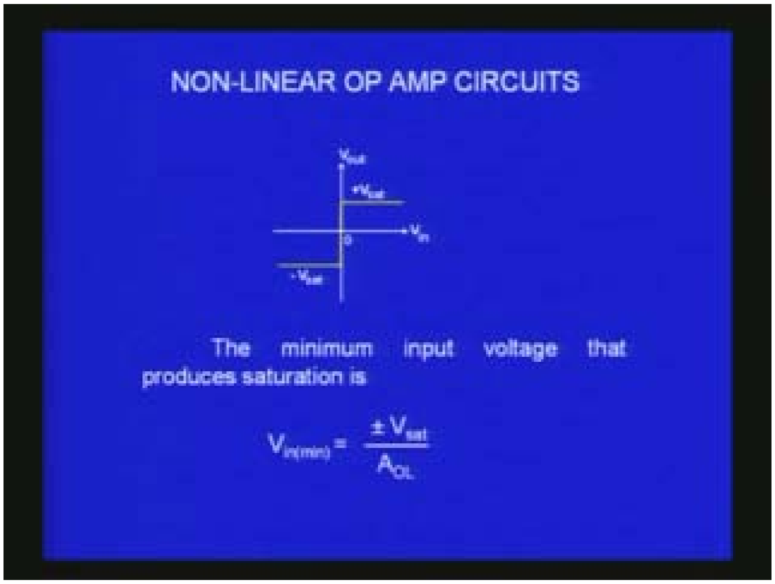

If you ask this question then it is very simple to answer. We know the output cannot be more than the V_{cc} or V_{sat} and V_{sat} divided by 10 power 5 will be the maximum input that I can give which will be within the linear region, the slope. V_{in} minimum is plus or minus V_{sat} by A_{OL} where A_{OL} is the open loop gain. The open loop gain is about 100,000, 10 power 5. V saturation can be, the power supply voltage, plus or minus 15 volts or 10 volts as the case may be and divided by this number will become a very, very small voltage.

I have taken a typical example to show you. If V sat is let us say 14 volts the output swing of the comparator is from -14 to +14 and if the open loop voltage gain is 100,000 as we took as a typical value the input needed to produce saturation is plus or minus 14 volts divided by 100,000 and it will be 0.14 millivolt and this 0.14 millivolt is about 140 microvolt.

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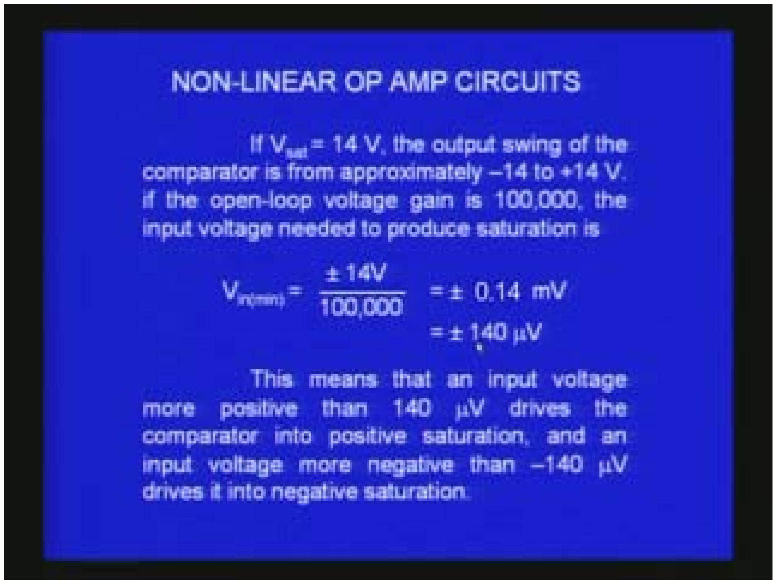

What you understand here is that the input voltage if it is more positive than the zero by 140 microvolt the output will go to $+V_{cc}$ and if the input voltage goes below zero by 140 microvolt the output will go to -14 volts. The output is within a range of plus or minus 140 microvolt at the input. +140 - 140 total 280; over 280 microvolts it will make a transition from minus to plus or plus to minus and that helps us to detect the difference in voltage when I compare two voltages within plus or minus 140 microvolts. That is the whole principle of the comparator.

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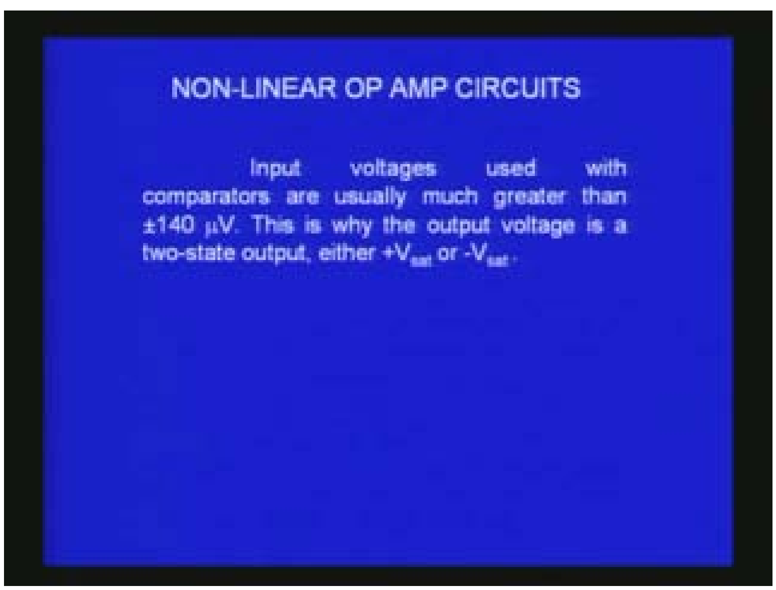

If I have one of the inputs at a particular voltage in this case at zero the other voltage when it goes plus or minus 140 microvolt the output will go to plus or minus V_{cc} either +14 or -14. So I can detect two voltages within a range of 280 microvolts or to be precise plus or minus 140 microvolts. That is the basic principle of the voltage comparator. In this case one input is connected to the ground; this is the zero.

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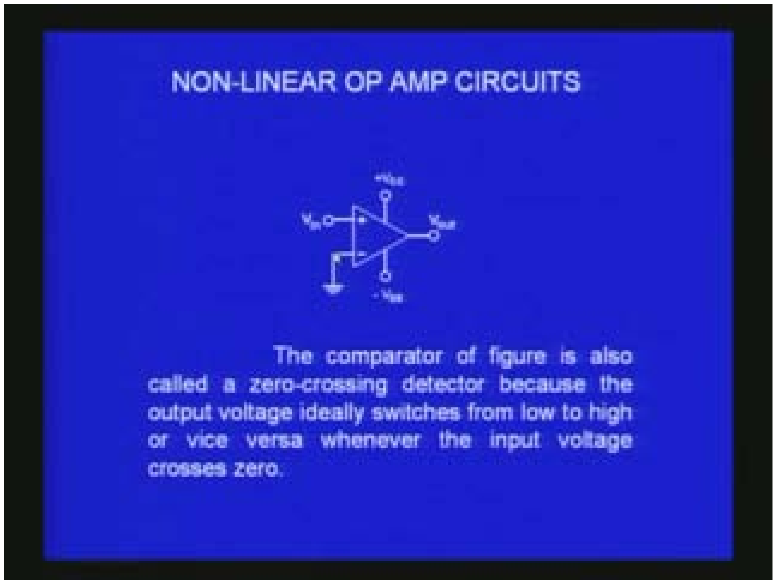

If I now make this voltage go from minus to plus, the input voltage, when I am crossing the zero within plus or minus 140 microvolt I will be able to get a change in the output from either $+V_{cc}$ to $-V_{cc}$ or $-V_{cc}$ to $+V_{cc}$ depending upon the direction in which I am increasing the input voltage. Whether I am increasing the input voltage or decreasing the input voltage while crossing the zero will decide which way this V sat will shift from one to the other. Therefore this circuit is also called a zero crossing detector. It is able to detect whenever the other input crosses zero by switching states at the output from plus to minus or minus to plus. You should always remember that this circuit is corresponding to open loop condition. There is no feedback here and that is very important. Without any feed back only it works as a comparator.

I have shown another simple circuit where I have got a potentiometer which has got three terminals. One terminal is connected to $+V_{cc}$, +15 volts and the other terminal is connected to -15 volts and the wiper which is corresponding to the variation is given to the inverting input or the non-inverting input as the case may be while the other input for the op amp is grounded. What will happen at the output? Whenever I cross this +15 to -15 it should cross somewhere at the middle of this potentiometer where it will be very close to zero. When I move the wiper above and below the zero point the output will shift to $+V_{cc}$ and $-V_{cc}$ as the case may be, because I will be exceeding that 140 microvolt range while moving up and down and this is one way to see in the lab to perform the experiment. I can use a simple potentiometer and move the wiper monitor in the multimeter and it will change from $+V_{cc}$ to $-V_{cc}$.

You can also do that by continuously giving a waveform. For example I have shown here a sine wave. I can give a sine wave to one of the inputs and the other input can be grounded then what will happen at the output?

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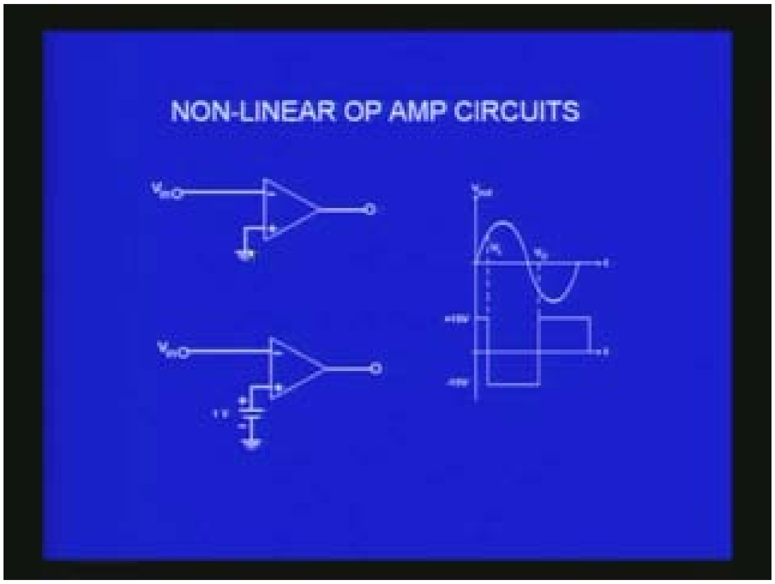

If the sine wave amplitude for example is about 1 volt then what will happen? Can you guess? Whenever the sine wave input crosses zero and goes above 140 microvolts then the V_{in} becomes more positive and the output will become $-V_{cc}$. That is what I have shown in the circuit. There it becomes $-V_{cc}$, -15 volts and when the sine wave automatically comes to zero next time and goes below zero by again some 140 microvolt. Because this will become less compared to this the output will become $+V_{cc}$ and the output will again shift to $+V_{cc}$ as you see on the graph. In the bottom graph the square wave that you see corresponds to the output and the sine wave above corresponds to the input for any of this circuit.

The V low and V upper I have marked this point as V_L corresponding to lower threshold or lower tripping point and this one to the upper tripping point at this point and these two will be 140 microvolt for this case when one of the inputs is connected to ground. But instead of connecting to ground instead of making the zero crossing detector I can connect a battery to that, fixed voltage of 1 volt for example in the second circuit. Over this 1 volt when it exceeds by 140 microvolt the output will become $-V_{cc}$ and when this input becomes less than 1 volt by about 140 microvolt then the output will go to $+V_{cc}$. This V_L and V_O now will be enhanced from simple plus minus 140 to 1 volt plus or minus 140 microvolt. Then the transition point can be now shifted wherever you want. If it is 1 volt when the other voltage exceeds 1 volt by plus or minus 140 microvolts then you will get an output which is a square wave. You can also provide an additional bias or a level to the verification of comparison of the two voltages.

That is exactly what I have shown in the next slide.

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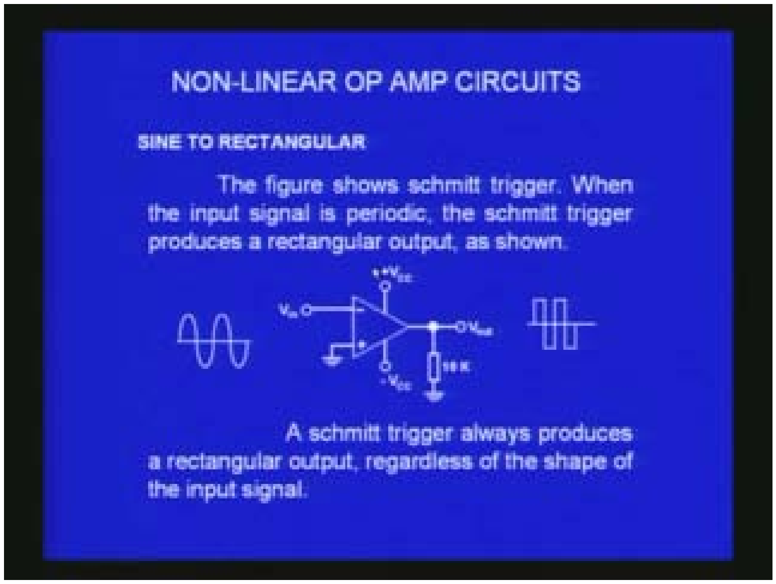

The figure shows something what is known as a schmitt trigger. When the input signal is periodic as it is in this case because I have given a sine wave the schmitt trigger produces a rectangular output of fixed amplitude. The amplitude of this is $+V_{cc}$ and $-V_{cc}$ or $+V_{sat}$ and $-V_{sat}$. It can be a sine wave or it can also be a triangular wave or any other wave. As long as the excursions go towards both positive and the negative voltages and the amplitude is larger than a minimum of few microvolts, 140, 150 microvolt the output will always be the square wave. It will always be a square wave between $+V_{sat}$ and $-V_{sat}$ but the width or the period of this square wave that you get out will depend upon the threshold that you have provided for the other input. This is one simple example.

I would like to show you how a simple comparator behaves by actually going over to the demonstration lab and showing two examples. In one I will use a millivolt source and vary the input voltage and show you that output changes from $+V_{cc}$ to $-V_{cc}$ and in the second case I will give a sine wave input and show how it is converted into square wave at the output to realize the basic principles of operation of the comparator. Here this is the comparator. I have put two circuits here. I want you to first concentrate on this circuit to the right.

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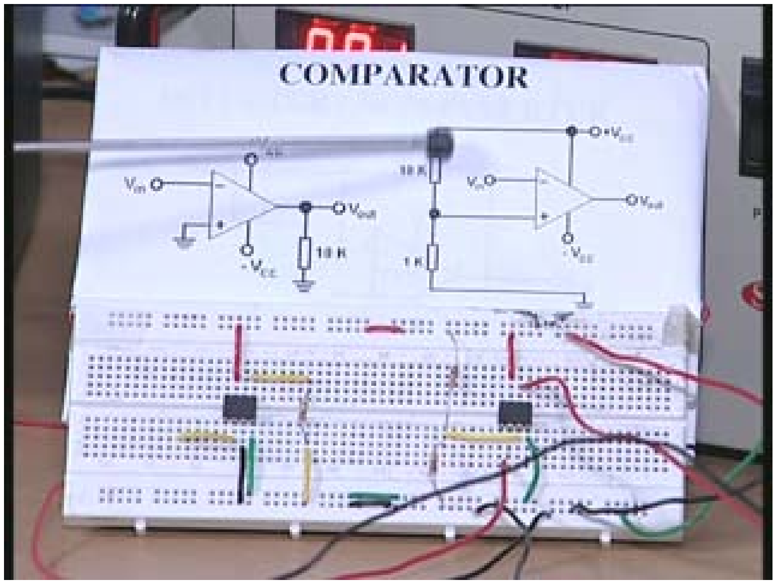

You have a potential divider a 10K and a 1K and the midpoint of that is what is connected to the plus input and to the inverting input I am going to give an input from a millivolt source. This is a familiar millivolt source which we have used in number of our experiments and I can vary the output voltage by making use of these knobs and that is connected to the circuit at the input corresponding to the pin number 2 which is the inverting input. To pin number 3 which is a non-inverting input I have put a potential divider with the 10K and 1K and I have connected the mid point. This will be approximately about $1/10^{th}$ of the voltage that I have applied for V_{cc}. If I apply for 12 volts it will be around 1.2 volts. That would be the threshold voltage. Now we have to monitor the output voltage. For monitoring the output voltage you will use a multimeter.

The same circuit is wired here. You can see the 741 and the 7 is connected to the rail voltage the $+V_{cc}$ and the green corresponds to the $-V_{cc}$ from the pin number 4 and I have the potential divider 10K and 1K here which is connected to pin number 3 corresponding to the non-inverting input and to pin number 2, I have connected the millivolt source. This millivolt source red line is actually going to pin number 2 in the circuit and the output is monitored by using this red wire which is actually connected to a multimeter. The multimeter here is actually in the voltage mode and it now shows 11.31 volt. That means it is positive. The pin number 2 which is corresponding to inverting input is lower than 1.2 volts and I am getting positive V_{cc} here nearly 12 volts.

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Now if you look at the dial the voltage here is indeed about 1 volt and it is less than 1.2 volts and that is why you are getting 11 volts. I am going to now vary the input voltage at the millivolt source by 1 more volt. That means it is going to become 2 volts. When I do that I want you to look at the multimeter. See what happens with the click sound. Now I have changed to 2 volts. Immediately you see the multimeter has changed to -10 volts. That means it has gone to the $-V_{cc}$ because 2 volts is larger than 1.2 volts and the inverting input voltage is larger than the non-inverting input and it goes to $-V_{cc}$.

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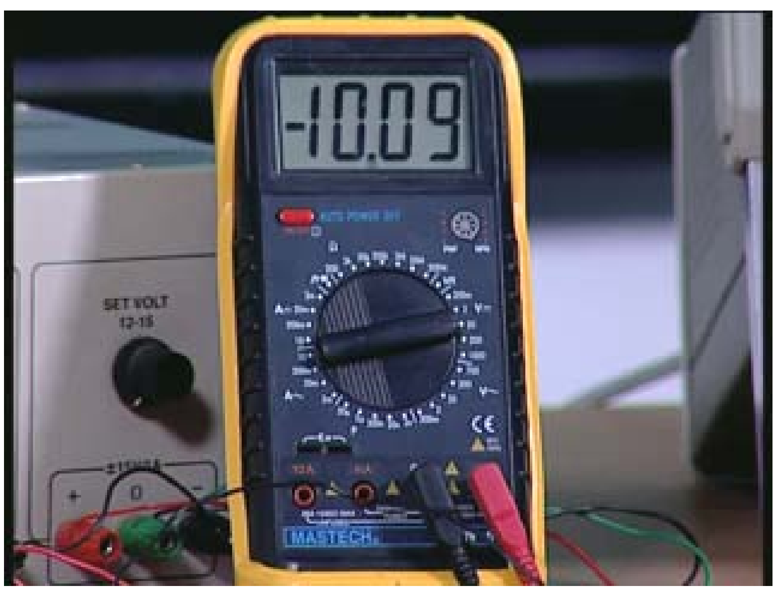

I can also do in another way. Now I bring back to 1 volt and vary this continuously. There is another dial here which can vary continuously. Now I would like you to watch the multimeter. As I keep increasing it you find when I just move by very small extent it has come to -V_{cc}.

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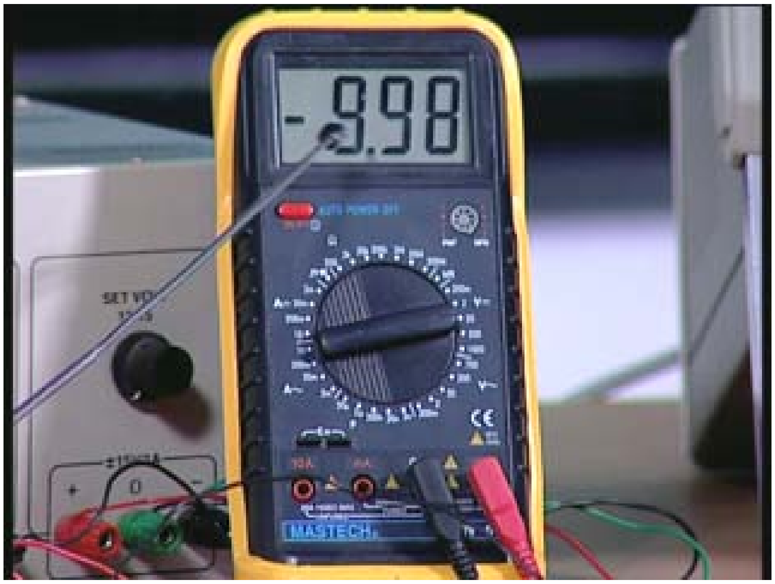

I again go back you will find again it comes to +V_{cc}. I go back again you wound find it becomes -V_{cc}. It is at this threshold that this happens and if you measure this it will be very close to 1.2 volts, the input at the positive input. That is at the non-inverting terminal. This shows that the comparator is capable of detecting voltages within the range of 1.2 volts, plus or minus 120 microvolt on either side and it can be used to compare two different voltages.

Now what I am going to do is modify this circuit and go to the second circuit. Look at the second circuit here where you find the plus input or the non-inverting input is connected to the ground and at the inverting input we are going to connect a sine wave and the output I have put simple load resistor 10 kilo ohms and monitoring the output. Whenever the sine crosses the zero and increases by even 150 microvolt or so immediately this voltage will be larger than this voltage. It will go to -V_{cc} and whenever this voltage goes below zero by about 150 microvolt again this will become less compared to this and because this is larger it will go to +V_{cc} and you will get a sine wave converted into a square wave.

The same circuit is put here. The operational amplifier with the 7 connected to plus and the green line 4 connected to ground and the input is connected to a function generator here which can generate sine, square, triangle, etc. It is put in sine mode and it is around 10K range. This is around 1.6 kilo hertz, this is the voltage. I have set the amplitude at some minimum position and the then the output is connected to an oscilloscope. As a matter of fact I have connected to one channel of the oscilloscope the input voltage and to the other channel I have connected the output voltage.

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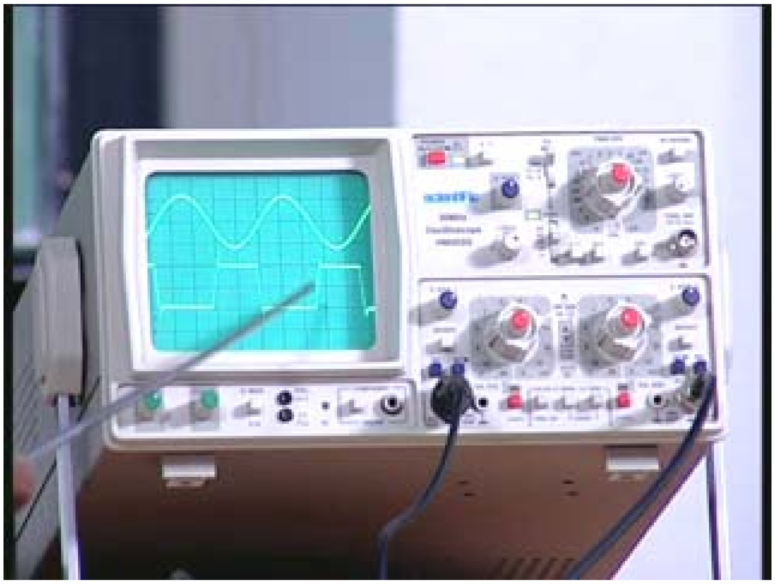

The input is sine wave and when I vary the amplitude you see the sine wave amplitude is also varying on the oscilloscope and what I get is a square wave at the output. This is the output.

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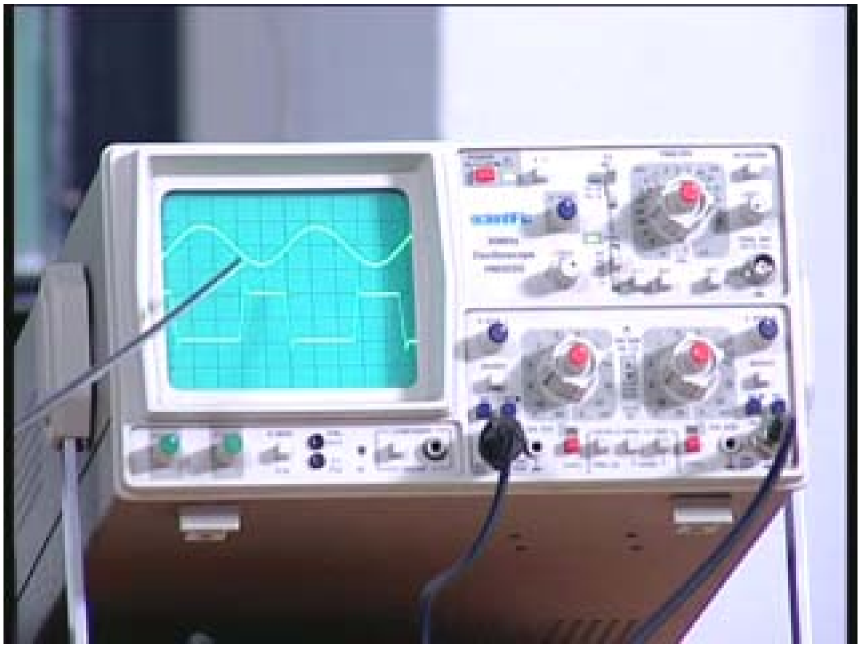

If you carefully observe, the zero of the sine wave will be somewhere here and it has slightly crossed that zero. Immediately it goes to $+V_{cc}$ on this side and whenever this again crosses that point it comes back to minus. These two are actually -15 and +15 or -12 and +12. If you actually look at the position here it is 5 volts per division for the oscilloscope. 1,2; nearly more than 2 divisions are there. That means about 10 volts plus or minus is what I get here. It goes to $+V_{cc}$ and $-V_{cc}$ every time the sine wave crosses the zero. This becomes a zero crossing detector and it is also called a schmitt trigger because the sine wave is converted into a square wave. The frequency will not change much because when I change the frequency in the function generator the output also changes; the output also modifies that is all. It is almost the same frequency but the levels are very important and you also get some feature which is corresponding to some ringing. This is better now; you are able to see. The voltage is now in 10 position. So it is about 20. The amplitude is 20 plus or minus 11 or 10 and therefore is about 20 volts peak to peak.

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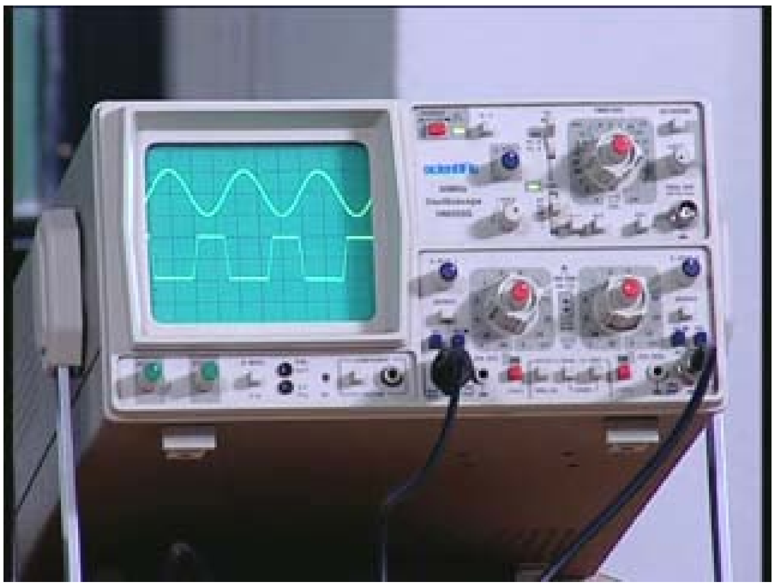

This is again another example of how a comparator can be used for a sine wave converted into square wave. Having seen that now let us look at some variations of the comparator circuit for some practical applications. One of the important things that we always worry about is that we should not overload the input. Because we can apply any voltage to the input we try to connect some protection to the circuits to make sure that the input is not increasing enormously. Two diodes are connected in opposition between the inverting input and the ground. This diode is in this direction the other diode is in the opposite direction. When I connect this what happens is whenever the input voltage goes beyond +0.7 or -0.7 this will be forward biased or when it is minus this will be forward biased and this voltage at this terminal can never be more than plus or minus 0.7 volts and that is good enough.

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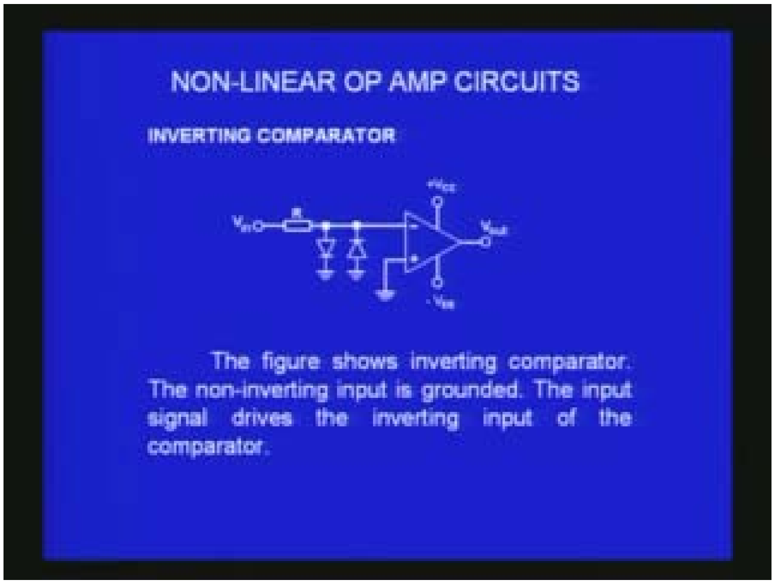

Because of the open loop gain condition this voltage cannot be different from this voltage beyond plus or minus 150 microvolt and 0.7 is 700 millivolt which is a very, very large voltage comparatively and we will never have any occasion to go beyond 0.7 volts and this will provide a protection for the comparator so that you will never over load the terminal beyond 0.7 volts. There is also another important consideration that you should take into account and that is even though op amp is a wonderful device almost an ideal device it is not quite ideal in the sense it does have difference in the two input bias currents. There is an offset voltage and several other things that come because of not being very ideal.

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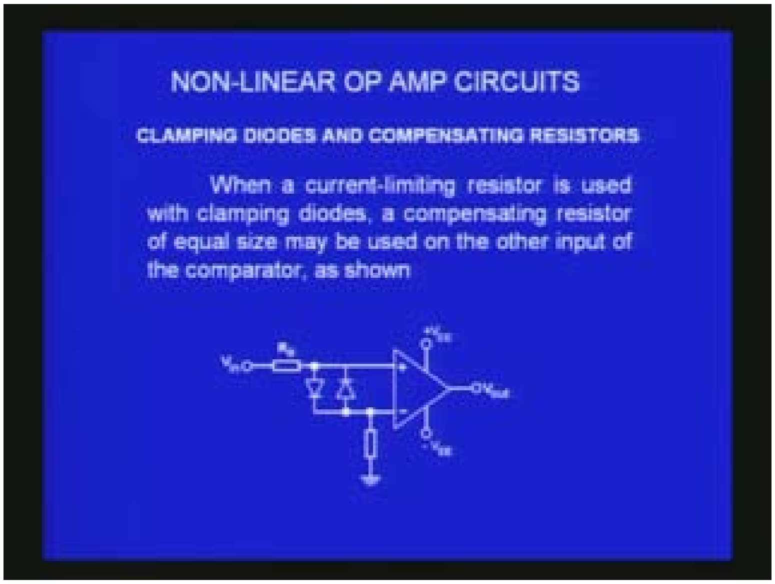

There are two input terminals and the voltage is compared between these two terminals. Those two voltages should be only precisely corresponding to what we set with reference to that. If it is not then it will become more complicated. When I have an input bias current variation which is a very typical situation in any op amp, normal op amp there could be a difference in voltage produced because of the input offset current or the input offset voltage. These input offset voltage or the input offset voltage generated due to input offset current passing through the resistors that are connected to the two input terminals can sometimes exceed 150 microvolts on the plus side or on the minus side. When that happens the output will switch state even though it should not according to the input voltage that I have applied at the input terminals. We would try to make as much as possible that the two input terminals are equal in voltages before I apply an external input voltage.

To do that in this circuit I have again used that two diodes in opposition plus I have used a resistor between the inverting terminal and the ground. This resistor takes care of the input bias current differences between these two. If I keep these two resistors the same then the voltage generated here and the voltage generated here will be almost equal even though it is very, very small because we are now talking of very small voltages between the two input terminals and the two diodes will make sure that the voltage between the two terminals will never exceed 0.7 volts plus or minus and this is another scheme to take care of the input bias currents and the two diodes are there for taking care of overloading the input currents. There is another small difficulty that we have with reference to the output and that is the output is always plus or minus 15 volts or plus or minus 12 volts whatever be the V_{cc}. If that is the case it is very difficult to use that for any useful application. Atleast if it is from 0 to some 5 volts or 10 volts we might be able to use it for some digital applications how do we control the output amplitude to any desired value is what I wanted to indicate to you. In the circuit that is shown, at the output I have connected a diode and I have also connected a R_L the load resistor.

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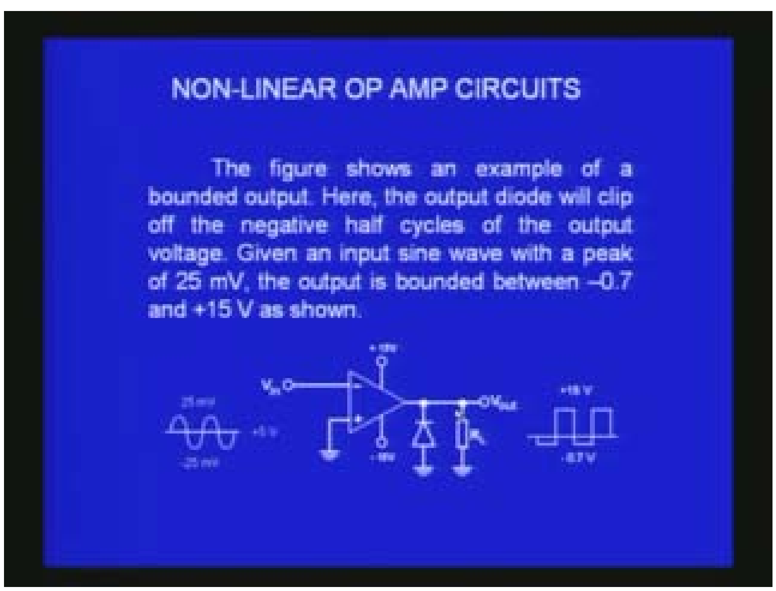

If you measure the input is a sine wave about 25 millivolts amplitude that peak amplitude that is enough for us because we require only plus or minus 150 microvolt above zero and one of the inputs is connected to zero. It is a zero crossing detector now and when the input goes beyond 150 micro volts the output will become $–V_{cc}$. When it becomes $-V_{cc}$ this diode will be forward biased and it will be conducting and I will have only about 0.7 volts as the output voltage which is the voltage produced across the diode and it is -0.7 because this voltage will be negative with reference to the ground because the current is flowing in the other direction and it is -0.7 and when I have the voltage going less positive that is it is going negative on this side, V_{in} then the plus will become more and it will go to $+V_{cc}$. From $+V_{cc}$ this diode is reverse biased and $+V_{cc}$ will come out as such. By using this diode I have cut the voltage on the negative swing. It is only 0.7 to +15; -0.7 to +15 it is almost like 0 to +15 and this can be used in different circuits for digital applications. This is one way. It will also be still better if I can also control the two voltages on both sides +5 to -5 or +3 to -3.

For that we can think of another application and this is the circuit where I have used in the feedback two diodes, two zener diodes to be precise and the two zener diodes for example I have used 1n749 which has got a break down voltage of about 4.3 and they are connected in opposition.

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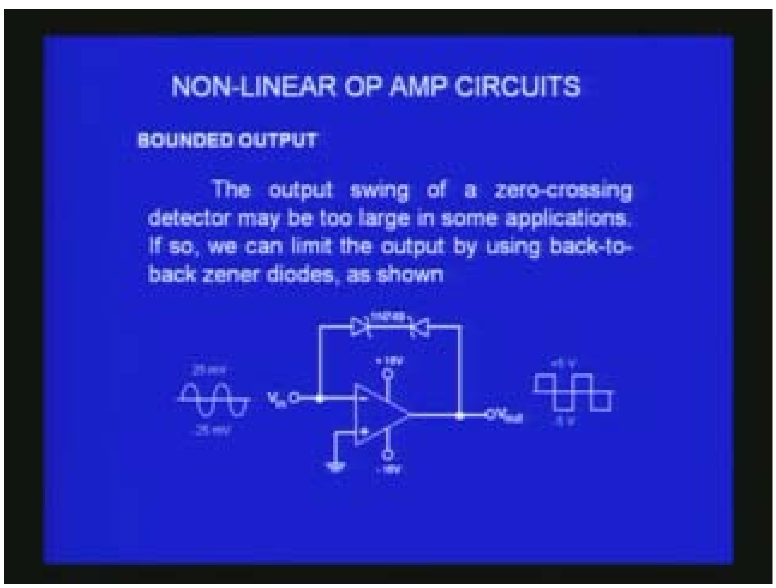

One is connected in this direction the other is connected in the opposite direction. Whenever I apply a sine wave this cannot be 25 millivolt. It has to be much larger. Whenever the output switches to +15 and -15 these diodes will break down first. One of the zener diodes will break down the other diode will be forward biased. 4.3 volts will be appearing across one of the diode and 0.7 will appear across the other diode. So the total voltage will be 5 volts and you will get the output swing from +5 to -5 when I have this type of a situation. You can have a +5 -5 variation. This comparator with two zener diodes in opposition connected in the feedback can be used to limit the output to any desired value by choosing proper zener diode with break down voltages. You also saw in the demonstration I showed that we need not have zero crossing but we can also have some reference voltage.

We have used a potential divider R_1 and R_2 and the midpoint was connected to the same circuit we showed in the demonstration and this is again a method by which I can convert a zero crossing detector into a comparator for comparing a threshold voltage which can be chosen by properly choosing the R_1 and the R_2 values.

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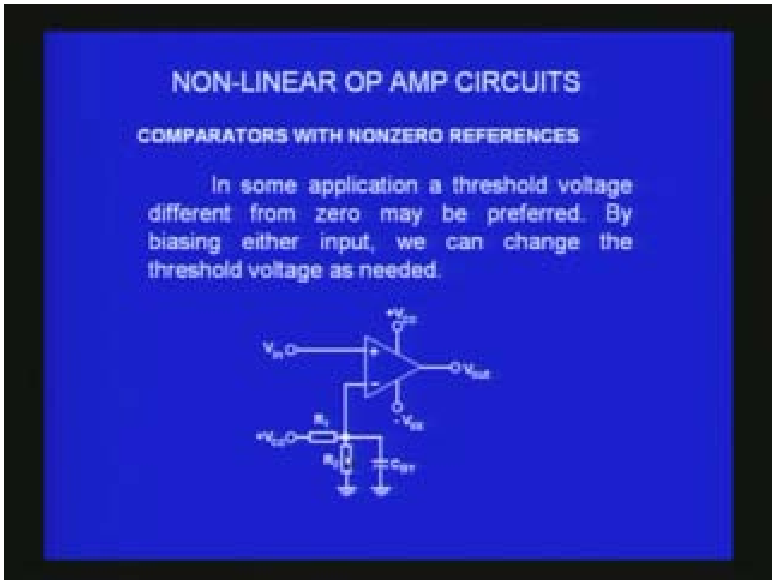

In the example I showed R_1 and R_2 was 10K and 1K. So the threshold was around 1.2 volts. But if you choose for example R_1 R_2 equal 10K, 10K then it will be half of the V_{cc} may be 7.5 volts. The reference voltage is R_2 divided by R_1 plus R_2 times V_{cc} and this is one way to change and the capacitor there is used to speed up the operation and when you use that cut off frequency then you must make sure that the ripple frequency of the power supply, etc will come into the game and the cut off frequency of this bypass should be much, much lower than the ripple frequency of the power supply.

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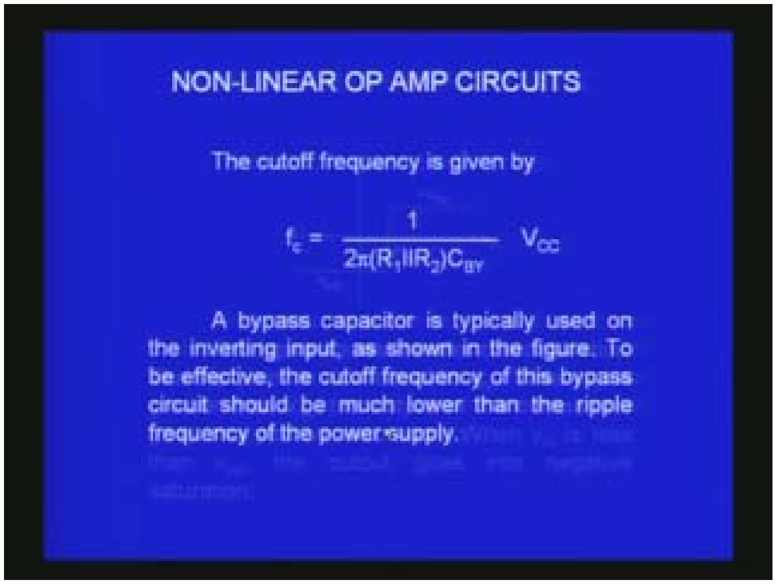

If you look at the transition corresponding to the input output voltage relationship corresponding to this circuit it is $-V_{sat}$ up to that V_{ref} and only at V_{ref} it goes to $+V_{sat}$ and because the V_{ref} is positive it is on the positive side.

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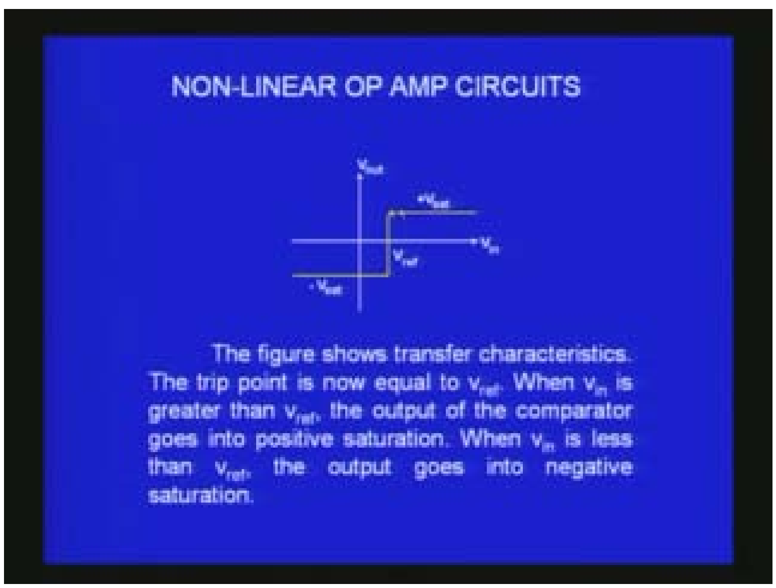

The transition happens at this 1.2 volt or 1 volt or whatever may be the reference depending upon the R_1 R_2 value that you have chosen. You can also have a very similar circuit. Instead of $+V_{cc}$ I connect the minus. Then what happens? The reference becomes negative voltage. When the reference becomes negative voltage correspondingly the input output relationship will be as shown in the picture. Up to the $-V_{ref}$ it will be $-V_{cc}$ and when you go beyond it goes to $+V_{cc}$ or $+V_{sat}$.

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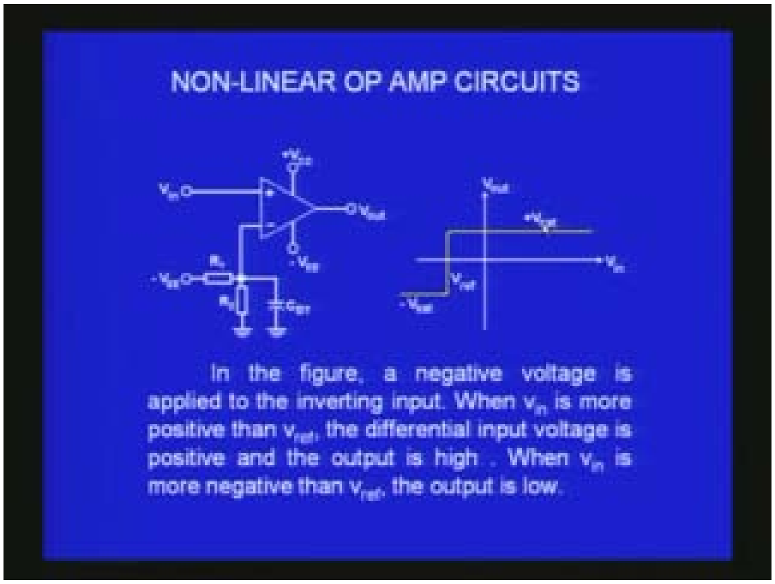

One can easily choose the reference points to be either zero or positive or negative by these options and you can have the comparator to verify two voltages which can be either zero or some other number on the positive or negative side. Apart from 741 we have also comparators which are commercially available because 741 is not actually meant to be a comparator. The output swing cannot be too fast. Even in the demonstration I showed the transition from $-V_{cc}$ to $+V_{cc}$ was not vertical. It had finite slope and that slope is due to the slew rate of the operational amplifier. So manufacturers have made comparators exclusively for comparative purposes, comparing voltages and not for amplification and …. will have much a better slew rate behavior and I have given one example of LM339 which is an open collector device.

The advantage of having an open collector device is to restrict the output voltage to any desired levels. For example in this picture that I have shown you have V_{in}; you have R_1 R_2 divider, you have V reference here and at the output I have connected +5 volts through 1K resistor. This comparator is compatible to digital circuits because now the output can never be more than 5 volts and less than zero volts.

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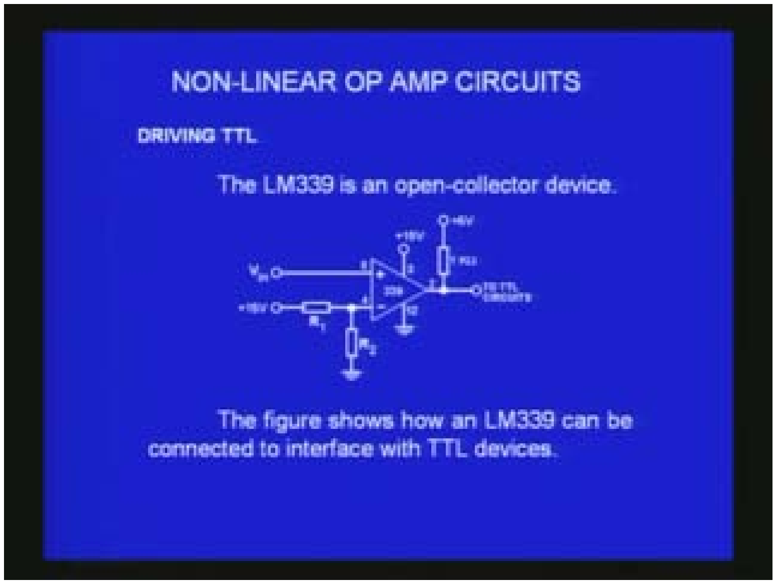

Because it is connected through an open collector output to 5 volts the output will be clamped at 5 volts and zero volts and it becomes compatible to TTL devices or digital circuits.

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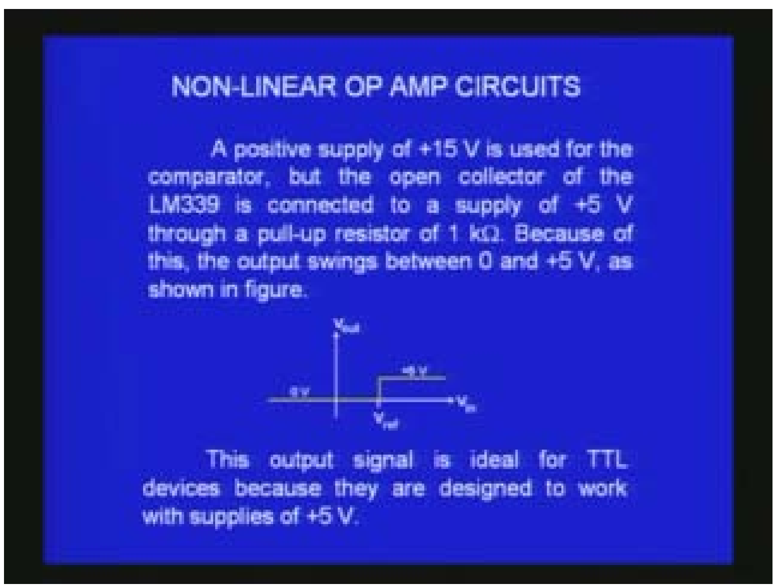

The pull-up resistor is around 1 kilo ohms. The transfer current for that circuit will be zero volts till I come to the V_{ref} and beyond that will be +5 volts. All these comparators so far that I talked about will have transition occurring at plus or minus 150 microvolts.

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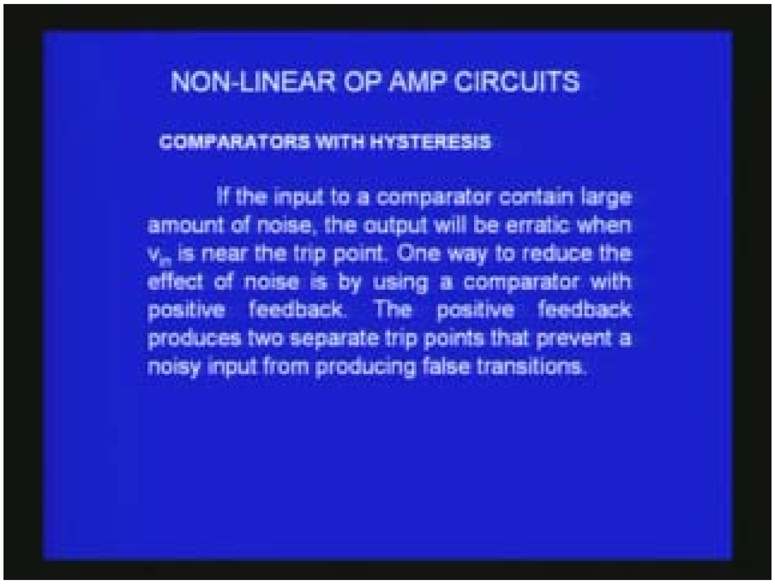

But this plus or minus 150 microvolt is what is called hysteresis for a reason which I will explain to you in a moment. It would be better in many applications to have this difference +150, -150 much larger than the small value. For example plus or minus 1 volts or plus or minus 2 volts as the case may be. This is because in every circuit there is always the noise component which are all unwanted signals coming from various sources all around us and some of them are harmonic.

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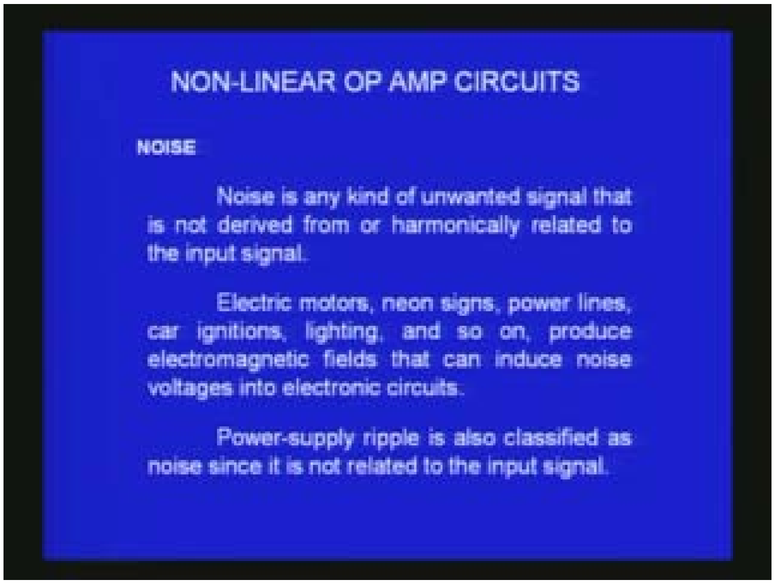

For example some of the transmissions coming from different radio stations, television stations, etc will all be sinusoidal harmonic. But we are not interested in them. They are considered as noise voltages. There are other transient voltages coming from different devices like electric motors, neon signs and power lines and they also will contribute to some fluctuations at the input. All these noise voltages are random and they can either increase or decrease the input voltage randomly and if it increases or decreases by more than 150 microvolt the output will change even though my input voltage is not changing. Purely because of the noise voltage the magnitude of the noise voltage is exceeding the 150 microvolt limit and the output switches automatically without waiting for the input to change. This is an undesirable effect. We don't want that to happen. So what we do is we increase the hysteresis, the levels at which the voltage transition occurs at the output.

The corresponding circuit I have shown here.

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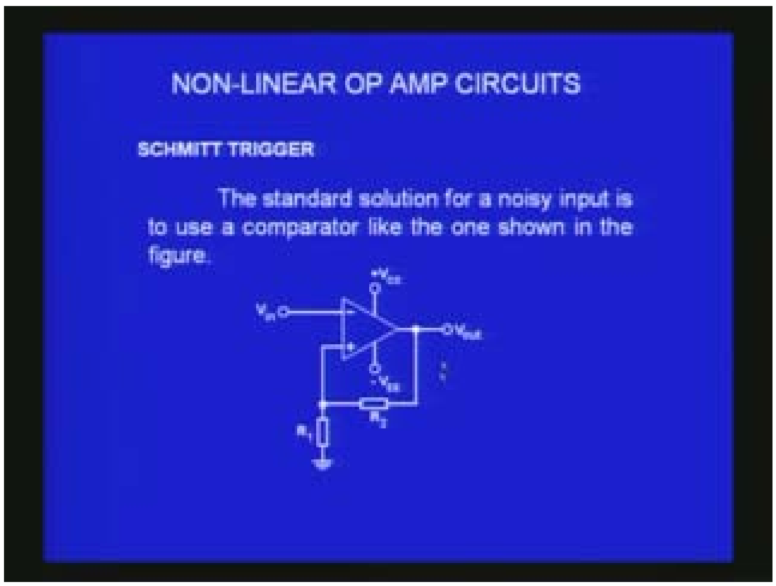

What I have done is from the output I have connected a potential divider R_2 and R_1 and I have taken the potential divider output to be given to the plus input of the op amp. This is actually a positive feedback; from the output I am giving it to the plus side. It is called a regenerative comparator; this is also called regenerative comparator. Because I have connected like this V output will decide the threshold or the reference voltage here. The reference voltage now is R_2 divided by R_1 plus R_2 times V output. But the V output itself can be either $+V_{cc}$ or $-V_{cc}$. When it is $+V_{cc}$ this voltage will be R_1 divided by R_1 plus R_2 times $+V_{cc}$ and when the output is $-V_{cc}$ this reference will become R_1 by R_1 plus R_2 times $-V_{cc}$ and in the typical demo that we showed the R_2 is 10K R_1 is 1K. So it was about 1.2 volt and in one case it will be +1.2 volt and in the other case it will be -1.2 volt and Vin whenever it exceeds +1.2 or -1.2 the output will change state and the gap between the two transitions will be +1.2 to -1.2. That means 2.4 volts.

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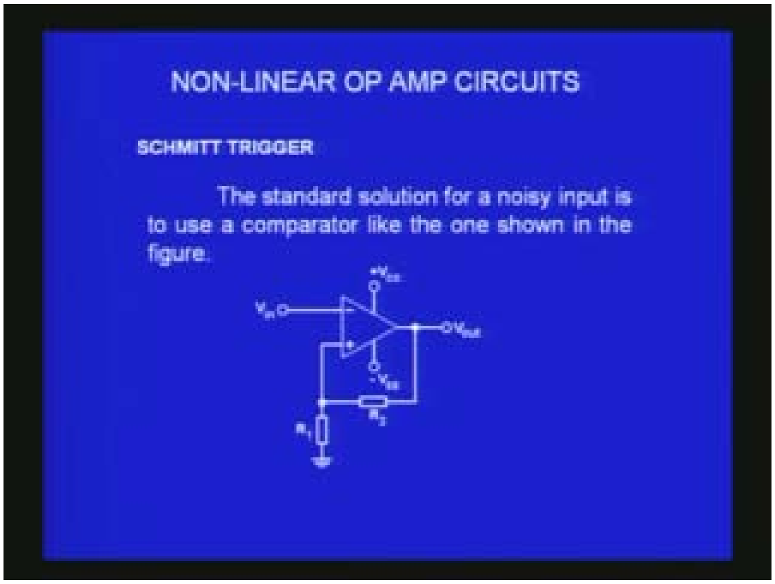

From plus or minus 150 microvolts we have now expanded the variation to plus or minus 1.2 volt which is a very large difference and this 1.2 volts cannot be generated by any of the noise voltage in normal course and we don't have to worry that the output is switching state because of the input noise. This is also called by another name Schmitt trigger.

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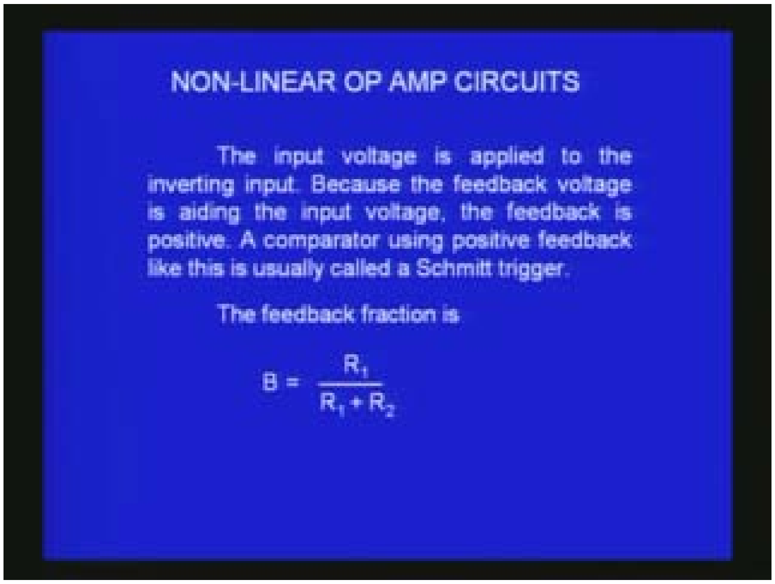

Some of you might have studied in transistor circuits that by using two transistors one can make a Schmitt trigger which is designed by the Schmitt as the name goes. What the circuit does is it is sensitive to some threshold voltage at the input and the output will go to plus or minus voltage levels; two levels corresponding to the input and there are two levels at the input for which this transition will occur and the two levels are called LTP and UTP. LTP means low tripping point and higher tripping point. In this case what we have as LTP and UTP are the V reference voltages corresponding to plus b V_{sat} or beta V_{sat} and -bV_{sat}. These are the two tripping points. The tripping point is the point at which when the input voltage exceeds that the output changes state from +V_{cc} to -V_{cc}.

In the graph the transition happens this way. V output versus V input if I draw till it comes to - beta V_{sat}, the minus reference the output is -V_{cc} or V_{sat} and at this stage it makes a transition and goes to +V_{sat}.

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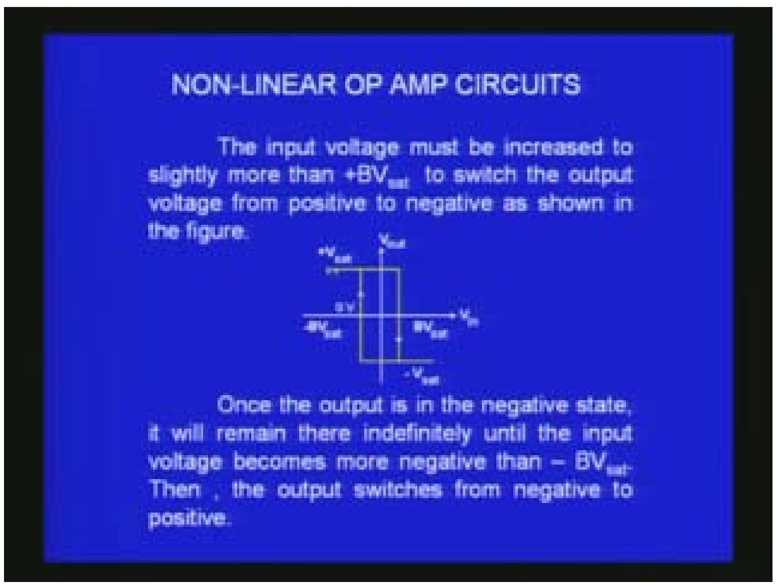

Once it goes to +V_{sat} the V reference becomes plus and when I come back with the input voltage till I come to +V reference there is no transition. Only at +V reference there will be a transition. This graph traverses along this direction and it goes up, comes over here and when it goes back, it goes back by a different route. This is called hysteresis. Some of you may be familiar with the hysteresis graph that we get when we take a magnetite, a magnetic material through a cycle of magnetization and it will not be square loop like this unless it is a highly ferromagnetic material like a ferrite. You will get a hysteresis behavior in those devices also. Similarly we get a hysteresis behavior here. It is called a hysteresis and the difference in voltage is what actually matters for us with reference to the comparator and this is made to be like this because it can be unconcerned about the voltages corresponding to the noise.

We can have two different types of circuits. You can have the non-inverting Schmitt trigger and the inverting Schmitt trigger. The figure shows a non-inverting Schmitt trigger and the corresponding input output relationship.

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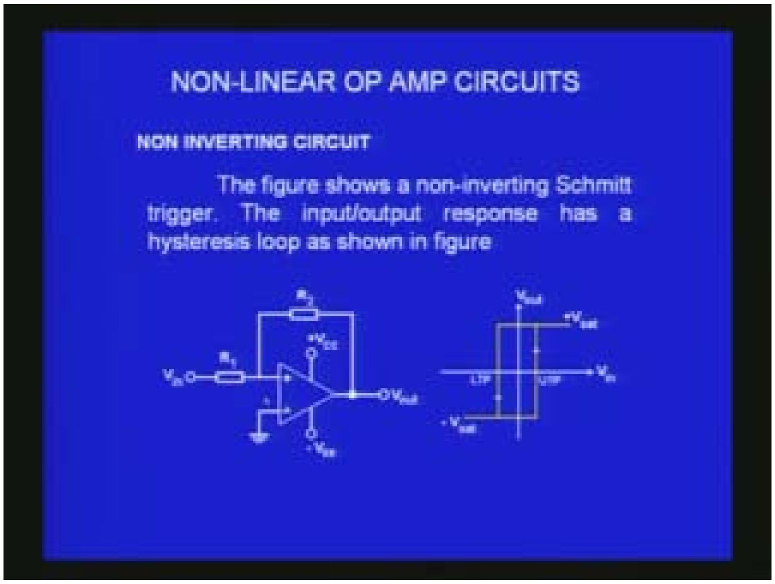

$-V_{sat}$ and $+V_{sat}$ you get and the UTP, LTP in non-inverting will be R_1 by R_2 times V_{sat} and $–R_1$ by R_2 times V saturation.

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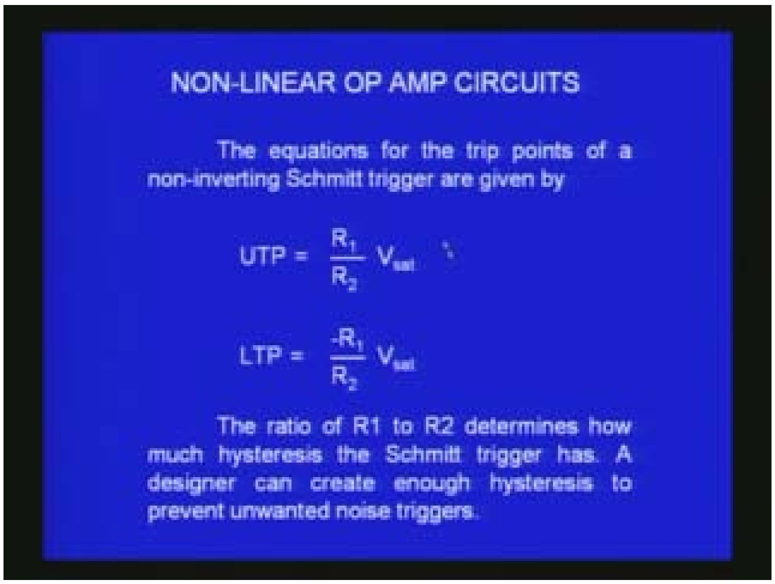

In the other case it was R_1 by R_1 plus R_2 times V_{sat}. Here it is R_1 by R_2 times V_{sat} and this also will help you to make a Schmitt trigger with a regenerative comparator. I will show you the demonstration with reference to a regenerative comparator and then there are also other comparator designs and the applications of this comparator circuits in different situations which also we will discuss later. Now I will show you the demonstration. This is the circuit of a regenerative comparator.

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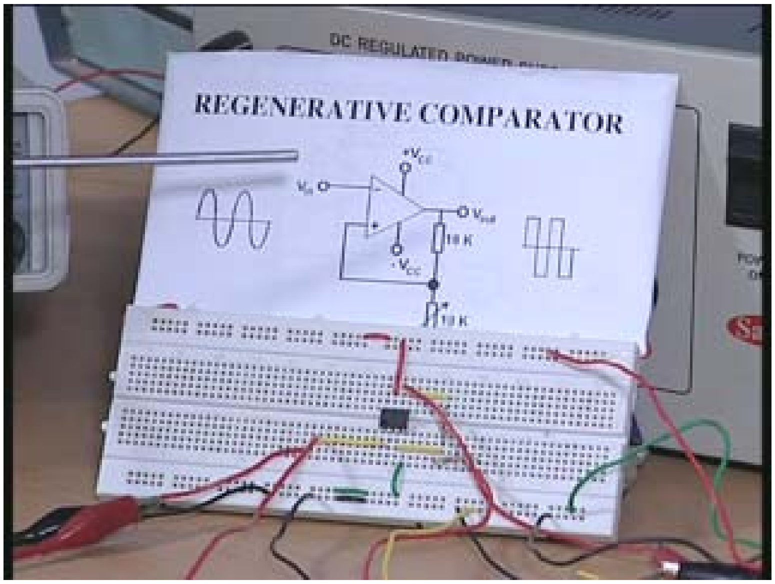

From the output we have taken a potential divider 10K and 1K in the example. The divider potential is applied at the plus terminal at the input as a feedback. This becomes a positive feedback and to the inverting input a sine wave input is given and what you get will be a square wave. But now what is going to happen is because it is a regenerative comparator whenever this is $+V_{cc}$ this point will become beta times $+V_{cc}$ and when it becomes $-V_{cc}$ the reference point becomes minus beta times V_{cc} and whenever the input voltages exceeds plus beta times V_{cc} or goes below minus beta times V_{cc} there will be transition instead of plus or minus 150 microvolts as we had in the earlier cases. That shows it has got a hysteresis. In order to show the hysteresis what we have done is I have taken this input and given to X-axis and the output I have given to the Y-axis and I am trying to look at what happens in the oscilloscope.

Look at the circuit. Again this is a 741. The $+V_{cc}$ and $-V_{cc}$ are connected to the pin number 7 and 4 and the input is connected to a function generator which we also saw previously and this is now in sine wave and the input and the output are connected to the oscilloscope. I have used both; I have put it in XY mode and this is the sine wave, one of the channels and the other channel is output. When I connect what you see is exactly the transition hysteresis graph that I already explained to you. Till it comes to $+V_{cc}$ there is no transition and at that time it goes to $-V_{cc}$ and after it goes to $-V_{cc}$ the reference becomes minus beta times V_{cc} and till it comes here there is no transition and the transition occurs here.

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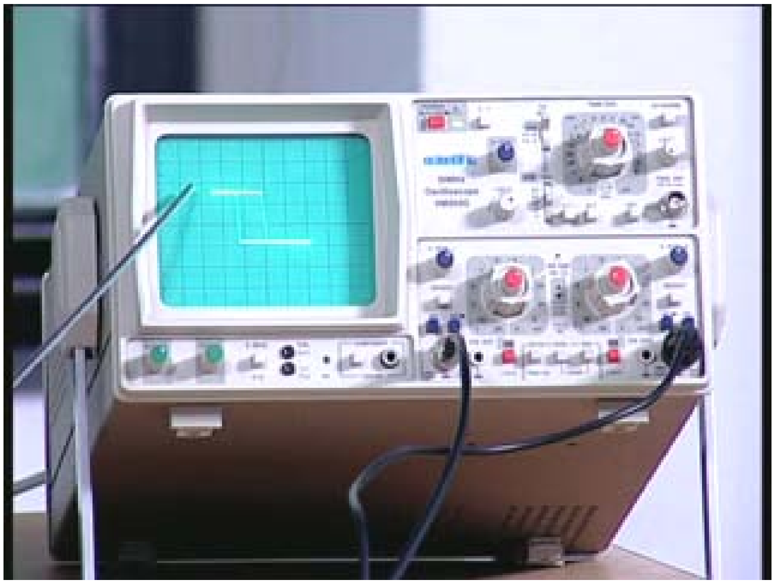

You can very clearly see the transition happening here and this is the hysteresis graph that you get corresponding to the circuit. When I remove the XY mode what you see is the normal sine wave as the input and a square wave as the output.

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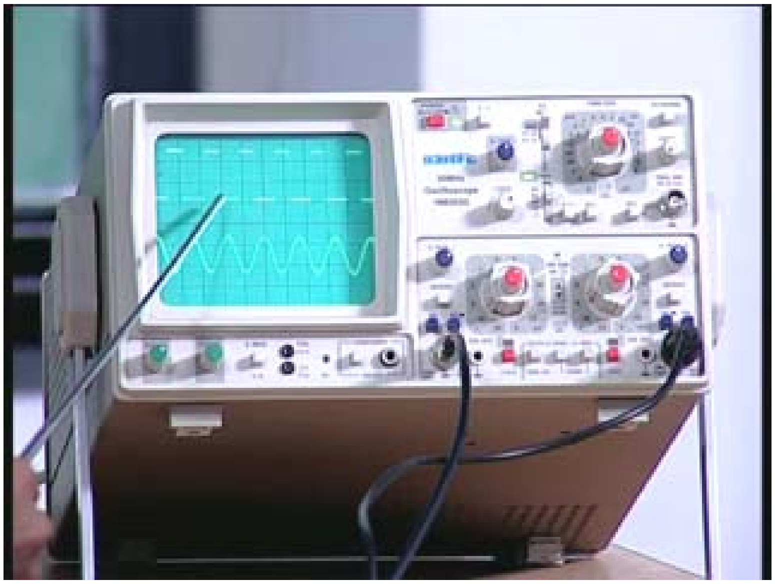

These transitions occur at two different reference points now. Exactly similar to what we saw in the earlier case. In the earlier demonstration also we used a sine wave and we got a square wave. But the square wave transitions were happening at plus or minus 150 microvolt. Now it is happening at plus or minus some other voltage and that voltage is decided by a potential divider that you see in the circuit. To show you that the V reference depends on the potential divider in this place I have connected a 10K potentiometer and now I am going to vary this potentiometer and when I vary the potentiometer I want you to observe the output of the oscilloscope. Now I am going to vary this. See the oscilloscope. What happens? You can see the width is changing corresponding to this variation.

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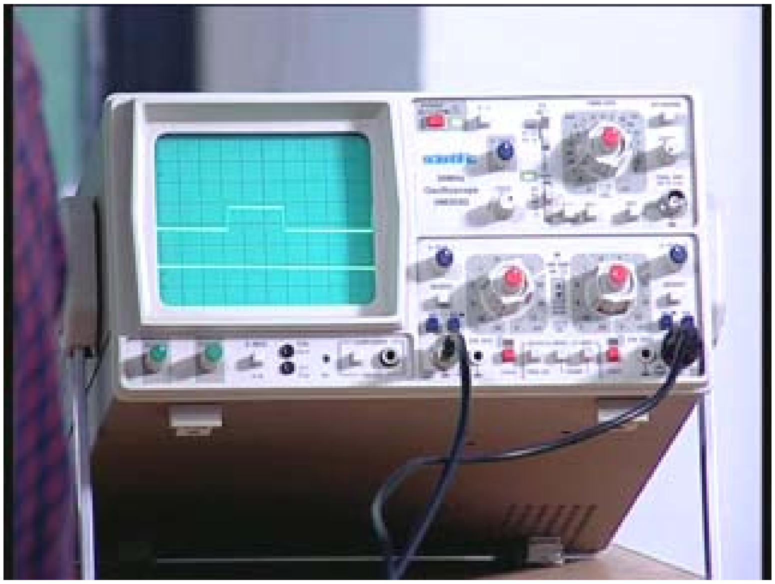

When I vary this nearly by half a scale it is changing. What we saw is a demonstration of the regenerative comparator where the input was given as a sine wave and the output is given as a positive feedback by having a resistor network R_1 and R_2 and when we change one of the potentiometers the output was also changing. That means the reference point was changing and it will have some effect on the output period or the frequency of the square wave.

In the next lecture I would like to discuss another type of a comparator which is called a window comparator. That window comparator will actually have two threshold voltages. You can choose any two threshold voltage and thereby you can have a comparator constructed so that whenever the input voltage varies between the two limits the output will change; otherwise it will not change. This will be very, very useful in different applications in window comparator and we will also see another application of the comparator in terms of a relaxation oscillator. Without any input you can get a square wave output by making use of the same comparator configuration and that is what I would like to discuss in the next lecture along with the rest of the things. Thank you!