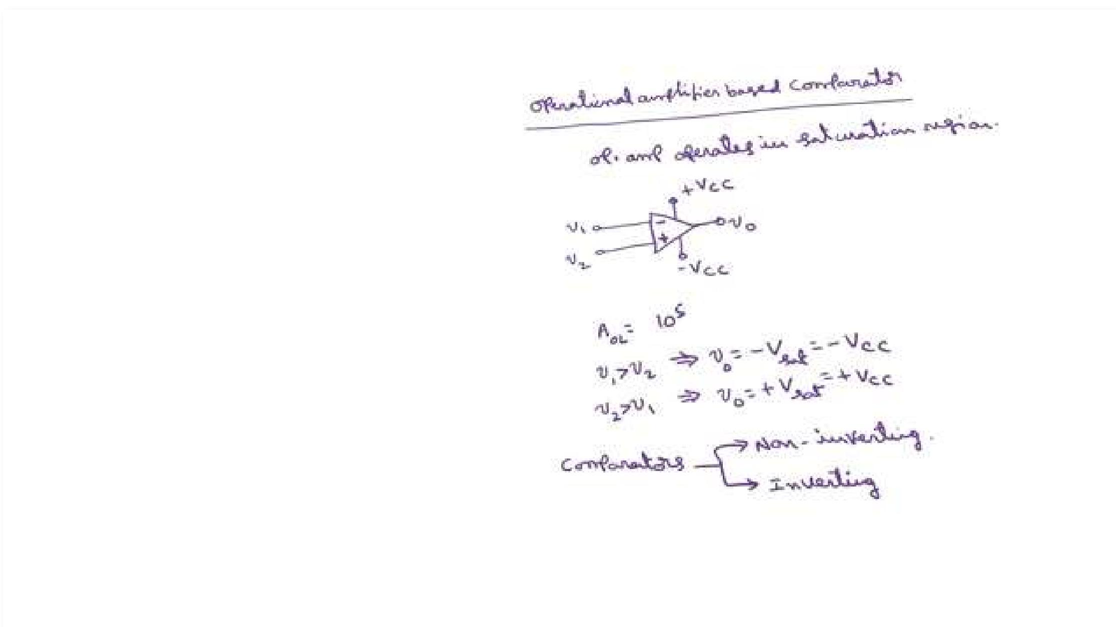
Integrated Circuits and Applications

Prof. Shaik Rafi Ahamed
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati

Oscillators and Waveform Generators
Lecture - 24
Comparator and Schmitt Trigger Circuits

Okay In the last few lectures we have discussed about the various sinusoidal oscillators or sinusoidal waveform generators. So, the next type of waveform that can be generated by using the operational amplifier is rectangular wave as well as triangular wave okay. So, in order to discuss the waveform generations which generates the rectangular and triangular wave, we have to first understand the operation of the op-amp comparator. So, first I will start with the operational amplifier based comparator, then based on this principle I will discuss how a rectangular wave will be generated and from this rectangular wave generator how to generate the sawtooth or triangular waveform. So, first I will discuss about the op-amp comparator. As the name comparator implies it compares two signals.

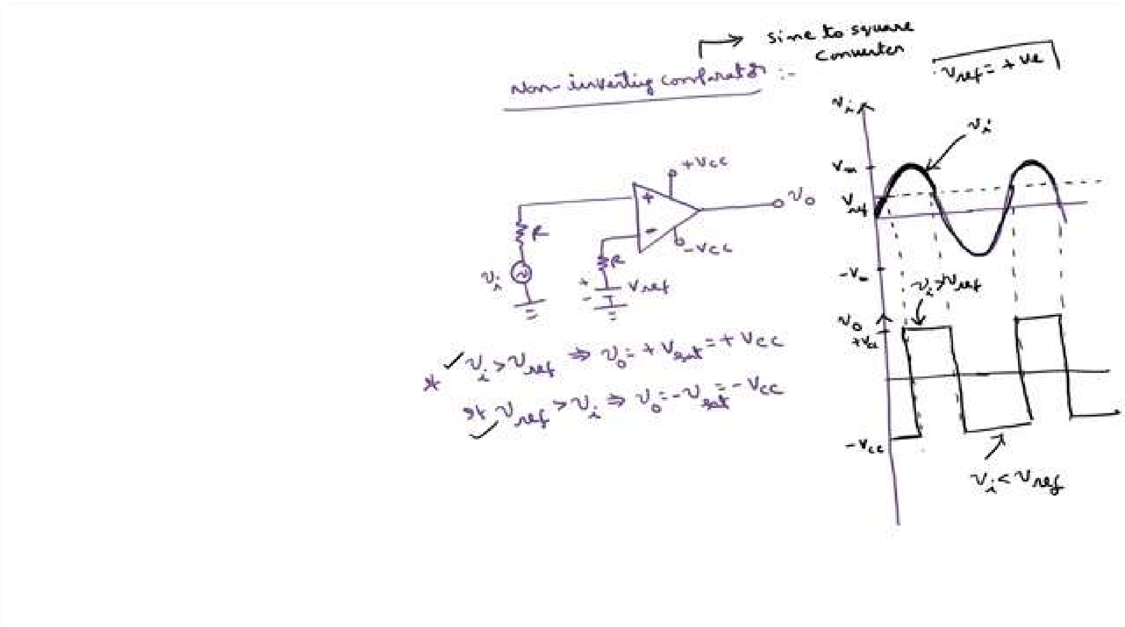
(Refer Slide Time: 04:12)



So, depends upon whether the first signal is greater than or less than the other signal the output will be varies. So, normally in this comparator operation op-amp operates in saturation region. As I have discussed in the early lectures that suppose if I take a operational amplifier this requires $+V_{CC}$ and $-V_{CC}$ this is the output. Here if I operate this in open loop configuration the open loop gain is of the order of 10^5.

So, if v_1 is slightly greater than v_2 the negative voltage greater than positive voltage means output will drive into negative saturation. If v_2 is greater than v_1 output will be drive into positive saturation. Here also in the comparator we are going to use this type of a principle. So, if I take the comparator circuit there are two types of the comparators non-inverting and inverting. There will be two voltage one is input voltage another is reference voltage. Depends upon where the input voltage is applied, reference voltage is applied we have two types of these comparators.

(Refer Slide Time: 09:14)



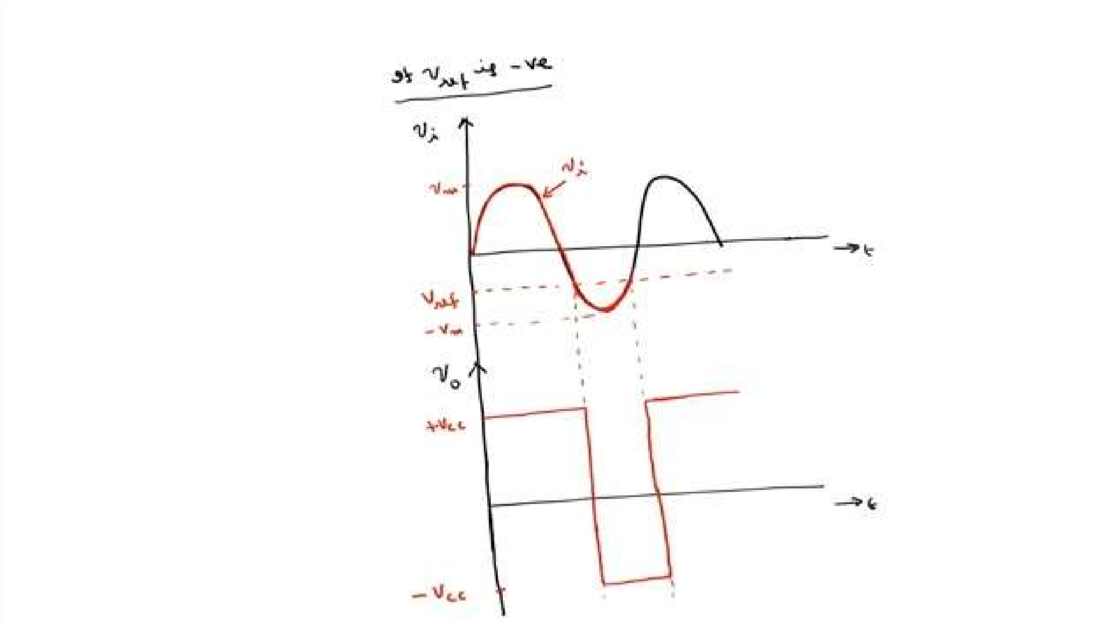
If I consider the non-inverting comparator. Here the input voltage is applied v_i normally sinusoidal type of input. Here v_{ref} voltage is applied both will take R resistance and this is output v_o. If $v_i > v_{ref}$ then the positive voltage is greater than negative voltage means output will be positive saturation that will be $+V_{CC}$.

If v_{ref} which is applied to the inverting terminal is greater than the v_i input which is applied to the non-inverting terminal. So, the negative voltage is greater than positive voltage means output will drive into the negative saturation. If I draw the input and output waveforms of this comparator. If this is input waveform, v_{ref} is less than the maximum value of the input signal let this is v_{ref} and this is v_m this is $-v_m$ then what will be the output. This is input v_i what will be the output v_o?

So, in this portion in this portion $v_i < v_{ref}$ this is v_i signal and below this v_{ref} this portion $v_i < v_{ref}$. So, $v_i < v_{ref}$ means this one output will be $-V_{CC}$ this is $-V_{CC}$ and during this portion $v_i > v_{ref}$, vi is greater than v_{ref} means output is $+V_{CC}$ this is $+V_{CC}$. Again, during this portion from here to up to here $v_i < v_{ref}$. So, negative saturation again during this portion way is greater than so, output is positive saturation like that this will be the output waveform for a input sinusoidal signal. That is why the comparator can also be called as sine to square converter.

This is converting the sinusoidal signal into a square signal. So, this portion $v_i > v_{ref}$ in this portion $v_i < v_{ref}$. So, here I am assuming that v_{ref} is positive, v_{ref} is positive.

(Refer Slide Time: 11:42)



If v_{ref} is negative also you can draw the input output waveforms. Means you have to change the polarity of this, this is input v_i and this is output v_o. This time axis. Second input will take sinusoidal signal, but this time v_{ref} is negative. So, somewhere here this is v_{ref} this is of course, v_m and this is $-v_m$. So, what will be the output waveform? So, during this entire portion from here to up to here what will be v_i? This is v_i. So, $v_i > v_{ref}$.

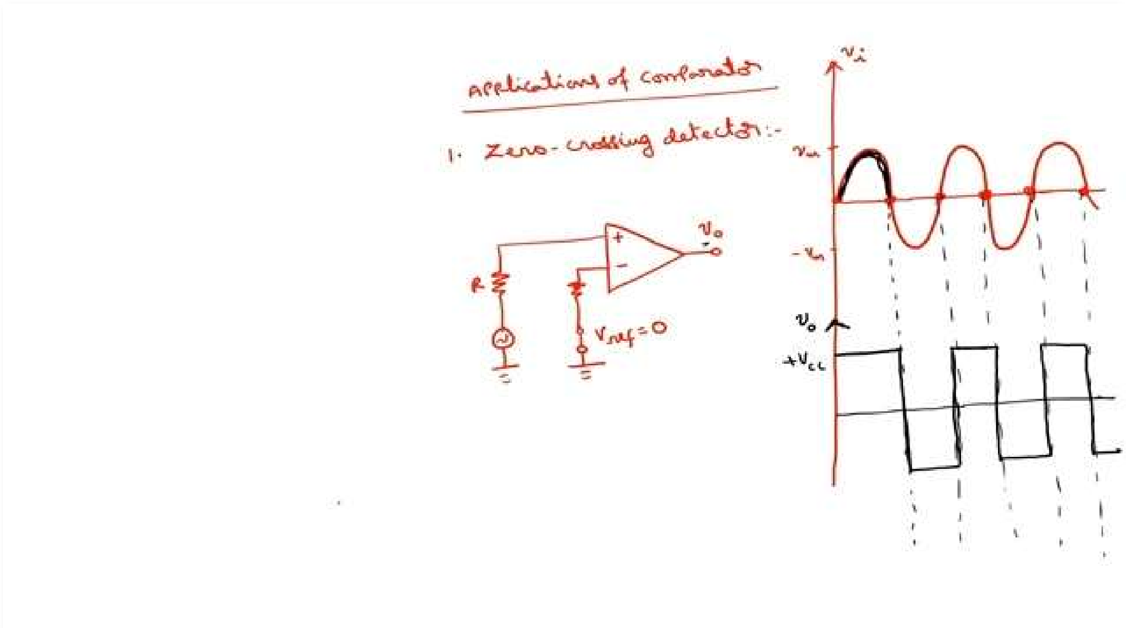
$v_i > v_{ref}$ means, $v_i > v_{ref}$ positive terminal. So, output is $+V_{CC}$. Only during this small portion from here to here $v_i < v_{ref}$. So, negative saturation. Again, during this portion positive saturation.

So, like that you will get a square wave. In fact, this can be a square wave or rectangular wave okay. So, this is about the v_{ref} positive and v_{ref} negative for a non-inverting comparator. Similarly, if I want the inverting comparator you have to just change the polarities of this positive and negative. Accordingly, you can draw the input output waveforms of inverting comparator also.

So, one advantage is this comparator will convert the sine wave into square wave. There are lot of applications of the comparators. I will just discuss two of these applications of comparator. One is zero-crossing detector. This is one of the very very important circuit in many of the practical applications.

So, in the ECG signal analysis, EEG signal analysis many waveforms whenever they crosses the 0, we have to detect that zero crossing to process those signals. So, this zero-crossing detector can be implemented by using comparator. So, if I take this either positive either inverting comparator or non-inverting comparator, the only difference here is we are going to make v_{ref} 0. This v_{ref} we have short circuited means v_{ref} is 0. Now, what will be type of the output that we will get? If input is sinusoidal signal.

(Refer Slide Time: 16:20)



So, this is crossing the 0 several points. Here it is crossing 0, here also it is crossing 0, here also crossing 0, here also crossing 0. This, this and all. This is type of input we have applied. So, what is the type of output we will get? The type of output we will get here will be.

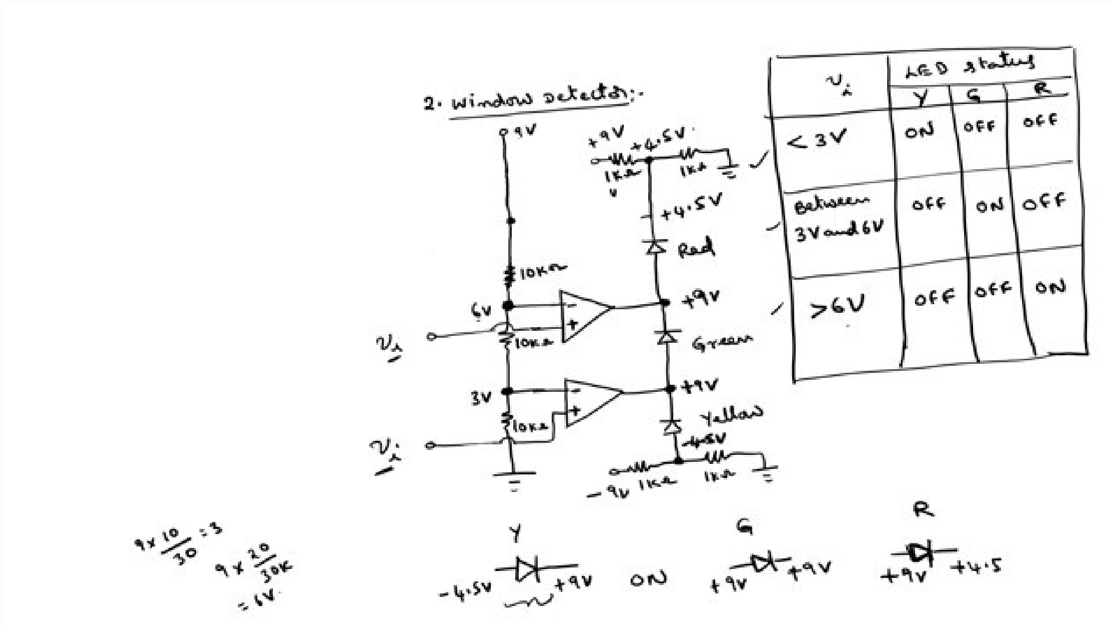
So, these are the points where it crosses the 0. So, above 0 this entire portion v_i is greater than v_{ref}. So, this will be positive we will get $+V_{CC}$. And, the negative portion v_i is less than v_{ref}. So, we will get negative V_{CC}.

So, for all positive values we will get positive V_{CC}, negative values we will get negative V_{CC}. This is the type of waveform that we will get at the output of this zero-crossing detector. Whenever it crosses the 0 the direction of v_o will changes. So, initially here this will be positive then it is changing to the negative at first zero-crossing and again at another zero-crossing negative to positive. So, if you just count the number of transitions then you can find out the number of zero crossings of the input signal.

You just count the number of transitions of the output to find out the number of zero crossings in the input. This is one of the very important application which has lot of practical uses.

Second one is window detector. In many applications it is required to perform a operation. So, whenever say input crosses a particular value and if it is below another particular value then you have to do some operation. If it is above the second value and below the third value you have to do some other process. So, like that there will be a window within this window you have to perform this operation. So, in the second window you have to perform the second operation, third window you have to perform the third operation and so on. So, like that here I will take just I mean 3 LEDs yellow, green and red. So, under different conditions so, these LEDs will on or off. So, I will just take 3 LEDs controlled by comparator. Here I am going to connect 3 diodes. So, I will just connect 3 diodes.

(Refer Slide Time: 27:19)



This is yellow LED, this is green, this is red. This is also $9V$. This is $10\ k\Omega$, $10\ k\Omega$, $10\ k\Omega$. Here the voltage will be now voltage divider $9V \times 10$ by the total resistance is 30 is equal to $3V$. And the voltage here will be $9V$ into the resistance just below this point is $20\ k\Omega$, your total is $30\ k\Omega$. This is equal to $6V$ and here it is complete $9V$ and then the input v_i is applied here. The same input v_i is applied to the second terminal of all the op-amps. This is same v_i only. I am just showing for the sake of simplicity three different v_i's. Now here what is the voltage here? This is $1\ k\Omega$, $1\ k\Omega$. This is also another voltage divider $9 \times \frac{1}{2}$ is $4.5V$ here plus and here this will take $-9V$.

So, this voltage is $-4.5V$. Now, what will be the conditions of this red, green and yellow LEDs? If I assume that this $+V_{CC}$ and $-V_{CC}$ also say $9V$ only for all the three operational amplifiers. v_i LED status, if you form the table, if v_i is below $3V$, what will be status of Yellow LED, green LED, red LED? We can see that here if this input voltage v_i is less than $3V$ means negative voltage is greater than positive voltage. So, this is equal to $-9V$. Assume that $+V_{CC}$ and $-V_{CC}$ are $+9V$ and $-9V$. So, what about the voltage here? This v_i is applied here. So, this v_i is less than $3V$ means less than $6V$ also this is also $-9V$ and here also this is $-9V$. In fact, this operational amplifier is not at all required I think. This is not required only two operational amplifiers are enough and what will be this anode voltage? This is $+4.5V$ and here this anode voltage is $-4.5V$.

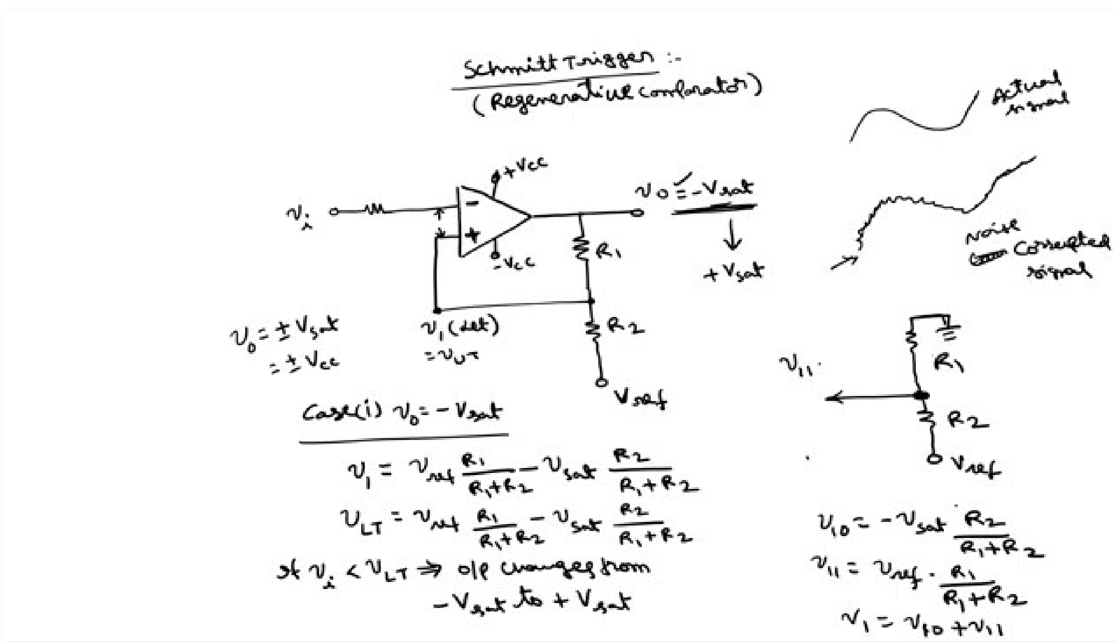
Now, tell me the status of 3 LEDs? For the yellow LED, the anode is at $-4.5V$. This is the case of yellow LED, cathode is at $-9V$. So, cathode is more negative than the anode. So, this will be on. For the green LED, cathode is at $-9V$, anode is also $-9V$. So, resultant is $0V$. So, this is off. For red LED, anode is at $-9V$, cathode is at $+4.5V$. So, this is reverse bias because cathode you have to connect to negative voltage, anode you have to connect to positive voltage, but here it is reverse this is also off.

Now, the second case is if the input voltage is between $3V$ and $6V$. It is just slightly less than $6V$ slightly more than $3V$. So, if this v_i is slightly more than $3V$ positive voltage is greater. So, this becomes $+9V$. This is of course, $-4.5V$ only. Now, less than $6V$, this $v_i < 6V$ means this remains $-9V$ only.

Now, what will be the status of the 3 LEDs? For the yellow LED, what is the voltage at the anode? what is the voltage at the cathode? Anode remains same -5 $4.5V$, cathode is $+9V$. Now cathode is at more positive voltage than the anode means this will be off. And what about the green LED? Anode is at $+9V$, cathode is at $-9V$. So, cathode more negative, the anode is positive. So, this is on. What about red LED? Cathode is at $+4.5V$ and the anode is $-9V$ same as the previous case this is off.

Third case input voltage is greater than $6V$. What happens now? So, this anode is at $-4.5V$ only. So, this v_i is now greater than $3V$ means this is $+9V$ only. So, this remains same status. So, this will be off. So, what about the status of the green LED? Now v_i is slightly greater than $6V$. So, this will be $+9V$. So, for a green both the anode and cathodes will be at same $+9V$ as a result of that this will be off. Whereas for red LED this is at $+9V$, this is at $+4.5V$. So, anode is more positive than the cathode implies it is on. So, like that depends upon the v_i in these three ranges. So, three different LEDs will glow okay. $v_i < 3V$, yellow LED will glow. If it is between the 3 to and $6V$ green LED will glow. If it is greater than $6V$, red LED will glow. So, this type of circuit is called as window detector. This type of operation is required in many of the industrial processes okay. So, these are some applications of the comparator.

(Refer Slide Time: 35:30)



Next another important circuit is called as a Schmitt trigger. So, we can use this comparator to detect the zero crossings. Suppose if you have a many zero crossings, suppose there is a useful signal, this is the useful signal if it is corrupted with the noise. Say it is like many zero crossings are there, this is corrupted with noise, this is actual signal. From this if you want to find out the original actual signal, you have to find out the zero crossing and lot of zero crossings are there.

So, in this case we can use the Schmitt trigger. We cannot use the ordinary zero crossing detector based on the comparator, but Schmitt trigger can detect the zeros if the number of zero crossings are more. So, the circuit diagram of this Schmitt trigger is this is v_i, there will be positive feedback this is negative. So, the feedback that we are going to use here is positive feedback and that is why the another name for this Schmitt trigger is regenerative comparator. This is v_{ref} and this is output. So, there are only two possibilities for vo, vo can be $+V_{sat}$ or $-V_{sat}$ that is $+V_{CC}$ or $-V_{CC}$.

Because of the positive feedback the gain will be more. So, the output will saturate even if this difference is very less. If this difference is very small positive value output will be positive saturation, if this difference is very small negative value output will be negative saturation.

Let us take the case 1 output v_o is at $-V_{sat}$. So, what will be the voltage at positive terminal? Let us call this one as say v_1, what is v_1? Now, this will be at $-V_{sat}$ and this is v_{ref}. So, we have to apply the superposition principle. We have to take the output here which we are calling as v_1, this is $-V_{sat}$ and this is $+v_{ref}$ and this is R_1 R_2. So, what is the voltage here? So, you have to short circuit this v_{ref} first you find out the response due to $-V_{sat}$, then you short circuit this $-V_{sat}$ you find out the response due to v_{ref} then finally, you add these two responses okay.

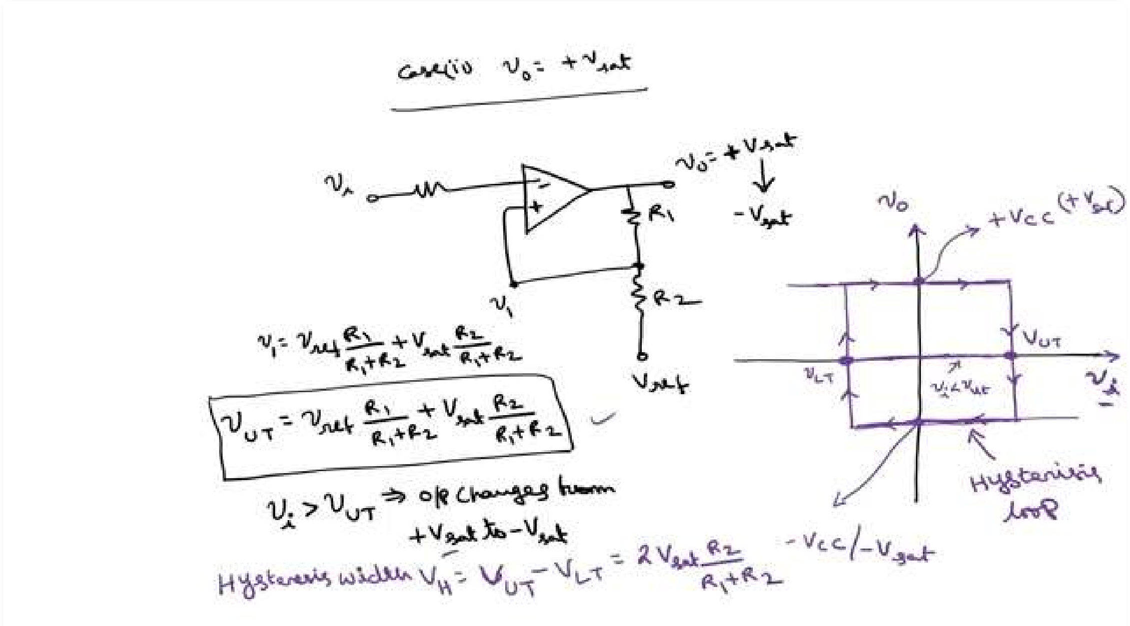
So, if I short circuit v_{ref}. So, what will be output? You can call this one as v_{10} is $-V_{sat}\frac{R_2}{R_1+R_2}$ this is voltage divider. Now, if I short the other one this I am going to short circuit. This is v_{ref}. Now, the output voltage between this point and this ground.

So, this will becomes R_1 now. So, let us call this one as v_{11}. Now, v_{ref} is positive into $\frac{R_1}{R_1+R_2}$. Therefore, what is v_1? is $v_{10} + v_{11}$. So, this is equal to $v_{ref}\frac{R_1}{R_1+R_2} - V_{sat}\frac{R_2}{R_1+R_2}$. Now, this will be called as the upper trigger point. Now, if v_i is greater than upper trigger point what will be the output? So, this v_1 we are calling as v_{UT} upper trigger point, this is positive terminal, this is a negative terminal.

If v_i is greater than upper trigger point then the output remains in the negative saturation only. If v_i is less than the upper trigger point then it will changes from minus saturation to positive saturation. Now, this is called as lower trigger point v_{LT} lower trigger point $v_{ref}\frac{R_1}{R_1+R_2} - V_{sat}\frac{R_2}{R_1+R_2}$. Here the operation is initially this v_o is at $-V_{sat}$. So, what is the condition for the output to change from $-V_{sat}$ to $+V_{sat}$? If $v_i < v_{LT}$, If $v_i < v_{LT}$, what happens? Negative voltage is less than positive voltage. So, output will becomes positive saturation implies output changes from $-V_{sat}$ to $+V_{sat}$. This is the first case.

Second case is v_o is already at $+V_{sat}$. This v_o is at $+V_{sat}$. This is vref. This we are calling as v_1, this is v_i applied to the negative terminal. Then what will be v_1? Same principle, but here this is $+V_{sat}$. So, in the previous expression this expression you replace $-V_{sat}$ with $+V_{sat}$. So, you will get $v_{ref}\frac{R_1}{R_1+R_2} + V_{sat}\frac{R_2}{R_1+R_2}$. This will define as v_{UT} upper trigger point. Now what is the condition for the output to change from $+V_{sat}$ to $-V_{sat}$? v_i should be greater than v_{UT}.

(Refer Slide Time: 41:48)



If vi which is negative voltage is greater than the voltage at positive terminal means output will be negative saturation. Implies the output changes from $+V_{sat}$ to $-V_{sat}$. Now we can plot these two cases in a single graph. This is called as hysteresis loop. This value is $-V_{cc}$, this point is $-V_{cc}$, this point is this entire line is $+V_{cc}$ or V_{sat} and this entire line is $-V_{cc}$ or $-V_{sat}$ and this is v_{UT} upper trigger point.

This is input v_i, this is output v_o transfer characteristics of this circuit, this is lower trigger point, lower trigger point is negative v_{LT}. So, we can easily explain the operation that we have derived now. So, we can see that if initially v_o is at minus V_{sat}, if $v_i < v_{LT}$ output changes to plus V_{sat}. If $v_i < v_{LT}$ this portion initially it was in negative saturation, if it is slightly greater than this v_{LT} then the negative saturation will goes to the positive saturation. And if v_i is slightly greater than this v_{UT} below this v_{UT} this is at positive saturation, slightly above this v_{UT} this will comes to the negative saturation.

You can see that this v_i. So, during this period $v_i < v_{UT}$. So, during this period v_i is less than v_{UT}. So, what is the output is positive saturation. Whenever this input just slightly above this v_{UT} this comes to the negative saturation, this is negative saturation line. And it remains in the negative saturation till $v_i < v_{LT}$, less than v_{LT} this is in negative saturation, slightly greater than v_{LT} it will go to the positive saturation.

This particular loop is called hysteresis loop. And the difference between the v_{UT} and v_{LT} is called hysteresis width, called v_H is equal to $v_{UT} - v_{LT}$. This is this gap from here to here, this is given by v_{UT} is this expression v_{LT} is this expression the only difference is minus V_{sat} here we have to plus V_{sat}. So, v_{ref} is same. So, v_{ref}, v_{ref} will get cancelled this becomes $2V_{sat}\frac{R_2}{R_1+R_2}$. So, this is about this Schmitt trigger, this is also having lot of applications like as I have told I want to find more zero crossings.

If the zero crossings occurs frequently then we can use this Schmitt trigger to detect the type of zero crossings okay. So, based on this principle we can go for the square wave generation circuits that we will discuss in the next lecture. Thank you.