**Op-Amp Practical Applications: Design, Simulation and Implementation**

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**Lecture – 18**
**Op-amps as Comparator: Window Comparator**

Welcome to this particular module and in this module, we will see the other applications of the Operational Amplifier.

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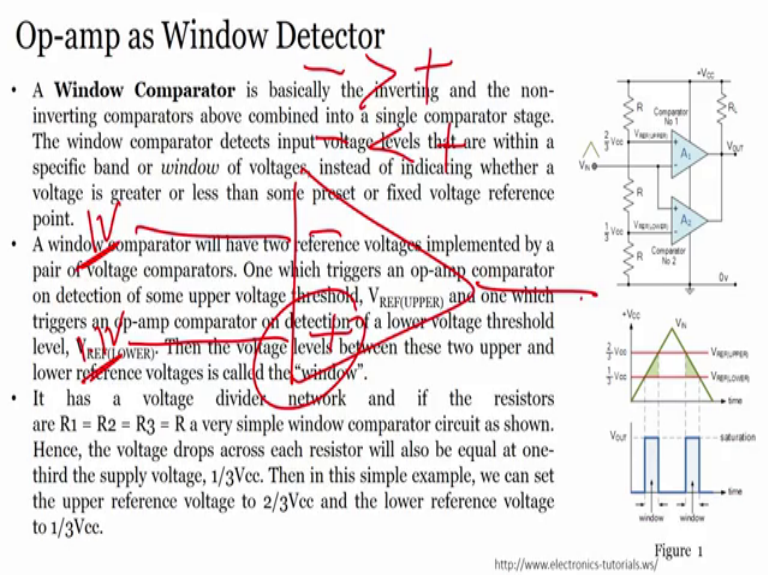

Figure 1

So, what are the other applications of Op-Amp and how we can use that applications or this particular circuits are used in which kind of other applications. Not only the application of Op-Amps, but the circuits that we form out of the Op-Amp, that circuits are used where; that is also the details that we need to understand, alright. So, having said that in the last texture, we have seen not only on the bread board, we have also used the multi-sim, right.

This lecture or the set of modules in fact, we will show you in both breadboard and multisim, so that you also understand. In case if you do not have the equipment, what I am showing it to you right now you can also perform using the simulation tool, right. The sim experiments you can also perform using the simulation tool. So, the point is you whatever we learn in theory, we have to apply that is the point, alright. So, if you come back to the screen, what is today's experiment? First experiment today is the window

detector and we will see how this window detector can operate. Before we understand a window detector, one thing we need to understand is the comparator.

So, we have already seen the role of the comparator. Comparator is nothing, but if I draw Op-Amp, right I have two inputs and I have one output. If my inverting input is greater than non-inverting input, right. Now output will be low or negative saturation. If my inverting input is less than positive or non-inverting terminal, the voltage at non-inverting terminal, then what will I have my output will be positive.

Saturation comparator will compare and compare is like if I have 1 volt, 1.1 volt, then 1.1 minus 1 is point 1 and this is because 0.1 is greater than, 0.1 is the difference of 1.1 and 1, then we have inverting voltage at inverting terminal which is more. That is why it will go to the saturation mode which is positive saturation. This was the understanding about the comparator.

Once you understand the comparator, you will easily understand what the window detector is.

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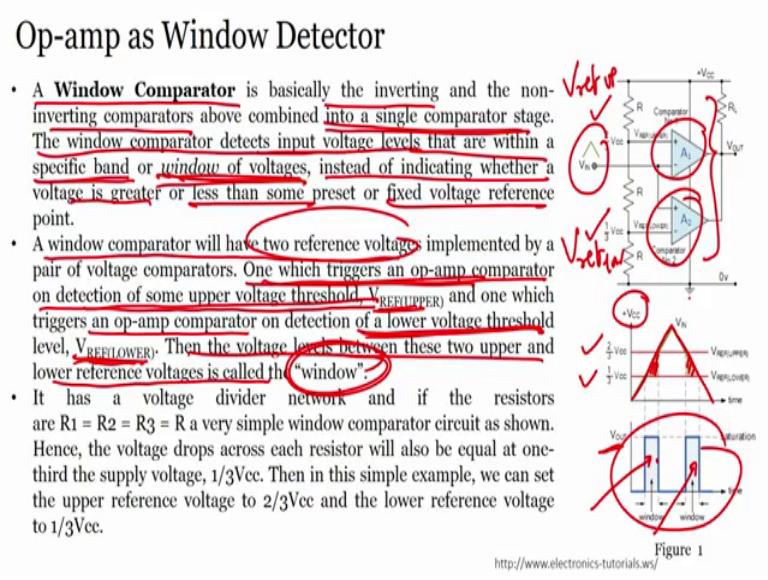

Figure 1

Now, you see this particular circuit, you see this particular circuit what is there? There are two operational amplifiers. We named one as A1 and we named second amplifier as A 2, alright and then, we have resistors, 3 resistors here. So, we have a load resistor connected to both the output of both the Op-Amps, right. It is connected here load

resistor and we have V cc, we have ground. Now, what we are looking at if I take the value here that I take the voltage value here, then it will be 2 by 3 of V cc, correct. We have 2 by 3 of V cc. If I take the value here, it will be nothing, but 1 by 3 V cc.

So, this was easy. So, we are applying 2 by 3 of V cc voltage. Suppose V cc is 10 volt, then 2 by 3 of 10 volts. If V cc is 15 volts, 2 by 3 of 15 volts, alright, so that one that much voltage is constant voltage. We are applying to the non-inverting terminal here, constant voltage we are applying to the inverting terminal, constant voltage to non-inverting, constant voltage to inverting terminal two things are easy.

Now, what we are looking at further that the voltage hear that we are applying it is fed to the voltage here as well you see the voltage there, where applying to the inverting terminal is fed to the non-inverting terminal here and here the constant reference voltage is given to the non-inverting terminal. Here constant reference voltage is given to the inverting terminal.

So, now you understand if I have 3 resistors, if I have 2 Op-Amps, I have to give the first reference voltage to non-inverting terminal, second reference voltage is 1 by 3 V cc to the inverting terminal. I had to give a voltage and short the inverting terminal of first Op-Amp with the non-inverting terminal of the second Op-Amp extremely easy, right. So, now once you have this configuration, how the circuit will work? So, let us see how the circuit works.

A window comparator is basically the inverting and non-inverting comparators, right. Comparators combined into single comparators stage, they are all integrated. The window comparator detects input voltage levels that are within a specific band or window of voltages. It will measure the voltage which is within the specific band. We will see how, alright instead of indicating whether a voltage is greater or less than some preset or fixed reference voltage point, alright.

What is that? Let us see again. The window comparator detects input voltage levels that are within the specific band or window of voltages instead of indicating whether voltage is greater or less than the preset or fixed voltage reference, right. So, window comparator will have two reference voltages. We can see reference voltage 1, reference voltage 2 implemented by a pair of voltage comparators 1, which triggers an Op-Amp comparator on detection of some upper voltage threshold V reference upper and one which triggers

an Op-Amp comparator on detection of lower voltage threshold V reference lower. We have V reference up, here is V reference up, this is V reference lower, ok.

So, that is what it says one which triggers if this has two reference voltages; tow reference voltages 1 which triggers an Op-Amp comparator on detection of some upper threshold voltage and another one detection of lower voltage threshold which is V reference lower, then the voltage levels between the two of these two upper and lower reference voltages is called the window, alright.

So, if you see here if I have a input signal, you see here what V cc is, right. I have this reference 2 by 3 V cc which is my upper reference. I have 1 by 3 V cc which one is my lower reference. If I have an input signal as shown here like this which is a triangle triangular view, then what I look at my output, my output is between my upper and lower reference voltages

That is why I can detect this window and that is why the signal at the output looks like the window that we are kind of detecting, right. So, we have V output right, which is only in this region, only in this particular and this is because of the comparators integrated in this particular fashion right and when we apply input voltages, then corresponding you will get the output voltage in similar fashion.

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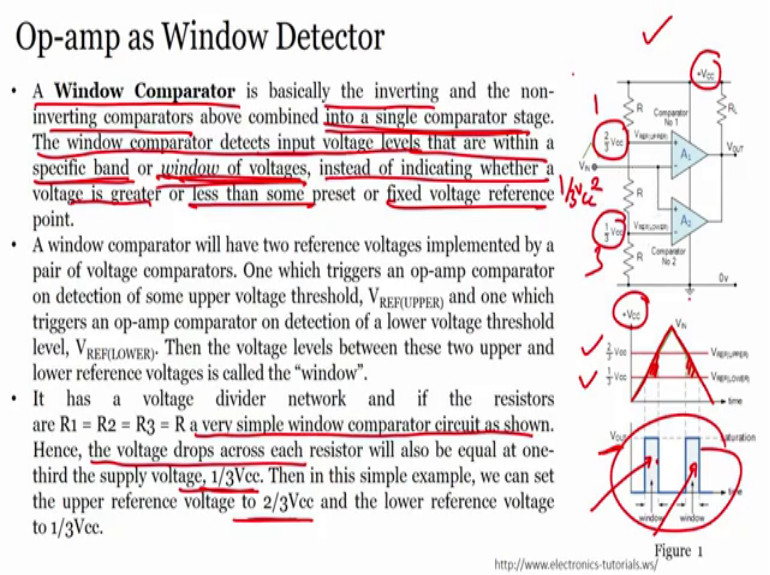

Figure 1

Now before we go to let us see quickly what the circuit it has. It has a voltage divider network we can see that. Where is voltage divider network? Voltage divider network is in front of you which is your R 1 2 and 3 resistors are there, that is R1 R2 and R3 and is a very simple window comparator circuit.

As shown here is this is a circuit, hence the voltage drop across each resistors will also be equal to one-third of the V cc, right. So, you see if the total is V cc, then across each resistor the voltage drop would be one-third of V cc, right. Then, in the simple example we can set the upper reference voltage 2 by 3 V cc, that is what we have said 2 by 3 V cc in the lower reference voltage, we have set it 1 by 3 V cc, right.

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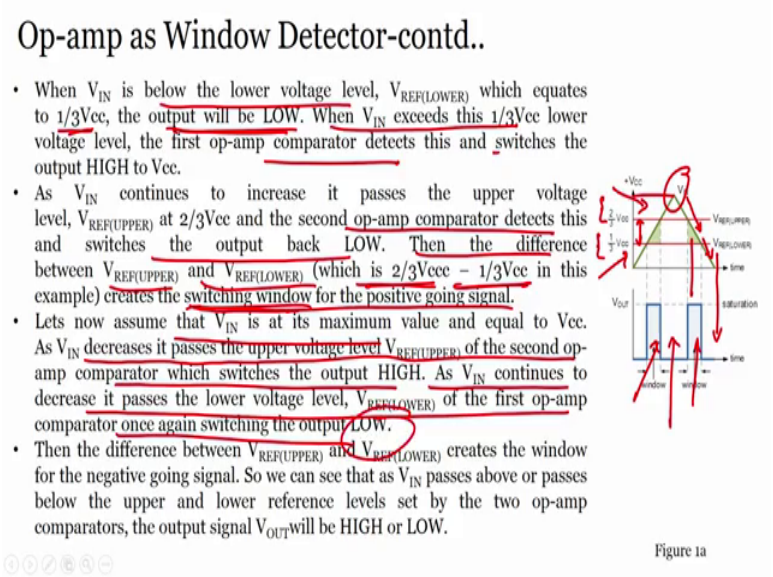


Now, when V is below the lower voltage level here, below the lower voltage reference which equates to 1 by 3 V cc which equates to this particular value, the output will be low. The output will be low when V in exceeds 1 by 3. So, why output will be low because you see here see V in is less than 1 by 3 V cc, right. So, you have to understand that if I apply voltage here, this one I had 2 by 3 V cc. How the output will come according to the comparator that is why I said that you understand first comparator and then, you can easily understand how the window detector works.

So, when you apply V in below the lower voltage level which equates 1 by 3 V cc, the output will be low. When V in exceeds 1 by 3 V cc, the first Op-Amp comparator detects this which is the output high to V cc, right. As soon as when V exceeds 1 by 3 V cc, you

see here when V in is exceeding 1 by 3 V cc, the first Op-Amp comparator detects, right. Very easy, hence which is the output high to V cc as V in continues to increase. It passes the upper voltage reference 2 by 3 V cc when it continues to increase. Now, it has passed this upper reference voltage 2 by 3 V cc. In this case, the second Op-Amp comparator detects these, hence switches the output back to low.

Why? Because if this is 2 by 3 V cc is less than the voltage which is at V in there output would be high, right. When you have this voltage this voltage which is see here let me just rub the other thing. So, is not confusing.

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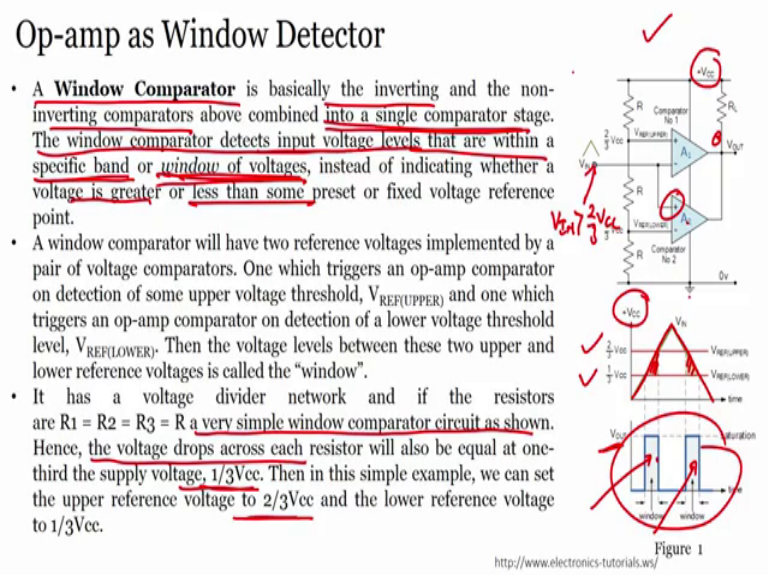


When your this voltage V in is less than 2 by 3 V cc is less than 2 by 3 V cc, right my output is high. When my V in is greater than 2 by 3 V cc, my output will be low. That is what we says here right same way here what it was saying in here where when my input is less than V 1 by 3 V cc. My output is low when my input is greater than 1 by 3 V cc slightly greater than V in slightly greater than 1 by 3 V cc.

Then, immediately this comparator will go as at one, it go as one or high, right. This is what it is said here that let us see here once again when V in below lower voltage right with equates 1 by 3 V cc output will be low. When v in exceeds 1 by 3 V cc output, suddenly the comparator detects and this switches the output to high when v in continuous to increase. When it increases below this above this, then the second Op-Amp comparator detect this and switches back to the low.

So, that means in this particular region, you cannot see any output. The output is low in this region which is greater than 1 by 3 V cc, lower Op-Amp was switched on. So, you have high here in this region again lower Op-Amp is switched on. So, we have high. That means, we can get the pulses right depending on the input signal that we apply, right. By using this particular configuration, then the difference between V reference upper and V reference lower which is 2 by 3 V cc minus 1 by 3 V cc creates the switching window for positive signal.

What does that mean? It means that when you have this particular reference 2 by 3 V cc minus 1 by 3 V cc, then it will create a window which is the switching window for positive signal right because as soon as it goes between this particular value in this particular region, it will switch on, right. If it is less in this region, switch off less in this region, switch off only in this particular window, it is switched on. That means, by changing this reference voltage, we can create the different windows, we can create a switch on and switch off time. So, that is what is written here.

Now, let us assume that V in is at maximum value and equal to V cc which is here right, then in this case as V in decreases, it passes the upper voltage reference of the 2nd Op-Amp comparator which switches the output high. That means, that when V in goes back to low, suddenly the output becomes high because the 2nd Op-Amp turns high. As V in continues to decrease, it passes the lower voltage level of the Op-Amp again and you see if it continues to increase decrease, then again it passes this particular level and this will Op-Amp which will turn the output to 0. That means, the V reference voltage slower Op-Amp, it will again switch the output to low.

Thus, high and low creation by the Op-Amps, 2 Op-Amps, right. This particular configuration helps us to create a window that we can detect. That window is created by the reference voltages of the upper reference and lower reference voltages now, then difference between V reference upper and V reference lower create the window for negative going signal. So, we can see that V in passes above or passes below the upper and lower reference set by 2 Op-Amp comparators, the output signal V out will be high or it will be low. You got it?

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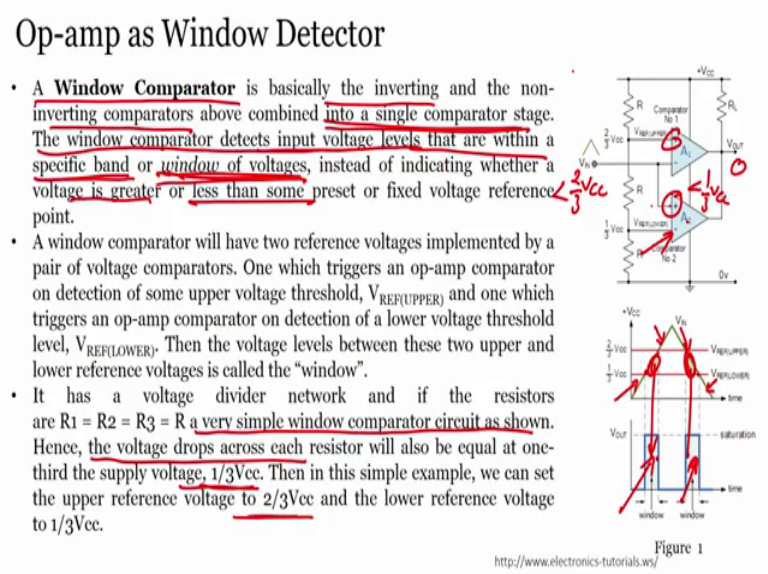

Figure 1

So, now in this particular circuit what we see is that when initially our input signal right is here, my output is 0. When this input signal reaches in this particular region, this Op-Amp right slightly greater than this, this input signal is slightly greater than 1 by 3 V cc, then this Op-Amp will turn the output to 1. When this input voltage increases to this in this region, when it goes to this particular region right, then your V in becomes greater than 2 by 3 V cc, then my output would be 0, right.

When you do again followed back, then you will again see this will switch to 1 because as soon as it becomes less than 2 by 3 V cc, then this you see is positive, right. So, this output becomes 1 if it is between 2 by 3 V cc and greater than 1 by 3 V cc. So, as soon as is goes less than V reference voltage means that this value is now less than 1 by 3 V cc, your inverting voltage is higher compared to non-inverting and output will become 0, right. Thus, how the switching occurs between high and low in the particular reference voltage in this region and this is my window that I can detect using this circuit.

So, it is super easy circuit to understand. If you understand how the comparator works, for understanding how the comparator works, you have to go back and see the video in which we were talking about the comparators, alright.

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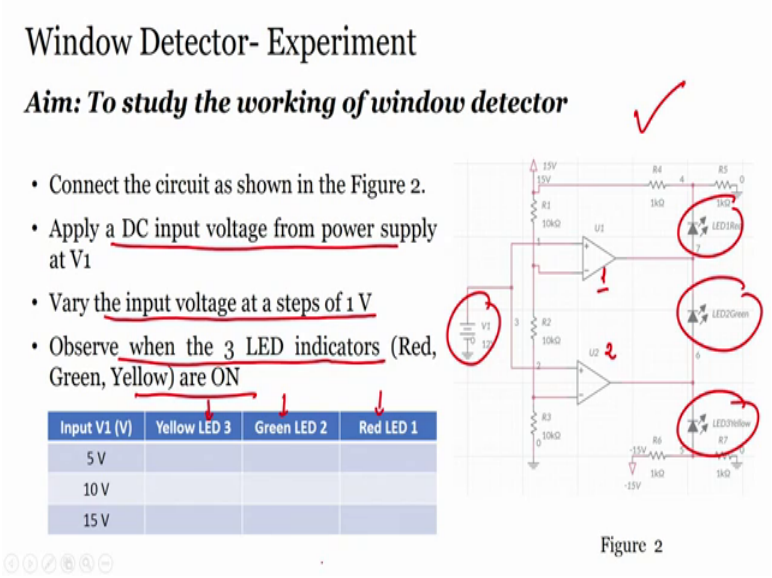


Let us see in this particular case if I want to design a window detector, that means that how can I design window director. So, here how you will know output is on or output is low or output is high. So, here what we have to create is a LED, we have created a LED that will give us the indication right of this window. So, what is that connect the circuit shown in figure 2, ok we will connect the circuit like this.

Here you can see the comparator 1, this is my comparator 1, this is my comparator two 2. As you can see here the reference voltage is given to my comparator 1 here. Second reference voltage is given here and then, you have given signal. So, apply a DC input voltage from power supply vary the input voltage at steps of 1 volt and observe when 3 LED indicators red light are on, right. That means we keep on applying the step voltages from the input 1 volt 2 volts 3 volts 4 volts and what you have to see which LED will turn on and which led will turn off, alright.

So, to create this particular circuit, we will use two different ways. One is we will create using the breadboard and another one we will create using the multisim, alright. So, you have the idea of both how to design this comparator using a breadboard and how to design this comparator using a multisim. So, to perform this experiment let us call Seetharam who will join us to perform this particular experiment on the breadboard and then, he will join us on the multisim, so that I can tell you how the breadboard thing

works and while he is operating a multisim, I will again tell you how the multisim he is operating and how we can see the change in signals, alright.

So, seetharam can you please come?

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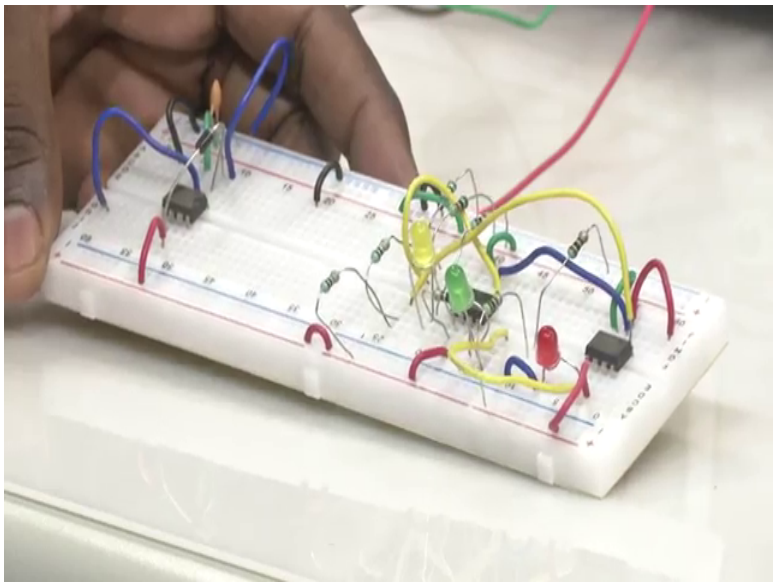

So, now we have the breadboard. If you can focus on the breadboard, the circuit for the window detector is shown on the breadboard, is shown in the breadboard here. Also we have used red, yellow and green LED to indicate the output voltage. We can see here, we have used registers form the reference voltages, right and we have 2 Op-Amps here, right 1 and 2, right because we want to have two comparators. Now, you see you can also use the duel Op-Amp in this case, but we are using the single Op-Amp because until now whatever experiments we are shown, you are using a single Op-Amp single Op-Amp is here 7 4 1, alright

So, to perform this, to operate this circuit first thing we have to do is to apply the bias voltage. How we can apply the bias voltage? We have DC power supply. So, you can see here in the DC power supply if you yes.

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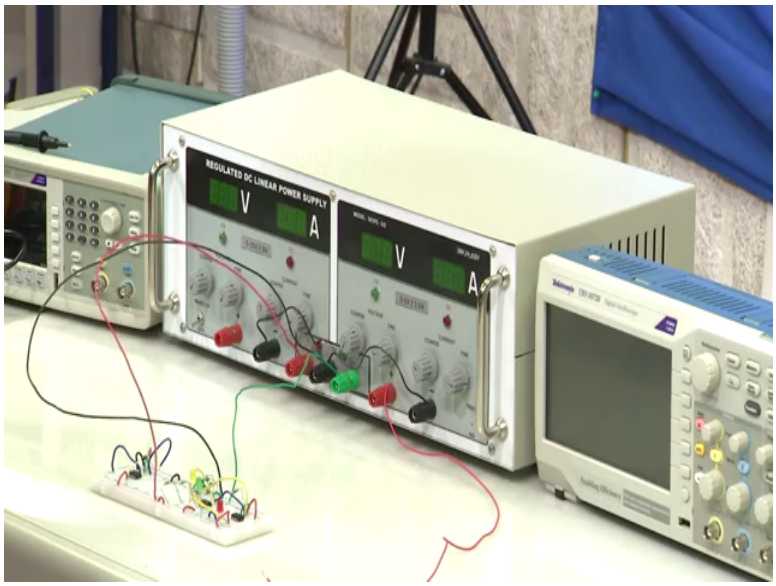


Now, he has not connected the wires to the Op-Amps. He will first connect the wires was a biasing voltage and then, he will start the power, alright. First he will connect it, then he will start the power you can see, ok. Now, we have applied plus V cc is plus minus 15 volts and minus 15 volts onto the Op-Amp that is the bias voltages plus 15 volts minus with the help of DC power supply, ok.

Now, what we will do? We will apply the input voltage in steps of 1 volt, right.

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So, you can see he is now applying 1 volt with the help of DC power supply and when he is applying 1 volt, what you are looking at, you are looking at the first LED is still on, 2nd and 3rd are not on. Now, he will subsequently increase the power. This first one led is on, this is yellow one is on; green and red is not on. Now, he is going to increase the power, he is going to increase the voltage, sorry either input 2 volts.

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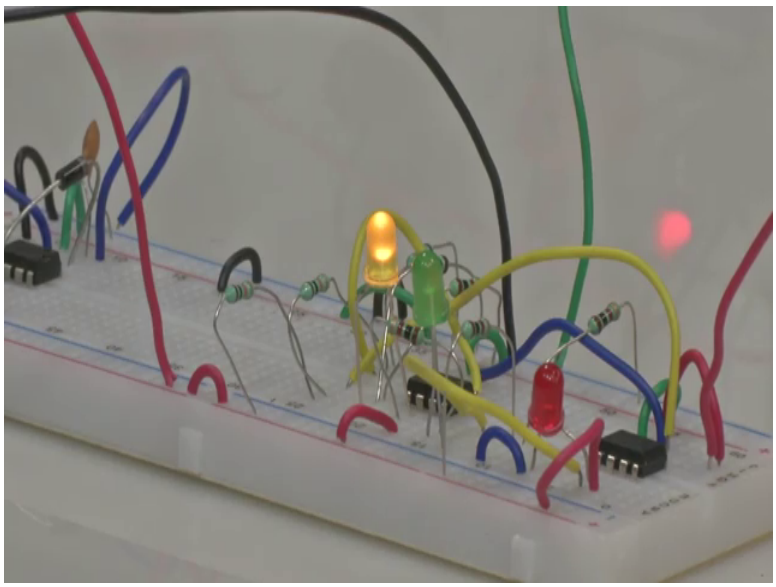

We cannot see any change increase it to 3 volts 4 volts and then, we are increasing to 5 volts. So, you see as soon as he reaches around 5 volts, we can see the change in the green LED. You can see here on the DC power supply, it is 5 volts, right ok.

So, as soon as he will change it, I can hold it this circuit in my hand, so that you can also see LED is glowing along with the, voltage. So, now reduce it back to 4 volts please. So, you can see as soon as it is less than 5, we can see the first led glowing, right.

So, this is exactly it is comparing the window. It has to go high. Now, if I increase the voltage from 5 to 6, 7, 8 and you see he is increasing slowly right, I may be speaking very fast, but he is increasing extremely slow. This is how you have to slowly increase the voltage, alright. 9 volts and then, you can see 10 volts. As soon as it reaches 10 volts, you can see change in the LED.

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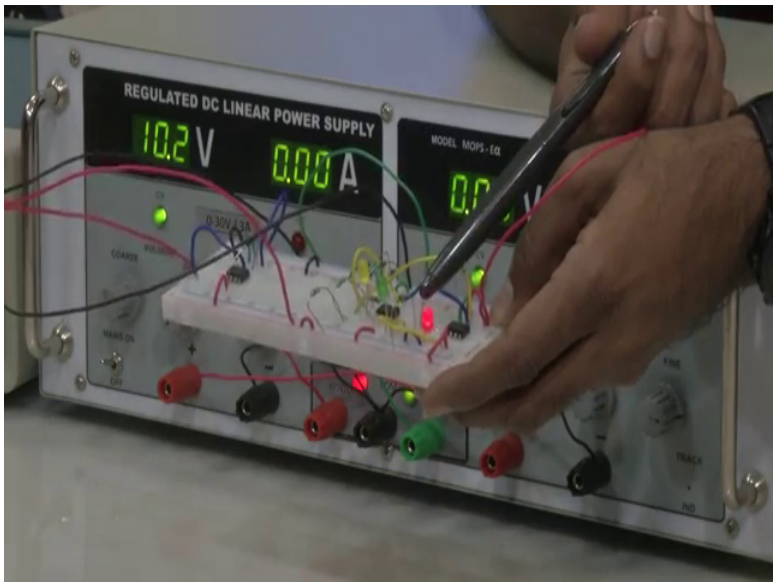


Now, my red LED is on. You see just about 10 volts my red LED is on. If I reduce back to 9, see 9.5 slowly, can we increase with 5; 9.7 9.8 9.9 10 and you can see green to red right see and now, you can decrease again from red to green. You look at the green, yes see 0.1 volts. There is 0.1 volts was difference and suddenly the comparators switch, these output comparators switch this output.

Now, this is how we can see the comparator if you go down. Now, some from 10.1 to 10 and 9.9, then you will suddenly see again the green color from red LED, the green led is on and if you back to 5 volts, go back to 5 volts, then you will see the red LED turning on and a green LED would be, sorry the yellow LED will be on and the green LED would be off. Yes see yellow LED is on and green LED is off. This is how you guys form the window detector. It is detecting a window, right for this particular circuit and here we had demonstrated how you can use the LEDs to show the window detector, right excellent.

Now, let us see the similar application using the multisim and here we will see how you can design the circuit. That means, he will take the operational amplifier, he will take the resistors, he will take the, you are going to show LEDs there, ok. He will use the LEDs from the library and then, he will apply voltage and you will see that when you keep on employing the voltage from your 1 volt to your 5 volts to your 10 volts, you will see the change in the output with respect in terms of comparing means when you increase

slightly less than 5.1, your comparator will start changing the output and you increase more than 10 voltage. Again the comparator will change the output.

So, how to see that particular window of voltage is in which we can see the change in the comparator output, we will see using the multisim. So, let us see the multisim can you focus on the screen please? And now what we are going to do is, we are designing the same circuit on the multisim.

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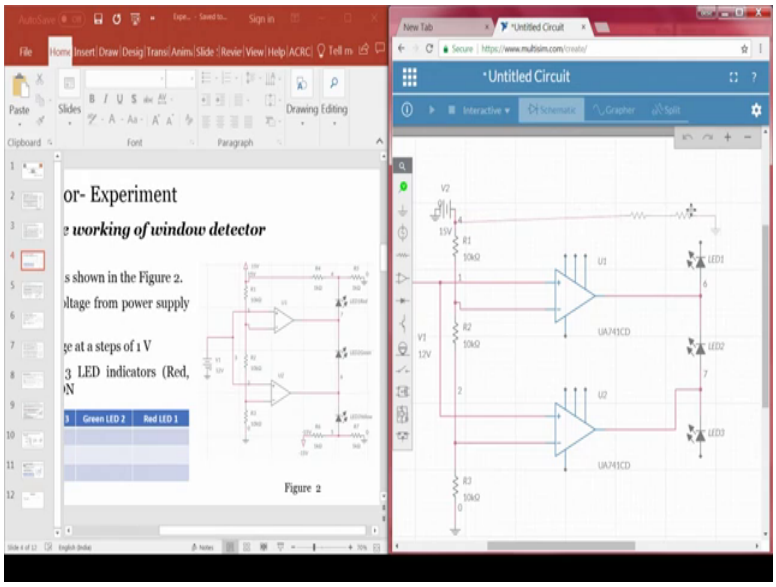


We are designing the same circuit on the multisim, ok. Now, you guys can see right we have this multisim here, we can see multisim he has opened it and then, now he is going to drag one by one the circuit components that are required to design the circuit. The components required first. He starts with the Op-Amp. So, he has to select the Op-Amp. So, he is selecting UA 741 and then, once he selects it, he can see you can see here the Op-Amp 741.

Now, he requires two of this, right. He requires two of this. Again he is clicking on the terminals and then, selecting 741, you can see now he has 2741 Op-Amps. Now, what we require? Now, we require resistors. So, we will select resistors you can see and you can select resistor and then, you have to place the resistor you have a option of rotating the resistors, right and the you have option of changing the value of resistors. Here he is adjusting the resistors as per the circuit, right. So, in circuit we have register of 100 ohms, so 10 kilo ohms. So, he is using 10 kilo ohms, another resistors of 10 kilo ohm and

third resistors of 10 kilo ohm. All the resistors once he has done, then he will connect it. So, he will connect it, you can see you can just drag it and you can connect the resistors, alright.

Now, what is next thing? Next thing he is going to select a ground and connect it below R3. Next thing is he has to connect the inviting to the as 2 by 3 V cc, then another one 1 by 3 V cc, then we have input signal which again ground because we are applying this is a power voltage, DC voltage that we are applying to the non-inverting terminal and we are connecting the another non-inverting terminal of the operational amplifier with the same DC voltage, right.

So, he has applied 12 volts as you can see from the figure also same voltage. Now, what we are doing? We have to apply another DC voltage which is your 15 volts. So, we can apply 15 volts, right. Now, what we require? We require another two resistors. So, we are selecting resistor and one more resistor we require and the value of resistor is 1 kilo ohm, excellent.

Now, we have to ground it. So, we have to drag it to the ground, connect the resistors, excellent. Now, what we have to do? We have to have LEDs and you have LED, right. So, you have to connect in a reverse direction. So, you see there is a rotation feature. So, you can just select the LED and drag it similar to what is shown here. Connect those LEDs, then connect the output of the second Op-Amp and first Op-Amp to the between the LED 1 and LED 2.

Now, what we have to do? We have to connect the LEDs between resistor 4, R4 and R5, right.

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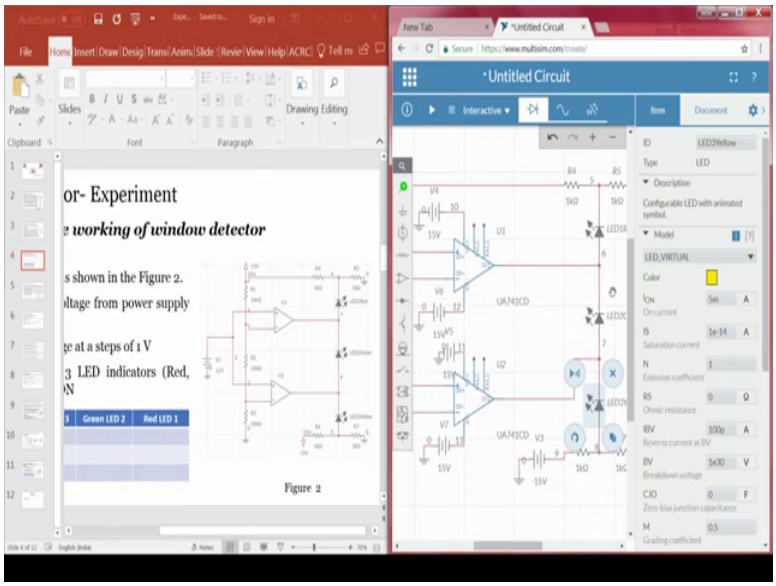


So, we can just select both, drag it and connect it, right. This is done. Now, we have to select this R6 and R7. R6 and R7 for that he is again have to select 2 resistors which is selecting the resistors R6 and R7 and we have to correct the resistors values are 1 kilo ohm. You have to connect with the LED, ok. Now, one side you have to ground it. So, we are selecting ground; another side you have to apply plus minus 15 volts. So, we are applying DC voltage and we have to attach it and another terminal we have to ground it. So, we have grounded it.

Now, what we look at that we have to apply the back voltage, also we have to apply change, the DC voltage also which is 15 volts, minus 15 volts ok. Now, we have to name the LED. So, let us say our first LED should be red, second LED is green and third LED is yellow, ok. Now, you can also color it. You can see yellow, ok. This one is yellow, ok. Now, if I use either comparator, how can I see the change in the output.

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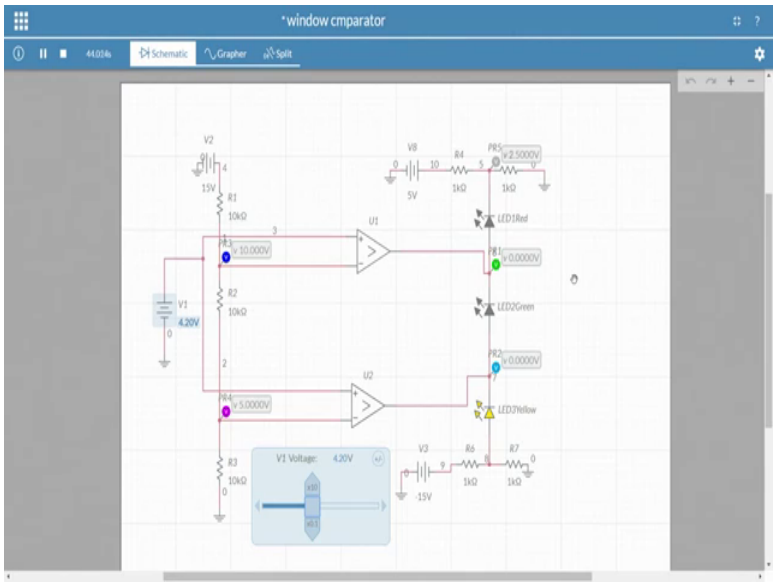


So, if you go back to the screen, what you are looking at right now is the same circuit considering the actual of Op-Amps. We are just taking ideal situation, right. Now, the input voltage is 0 volt. Now, you see that when your input voltage is 0 volt, right that means that your U2 is reference voltage is about 5 volts because it will be 1 by 3 of 15 volts. This is 5 volts

So, now if I start increasing the voltage, right now my input voltage is 5 mill volts. 10 milli volts you can see that there is. So, if you see the yellow LED is on because the positive terminal is higher than the negative terminal that is anode is higher at voltage compared to the cathode because output is right. Now, at 0 volt you can see 0 at pin number 7 are blue. Now, he is increasing the voltage to 2 3 4 and as soon as he increases more than 5, suddenly see there is a change. Now, what you can see in now your green LED is on because you have your non-inverting terminal at a higher potential compared to the inverting terminal in operational amplifier 2, Op-Amp 2 or comparator 2.

Thus, you can see LED is on. Now, he is going to increase it further and when we see on increasing it to about 10 volts, suddenly you see LED 1 that is your red LED is on, right. Same way if you see the voltage is also we can measure the voltage across the LED at the cathode of LED, we have 4.31 volts at the anode. It is 5 volts.

That is why the anode is at the higher potential compared to cathode and that is why our LED is on and then, when we decrease it, when we decrease it, again you see that as

soon as we go less than 10 volts, then we have the yellow LED on because in the non-inverting terminal of U1 is at higher potential compared to the non-inverting terminal and then, why it is high potential because the non-inverting terminal we have 8.55 volts inverting terminal. We have 10 volts.

That is why inverting terminal is higher compared to non-inverting terminal and that is your output voltage would be 0 because is a comparator, right. That is why your LED, anode LED 2, your cathode will be at 0 volt and anode is at 5 volts. That is why LED 2 will start glowing same way if we keep on decreasing and it is less than 5 volts. You will see that LED is 3 is on. It was already on LED 2. LED 1 will not work. This is how you can find the detection or the window voltages when you set the reference voltages.

So, here we can set the reference voltage; upper reference and lower reference. Upper reference will be about 10 volts and lower reference is about 5 volts. You can see it, right and this is how you can do the simulation and it kind of matches what we have understood in the theory. So, that is why it is good to learn. I do not say that multisim or any other tool of simulation you should not use.

You should definitely use it, right but just do not rely on simulation every time. You just rely on simulation and assuming that it will work in the experiment, it may not work. In that case, you should not really come out with a thing that oh I did simulation experiment and it is not working or experiment is working simulation not working. You would try and figure it out, right. Try each circuit, open it, close it, right.

What you will see? You would not get the output. If you do not get output, you ask us I have designed the circuit, I integrated the circuit. We cannot see the output, so what should be possible problem? First you have to find it out if you do not get it, then you can ask, alright. So, here what we have seen one more application of operational amplifier and that is a window detector.

Now, we will see the next application of operational amplifier in the next module. So, at a stretch if you see this module, you will understand that we have used Op-Amps 2 Op-Amps as a comparator and then, we have used reference voltages with upper reference voltage and lower reference voltage and then, we have seen how this Op-Amp is a comparator when connected in a particular format can be used to detect the peak

voltages, alright. So, with this we will finish this module and I will see you in the next module. Till then, you take care. Bye.