Integrated Circuits, MOSFETs, OP-Amps and their Applications

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Lecture - 47
Experiment: Differential amplifier using op-amp

This module is for the Differential amplifier. So, if you all remember that we have seen the summation right or summing amplifier, where we can add the voltages and then we can amplify according to our amplification factor to get the final output.

That means, adding of the voltages; adding is summing of the voltages. That is why because summing and then amplifier because it is amplifies it. Same way if you want to take the difference of the voltage, there if you apply two voltages we take difference of two voltages. It end and we have to amplify it. It is a differential amplifier. But before we go to the differential amplifier a very important point that I kind of thought of letting you know and most of you may know. So, this a this is a wire right, this is a wire that we used for the for connecting to the breadboard.

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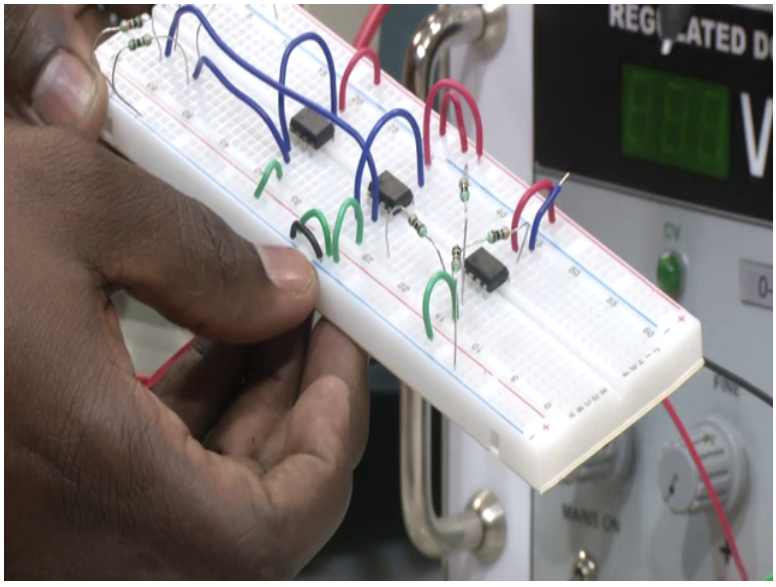

So, if I have a breadboard which is right in my hand these are the wires that are used to connect it right. This is a wire in my hand. How to take out this wire? So, we had to get this particular pin. Right?.

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You see here on the black background it may be more visible. You see this pin, this one and what I have is I have is this one. So, what is a way of clipping out this? Clipping out this? So, this is in my hand clipper right you can see and I am placing this wire here. Right? You can see let me let me put it so, that it is easier. You see I am placing it here all right in this particular area like this and then I had to press it all right. So, if I press it I get this you see.

So, I am not putting the wire in my mouth. I have seen lot of laboratories right people use this wire they put in their mouth and they clip out the things. This is the wrong way of doing it right. What I mean is if you can focus on my mouth I will show it to you; I will show it to you practically. So, you understand this is the wrong way. You see what we do most of the laboratories right, we take this wire we put in mouth and this is how we, we take out the clip. This is wrong way, all right. This is the wrong way of performing experiment, wrong way of understanding the things, this does not qualify you for good laboratory practices right. So, do not do that what I did. I was just showing you because I have seen and in fact, when I was in my undergrad right, I used to do it.

So, it is from my own example right. It is it is not bad if you if you if you have done some errors or if you have done something wrong to admit it right. A brave person can only admit his mistakes or her mistakes. Do not worry, if you have done something wrong. The important is whether you learn from this errors that you made in your life

right. I learned that this is not right way of taking out the wire, way before all right not now way before. And once or twice when I did it, I found why I had to use my teeth? Is wrong right? There should be some equipment right.

Now this is the one, there is another one which is automatic clipper, but anyway the point is again once let me show it to you. We do not have to use your mouth guys right. Teeth are teeth's are very precious; our body parts are very precious. Even if we do not understand it is very important. So, do not do not use teeth, do not use your hand, do not pull it like this, do not do not put in some do not use knife to cut it is wrong; use this right; place the wire in this you see very easy I am placing it right and I am pulling off, I am just pulling off my wire you see ready easy all right.

So, so use this and then you insert this one into your breadboard. Breadboard is here right in front of me, I am see it is very easy. When you do is perfect one two done. Right? Again depends on how much you want you open this the open this all right. There are lot of other effects that we are not learning in this particular course which will cause when you when you take out when the wire is longer, when the wire is shorter, how much you are opening the contact area lot of other things that comes into the circuit which we are not covering in this particular course. However, it is important that you follow the good laboratory practices.

So, coming back to this particular module, here we will be looking at the differential amplifier. So, like I said differential amplifier is nothing but it will difference the voltage and amplify it. So, the advantage is if I have noise at the input signal in the input signal not as an input signal, if they have a noise right I am applying voltage V1, applying voltage V2, I have noise here and I have noise here. Then the noise will also get difference. So, there is a difference of noise right. So, the point is let us see how we can so, quickly derive the formula of differential amplifier.

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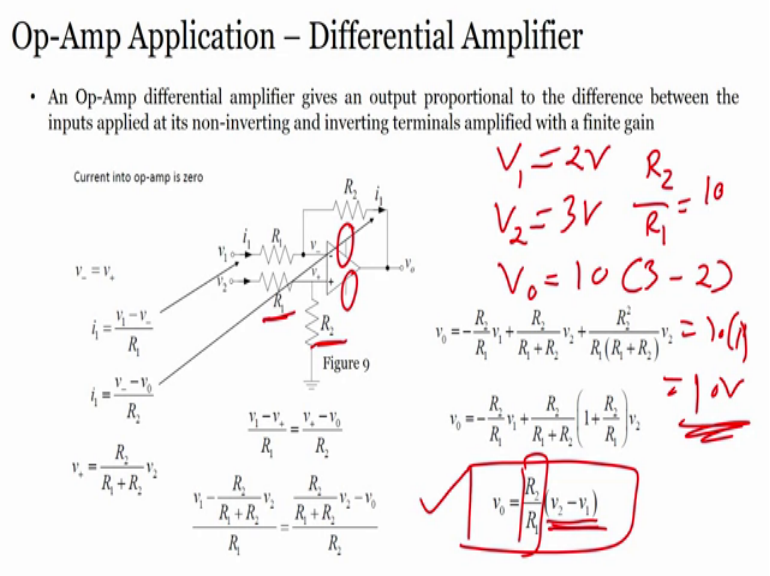

And you have this on the on your screen and op-amp as a differential amplifier gives an output proportional to the difference between inputs applied at it is non-inverting and inverting terminals amplified with a finite gain, with a finite gain all right. This is a definition what an op-amp differential amplifier or op-amp base differential amplifier gives an output proportional to the difference between the inverting and non-inverting terminal and it will gain, it will amplify with a finite gain; it will amplify with a finite gain.

So, let us come back here. So, you see this figure number 9, figure 9. This is the this is the differential amplifier; this is the differential amplifier all right. What we have here? We have voltage V1, we have voltage V2, we have R2, R1, R1, R2 all right; easy circuit very easy. Now what will be the voltage V o at the output? What will be voltage V o at the output? I told you if you remember that it is always good to understand how you can derive the equation, but not really necessary that you remember the way of deriving it. If you remember the final equation you can use this equation or formula for understanding your experimental circuits all right. So, but if you want to just quickly see how we can derive this particular formula, we can see it and it is very easy derivation is always very easy see.

Now, you see this V minus V plus all right, these two things are there; V minus V plus all right this one and this one. So, V plus will be equals to V minus right. Current into the

op-amp is 0. V plus equals to V minus. Now i1, which i1? This one you can see the arrow; this i1, i1 equals to what is that? V1 minus V minus upon R1 or divide by R1. What will be V2 or i i1 which is here; i1 here will be V minus right, minus V o divided by R2 very easy right. So, we have formula for this. We have formula for this right? Now V plus V plus is this one; V plus all right. V plus is R2 right, see here is a, what is this? Is a voltage divider, if you really see. So, what is that? R2 divided by R1 plus R2 into V2 into V2. So, that it will be your V plus right?

Now, V1 minus V plus upon R1 V1 this one; just see this one all right, V1 V2. So, if I want to have i1 then V1 minus V plus by R1 V plus minus V o by R2. How, because I am considering i i1 here and i1 here. So, I am substituting not this one. Forget about this. Just consider this i1 and this i1. So this i1 if I put the formula here, that will be V1 minus V plus upon R1 equals to V1 minus V plus minus V upon R2. Now what is my V plus? My V plus is R2 upon R1 plus R2 right here, V plus R2 upon R1 plus R2 into V2 all right. So, if I put this formula I further solve it. I will have this particular equation and for the solving this equation I will arrive to this the particular equation. So, if you solve it, it becomes very easy to understand how we can derive to this particular equation.

Now, if I do not consider anything only I consider the final equation what I see? What I see is that the final equation depends on final equation depends on R2 by R1. So, my R2 by R1 is my amplification factor; R2 by R1 is my amplification factor and the difference of voltage V2 minus V1. So, this is the difference of voltage V2 minus V1. So, let us assume that V1 equals to 2 volts, V2 equals to 4 volts and R2 by R1 equals to 10 all right. If this is given, what you will we have? V o equals to 10 into 4 minus 2, 10 into 2, 20 volts. Would I get 20 volts at the output? I will not get 20 volts out at the output. Why? Because my bias voltage is plus 15 minus 15. Right? But what if I have V2 equals to 3 volts? Then I have 3 minus 2. So, that will be equals to 1, 10 into 1 equals to 10 volts. Would I get this? I will get this. Right? So, very easy if you remember the formula you can solve the differential amplifier.

Now, let us see that actually if you want to use the differential amplifier and you want to see whether it is working or not in case in terms of experiment, how to how to perform the experiment, all right? How to perform the experiment?.

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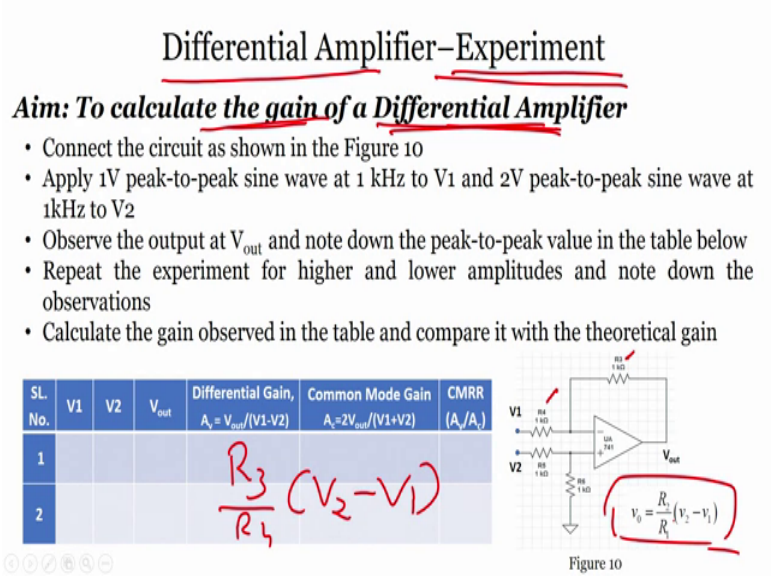

So, we go to the next slide and here you can see differential amplifier in terms of experiment. So, what is the experiment and how we can calculate the gain of a differential amplifier. Here the idea is to understand what is the gain of the differential amplifier? All right? The first thing is you should connect the circuit as shown in figure. A circuit is similar. Circuit is similar, it is very easy; V1 V2. You have R1, R3, R4, R5, R6, it does not matter what you say here. It is finally, R2 by R1 or R3 by R4 all right R3 by 4. So, you do not do not get confused when you see R3, R4, R5, R6 and suddenly you have equation V o equals to R2 by R1 V2 minus V1. It is similar. It is nothing but R3 by R4; R3 by R4 all right. So, this is your feedback register. So, I can still write 3 by R4 into V2 minus V1 all right. So, if you cannot see let me write it here, here I will write; R3 by R4 right into V2 minus V1 right. So, do not do not worry about if the formula says R2 by R1 all right.

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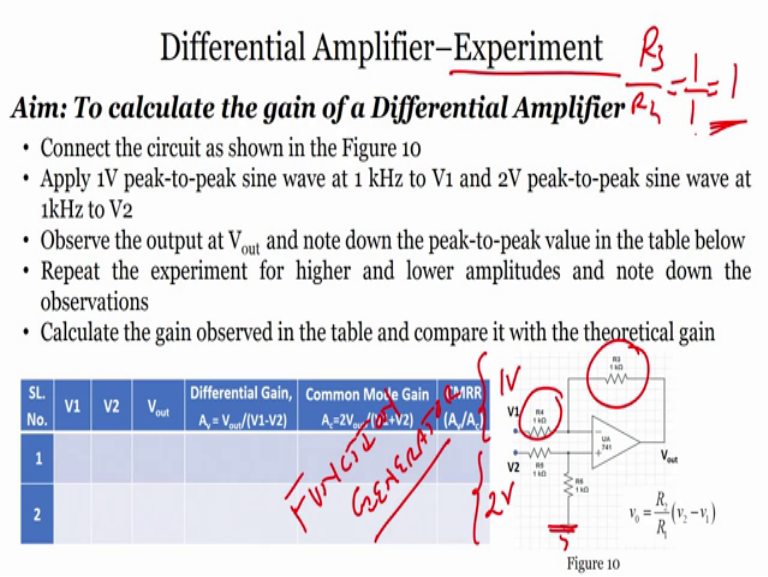

Figure 10

So, coming back to the circuit, we had to connect the circuit as shown in figure 10 which is this figure right. Apply 1 volt peak-to-peak sine wave at 1 kilohertz to V1. So, we are here V1 we are applying 1 volts right, peak-to-peak you know what is peak-to-peak? Sine wave peak-to-peak voltage, peak-to-peak voltage; let me draw it correctly 1 volts peak-to-peak all right, 1 volts peak-to-peak. What is a frequency? Frequency right, frequency 1 kilohertz; 1 kilohertz we apply. 1 volt we apply to V1, 2 volts we apply to V2. Frequency is same 1 kilohertz.

So, 1 volt here, 2 volts here right, add then we had to observe the output V out and note down peak-to-peak value sorry in the table below all right. Try to see how to write the things correctly all right. So, figure if I use figure if I say F capital here, I should have table t capital here all right. So, try to be consistent even you do not see consistency in my note always understand that consistency is very important when you write when you present all right. So, table was always when we write t should be capital right, t should be in a uppercase. So, repeat the experiment for higher and lower amplitudes and note down the observation.

So, let us let us see how to do this experiment on the breadboard and we will note down the values all right for this particular differential amplifier. So, let me request Sitaram Gupta right you guys already know him. He will help us with this particular experiment which is the differential amplifier. Sitaram can you please come here and show the

differential amplifier to the audience. This particular one yes this one. You can see four resistors right? One is RF or R2, one is R1, another is R2, another is R1. So, our formula if you remember is V o equals to R2 by R1, V1 minus or V2 minus V1. So, he has connected this four resistor with this operation amplifier and he has applied or he will apply plus 15 and minus 15 as a bias voltage to this amplifier and then we will see what is the input, that is V1 and what is the input V2 and what is the output voltage correspondingly. We have to use here the DC power supply, we are here to use function generator and we can use oscilloscope or we can use millimeter all right.

So, let us see can you please connect the plus 15 minus 15. So, you see the this is a right way of performing the experiments. The power supply is off; you see power supply is off all right. Now again understand that if you are careful it is, but generally always try to be more safe right and close your power supply all right. So, plus minus 15 is connected excellent. Now he is applying the plus minus 15 to the to the operation amplifier as a bias voltage. Now what is the second step? Second step if you see the screen it is written that now you apply 1 volt peak-to-peak sine wave at 1 kilohertz to V1. So, if you come back to the experiment board and you see the function generator which is on my right; this one ok.

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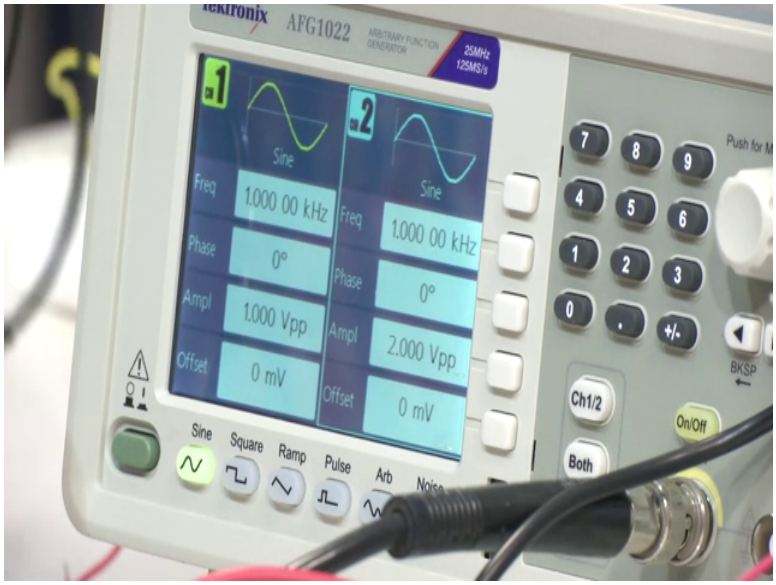

What he has applied if you can focus 1 kilohertz right and he has to apply 1 volt peak-to-peak. So, you guys already know how to use function generator or you have seen at least

right. So, you see what he is applying? He has already applied 1 kilohertz frequency and now he is applying 1 volt peak-to-peak. So, let us see 1 volt peak-to-peak, 1 volt peak-to-peak. You can see here in the amplitude it is already written 1 volt peak-to-peak right frequency 1 kilohertz. Now, this particular is one channel; second channel he will apply 2 volts peak-to-peak. So, we are just adjusting the function generator. Now again 1 kilohertz is same, but we had to change the voltage. Voltage you have to press the amplitude button and then change your voltage. Here it is 2 volts peak-to-peak right. Earlier it was 1 volt for one channel, second channel is 2 volts peak-to-peak.

So, if you want to see both the channels you can see that that as well. If but the point is that we have now connected 1 volt to one channel and second volt to second channel all right. You can see here 1 volts applied to channel 1, 2 volts applied to channel 2, 1 kilohertz frequency for both the channel, phase is 0 degree, offset is 0 millivolt. Now you he will connect this voltages, input signals to the differential amplifier. So, again you come back to the circuit once again for a second yes. So, what he has done? He has 1 volts here. He has adjusted 2 volts here and then he has to do this 1 volt and 2 volts is coming from the frequency generator. This 1 volt and 2 volt is coming from function f u n c t i o n function generator g e n e r a t o r generator; function generator. You applied 1 volts and 2 volts the input signal of this differential amplifier. So, you have to connect V1, V2 and ground right with the function generator.

So, when you always take a probe always try to you know see whether probe is you of working or not, you have to connect the probe in a proper manner. So, you understand whether the voltage that you are applying make sense or not. So, a lot of things you have to understand. Do not just think that you know once you once you are applying 1 volts, it is done. You have to you have to check it with oscilloscope, you have to check it with your multi-meter, see the probe whether they are properly set and then you apply to the circuit ok.

So, now once you once you make sure that the probes are ok, then you can apply 1 volts to the V as V1, 1 volt. There is one from channel 1 to V1, second 2 volts. So, another terminal will be ground, then we have to connect 2 volts. So, if you see and if you can focus on what he is doing please it is easier. We focus on what he is doing yes. So, he is connecting the ground to ground and he is connecting the signal to signal, he is testing this thing on the oscilloscope, he is testing this thing on the oscilloscope and now he can

see that it is ok; whatever he has applied 2 volts, it makes sense and now he will apply these 2 volts which you can see he is connecting to the V2 and black one to ground excellent.

So, now we have applied V1 and V2 and there is a ground signal. Now what we have to measure? We have to measure the output of the differential amplifier. So he is connecting to the output of the differential amplifier and if you see on the oscilloscope please.

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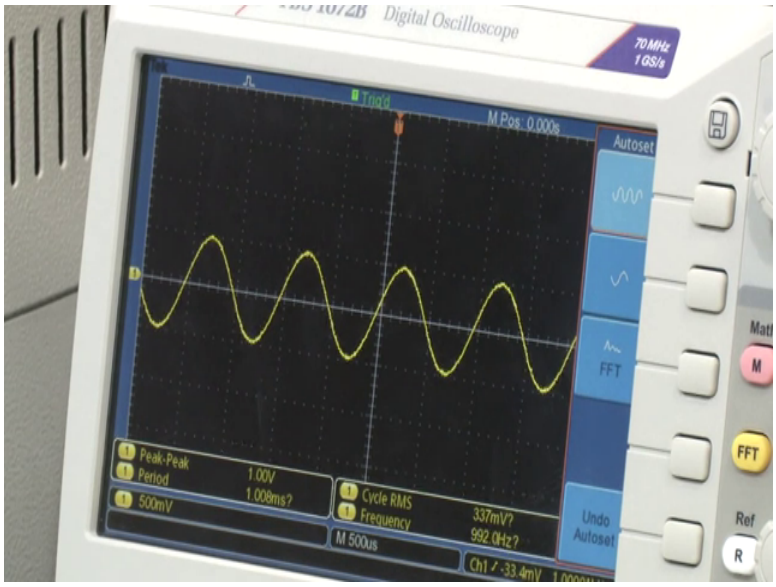

So, what we see? Can you show us Sitaram, where is the output? Output is this one which is a signal and which is about 1 volts on about close to 1 volts peak-to-peak. That is that what voltage we have applied? We have applied 2 volts right at V2. We applied 1 volts at V1. What we are getting; 2 minus 1 which is 1. Why? Because the gain here is 1, the gain that we have set here is 1; that means, if you come back to the circuit what is the what is R3? R3 is 1 kilo ohm. What is R4? R4 is 1 kilo ohm; that means, your gain would be R3 by R4 1 by 1 equals to 1. Gain is 1 right? What is sorry, what is the what is the input signal? Input signal is 2 volts, input signal is 1 volt; 2 minus 1 right. So, formula is here, formula is here.

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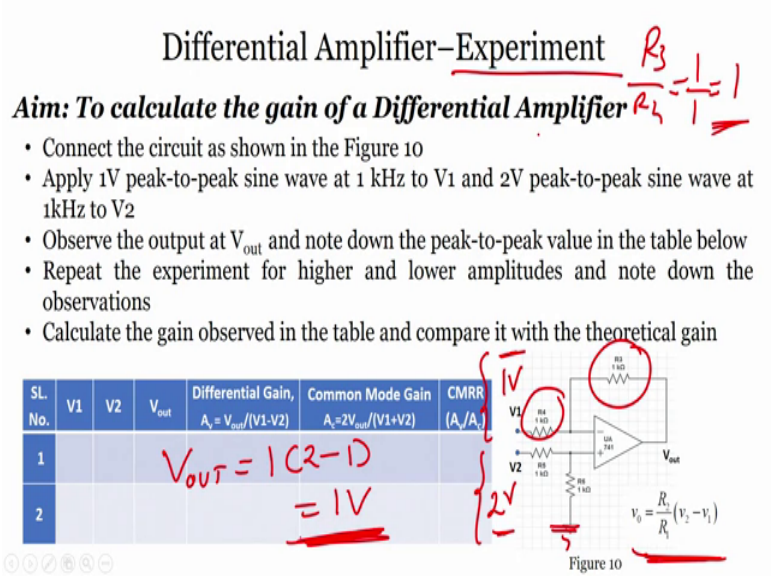

So, I will write it down here once again. V out equals to gain is 1 into V2, 2 volts V1 1 volts. This is equals to 1 volt. That is what we see 1 volt on the oscilloscope. That is what we see 1 volt in the oscilloscope. So, if I want to write in the table when you write in the table right.

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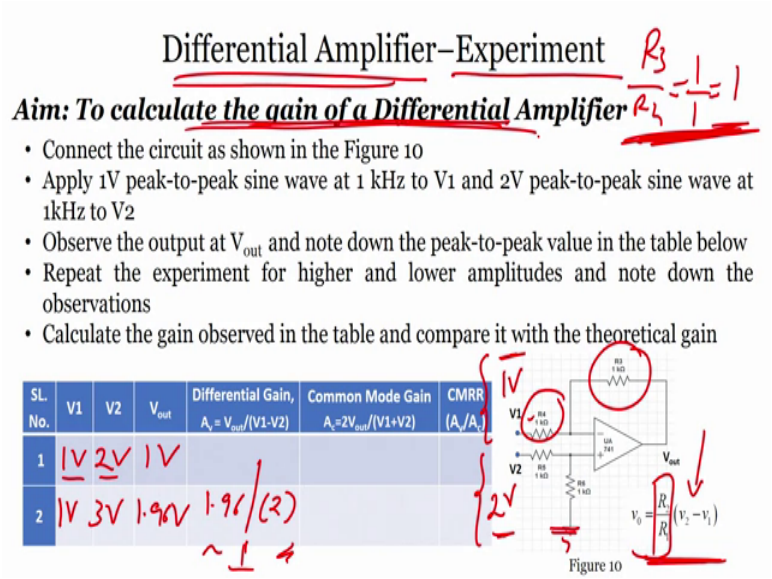

What I will write? 1 volt, 2 volts, V out is 1 volt right. Differential gain if I want to write then we it will be 1 divided by 1 or 2 minus 1 right; which is equals to 1. So, gain is 1 all right; common mode gain we will not worry about this right now, will not worry about

CMRR because this experiment is not to understand common mode rejection ratio; these are experiment to understand the differential amplifier right. So, we will we will do a separate experiment where we will understand common mode rejection ratio. So, here my output is or my gain is 1. So, is easy to understand how can measure the gain of a differential amplifier like it is very easy right.

Now, let us change the voltage, V out 1 divided by V1 minus V2. So now, V1 and V2. So, let us apply different V V1 and V2; just apply whatever you like; see this is this is not something that we have already prepared all right guys. You should understand this thing that we have not prepared some experiments to show it to you, this is live. We are we are we are assuming any voltage and to and to make you understand that you do not have to really prepare for experiment. Think 1 volts, what will happen? 0.5 volts what will happen? 2 volts what will happen? So, this is this is how you should do the experiment. It is not something that you already have said ok, it is when Sitaram I called you apply 1 volt, so when I called you applied 2 volts. No. Right? I give him the freedom and he is applying voltage according to his understanding. Let us see what happens at the output all right. So, that is even interesting right. So, let us see.

Ok, so let us see what voltage is he has applied as an input signal. Can you show both the both the channels please. See if you see function generator; if you see function generator and if you can focus it. Then you can see here, he has applied 1 volts and 3 volts; channel 1 volts, channel 2 3 volts right, we can see same thing frequency is same. In this case when you change the voltages 1 volt and 3 volt, what is the expected output? What is the expected output of the differential amplifier? Let us see the theoretically; theoretically should be 3 minus 1 right which is 2 into what is a gain? Gain is 1. So, output should be 2 volts correct.

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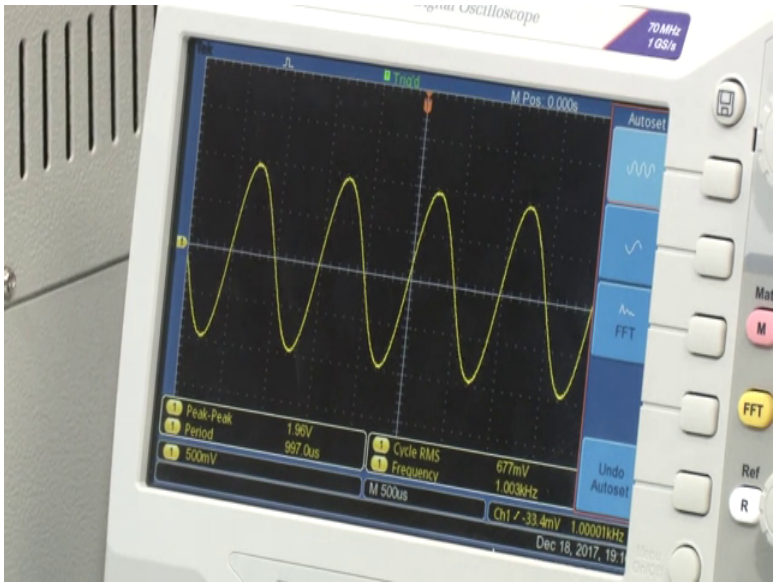

Now, let us see what is the output? Let us see what is the output? You can focus on the oscilloscope. And you see 1.96 right, close to 2 volts; close to 2 volts; again why this is the case, because we have resistors which may not be exactly 1 kilo ohm. See this tolerance is making so much of effect right; 1 thousand ohms and 950 ohms will change the gain. We cannot have same gain which is 1. So, always understand that the small changes, small tolerances that you see in the resistance value will have a significant difference on your overall output. So, point 1.96 and 2 volts has 0.4 volts difference, 0.04 volts difference right; 0.04 volt difference for you it may be like it is 0.04. It is not because when you are when you are understanding the sensitivity of a sensor, this is a big difference it as a big difference. So, you had to compensate your circuit right and that is why the selection of your resistors, accurate resistors is extremely important right.

So, coming back to this one, which is our differential amplifier. What we see? In another case he applied 1 volt and 3 volt, output was output voltage that we observed was 1.96 volts right and if I calculate gain then this is the practical gain; particular gain would be 1.96 divided by] 1.96 divided by 2 right. See 3 minus 1 is 2; so, which is approximately close to 1, close to 1. So, my gain is 1. In fact, we have already known, the theoretical it is 1; experimentally it will be close to 1 not 1 all right. So, this experiment shows how to calculate the gain of a differential amplifier, gain of a differential amplifier; differential amplifier because it has it takes a difference of voltages; amplifier because we can

change the gain of the voltage that is difference of voltage by changing the value of feedback resistor and the input resistor.

Now, one thing you understand is that the R4; in this case R4. Let me just clear this screen, it is easy to understand ok; R4, R5, R6, R3; they are same here. But if you want to change it then it will have a different kind of function all right. So, we are assuming that all the resistances are same in this case it is like this. But this value and this value should be same. This value and this value should be same. All right, then you can have the similar formula; so if the value which have crossed and value which I have double ticked right; this should be same all right. Then in that case this formula is still valid, this formula is still valid right. So, I hope that you understood the function of the differential amplifier and let us see another experiment and understand what are the instrumentation amplifier. This is a differential amplifier. So, let us see in another module what do you mean by instrumentation amplifier and how it is different than the differential amplifier all right.

So, I hope that you understood the function of the differential amplifier and how it is useful and how you can change the signal from the function generator? How you can use the oscilloscope to look at it? What are the bias voltages? How we can use multi-meter? How you can use probes? How you can use wire? Wire right. How to take out the wire right? How to take out the wire using the device that I have or the equipment that I have or the tool that I have; this is tool; tool t o l tool. This is equipment; equipment right. Understand the understand the difference. The tool is difference, equipment is different, devices different, systems is different all right. So, do not confuse yourself all right. And the best way of learning is done in your own language. English is one medium through which we can communicate, but you it is not a mandatory thing to understand only everything using English. If you if you know how to speak Kannada; you speak Kannada, you speak Tamil; Tamil, Telugu, Hindi, Guajarati, Marathi; whatever language you speak Punjabi. It is it is on you how you understand the concept all right.

So, do not worry if you do not really understand in terms of English, understanding your own language. It is always easier all right. Do not do not just focus at oh my god I cannot speak in English. So, or I cannot communicate in English in such a good way. What can I learn electronics? Yes you can. Yes you can right. If you go to China, China people they learn English directly in their graduation on maybe not. So, till there they are learning

everything, you can see lot of electronic items right. They do not know electronics, I know electronics. You go to Germany, they speak Germen. So, it is not exactly that the only thing that you learn through a through a course is only through English. English is just a medium because most of us here in India we try to understand or communicate in a in a language which is easier and I feel that English is really easiest way to communicate, but not easiest ways to understand all right. To understand anything your mother tongue is the best way to understand the things.

So, keeping in mind we will finish this lecture and I hope that you have a good time ahead and you learn more things and I keep on showing you new experiments which would be helpful for you to understand the concept of op-amps and in general their applications and the indicator circuit which is again our operation amplifier.

So, I will catch you in the next module till then you take care. Bye.