Basic Electronics
Learning by doing
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Lecture – 33
Application of op Amps

(window comparator, relaxation oscillator …..)

Hello everybody! In our series of lectures on basic electronics learning by doing let us move on to the next. Before we do that let us quickly recall whatever we discussed in our previous lecture.

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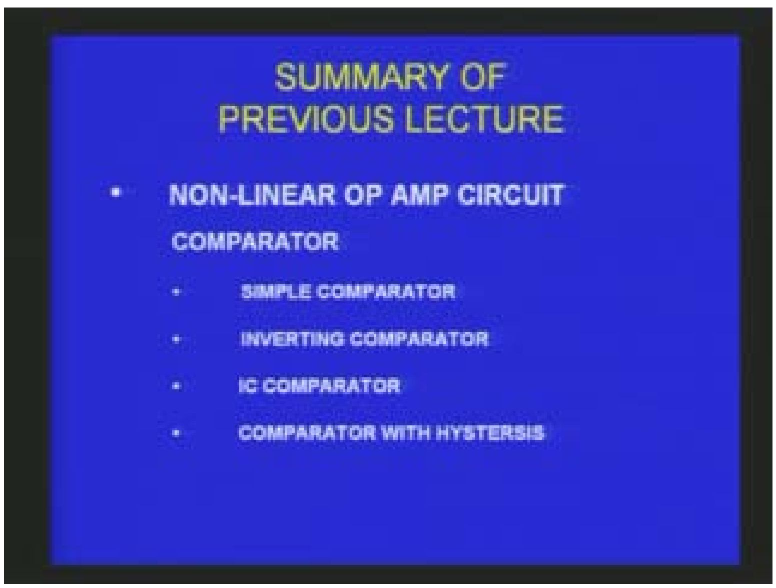

You might recall we discussed in the last lecture about the non-linear applications of operational amplifiers specifically the performance of comparators. A comparator is a device which compares two voltages and the output will change to either V_{cc} or $-V_{cc}$ depending upon the voltage applied to either the inverting or the non-inverting inputs of an operational amplifier is larger. We have got different varieties of comparators. We discussed a simple comparator which can also be considered as a zero crossing detector. We also looked at an inverting comparator, an IC comparator like LM339 and we also saw a regenerative comparator that is the comparator with a hysteresis. These are the various circuits that we have seen. Let us move on to find out whether we can also have other types of comparators.

One of the very important types of comparator is called a window comparator. A window comparator is basically a comparator which has got threshold voltages which are corresponding to a lower limit and an upper limit in voltage.

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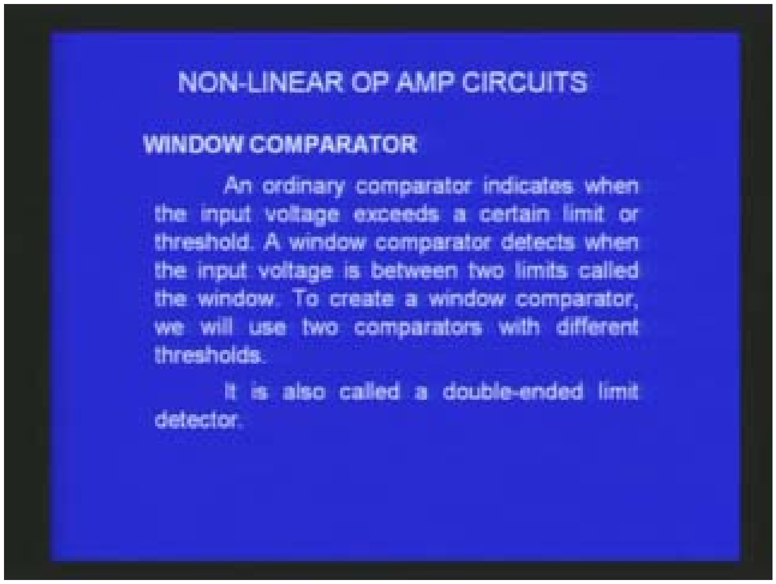

One can set this lower and upper limit in any range that you require within the zero to V_{cc} or $-V_{cc}$ to $+V_{cc}$. A window comparator will have again two definite thresholds corresponding to lower tripping point and upper tripping point about which also we discussed in the last lecture and you would be able to detect input voltages which are within these two limits. For voltages which are within these two limits you will have a particular output stage. For all other voltages which are either below the lower tripping point or above the upper tripping point you will have a different output stage. This is what the window comparator will do. It will show whether a given input voltage is between specific two limits.

I can give you a very simple circuit which is a window comparator. Because you have got two definite threshold levels to set up you have to have two comparators. Each one of the comparator will be associated with a very specific threshold. For example the A_1 operational amplifier which is at the top has got an LTP as one of the threshold while the A_2 which is at the bottom, the second operational amplifier which is here used as the comparator has got an HTP as one of the threshold. The other free inputs of both the op amps are connected together and that is the point at which the input voltage can be given. When you give the input voltage here these two comparators have got two different thresholds corresponding to LTP and HTP or UTP and whenever this voltage goes beyond these limits something will happen at the output stage. These two op amp outputs we have connected diodes D_1 and D_2 and we have combined the two outputs together and through an R_L we are looking for the output voltage at this point. This is a very, very simple circuit where you have two operational amplifiers used here as a comparator and you choose through two of the inputs for the two op amps as LTP and UTP. The other two inputs, free inputs are connected and given to the input. The output of both op amps are connected through diodes and that is the output that we monitor.

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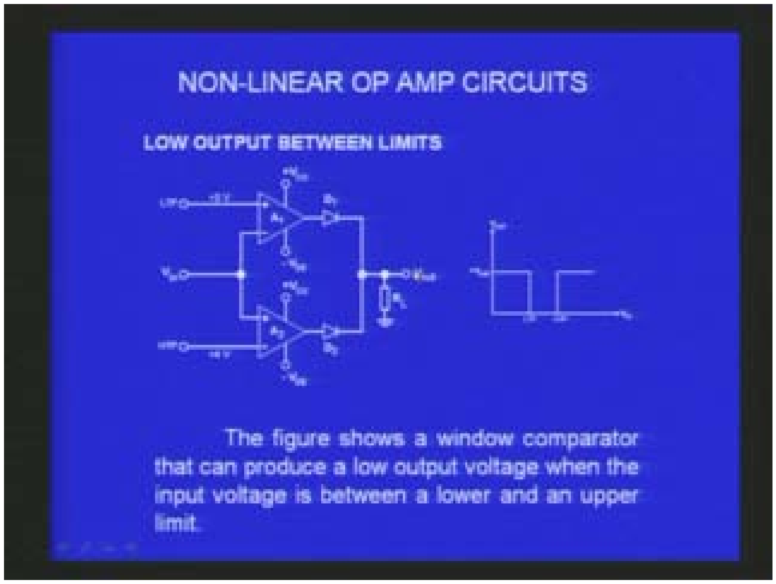

Let us assume that the LTP is +3 volts by some means. May be I can use a potential divider and give a voltage which is 3 volts from the V_{cc}. Similarly the HTP here I have taken as 4 volts which can again be considered from the same V_{cc} by using a potential divider. I have 3 volts as the LTP and 4 volts as the UTP and I give voltages here which are going from zero to a larger value may zero to 10 volts or 12 volts. As I keep on increasing the input voltage what will happen at the output? As I increase this voltage, as long as this input voltage is less than 3 volts you can see this is less than the LTP in this op amp and 3 volts will be larger than the input voltage in this op amp A_1. The output will be $+V_{cc}$ trying to go to $+V_{cc}$ because the plus input is larger than the minus input. When this becomes plus the diode will conduct and you will get a high voltage at the output. As long as the input voltage is less than 3 volts the output will be high and that is what is shown in this graph. Starting from zero output is high nearly V_{sat}, the saturation voltage till you come to LTP, till you come to 3 volts. In this case LTP is 3 volts.

When I go beyond 4 volts let us assume the input is more than 4 volts. Here this 4 volts is more than 3 volts. Therefore it will be minus at the output in this A_1; but minus here will make the diode open. It will not conduct because diode has to be forward biased with a positive voltage on this side. Because it is negative V_{sat} the diode is off, D_1 diode is off. Whereas if you Look at voltages more than 4 volts. In this second op amp A_2 this is more than 4 volts means the plus input is more than the minus input and the output becomes $+V_{sat}$. The $+V_{sat}$ again will make the diode conduct and you will get a very high positive voltage at the output. For voltages which are less than 3 volts or less than LTP you will get a high as you see on the graph and for voltages which are above 4 volts again you get a high at the output.

Let us see what happens when I am at 3.5 or 3.1 or any voltage in between the LTP and HTP, 3 volts and 4 volts in our case. For any voltage in between it will be more than 3 volts but less than 4 volts. That is the condition. It should be more than the LTP more than 3 volts but less than 4 volts, the HTP. Let us take an example of 3.5 volts. When the input is 3.5 volts let us look at each of the comparators. A_1 comparator 3.5 is more than 3 volts and the output should be minus. If the output is minus the diode is blocked. It is not conducting. It is open; nothing comes at the output point. Because this is 3.5 volts input if you look at the A_2, 3.5 volts is still less than +4 volts which is connected to the other input. The 4 volts is larger than 3.5 volts and the output will be minus again and this diode is also open. Both the diodes are open. No voltage comes from any of the comparators. But the output is connected through R_L to the ground and there is no output voltage and this output voltage will only be the ground voltage because it is connected to the ground through the R_L and as long as the input voltage is more than the LTP more than the +3 volts and less than 4 volts, the HTP the output remains zero and that is what is shown in the graph by the side of the circuit. The output is high till LTP is reached and at LTP it comes to zero and remains zero till it reaches UTP and beyond UTP if you increase the input voltage you get high at the output, V_{sat} at the output. The X-axis is V_{in} and the Y-axis is V_{out}. This is the basic principle of a window comparator.

I am able to now detect all voltages which are between two limits. Whenever I get zero output I know I am within the window. Whenever I get a voltage more than zero that is $+V_{sat}$ I know I am out of that window. I can be either more than the higher tripping point or less than the lower tripping point but I definitely know it is not between the two window limits. This is the principle of a simple window comparator made out of a very simple 741 op amp. You can do this with ordinary op amp 741 and you use ordinary silicon diodes and you are ready for the comparator. We can also have a variation of this circuit so that the output is not low within the window but high within the window and it is zero for every other voltage.

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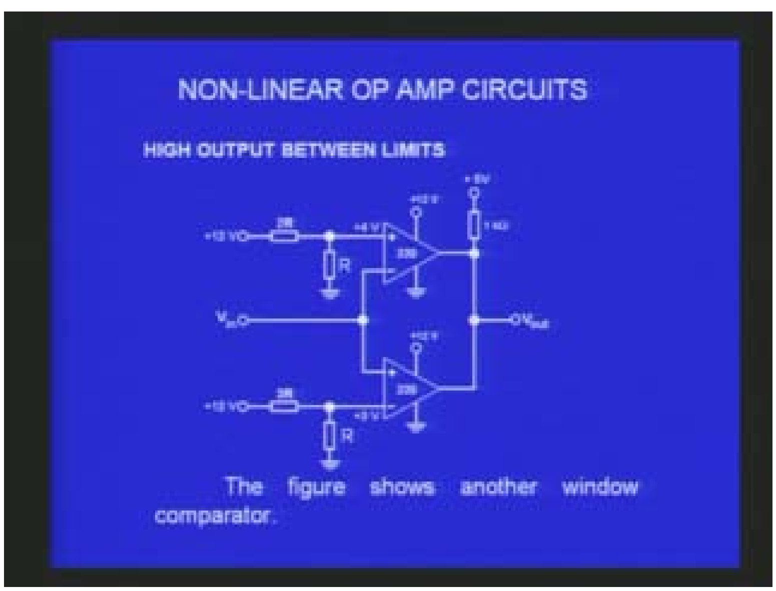

It is sometimes more useful if I have the output of the comparator zero all the time. Only when the voltage is within the window plus and minus LTP and UTP then you get high voltage at the output. For all other voltages outside the window I get zero volts will be a better scheme. How do I make that? The simplest way to make that is that you can perhaps use a standard IC comparator. In this case it is called LM339. I mentioned that even in the previous lecture. The LM339 is a quad comparator. Quad means four. So in LM339 you have four comparators in one package and so you can use them in any way you want. We need two comparators for designing a window comparator and if I use half of the LM339 that means two of the op amps comparator that I have in LM339 I will be in a position to design a window comparator.

In the circuit that you see on the screen you have got two op amps from the LM339 Ic. This is one comparator this is another comparator like you have A_1 and A_2 and one of the threshold the LTP or UTP is obtained by using a potential divider. You could have done that even in the previous circuit. That is exactly what we are going to do when we show a demonstration at the end. This LTP and UTP will be normally chosen from the already existing V_{cc} by using an appropriate potential divider circuit. For simplicity I have taken one of the resistors in the potential divider to be 2R and the other resistance to be R. This point, the midpoint between these two will be 1 by 3R of the applied V_{cc} and it will be 1 by 3 times of 12 volts that means 4 volts. This is the HTP or upper tripping point corresponding to 4 volts here. If you look at the other threshold that is also derived from the same 12 volts by using two resistors in the potential divider arrangement and in this case I have 3R and R connected in series to get the potential. 3R and R will make it 1 by 4 times the V_{cc}. This will be 3 volts at this point.

It is very similar to what we had in the previous circuit. We have 4 volts and 3 volts as LTP and UTP; UTP and LTP to be precise and I have two op amps and the input is common to the other inputs of both the op amps. In the output there is a slight variation from what you saw in the previous circuit. I need not use any diode here but we have connected them together and then this is called a pull up resistor. This 1 kilo ohm resistor which I have connected is called a pull up resistor. That pulls up the output to +5 volts level. Deliberately I have kept the output by using the pull up resistor to 5 volts so that the output voltage can only vary from zero to 5 volts. It will never go to +12 or -12. Thereby the output becomes compatible to TTL logic, the digital logic circuits. TTL logic is one of the good families of logic circuits where the operating voltage is zero and 5 volts only and if I use a pull up resistor and connect it 5 volts to the output of the two op amps then the output can never be beyond 5 volts. It will be zero to 5 volts only. But the actual op amp power supply in this case it is a single supply with +12 volts and the ground as you can see in the circuit. Only the output I use the pull up resistor and connect to 5 volts so that output will only go from zero to 5 volts and not -12 volts to +12 volts as in the case of 741 op amp.

This is the second circuit of the window comparator where the input is going common to both op amps and the two thresholds of the two op amps are maintained at +4 volts and +3 volts by using the potential divider and now let us see how this circuit works. When the voltage is less than 3 volts, let us take the similar discussion when the voltage is less than 3 volts, in this op amp the bottom one this 3 volts will be more than the input voltage and it will be minus at the output. It will tend to go minus at the output. But the output cannot go minus because the output transistor which is through the pull up resistor will become open circuit. It will become cutoff and nothing will come out if the output terminal is cutoff from the op amp and if you look at the first op amp this is about less than 3 volts that we have already said. That means 4 volts is more. I consider voltages which are less than 3 volts. Output will become zero in this case also. In both the cases both the op amps will be off and the output will be zero volts. Actually what is going to happen is this is 4 volts and this input voltage is around 3.5 volts and this is less than this. It will become plus and this transistor will conduct. The first op amp or the comparator will conduct and this pull up resistor will make sure that this voltage is close to zero. The entire 4 volts will be dropped across the 1K and the output will be zero. Whenever I have a voltage which is less than 3 volts this op amp is off and this op amp is on and the output will be zero volts because of the pull up resistors and you get zero volts.

When I have input voltage larger than 4 volts this first op amp which is larger than this will be minus and that means the output transistor will be cutoff. Whereas here this is larger than 4 volts mean this will be more and this will be this transistor will conduct at the output stage and again it will be zero volts; due to the pull up resistors this will be zero volts. Both for the range of voltages less than 3 volts and more than 4 volts one of the op amp conducts and try to get $+V_{cc}$ and that will make the output transistor to be in saturation and the output will show almost the V_{sat} voltage of the transistor which is about 0.1 and it could be very close to zero. For voltages which are between 3 volts and 4 volts let us say 3.5 volts if you look at the first op amp this is 3.5 volts; 4 volts is more. This will become plus on this side. But on this side 3.5 volts is more than this. This also becomes plus. Both the transistors will not conduct. Both will be off and you will get the same 5 volts at the output. So whenever the voltage is between 3 volts and 5 volts the output is 5 volts because both the op amps will be cutoff and you will get 5 volts. Whenever the voltage is less than 3 volts or more than 4 volts one of the op amps will conduct and make the output transistor into saturation and the output will become zero. This is what is going to happen and that is what is shown in the corresponding output graph that you see here. Below the LTP the output is zero above the UTP the output is zero. But between LTP and UTP the output is 1 or output is maximum. Voltage in this case is +5 volts or V_{sat}. In this case it is +5 volts.

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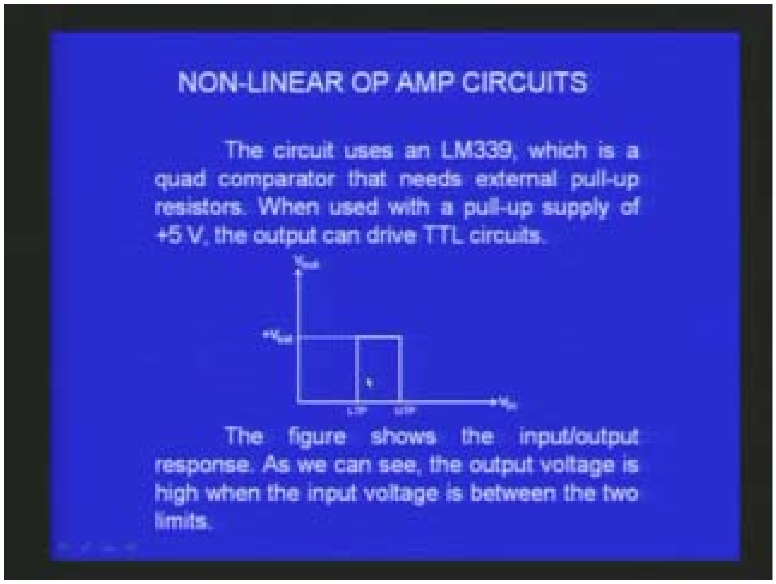

In this op amp compared to what you saw in the previous window comparator the output is low all the time. Only when the voltage is within the window output is high. In the previous example we always had output high; only within the window the output came low. This is a variation of the other comparator and this comparator will be very, very useful in several applications that you would see later.

Let us go to the demonstration table and take up these two circuits and I will show you the two different varieties of the op amp comparators, window comparators how they perform. This is the same circuit which we discussed in the first instance.

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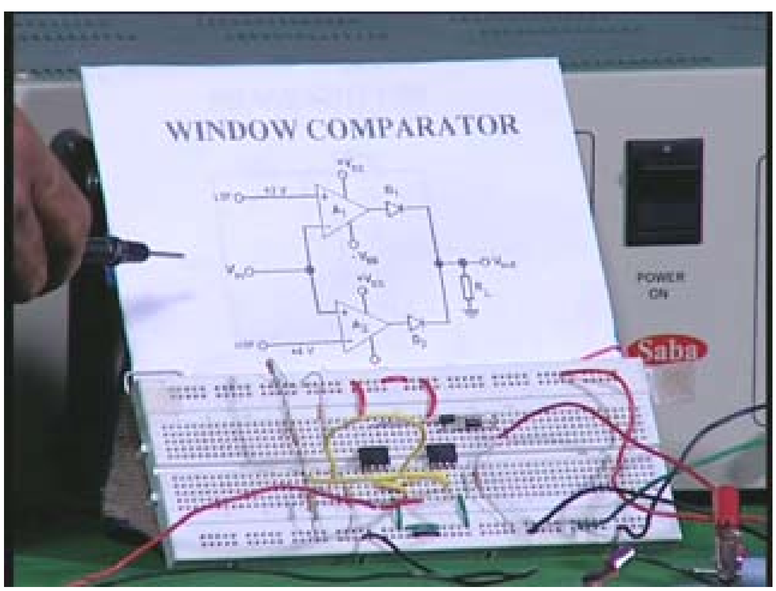

You have two op amps, normal op amps like the 741. You have the two diodes at the output. They are connected together and connected through a load resistor to the ground and the two inputs you have the LTP and the UTP here again approximately close to 3 volts and 4 volts and the other two inputs are connected to that. This is the V input. We are going to put a potential divider by using resistors here to maintain it close to 3 volts and this one close to 4 volts and the input we are going to give from a millivolt source so that I can keep changing the input voltage from zero to some high value and see what happens at the output. Here below you can see the two op amps. I have used 741; the two op amps are here 741 and I have the two potential dividers here. The two yellow lines actually connect to the two op amps LTP and the UTP and I have the two diodes here at the output of which I am monitoring using the multimeter the output voltage. The input which is common to both the comparators is connected here to a millivolt source and this is a very familiar millivolt source we have been using in all our experiments and that output is connected as the input voltage.

I am going to change this millivolt source from some low voltage to higher voltages and observe the output of the multimeter. The input voltage is very low and the output voltage is around 11.42 which is the plus saturation voltage. I have now very low voltage; less than that about 1 volt at the input. Now I am going to keep increasing it. I am increasing the voltage to 2 volts. Now I am going to 3 volts. Immediately the output voltage has become zero in the multimeter.

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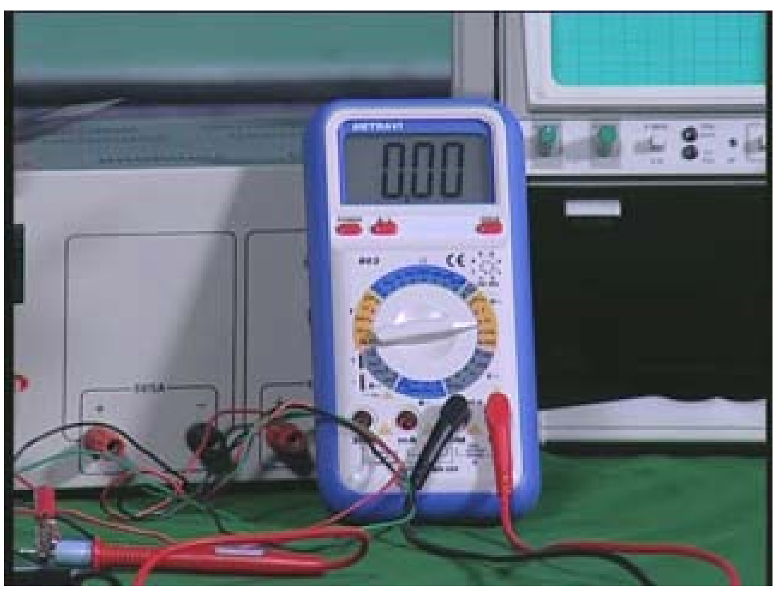

If I now keep increasing the millivolt output from here and when I cross the threshold point immediately the output has come to again 11 volts.

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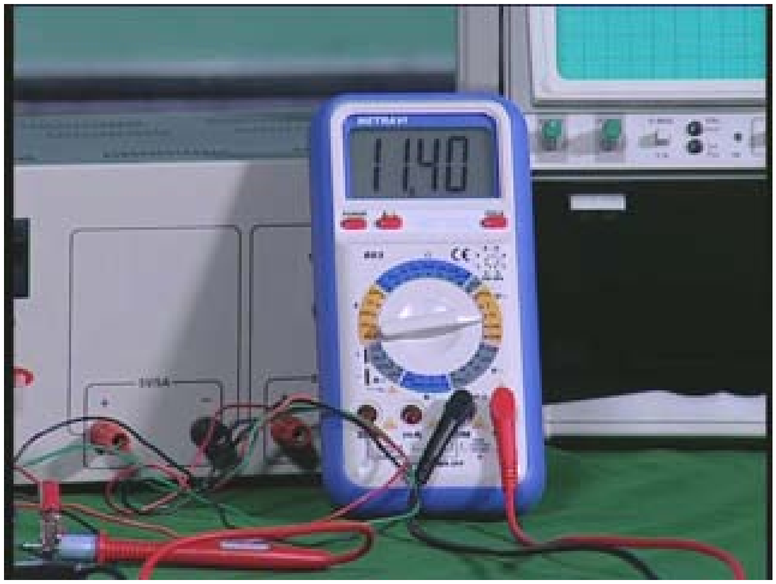

The output is 11 volts for all voltages less than the LTP and more than the UTP. But in between it was having low voltage. Again I am slowly reducing the voltage so that we can see at the output multimeter it is zero. As I keep increasing the output has become again 11 volts. It is about this place that I got 11 volts. I would like to measure the threshold. This is the upper tripping point. Let us measure the threshold by taking the multimeter out from the circuit. I will connect it to the threshold voltage. Let us see how much is that threshold? This is around 3.5 volts. This is the threshold that I have got using the potential divider and now I measure the input voltage. The input voltage is also 3.52 as you can see in the multimeter.

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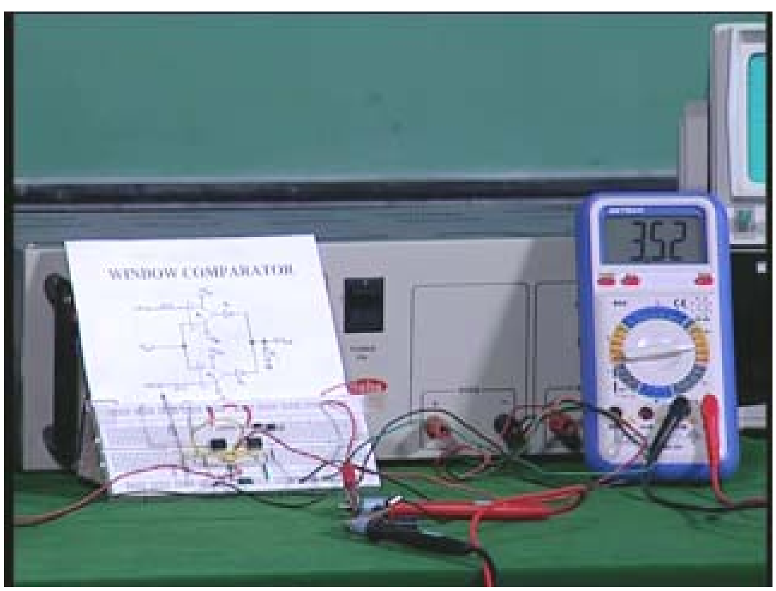

Both the input and the threshold are very close. This is the place at which the output went to 11 volts once again and that is corresponding to the threshold. The comparator is capable of detecting within the two window limits of +3 volts and +4 volts and always output is 11 volts and whenever you are within the window the output is low. Now let us change the circuit to the next one and let us see the second type of the comparator. Here we see the second comparator which I already discussed. Two comparators from LM339 are used and you have the two inputs where this is the 4 volts. This is 2R and R. That means this is $1/3^{rd}$. Therefore it is 4 volts and here it is 3R and R and therefore it is $1/4^{th}$. That means it is 3 volts.

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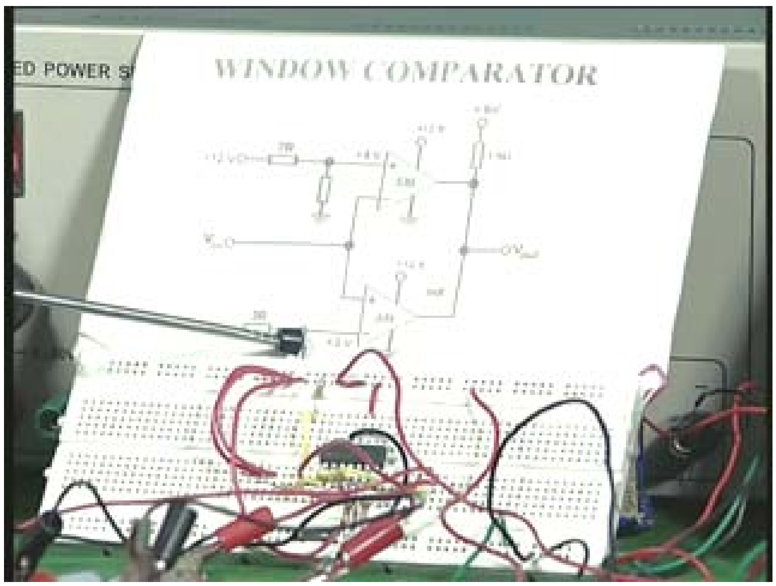

I have a 4 volts threshold here which is the upper tripping point and 3 volts threshold here which is the lower tripping point and the other two inputs are connected together and this is the input I am going to give. At the output we have the pull up resistor 1 kilo ohm going to +5 volts and the output is taken at the bottom. Now I am going to vary this input using a millivolt source which we have already seen. This is the millivolt source. I can select; I have put it in voltage and I can vary from zero to 10 here and I can vary in between here; fine adjustments. I am going to adjust this and try to do that. Right now it is at 1 volt and you can read the voltmeter it is around 1.21.

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If I now decrease still further I can get up to 1 volt.

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Now it is 1 volt. That is what I have set here. I am going to increase the input voltage and when I cross the lower tripping point the output you should see using the other multimeter. This is the second multimeter on the output side. This is right now 0.21. That means it is very low. It is low voltage. In this comparator when input voltage is between the two threshold lower tripping point and upper tripping point the output will be 5 volts here. That is what you should try to observe. You should observe what is in the first multimeter on this side and correspondingly what happens at the other multimeter. Now what I am going to do is I am going to vary the input. Right now the input in this multimeter is 0.99. That is 1 volt. I am going to increase it to 2 volts. Now it is 1.99 nearly 2 volts. I am going to vary this. Because this is at nearly 3 volts I am going to vary till I reach the threshold voltage; still the output voltmeter shows only very low voltage, 0.22. I am increasing the input voltage; as you can see in the other multimeter it is increasing. So I keep on increasing. This is 2.4 volts. This is 2.6, 2.8. Now it is about 2.84; even now the output multimeter reads only 0.22.

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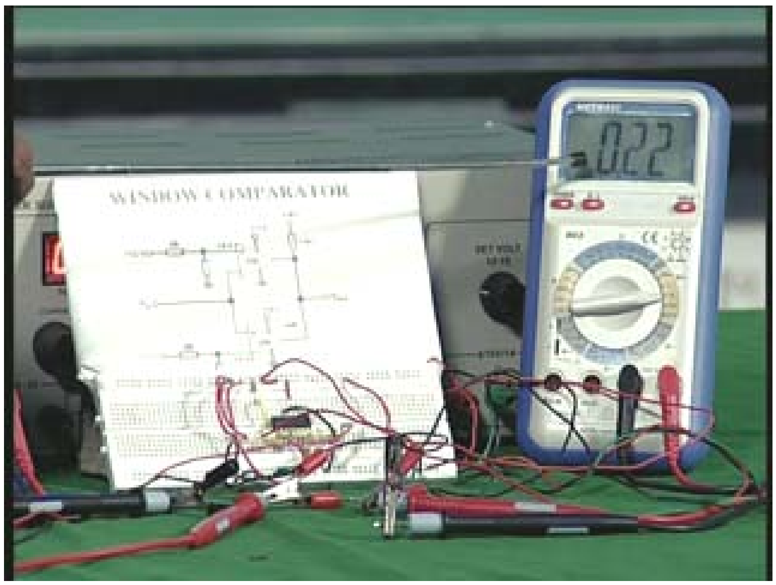

Now I am going to still further increase from 2.85. I am increasing; I have made 2.87. Now you see the output. It has already become 5 volts.

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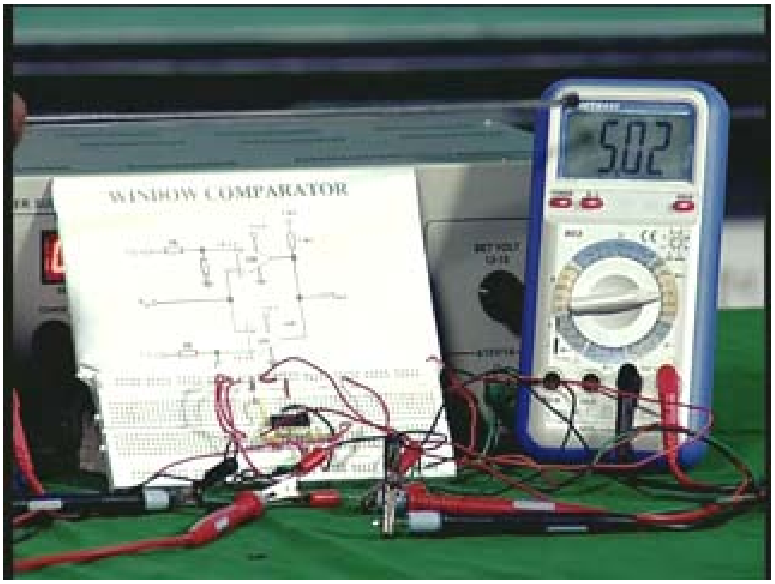

So the threshold is about 2.8 volts. Now I am going to increase still further the voltage. Let me put it in 3 and I will again reduce it to minimum. The input is 3 volts here. The input is 3 volts now and let me see the output. Output is 5 volts. Now we are within the two window levels and the output is high. Now as I increase from 3 volts to 4 volts let us see what happens? I am now varying the input voltage. It is increasing now; 3.1, 3.2, etc. At one point you will find the output will go to zero. As I keep on increasing I will show you the point where it becomes zero. Now we are at 3.95. If we observe the output it is still 5 volts. I am going to still increase the input. Immediately it has come down to low value 0.22 again. So the threshold is around 3.97 close to 4 volts.

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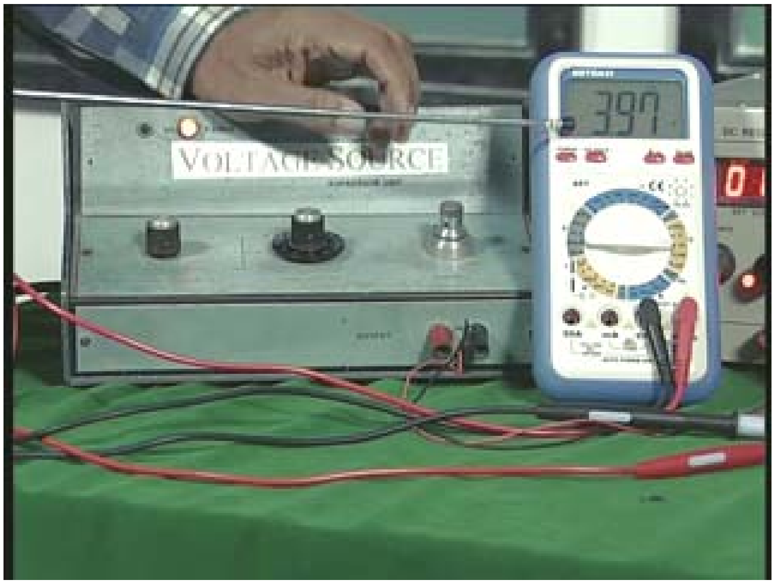

Between 3 and 4 volts the output is changing from zero to 5 volts. Below 3 volts and above 4 volts the output is zero. Right now it is 3.97. If I still further increase to 4.9, 5, etc the output remains at 0.23 that means low. The output is low if the voltage is above the upper tripping point; the output is low if the input voltage is below the lower tripping point. But between 3 volts and 4 volts the output becomes 5 volts. That is what I wanted to you to observe. I am again bringing it down and the moment I reduce the voltage the output becomes 5 volts. It is now 5 volts. The window comparator is low all the time. Only within the window region it becomes 5 volts. This is in contrast to what you saw in the first circuit which I also demonstrated. There it was high all along only within the window it was low. It is just opposite of this and this is done using commercially available LM339 comparator. This IC which is here, a 14 pin IC, has got 4 comparators inside. We have used only two of it. That means we have used only half of the IC here and the other half is also available for other applications.

What we have seen so far is typically two applications of the comparator circuit. They are called the window comparator where a specific window is generated with a lower tripping point and upper tripping point. Especially when the input voltage is within these two ranges the output is in one state and when it is beyond these two upper tripping point and lower tripping point the output is in a different state and we have seen two different examples. In one case beyond the window it was high and within the window it was low and in the second case beyond the window it was low and within the window it was high. I have demonstrated to you by actual experiment also these two different types of circuits. The comparator especially the regenerative comparator that we have seen is also very useful in another application which is as an oscillator. We are going to see one more application of the comparator circuit which is the relaxation oscillator. Let me move on to show you the circuit of a relaxation oscillator on the screen.

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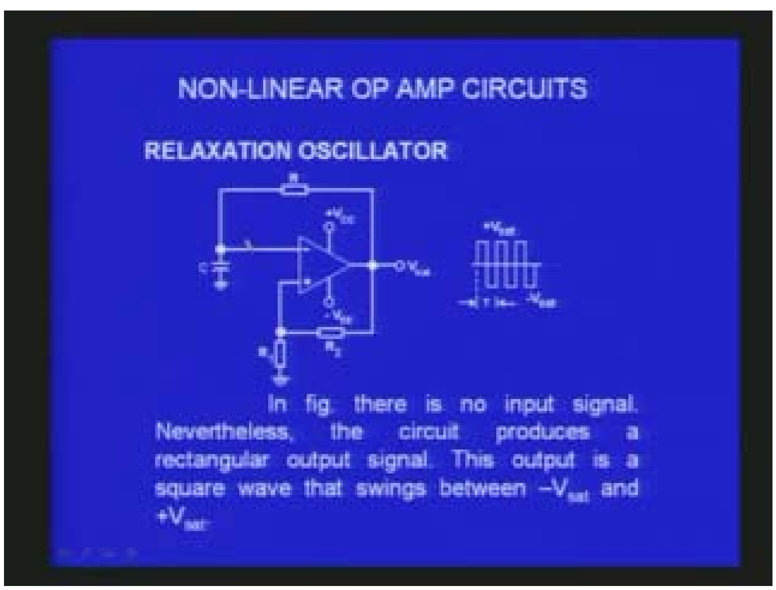

You have an operational amplifier which could be in this case 741 operational amplifier and the plus terminal is connected to R_1 and R_2 and this is a regenerative comparator. That means it will have an hysteresis associated with that. The lower tripping point and upper tripping point will be on either side of zero. One will be plus some voltage and the other will be minus some voltage. With this comparator what we have done is the output point is connected through a resistor R and a capacitor C and the junction of the resistor capacitor is connected to the inverting input of the operational amplifier. It is just a simple circuit with only three resistors and one capacitor. The output in this case can only be either $+V_{cc}$ or $-V_{cc}$ or $+V_{sat}$ and $-V_{sat}$. If you assume that it is at $+V_{sat}$ then the moment I connect the R and a C to the output, the output will start charging the capacitor through the R. By the time constant related to the RC the capacitor slowly accumulates the charge due to the output being connected directly to the R and C.

As the voltage here starts building up due to the charging of the capacitor this voltage at the inverting input will keep increasing and the voltage at the non-inverting input is obtained by a potential divider with R_1 and R_2 and it will be some fraction of the $+V_{sat}$ that we have. When this voltage across the capacitor increases beyond the plus fraction of the V_{sat} that we have here, decided by the R_1 and R_2 this input terminal will become higher in voltage compared to the plus and the output will go to $-V_{sat}$. This is the basic operation of the comparator. Once it goes to $-V_{sat}$ immediately what is going to happen is this point is no more fraction of $+V_{sat}$ but it is going to be a fraction of $-V_{sat}$ and when I have a $-V_{sat}$ connected to the R and C the capacitor will start discharging through the R towards the output and the voltage across the capacitor will start decreasing regularly. When it comes below the fraction of the V_{sat} that we have at the plus terminal again the plus terminal voltage will become larger than the minus terminal. It will again go to plus V_{sat}. Without our switching voltages the output automatically switches between $+V_{sat}$ and $-V_{sat}$ depending upon the charging of the capacitor or discharging of the capacitor. Whenever this charging and discharging crosses the LTP and the UTP you get the output shifting from V_{sat} to $-V_{sat}$, etc. I have also shown you the square waves that we get at the output. First it goes to $+V_{sat}$ and remains there for sometime till the RC time constant builds up voltage which will come beyond the tripping point and it goes to $-V_{sat}$ at the bottom and it remains again at $-V_{sat}$ till the capacitor completely discharges below the other tripping point. Then it goes to V_{sat}, etc. This device is alternate relaxing over the time period RC and then it is only changing state whenever the tripping points are the UTP and LTP. This is called a relaxation oscillator and it is very, very simple way of making a square wave oscillator. All that you have to have is an op amp with couple of resistors, 3 resistors and 1 capacitor.

How do we understand about the frequency of operation? How to get the expression for the frequency of the relaxation oscillator is what we would discuss now. Before we do that I have shown in the graph how the whole thing happens?

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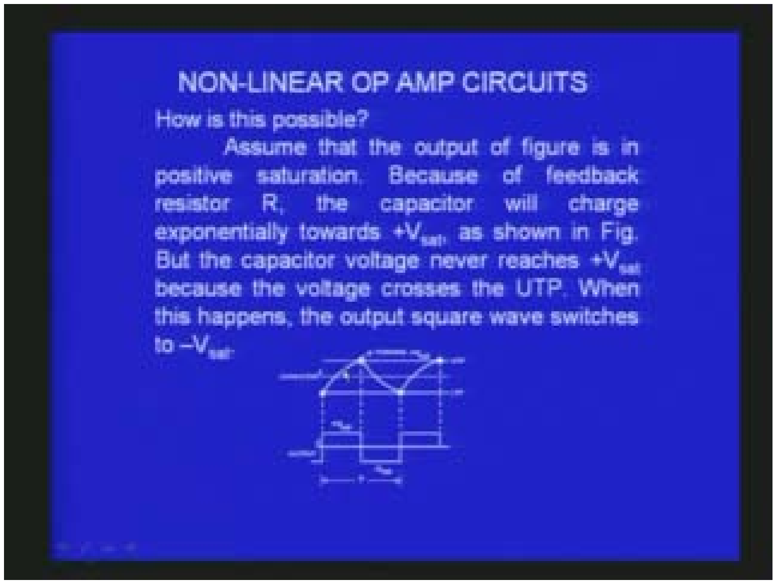

What you see here is the capacitor voltage. It starts from zero actually and starts going towards $+V_{cc}$ but …….. crosses the upper tripping point the output changes to $-V_{sat}$ and it starts discharging. It starts discharging till it comes to the LTP and again charging, discharging. The capacitor voltage only moves from LTP to UTP, UTP to LTP, etc and it is the charging and discharging graph that you get at the capacitor which can in principle for a large time constant can almost be resembling the triangular wave. If you have a large time constant this will become a triangular wave and whenever this change over from charging to discharging happens the output is actually changing from $+V_{sat}$ to $-V_{sat}$. You get a corresponding square wave as shown at the bottom. The total time period is the period corresponding to one excursion from UTP to LTP and LTP to UTP. That is what is shown in the figure as period T. One part of it is half of the period or T by 2 corresponding to this sign. Now we will try and see whether we can obtain an expression for the frequency of operation.

Any voltage across the capacitor in general can be written as whatever is the voltage is already there, we call it initial voltage V_i, plus whatever is the final voltage that you want to reach minus the initial voltage. This difference in voltage is responsible for driving a current through the R charging the capacitor. The charging voltage is nothing but V final minus V initial. V final minus V initial is the one which is charging the capacitor; 1 minus e power minus T by 2RC where the 2 factor comes because we are looking for T by 2, half the period how it is happening; T by 2RC. This is the equation that we should write and what is V_C?

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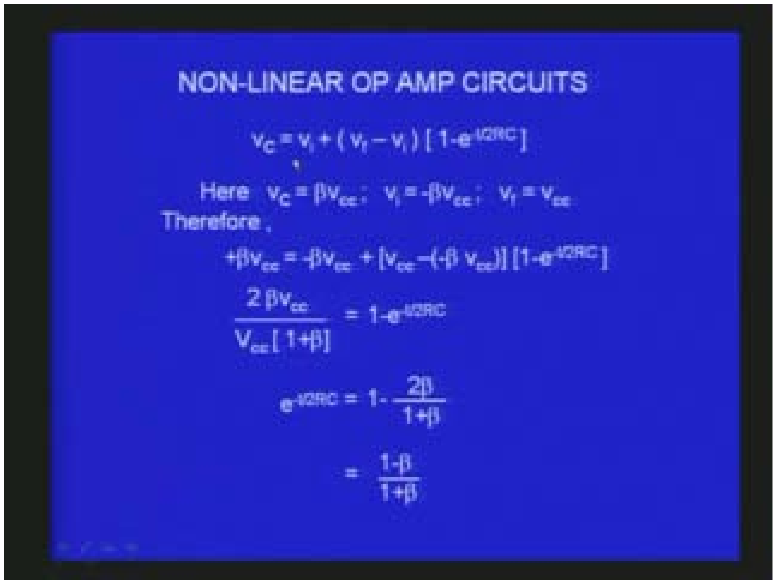

V_C is the voltage at the capacitor when the tripping happens and at that time let us say it is beta V_{cc}. If it is beta V_{cc} the initial voltage would have been minus beta V_{cc}. From minus beta V_{cc} it is building up to beta V_{cc}; then there is a change. Initial voltage is minus beta Vcc and the final voltage it wants to reach, it wants to charge is $+V_{cc}$, total V_{cc}. The three values now we understand; V initial is minus beta V_{cc}. V final is V_{cc} because that is the point towards which the charging happens and the exact voltage on the capacitor is plus beta V_{cc} just when it is tripping. I will substitute these values. V_C is now plus beta V_{cc}. That is equal to minus beta V_{cc} which is the initial voltage plus the final voltage is V_{cc} minus minus beta V_{cc} which is the initial voltage multiplied by 1 minus exponential T by 2 RC. This is the normal expression for the charging of a capacitor. When you simplify this, it becomes 2 beta V_{cc} by V_{cc} into 1 plus beta. That is equal to 1 minus e power minus T by 2RC. From this you can get e power minus T by RC is equal to 1 minus beta by 1 plus beta and if you remove the minus sign by inverting it T by 2RC will be logarithm of 1 plus beta by 1 minus beta. These are the natural logarithm corresponding to e.

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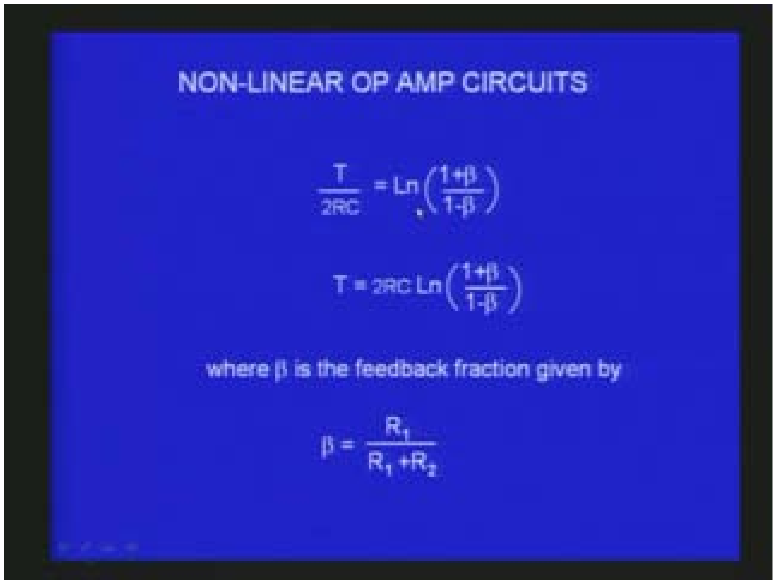

T by 2RC is Ln 1 plus beta by 1 minus beta and T is equal to 2RC Ln 1 plus beta by 1 minus beta. What is this beta? This beta is the feedback ratio which is given by R_1 divided by R_1 plus R_2. This amount of V_{sat} is being applied at the threshold point at the input. That is what it shows. Beta is decided by the R_1 and R_2 that you choose and the period is given by 2RC Ln 1 plus beta by 1 minus beta. If you substitute all the values correspondingly here you know R; you know C, you know beta. Then you will get the period and 1 by period gives you the frequency. That is how we can get the relaxation oscillator built making use of an operational amplifier in the comparator mode. We have only used in addition an RC to make it as a relaxation oscillator. You get a square wave with an amplitude $+V_{sat}$ and $-V_{sat}$ but we can also vary that output swing by adding Zener diodes or several other techniques which I already mentioned to you when I talked about the comparator. For example you can use two Zener diodes back to back connected at the output. Then depending upon V_z let us say +5 volts is the break down voltage of the Zener. You will get +5 to -5 excursion instead of $+V_{sat}$ to $-V_{sat}$ which in usual case will be +12 to -12 or +15 to -12 or -15? You can modify the output swing to any value you want either +5 to -5 or 0 to +5 and thereby you can have a simple square wave built around a comparator. Having said that I would like to show an actual circuit working and explain to you about the circuits.

Here you have the relaxation oscillator. You can see the operational amplifier which is again here 741 and the plus is connected to the potential divider and here the potential divider is both having 10K plus 10K. It will be half of the V_{sat} that you will get here as the threshold. When it is $+V_{sat}$ it will be +12 volt, the applied voltage. So 6 volts will be the threshold here. When it is minus it will be -6 volts, half of that and then to the negative input we are giving from the output a resistor and a capacitor in series and the junction is given to the inverting input.

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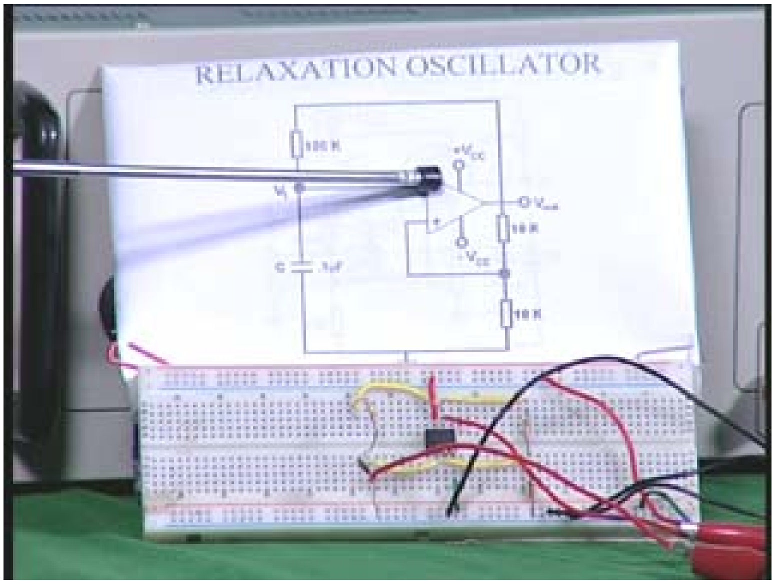

This is the simple relaxation oscillator. The same circuit is wired here. You can see the op amp and the two resistors that you have here both are 10K from the color code you can observe and the mid point is connected to pin number 3 which is the non-inverting input. Pin number 2 is connected to the RC here. The R is 100K and the capacitor is about 0.1 microfarad. I have the same circuit wired here and I am monitoring the voltage obtained at the capacitor end as well as at the output. I measure the output voltage wave form here as well as here, both the points. When you look at the oscilloscope the bottom trace is corresponding to the voltage across the capacitor. It is charging and then discharging and this should be corresponding to the LTP and this should be corresponding to the UTP. It keeps on moving between the two limits UTP and the LTP and whenever the transition happens at that stage it goes from low to high $-V_{sat}$ to $+V_{sat}$ and again to $-V_{sat}$, etc. That is what we seeing here. If I increase the amplitude you will be able to see much better the charging curve. This charging curve will become straight if I use larger resistor or larger time constant, the product RC. It will become much more like a triangular wave. Right now it does not resemble the triangular wave because it is basically charging and discharging that is happening and you get a square wave here. You have nearly about 2 divisions and that corresponds to nearly some 12 volts or so if you look at the dial of the oscilloscope.

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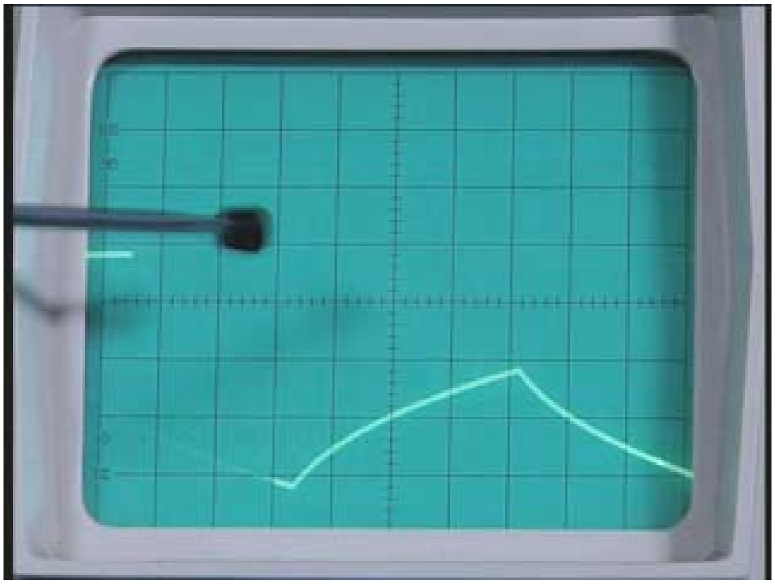

You can get a square wave and you can also get a triangular wave if you properly choose your RC time constant, RC value. You can also get a triangular wave. Once you get the triangular wave and a square wave you can get several other associated wave forms whenever you want. It is very, very simple scheme by which you can get a square or triangular wave by using an operational amplifier in the form of a comparator. That is the application of the comparator for preparing a free running square wave oscillator. The output again I set can be limited to +5 volts or -5 volts or 0 to +5 volts by correspondingly connecting here 2 Zener diodes or a Zener diode and a series resistors as the case may be and you can limit the amplitude to any desired value that you would like to have for a given application.

So far we have seen different applications of the comparator where the comparator can be used as a window comparator to identify a set of voltage values which are within maximum and minimum limit. We have seen two different types of circuits which can be used as window comparator and we also saw a very useful application of the comparator in the form of a relaxation oscillator where we have used couple of resistors and capacitors to have a square wave output. We can also for example have the R value; in RC combination you have, the R or the C you can vary. The R or the C as the case may be and thereby you can have a variable frequency or variable period square wave or triangular wave oscillator. Simply you remove the 100K resistor that you saw in the circuit and replace it with 100K potentiometer variable resistance. Then as you vary the resistance the time constant is changing. The upper tripping point and lower tripping point will be reached sooner or later as the case may be and that will correspond to a change in the period and that means the frequency of the output will be changed by changing the R value of the RC combination.

Again if you change the capacitor you will get much larger ranges of frequency variation that is possible. In most of the commercial function generators that you come across in a laboratory both the C and R are also varied in similar fashion if not in this circuit. The basic principle of varying the frequency is you vary the resistance continuously for the range and then switch the capacitor to a new value by 1 order or so and again vary the resistance for getting the intermediate resistance frequency values. By a combination of a variable resistor and switched capacitors you can achieve very large frequency range for these circuits. In principle you can prepare a very simple square wave oscillator by making use of an operational amplifier in the non-linear comparator mode. Apart from that the operational amplifier ……. applications have got many more similar applications.

What perhaps you would like to discuss next will be how we can measure very small AC voltages? If I have an AC voltage normally for example if the AC voltage is only 0.5 volts if I want to measure it without amplifying it there is no way I can do it. Because if I now try to rectify it using a normal silicon diode, normal silicon diode requires a minimum of 0.6 volts or 0.7 volts for it to conduct freely and if I apply 0.5 volts AC sine wave it will not be able to forward bias the diode and after rectification I will not get any voltage at all. A normal diode cannot be used for voltages which are very low in magnitude like 0.5, 0.4. You would see in the next lecture that by using an operational amplifier along with the diode I will be in a position to make the diode much more ideal diode without having to have above 0.6, 0.7 volts across it. Even when it is very, very small in the order of microvolts the diode will start conducting and it will be able to behave like a rectifying diode, ideal rectifying diode and thereby we will be able to study very low level signals also without any problem.

The applications of the active diode circuits, the principle of operation, how it can be used for full wave rectification, half wave rectification, how you can make a peak detector with the active diode and you can also make clipper and clamping circuits which we have already seen when we discussed about the applications of the diodes initially can all be discussed making use of this active diode. We would spend rest of the next lecture on active diode circuits and applications. Thank you!