Integrated Circuits, MOSFETs, OP-Amps and their Applications
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Lecture - 51
Experiment: To study op-amp based integrator and differentiator

Welcome back this module is on understanding the operational amplifier as an integrator and as a differentiator. So, what you mean by integrator right. So, first we have seen what you in my Op-Amp; operational amplifier it performs several operation what do you mean by integrator. Integrator means it will integrate a lot of things in one it will integrate, but if I talk about differentiator it will cut it; it will differentiate into a lot of fragments differentiator. So, understand from the from the meaning point of view first and then you understand the actual role of the operational amplifier, as an integrator or a differentiator alright.

So, if I tell you how to use operational amplifier as an integrator and what is the formula of an integrator or how can we derive this formula of an integrator. Since integrator and differentiators are very easy to derive the formula of the output voltage or the output voltage of integrator and output voltage our differentiator is extremely easy to derive. We will see quickly, how we can derive this integrator and differentiator, and then we will perform several experiments and see when we apply different input signals right; what are the output signals corresponding to those input signals?.

And you will see that if you want to convert your sin wave to a square wave or rectangle wave or triangle wave to a sin wave sin wave two triangle wave and lot of other ah changes of the signal you can change the signal by using this particular circuits. So, when you talk about the integrator, let us first see what exactly a i indicator means.

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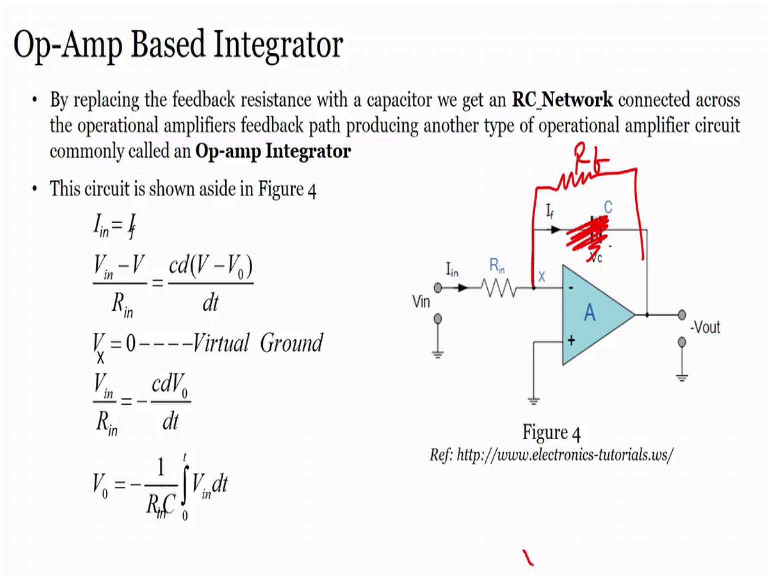

So, what we have seen until now; we have seen that there is a feedback register R f right; we have not seen this we have seen R f and if this is the case, it is your inverting amplifier, it becomes your inverting amplifier right.

Now, if you replace this R f by a capacitor by a capacitor it becomes your integrator so, easy; extremely easy right. So, how this works as an integrator how you can say that by replacing R f by capacitor C feedback resistance by a capacitor it becomes an integrator.

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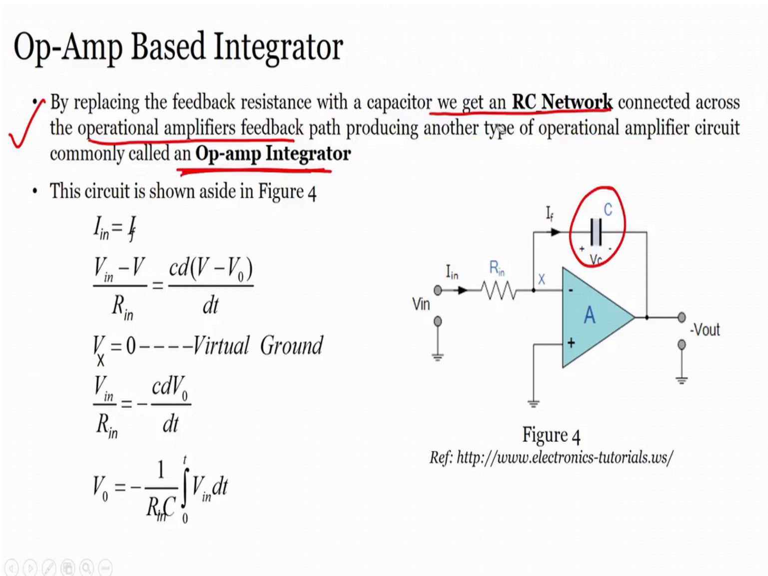

So, let us see you it is same thing is written; first point by replacing the feedback resistance with a capacitor, we get the RC network connected across the operational amplifier feedbacks. Path producing another type of operational amplifier circuit called Op-Amp integrator alright. So, if you replace R f by C it becomes a integrator let us see how.

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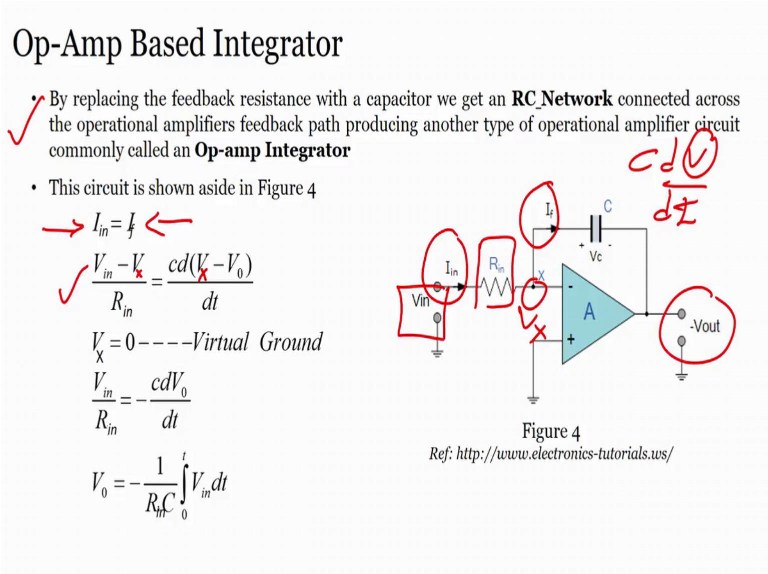

So, let us see I in and this value If. So, I in is equal to If this is easy right, your I in is equals to If right.

Now, what is I in I in is nothing, but you see you have resistor Rin we have voltage V in. So, what will be I; I will be you have V in minus V upon Rin what is V v is some VX some VX voltage here alright. So, you understand V in is nothing, but V is an even VX alright. So, if you want to consider I in you have to take the difference. So, V in minus VX divided by Rin ok; this is easy If I want to consider I f' what will be If C into dV by d t right C into dV by d t this is the formula. Now what is V here V is nothing, but VX we can say V or V X. So, as a VX minus V out V out upon d t alright.

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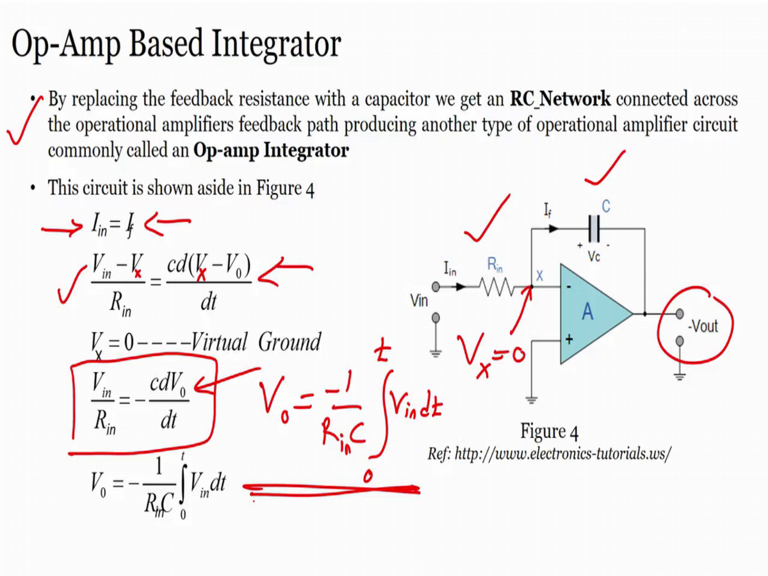

Now, you see here we have seen a concept of virtual ground in the theory class right, what if; what does that virtual ground means; if I want to consider voltage here my voltage VX voltage VX would be 0; voltage VX would be 0. So, if I substitute, VX equals to 0 in this equation, then what will I have V in upon Rin equals to minus C dV 0 by d t right or minus d C dV o by d t. So, from here I want to find V o what will be I have; what will I have V o is nothing, but integration of V in d t and here will be minus 1 upon RC minus 1 upon RC and the time is from 0 to t time is from 0 to t.

So, very simple right if I want to have V o from here V o right we have to say bring it here. So, it is minus 1 by RC right RC is what R in so, Rin into C integration of 0 to time t right; into V in V in V in into d t alright. So, this is the formula for your integrator this formula for your integrator.

Now, this is the ideal situation this is an ideal situation, where you will put a capacitor C and you will have register Rin and you will find everything working well, but in actual operation amplifier when you use as an integrator.

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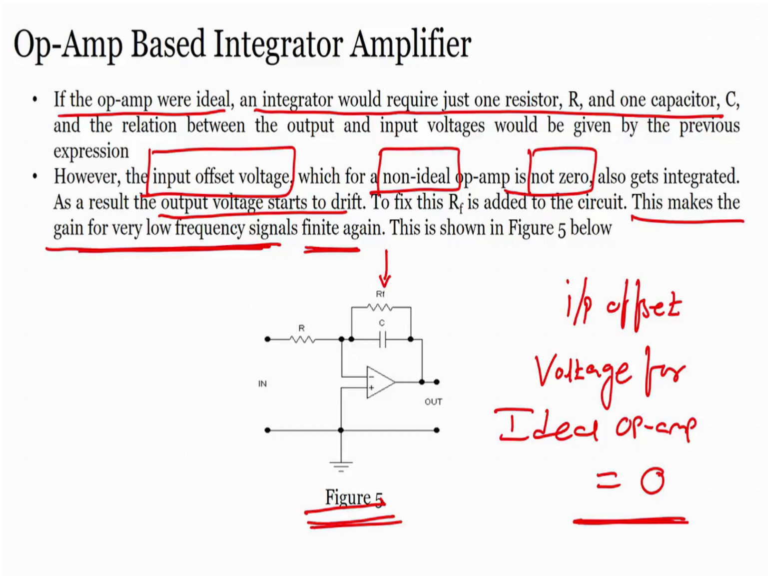

You will not find the ideal situation; that means, that the in that particular situation the input offset voltage which is for a non ideal Op-Amp is not 0 we have seen input offset voltage right. So, what is input offset voltage should be input offset voltage input offset voltage for ideal operation amplifier ideal Op-Amp should be 0 this we have seen right, but actually right actually we have practical Op-Amp.

In practical Op-Amp we will see that the input offset voltage input offset voltage is not 0 alright also; that is why which is now this is not 0; that means, it is not ideal Op-Amp it also gets integrated, whatever the input works our voltage is there also gets integrated as a result the output voltage as a result the output voltage starts to drift output voltage is it starts to drift to fix this drifting to fix this drifting, we had to add a feedback resistor R f, if you see in this circuit we have added a feedback resistor R f this will make the circuit or this makes the gain for very low frequency signals finite again alright and this is what we have shown here in the figure 5 right.

So, let us see once again what we have been discussing; in the case of integrator there is only capacitor in the feedback and there is a resistor at the input, but if the Op-Amp is ideal then an integrator would require just 1 R and 1 C alright, but in reality Op-Amp is not an ideal Op-Amp, and if he is not ideal Op-Amp it is not ideal Op-Amp, then the output or the input offset voltage input offset voltage would be not equal to 0; when it is not equal to 0, then your output voltage would start to drift right.

So, when the output voltage starts to drift, how to fix this drift; we can fix this drift by adding a feedback resistor or by adding a resistor R f across the capacitor alright. This will help this will help or this makes the gain for very low frequency signals very low frequency signals finite and thus it will help to reduce the drift alright; it will help to reduce the drift this is the this is the case of an practical operational amplifier used as an integrator alright. So, remember this alright you will perform the experiments remember this; what we have discussed for integrator alright.

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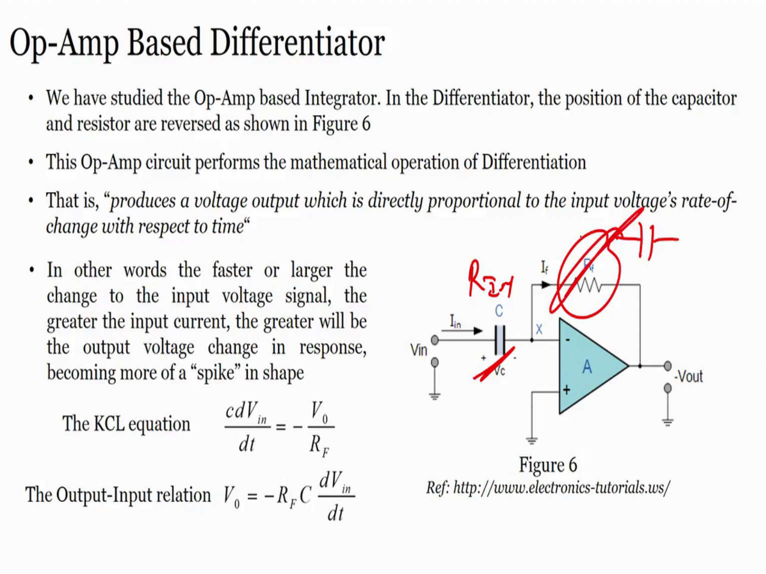

Now let us go to the next one and what you see you see the figure of an differentiator. So, look closely at figure 6 and think, what is the difference between integrator and differentiate in terms of circuit look at it understand and I will ask you in 10 seconds see; what is the difference between integrator and a differentiator right your time starts now 10 seconds 3, 2 and 1 alright, what is the difference very easy right all of you got it what we are done here instead of Rin we have changed by C right.

In case of integrator we what we did we have changed R f by C; in case of differentiator we have converted Rin by C easy extremely easy. So, you cannot forget this circuit you cannot forget this circuit, because it is super easy to remember integrator feedback capacitor differentiator input capacitor alright. The input signal goes to the capacitor in integrator the feedback resistor feedback resistor is convert is replaced by the capacitor to reduce the drift, we use a feedback resistor across the capacitor in this case.

Let us see how the integ how the differentiator would work.

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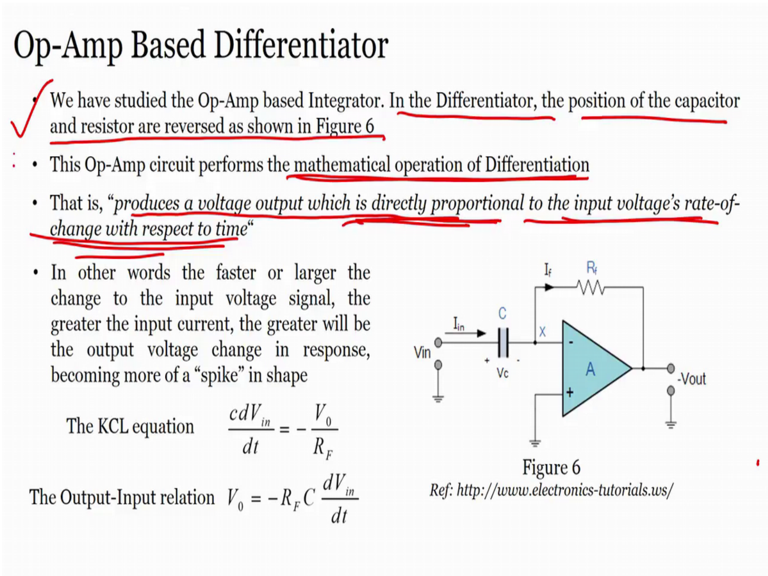

So, let us come back to the circuit what we see here in the differentiator the position of the capacitor and resistors are reversed as shown in figure right the answer is already here. Now the Op-Amp circuit performs the mathematical operation of differentiation, we all know mathematics we have all studied mathematics, what is differentiation? What is integration? So, if you want to perform this mathematical operation of a differentiator of a differentiation then we can use this circuit which is shown in figure 6 alright.

Now, if you see figure 6 this particular circuit produces a voltage output, which is directly proportional directly proportional to the input voltage rate of change with respect to time right this is, what differentiator does right see the output voltage is directly proportional to the input voltage rate of change with respect to time alright; that means, that you will see you will find it the equation similar to what we have done in the indicator. Let us find out the equation first let us understand further. So, there is second what we have understood, let us see once again quickly let us see once again quickly first point is a position of capacitor resistors are reversed in case of differentiator.

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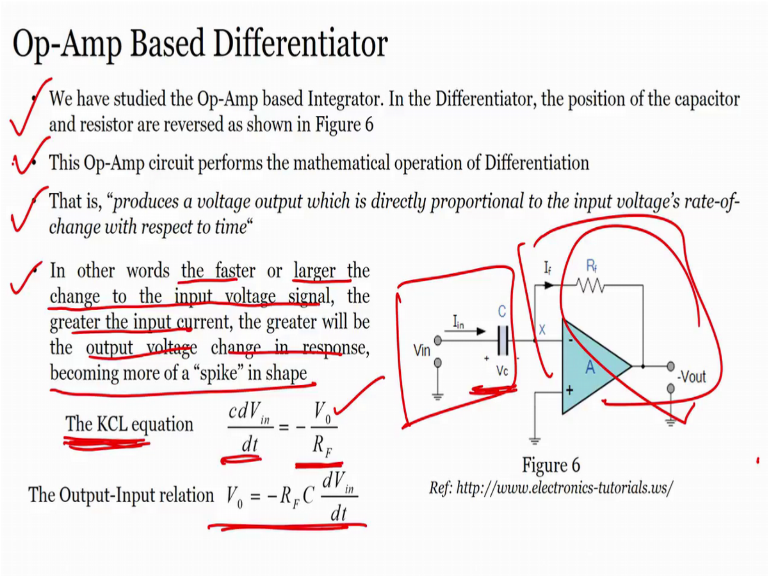

When you compare with integrator second point is it can perform mathematical operation called differentiation. Third point is the power output voltage is directly proportional to input voltage rate of change with respect to time fourth one is in other words the faster or larger the change of the input voltage signal faster or larger the change to the input voltage signal the greater input current the greater the output voltage change in response becoming more spike in shape becoming more spike in shape we will see this so, that you can understand what exactly we mean by this particular sentence right.

Now, you just understand that, if you have a faster or larger change of input voltage signal, then you will have greater input current and this will cause the output voltage change in response income in terms of a spike signal a spike signal is a result we will see this in actual experiment and yet then you will understand. So, how we can derive this equation for the differentiator, what is a way of deriving the equation for the differentiator.

So, what we see here is that if I apply Kirchhoff's current law see I use Kirchhoff voltage law Kirchhoff's current law many times I have used in the theory class right. And in last two last module also I have used Kirchhoff voltage law or Kirchhoff current when I mean when I use this thing you should go back and understand, what exactly Kirchhoff's current law is what, exactly Kirchhoff voltage noise once you understand and you will it will be easy for you to understand, how this thing we can write in this particular fashion alright. So, if you understand Kirchhoff's current law understand Kirchhoff voltage law.

Now, let us see that if we have this circuit, if we have this circuit then we can write C into dV it is particular one C into dV in by d t equals nothing, but this one if you see minus V o by R f minus V o by R f. So, the output, if I want to calculate which is voltage V of is nothing, but R f will go here minus R f into C into dV in by d t is very easy very easy right, understand Kirchhoff current law. We understand this part you understand this part, then you see that this is equal to this and then you from that we apply voltage we are going to find the output voltage output voltage is nothing, but V o which is equals to minus R f C into dV in by d t alright easy it is extremely easy.

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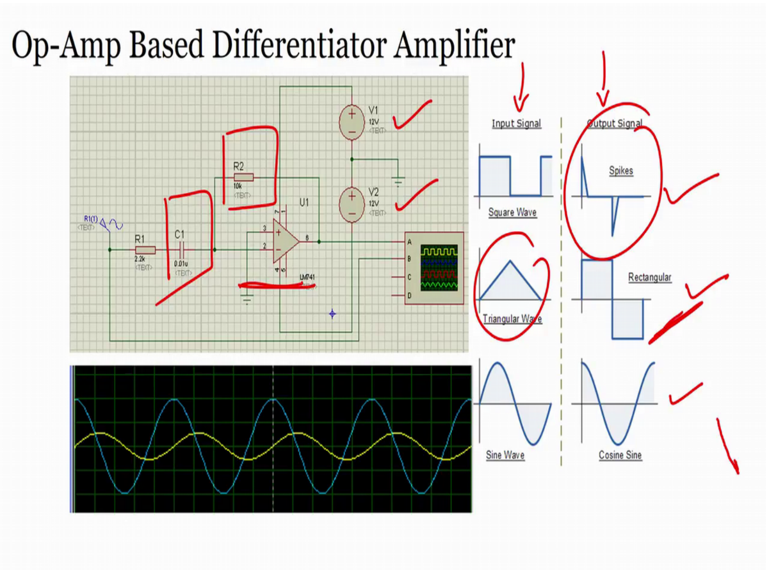

So, now let us see the next one um; so, here what we have seen ah we have used as pspice and using pspice we have form the differentiator amplifier, which is shown in the slide here, we have applied the voltage and correspond to the input voltage. We have measured the output signal, we will do the similar kind of experiment on the breadboard right, This experiment was done by Sitaram and this signal at the circuit he has drawn in pspice using pspice and he found this interesting observation this slide was special he prepared for you guys.

So, that you can understand how the input signal varies and how the output signals will vary with respect to input; when you take a case of a differentiator alright. So, you see here that input signal input signal and output signal right, how they are related in case of a differentiator first is when you apply square wave you will be able to see spikes, if you will apply triangular wave you can see rectangular wave we apply sin wave you can see cosine wave; that means, that you can use the differentiator as a signal converter as a signal converter right, if you want to get an output signal spike and if I give output as input as a square wave then I can get spike.

So, where I can use spike there is a different case, where I want to use the rectangular wave it is a different case where I want to use cosine wave it is a different case right, but the point is that you can also do the similar kind of study using pspice and understand and perform the experiment, if you do not have a breadboard with you if you do not have d C power supply, if you do not have other things you can use this tool and you can perform the experiments as well alright. So, this is a different way of understanding the experimental approach to the theory alright.

Now, we will see will also actually do this same study right you can see here. These are reference voltages or bias voltages this particular is an Op-Amp right; you have a resistor here and you have capacitor here right as in the input. Now, you see when we apply this signal if you apply a square wave we will actually perform the experiment and will see whether we can obtain these spikes or not alright, if we apply a triangular wave whether we can get this rectangular wave or it is just pspice or something and actually experiments or something right will cross check it alright.

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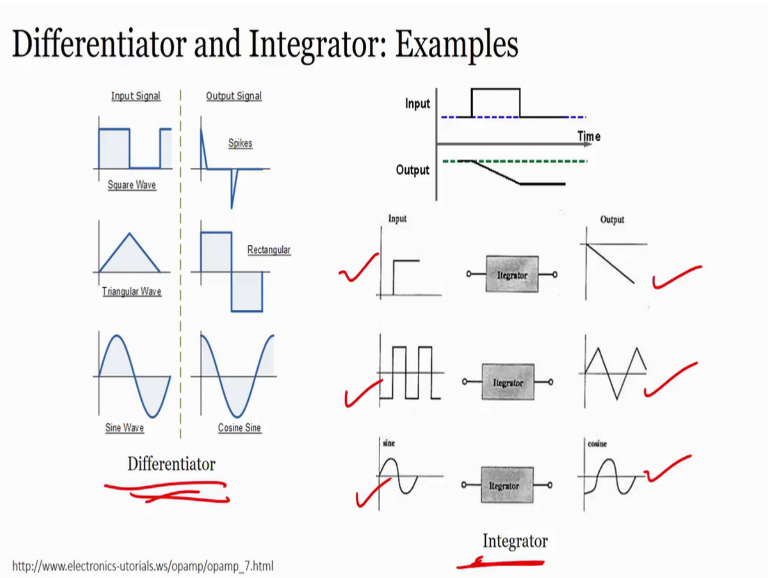

So, if I compare the differentiator and integrator right if I compare differentiate and integrator, what I find you see here I have differentiator I have integrator right and here like; we have seen in the last slide I give different signals at the input I get different signals at the output, what about integrator what about integrator. If I apply input, which is in this particular fashion my output is this which is a triangular wave I can make a triangular wave, if I input is rectangular wave I can make a triangle a square wave I can change it to the other signal right same way sin wave I can get cosine wave with indicator as well.

So, the role is the point is that by using integrator and differentiator we can convert the signal one second is we can integrate or differentiate the signal, that is it can be used as a mathematical operation and third point is that; how we can use Op-Amp is integrator and differentiator in actual experiments. So, let us see now if I want to cross check or if you want to understand the property of an operational amplifier as an differentiator what kind of experiment I can perform alright.

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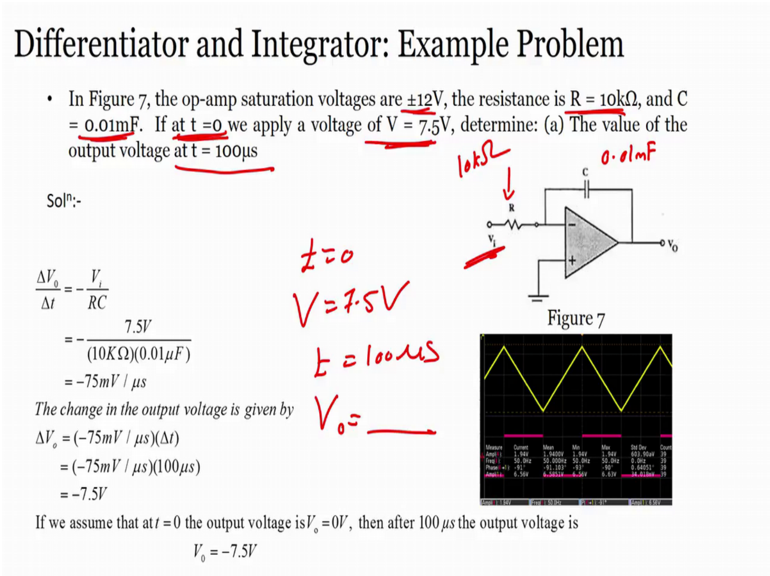

So before we move to the experiments; let us quickly see the problem alright, what is the problem? So, problem is it is not really a problem it is a it is a question to which we have to find the solution, there is no problem with the course problem with these slides do not worry about. So, if in this particular figure which is figure 7 what is this figure this is a figure of an integrator is a figure of an integrator alright. The Op-Amp saturation voltage is a plus 12 minus 12; that means, here if some I have told you earlier also, if we do not see plus VCC and minus VCC that does not mean that we do not have plus VCC minus VCC alright.

It is not mandatory to show every time bias signal the resistance R is 10 kilo ohm R is 10 kilo ohm 10 kilo, ohm C is 0.01 milli farad 0.01 milli farad if at t equals to 0 at time t equals to 0 we apply voltage 7.4 volts. So, at t equals to 0 V equals to 7.5 volts this V this V 1 right what we determine value of output voltage at t equals 200 microseconds. So, this is given at t equals 200 microseconds what is output voltage V o alright this is the question.

So, let us see how you can find the answer or why t can find the solution. So, now, we already know, if you see the circuit right what do we know we know that V o equals to delta V o by delta t equals to minus V 1 by R C.

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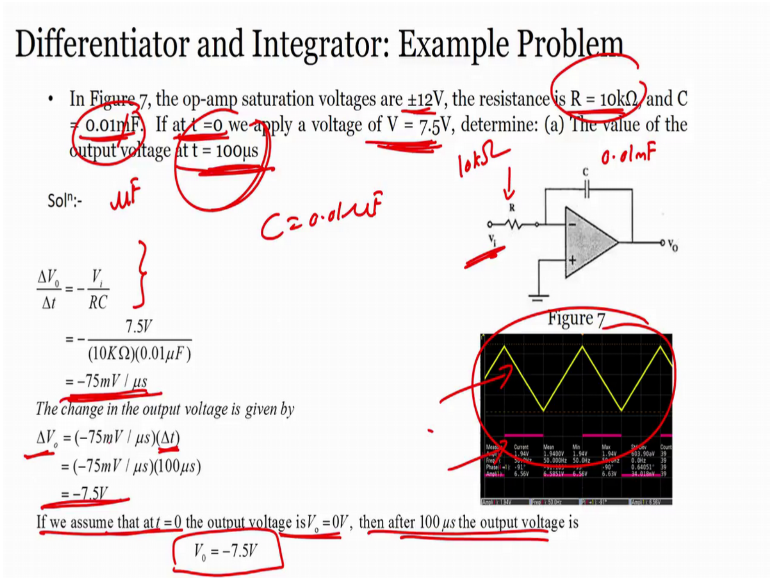

So, if I substitute the value here I have 7.5 volts as the input voltage here divided by R is my 10 kilo ohm C is 0.01 milli farad or 0.1 micro farad is it micro farad milli farad. So, I think let us consider micro farad let us consider 0.1 micro farad C equals 2.01 micro farad, then I will get this particular value alright the change in output voltage is given by delta V o equals to minus 75 milli volts by micro second into delta t what is delta t delta t is nothing, but at 100 microseconds what is the change. So, when I multiply this what is my delta V o delta V o is minus 7.5 volts; that means, that maybe if we assume that t equals to 0 the output voltage V minus 0 equal to 0, then at after 100 microseconds the output voltage is V o equals to minus 7.5 volts alright.

So, ah again you can see this same thing in this particular circuit see the circuit there are both the signals you can see signal 1, 2 understand, how the input signal is there; how you get the output signal and this is the easiest way of understanding an integrator by taking our input voltage is understanding, what will be the output at t equals 200 microseconds you can change this value and find it 200 microseconds 300 microsecond 10 microseconds and you can also put this value in your actual experiment and see what happens alright.

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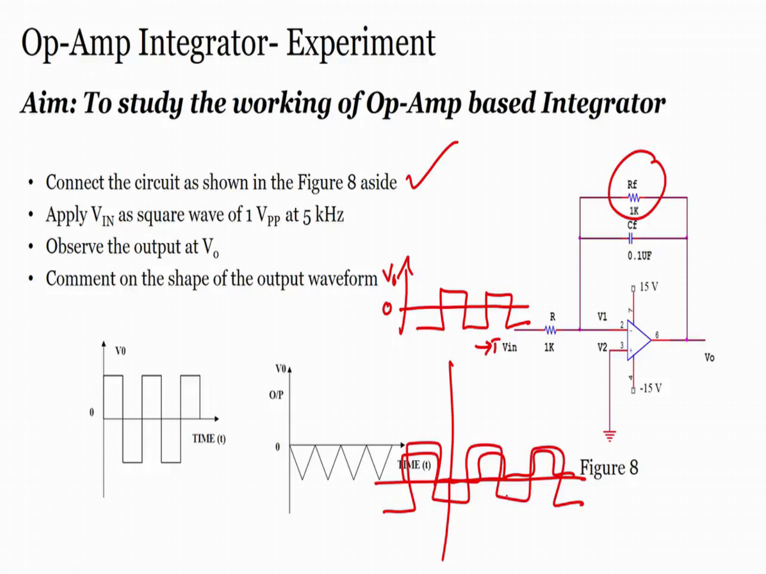

So, let us see one more ah let us now actually perform the experiment which is often integrator right. So, we have seen that in the actual integrator on the practical Op-Amps we have to use the R f right to remove the drift we have seen that correct, because if you do not use R f, then we will see the drift in the output voltage and to remove this drift the R f would help. So, let us see whether it is helping or not there is a question alright.

So, first connect the circuit as shown in figure 8 we will connect the circuit exactly in this particular format apply V in as a square wave. So, we will apply V in as a square wave alright. So, you can you can form square wave when we understand that that if this is 0 right, which is here this is your time t and this is your amplitude or you write V minus 0.

So, when you draw it draw perfectly like this alright if you want to draw like this and you can write like this also square wave you can draw like this also square wave right. The way of drawing the square wave it is not like one wave what heat is shown here is the right way. So, you can draw a square wave in your own format the point is you should be square wave there is one the point. So, what is the point and we apply square wave.

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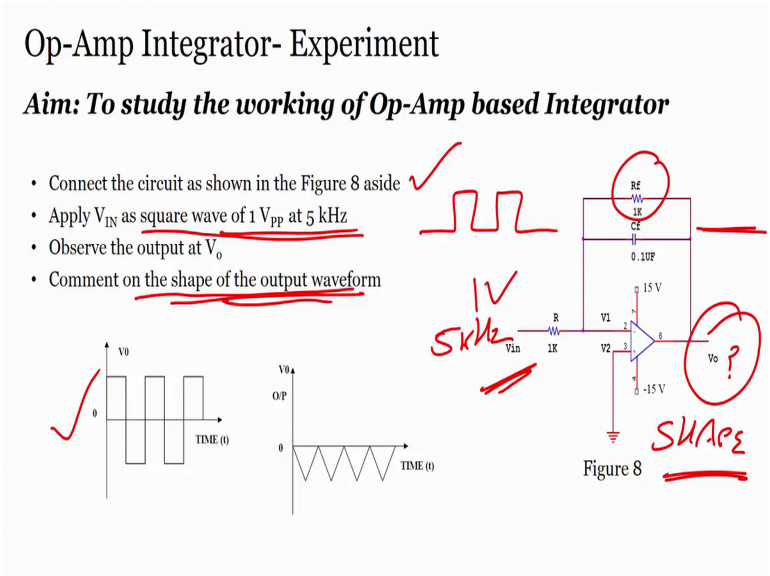

We apply square wave 1 volt 1 volt right; 5 kilohertz 5 kilohertz at the input we had to observe the output voltage and we had to comment on the shape of the output waveform; that means, first is what is V o and second is what is the shape of the output; that means, if I apply square wave what will be may output signal alright at this particular experiment we had to perform.

So, let us against connect the circuit and let us see how it looks, now on the breadboard and what kind of output voltage we obtained, when we apply V in of 1 volts peak to peak 5 kilo hertz frequency alright.

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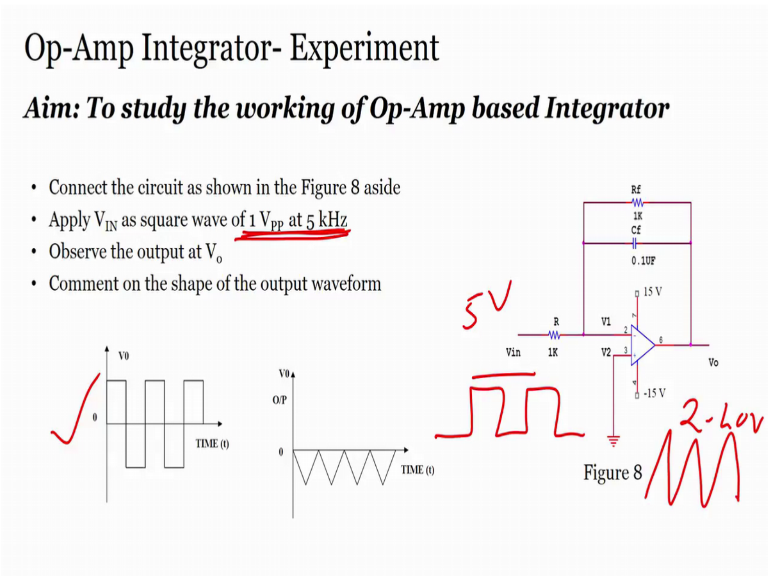

So, let us again called Sitaram and see the circuit. So, if we can see the circuit on the breadboard please alright.

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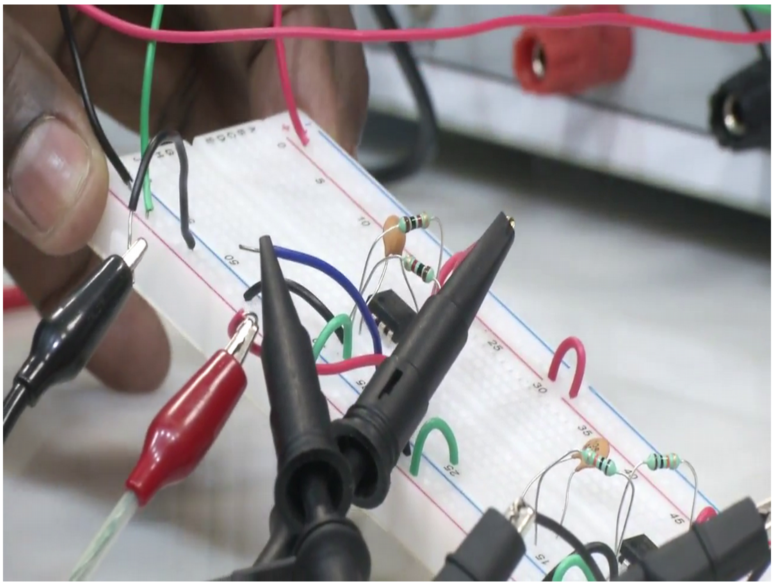

So, the circuit is if you see focus here, if you can lift little bit, then this is the integrator. We are we are first looking at the integrator you can see there are two resistors right resistors and, there is a capacitor here is a capacitor there is a capacitor and the resistor R f and then there is an input resistor Rin right one is a input resistor one is a feedback resistor connected with the feedback capacitor C f across it R f is there alright.

Now, we are applying at the input a sin wave which is one volt sorry a square wave. Let us see square wave 1 volt 5 kilo hertz and at the output we had to measure the voltage V o alright. So, let us see the function generator.

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Let us see function generator and what he is applying right now.

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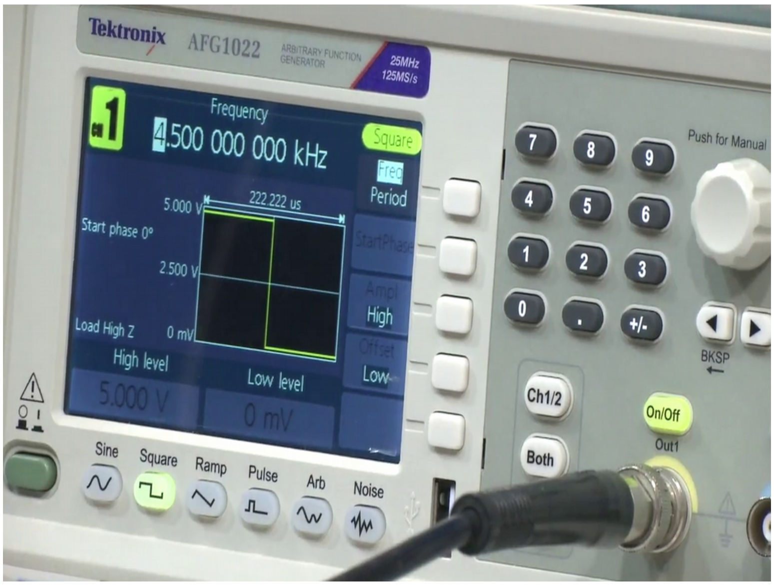

If you see he has given square wave square wave at 5 kilohertz.

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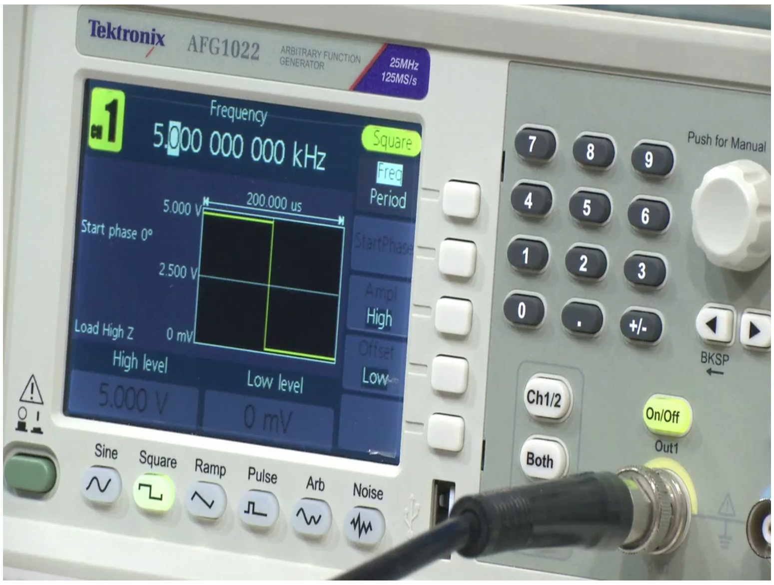

At 5 kilohertz peak to peak voltage is 5 volts peak to peak voltage is 5 volts. Again you should immediately able to see, when I say peak to peak voltage is from 0 milli volt to 5 volt and y axis right and the frequency is 5 kilo hertz. So, on applying this one what is output voltage let us see the output voltage please output voltage on the oscilloscope and if you zoom out.

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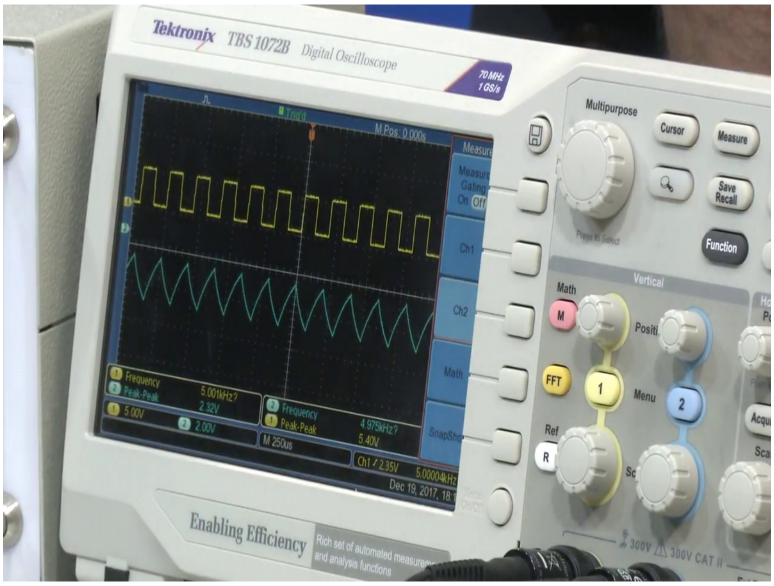

So, means ok; now, what we see peak to peak output voltages can you please show where is a value. So, square that you see yellow color is the input and output voltage is my 2.40 volt is it yeah 2.40 volt and input voltage is 5.4 volts. So, and what I see at the output you see what I see I see a triangular wave right. So, an application of a square wave at the output I am able to see the triangular wave this we can do with the help of an integrator with this you can do with the help of integrator now let us change the signal at the input alright.

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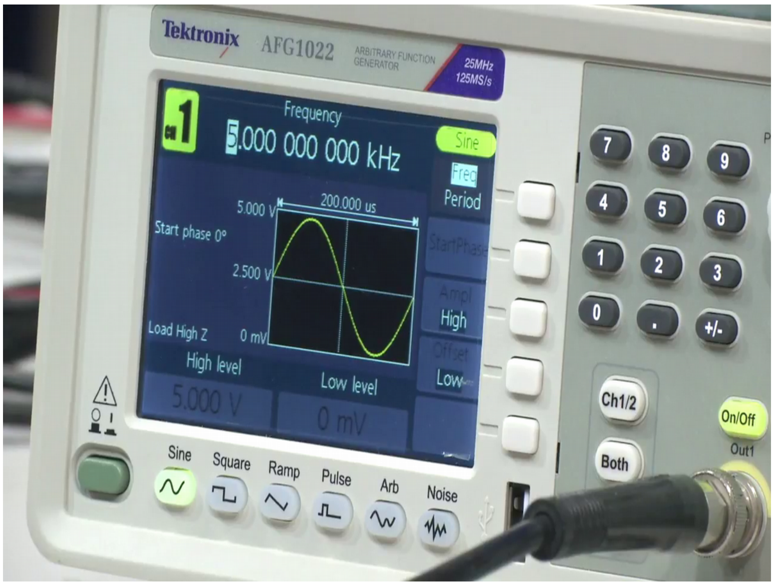

So, I can go back to the function generator please you see if you apply sin wave then, we can if we apply sin wave at the output we were able to see cosine wave at the output we are able to see the; if you see the output again at the oscilloscope we are able to see the cosine wave alright then. So, when application of a sin wave now let us apply another signal ah. So, if I apply triangular wave if I apply a triangular wave at the input right; I can see a sin wave with sin let me see it is almost similar the oscilloscope is almost a sin wave at the output alright.

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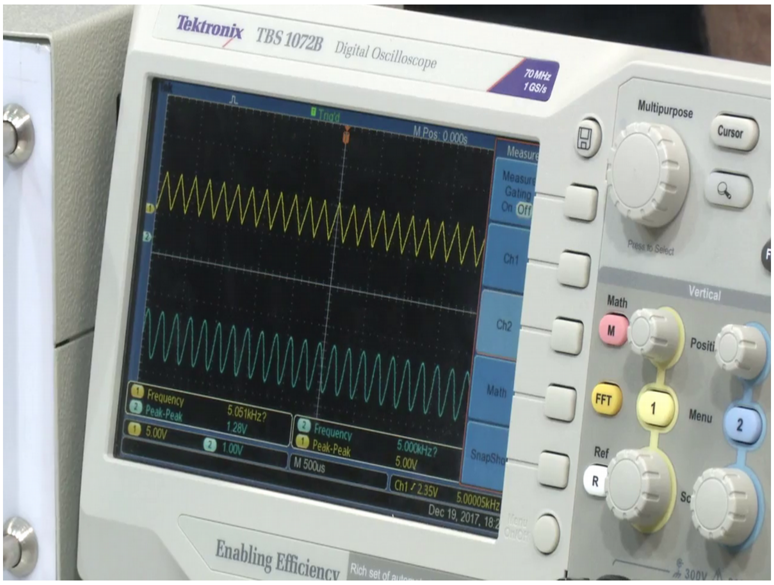

So, the point is that I can I can get different form of signals and when I apply different form of signals at the input. So, change it see observe, what is the change in the output signal alright, that is the that is the exercise that once we I saw you see what exactly that is a change when I apply different input signal.

Now, if you apply different input signal and see what kind of output you can see in the oscilloscope alright. So, that is the experiment that we have performed the output voltage is nothing, but 2.4 volts like we have seen 2.40 volts at the output input was 5 volts peak to peak and we were able to see that the output was a trying input was a sin wave or input was a square wave in one case like this square wave right and the output was a triangular wave alright.

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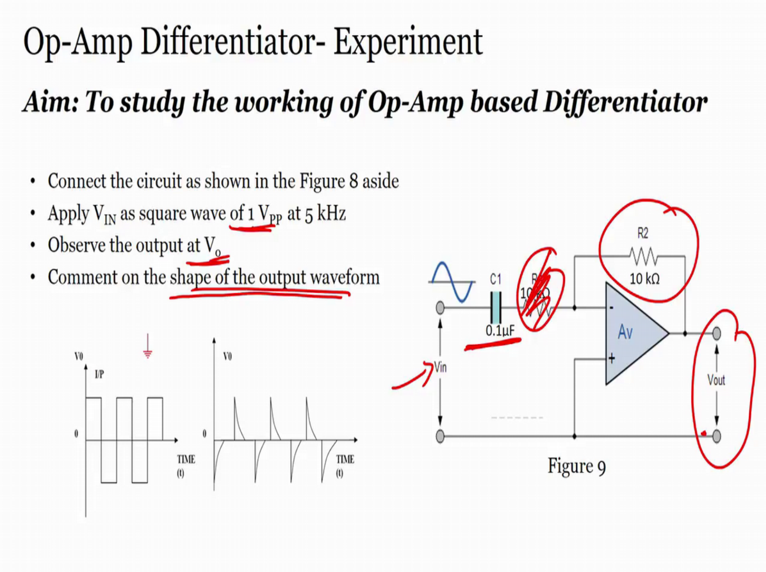

So, this is the case study where we have used operational amplifier as an integrator how about we take a differentiator how about we take a differentiator. Now we all know the difference in the integrator difference in the integrator and differentiator is that we have replaced the Rin.

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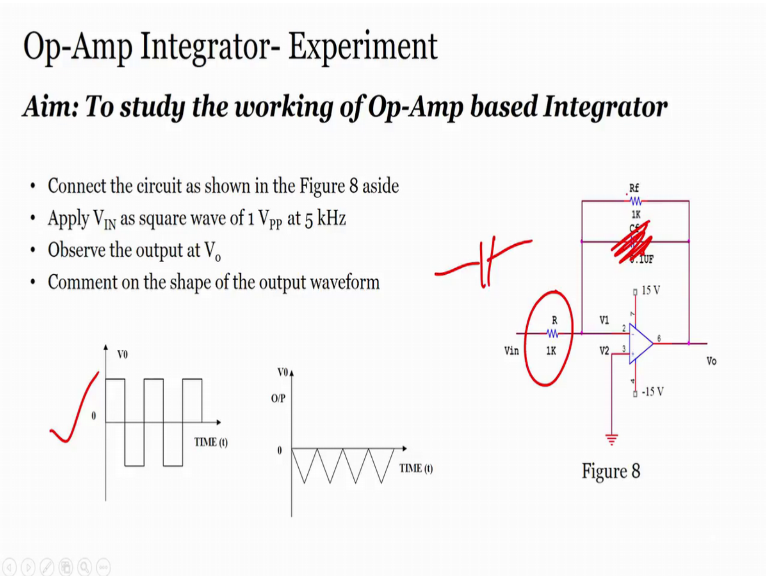

By capacitor and R f is a this Rin by a capacitor and R f is similar this becomes your in differentiator. So, if we consider the differentiator circuit consider differentiator circuit, what we are looking at we are looking at a capacitor we are looking at R 2 right and we have another resistor Rin in this series, but the input signal is fed to the capacitor.

So, if I apply V in of 1 volt we in of 1 volt at 5 kilohertz, then what will happen. So, see if you if you do not want to use this one then also it is it is it is perfectly alright. So, do not worry do not get confused that oh there is one more register in the circuit do not worry you can directly apply capacitor and you can have a feedback resistor R 2 alright.

So, if I apply one volts at the input here and I want to measure the output voltage V o right, I want was an output voltage V o and then I will have to comment on the output waveform; that means, if I apply a square wave again see in the integrator also we are applying we have applied square wave in differentiator also we have we are applying square wave and we are looking at the output voltage correspondingly we are also looking at the shape of the signal right.

So, again we need to connect the circuit we need to connect the circuit and we had to understand and we had to understand, what is the output voltage one what is the output voltage.

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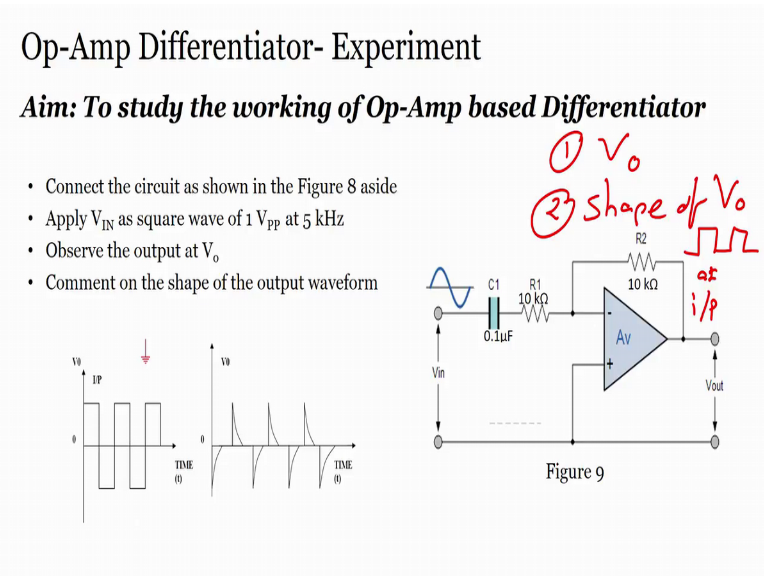

V o second what is the shape of V o on applying square wave at input alright. So, let us see this let us see this. So, again let us focus on the breadboard.

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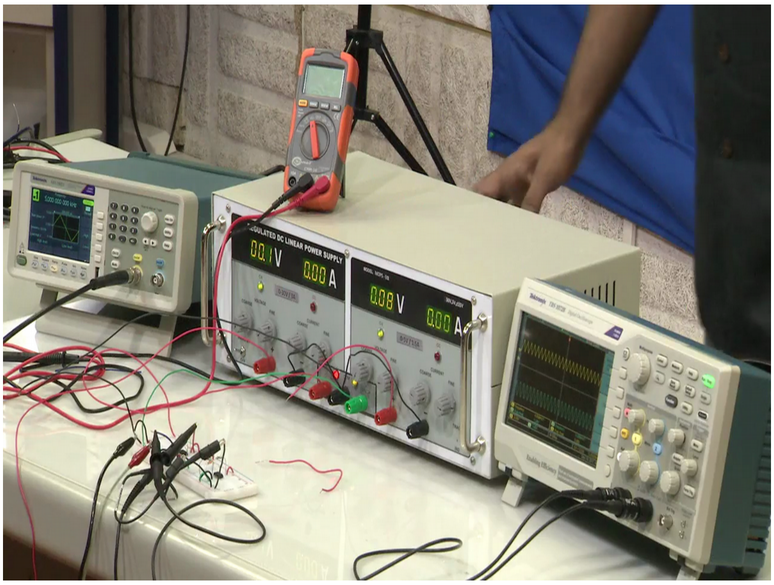

And let us see the differentiator circuit first. So, you can see the differentiator circuit. So, you can see here the differentiator circuit here we have the capacitor at the input and we have a resistor which we have seen here and then we have a resistor which is feedback.

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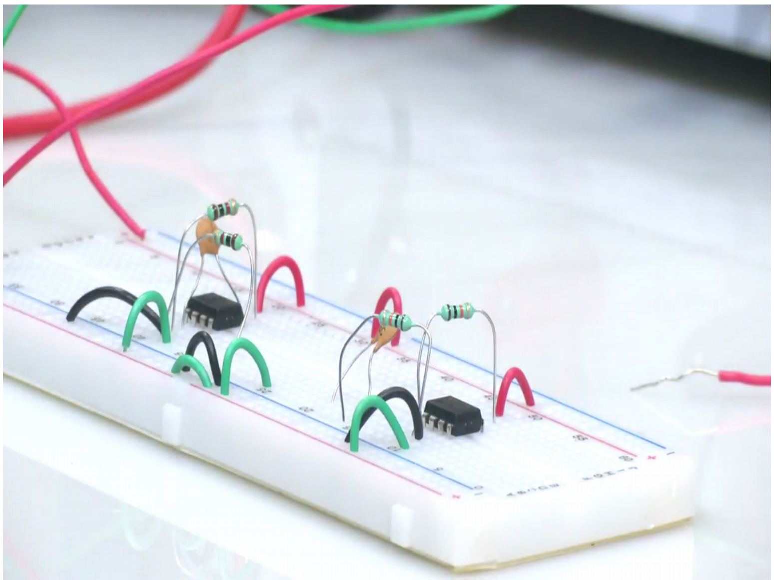

Now, we are applying the signal at the input before that we had to apply the bias voltage to the operational amplifier which will apply through the d C power supply then we had to apply, then we have to apply input one volt peak to peak at 5 kilohertz 1 volt peak to peak at 5 kilohertz it is a square wave 1 volts peak to peak 5 kilohertz frequency. So, let us see the first let us see the function generator please and we will be able to see when you focus on function generator that the input voltage is one volt peak to peak 5 kilohertz ok.

Now, we are applying this one volt at the input and we are measuring the output of the differentiator.

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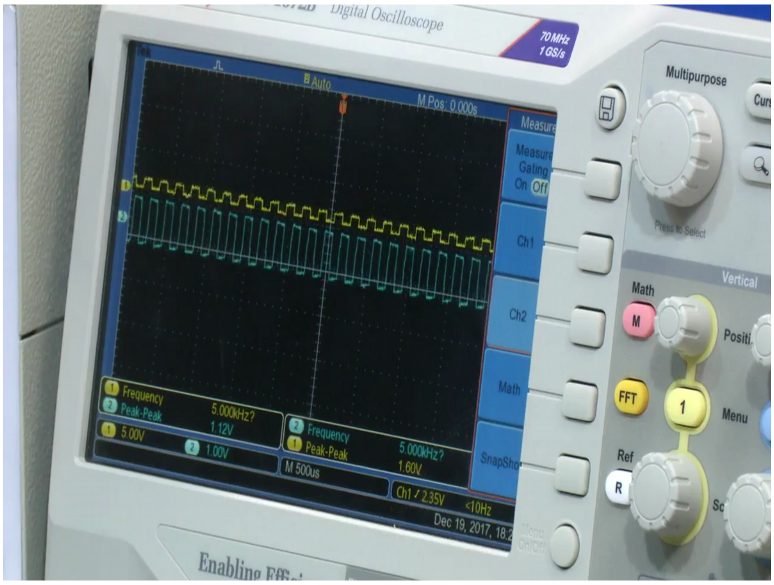

We are measuring the output of the differentiator so, as you can see on the screen right.

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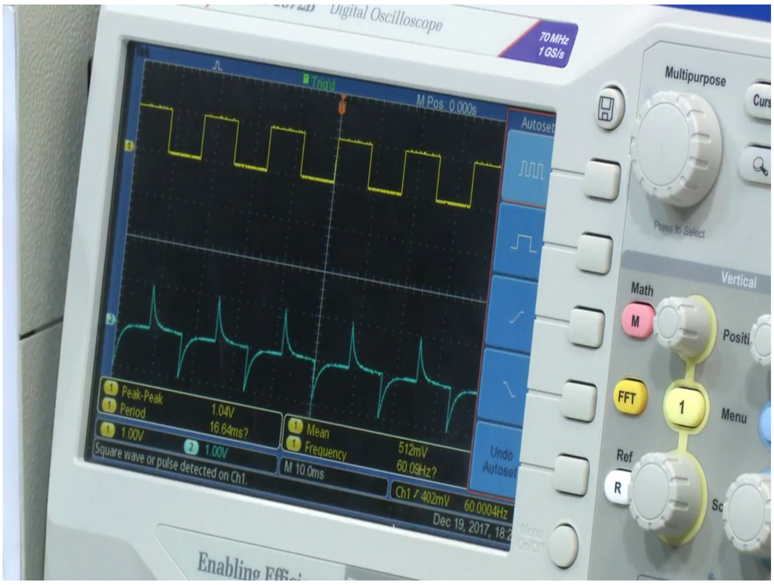

When we apply the square wave at the input the output results in a spike in a spikes so, let us see the voltage at the output the voltage of the output you can see the oscilloscope please oscilloscope yes ok.

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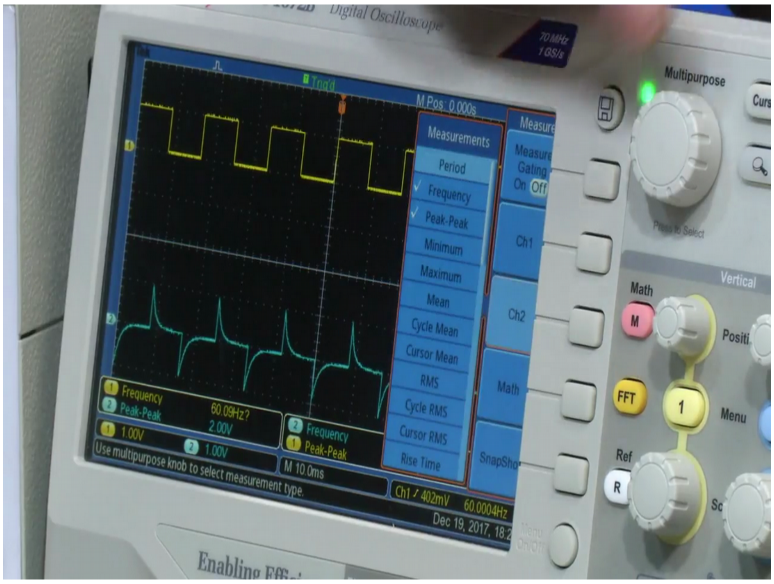

So, you see the voltage at the output is about 2 volts 2 volts, when we apply peak to peak signal of 1 volts 1.04 volts right here the case is different in case of integrator, when we are applying about 5 volts we are observing 2.4 volts here we applying 2 volts we are observing we are applying input signal as 1 volt and we are observing the output as 2 volts, but do you see how you do not have to only measure the output you also have to comment on the shape of the waveform and this shape of the wave is nothing, but a spike alright it is a spike.

Now, let us let us change it let us change it; that means, that we give a different signal to the input.

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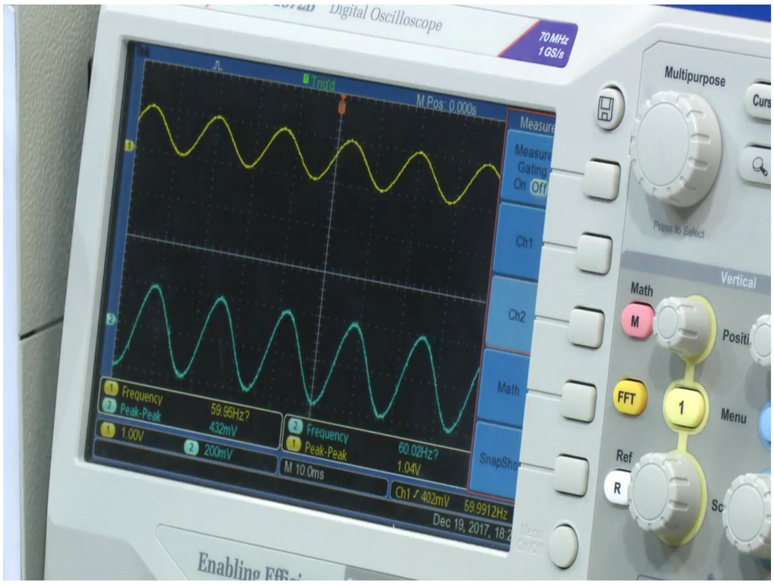

You know different signal to the input we have given a sin wave at the input and at the output we are able to see a cosine wave, we are able to see the cosine wave, let us see give another signal at the input which is the triangular wave.

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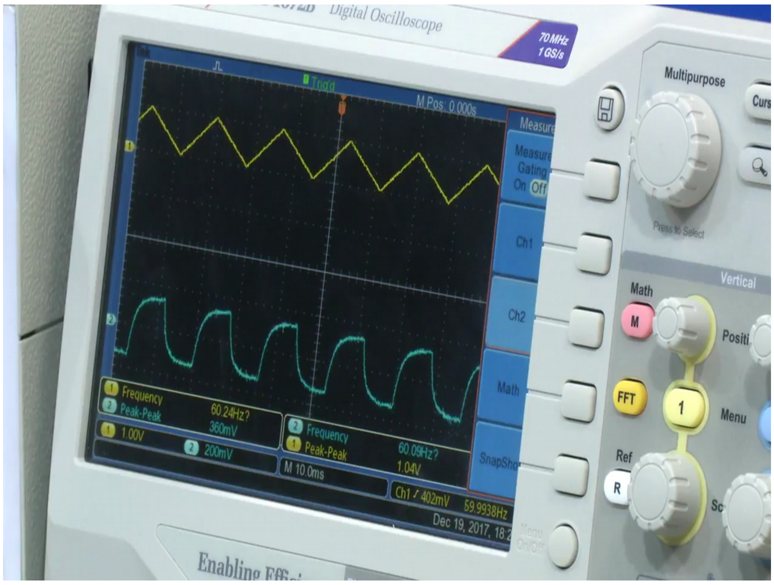

And you can see kind of square wave kind of square wave ah when you apply the triangular wave alright. So, the point is again that you have two different circuit one is differentiator one is integrator with both the circuits you can get different kind of waveforms at the output on application of the input signals right.

So, what we have to understand is that once we once we understand operation amplifier, we can use this operation amplifier as a different for different application and today for this particular module, what we have seen is a differentiator and an integrator and to quickly recap; what we have seen in this particular module is we have seen an integrator than in the integrator the R f which is a feedback resistor is replaced by a feedback capacitor C right in the feedback the back and then what we found is for the ideal situation is ok, but then there is a drift.

So, to remove the drift we put a ah resistor R f across the capacitor in the feedback and then, we have performed the experiments and we have seen we have applied different signal and we have seen the output at the integrator, then we took our differentiator the difference between the differentiator and integrator is nothing, but the capacitor. Now instead of in the feedback it will be at the input say of the differentiator.

So, now you are applying the signal to the differentiator at the input and you are measuring the output feedback, there is a resistor R and here the input that is capacitor C now we have a formula which we have derived and we can see that on application of square wave the output is nothing, but spike in case of the differentiator, but when you can take a case of the integrator then you are able to see a difference output signal right.

So, what we what we find from this experiment is that you can perform the not only using the breadboard, but you can also do similar kind of study using pspice and you can find out whether you can see the change in signals or not in case, if you do not have the facility which I am showing it to you can perform this experiment right. At your home using the tools similar to pspice alright again you can use any tool that is good for you it is I am not doing any marketing for pspice and just telling you that this of one of the tool that you can use for understanding the operational amplifier actual experiments of the operational amplifier alright.

So, now with that there are more applications of operational amplifier and in the following modules, what we will be looking at the following modules we looking at the filter it is in an amazing application of an operational amplifier and how it can be used to filter out signals, what is the role of filter what kind of filters are there and we had to see how the filters can be implemented using the operational amplifier. So, I will see you in the next module till then you take care bye.