**Integrated Circuits, MOSFETs, OP-Amps and their Applications**
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**Lecture - 48**
**Experiment: To study the gain of instrumentation amplifier**

Welcome to this module. And in this one we will look at the instrumentation amplifier. So, if you remember, in the last modules, what we have seen? We have seen the differential amplifier. And the differential amplifier was used to understand the how the difference of the voltages that we can apply can be used and we can amplify the signal of the difference voltage.

But what if I have to remove the loading effect, or what if I want to apply the sensor in terms of Wheatstone bridge, and see the signal at the output. So, so let us rather than you know confusing you, let us see the circuit and let us understand what exactly instrumentation amplifier is and let us go one by one so that you can understand how we can make a differential, amplifier or we can convert a differential amplifier to an instrumentation amplifier, alright? So, if we if we look at the circuit on the screen.

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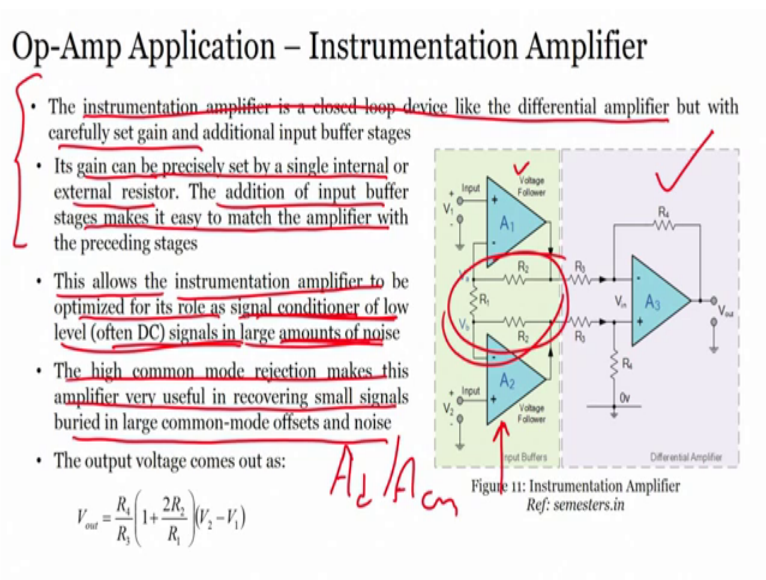


Now, what we see is that instrumentation amplifier is nothing but a closed loop device similar to differential amplifier, right?

So, if you see what is this is a differential amplifier. Now to this differential amplifier, but with carefully set gain an additional input buffers. So, what is this you see there is a voltage follower? This is voltage follower, but there is a resistors, there are resistors which are used to amplify the signal, which are used to amplify the signal; that means, that this differential instrumentation amplifier can be fabricated, or can be made by attaching or by integrating the differential amplifier with the buffers, or with the non-inverting amplifiers, alright?

So, it is gain can be precisely set by a single internal external resistors, the addition of input buffer stages makes it easy to match the amplifier with the preceding stage. We already know this, right? What that if I use voltage follower, then the loading would be negligible; that means that, I can match the impedance with the previous stage to the differential amplifier if I use my voltage followers, alright? This allows the instrument amplified to be optimized for his roles as a signal conditioner of low level signals in large amount of noise; that means, what that if I have a small signal in presence of huge noise, small signal in presence of huge noise. Then can I measure this signal in terms of ah, can I extract this information even presence of huge noise?

So, let us to one quick experiment, by the time I will just read on the on the screen, if one of my t a do you have a mobile, to find a YouTube where you see a screaming video screaming, right, just find out video and then. Let me know so, you come back that is fine. So, I will put a I will show it to you guys that how exactly what I mean by extracting the small signal in presence of huge noise, alright. So, the point is here that the instrumentation amplifier.

Let us quickly once again see, quickly once again see. The instrument amplifier is a closed loop device like differential amplifier, but with carefully set gain one. Second, it can the gain can be precisely set by a single internal external resistors. Third, the addition of input buffer stages makes it easy to match the amplifier with the proceeding stages, and 4th this allows so, because of this condition, this allows instrumentation amplifier to be optimized for it is role as signal conditioner of low level signals, you see, signal conditioners of low level signals in large amount of noise, right. So, the high common mode rejection makes the amplifier very useful in recovering the signals buried in large common mode effects and noise.

Now, you all remember, what is CMRR? Common mode rejection ratio, we have already seen in the theory class CMRR is nothing but differential gain by common mode gain Ad by ACM, right. So, if I want to understand why CMRR, CMRR should be extremely high. From a CMRR is extremely high; that means, by signal to noise ratio is extremely high; that means, I can measure the small signal in presence of huge noise, right, presence of huge noise. So, what is saying? That if I have a condition, where I have a signal, where I have a signal, and there is a presence of huge noise, there is a presence of huge noise, how can I use the instrumentation amplifier.

So, let me put a so, you see this is screaming is a noise, and I am seeking something else, also along with this. So, you see the, when there was third time, when I was third time, right, a man was screaming, right, why I got a YouTube video? Whether it was a screaming first you can see very clearly a screaming noise. Second it was screaming noise. Third time it was screaming I was also speaking.

So, that screaming you consider as a noise, and my whatever I am speaking as a signal. Can you extract this signal by reducing the noise? Can you extract the signal by reducing the noise? If that is the case, then the instrumentation amplifier is extremely important circuit, alright? You got it? So, it is an example so, if there is a crowd which is speaking in a one loud voice and suddenly one person is speaking in some other thing, you cannot here in presence of loud noise.

So, that is a small signal in presence of huge noise, can you reduce the noise and increase the signal? Can you amplify the signal? If you use instrumentation amplifier, then you can do that particular thing, which is also written in this slide, this allows instrumentation amplifier to optimize it is role a signal conditioner of low level low level signals in large amount of noise large amount of noise, alright? You may not be able to understand very clearly in terms of maybe the sound, but if you are, you understand this thing that if there is a signal and if there is a noise, then it is easy to extract the signals from this noise or our or our optimize these signals right with the help of instrumentation amplifier.

Now, the high common mode rejection ratio makes this amplifier very useful in recovering small signals, but it in large common mode effects and noise, alright? The output voltage is given by V out R 4 by R 3. So, if you see this particular circuit, this particular circuit, right? V out is nothing but you see differential amplifier, differential amplifier you consider only this part, alright? Only this part what was V out V out was, R 4 by R 3 into V 2 minus V 1, correct?

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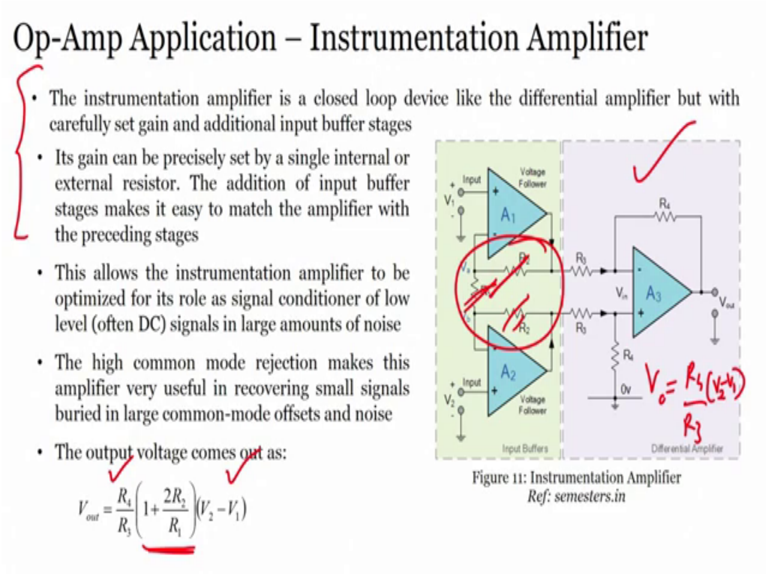


So, this was done so, you see here V out R 4, let me just remove it, V out R 4 by R 3 V 2 by V 1, right?

Now, what for this one, the what is the role of this R 2 and R 1, if I connect in this particular fashion, I have gained 1 plus 2 times R 2 by R 1. This gain comes from the voltage follower circuit in this particular fashion. But you will also see circuits where you are neglecting R 2 and R 1, we will see we will not have a R 2 and R 1, rarely connect as a buffer, alright? And let us understand the instrumentation amplifier in terms of experimental approach in terms of practical approach.

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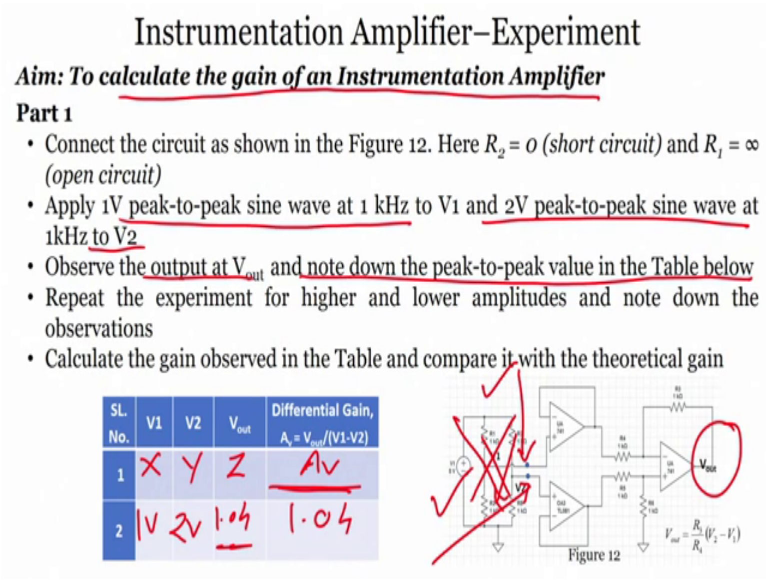


So, if I see instrumentation amplifier in this particular case, what we have seen? We have seen this particular circuit already right; that means, here there is a Wheatstone bridge, you see there is a Wheatstone bridge there is 1 2 3 4 resistors, right? And the output of Wheatstone bridge is given to the buffer to the buffer and then it is connected to the differential amplifier, right?

So now you see if I do not connect buffer then you know what will happen loading effect will happen, right? So, I am connecting buffer a to the differential amplifier, this makes my instrumentation amplifier, this makes my instrumentation amplifier. So, let us understand, how we can under how we can use the circuit to understand the gain of the instrumentation amplifier, the aim is to calculate the gain of an instrumentation amplifier, this is our aim for today.

The first one is connect the circuit as shown in figure we have to connect the circuit as shown in figure 12 right. So, one is you understand, only from here to here, alright? Another one is this circuit which is your Wheatstone bridge, alright? So, connect the circuit as shown in figure 12, you just connect in terms of this one apply 1-volt peak to peak sine wave, to V 1 2 volts peak to peak sine wave to V 2, observe the V out and note down the peak to peak voltage in the table below. So, will measure V 1 will measure V 2 will measure V out, and from that, we can measure the differential gain A V, alright? So, this is what we have to do, and then we can repeat the experiment for higher values and lower values.

So, let us see how we can do this particular experiment, on the circuit board and by applying 2 voltages at the inputs of the differential instrumentation amplifier. Like I said instrument amplifier is nothing but buffer connected or integrated with your differential amplifier, alright? So, let us apply the input voltages to the instrumentation amplifier, now we have already applied the bias voltage to the operation amplifier.

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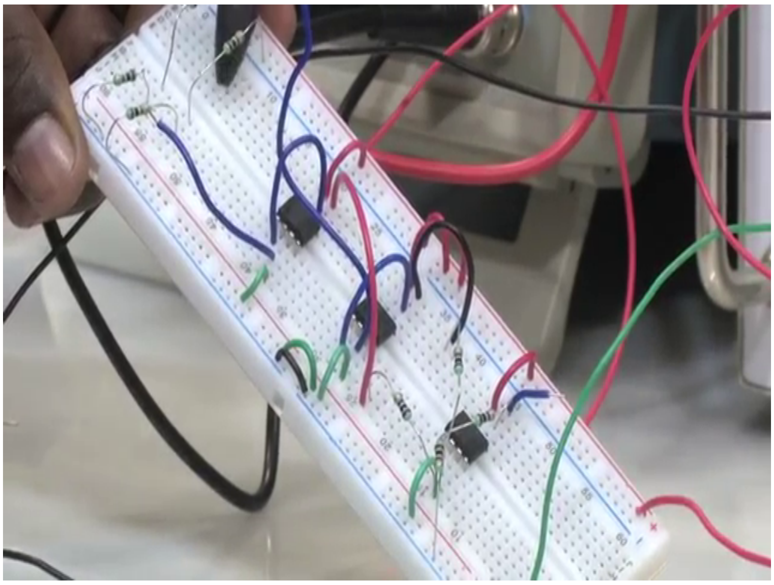

And now what we are looking at is we will apply the voltage V 1 and voltage V 2 to the instrumentation amplifier, before we apply voltage V 1 and V 2 to the instrumentation amplifier, we have to we have to adjust this voltage in the function generator. So, Seetharam is already working on the circuit. Like you see, the this circuit was not prepared earlier, right? In front of you only he is trying to connect the circuits.

So, if we can do in one or 2 minutes, right you guys can also do in at least 15 to 20 minutes. So, it is very easy that is what I am pointing out, it does not require really premeditated you know things which will take a lot of time or consumed lot of time, alright? Once you understand it is very easy. So, what he has shown is a is a Wheatstone bridge which are 4 resistors if you can focus here on these resistors please yes, this resistors. So, these are the resistors which he is showing which are 4 resistors right you can see here 4 resistors, this is the Wheatstone bridge. And then instrumentation amplifier is somewhere differential amplifier, can you please? So, differential amplifier, these are differential amplifier, right? And to this differential amplifier we are connecting buffers, where are buffers this is 1 and this is 2, alright? There are 2 buffers 1 2 differential amplifier is here, and Wheatstone bridge is here, right?

Now, let us apply first voltage to the differential amplifier. So, we will apply 2 voltages right V 1 and V 2. If you come back to the circuit, come back to the circuit on the slide, yes. What we are applying right now? We are applying voltage here and voltage here alright V 1 and V 2. So, let us go back to the breadboard.

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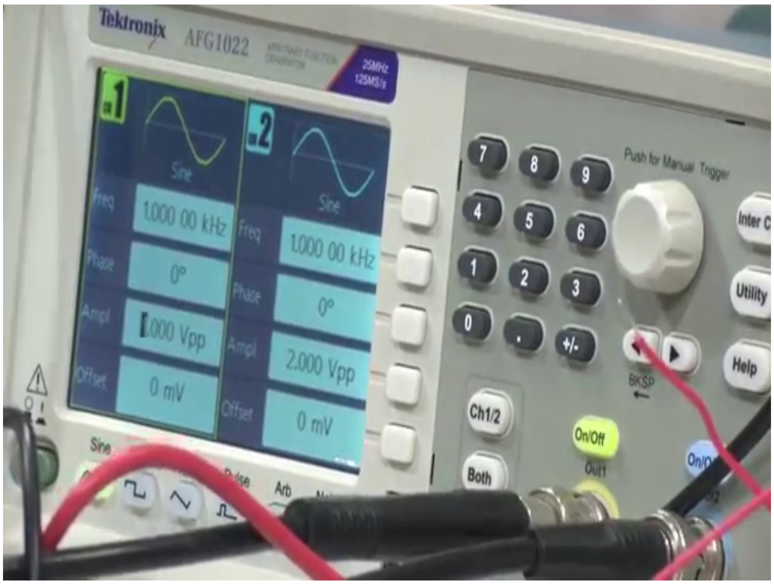


All right, you can apply 1 volts and 2 volts respectively, alright? So, what you see is function generator, you can see there is a 1 volt, there is 2 volt frequency we have set at one kilohertz phase is 0, offset is 0, and now we are connecting again to check whether it is 1 volt or 2 volt with the oscilloscope, as you can see right, ground with ground phase with phase or signal with signal, and then we have to understand.

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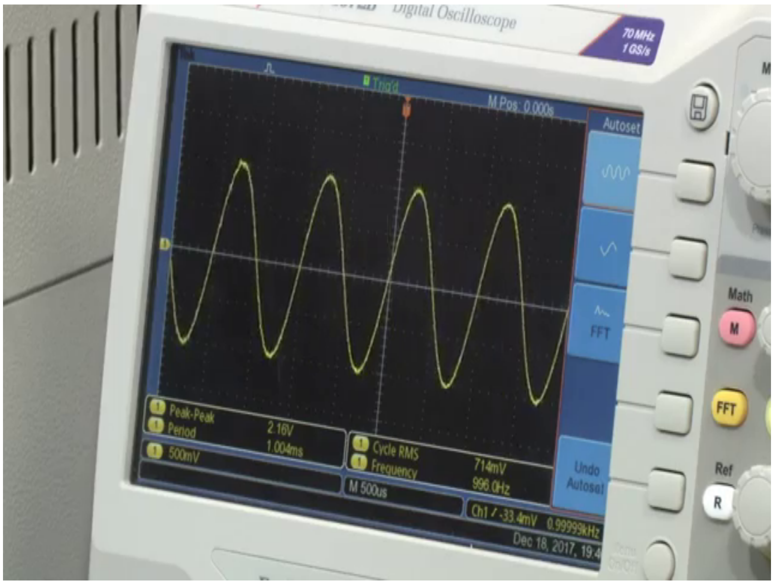


Whether it is correct or not, and we see it is ok, now we can apply it to the input. So, is applying to the input here if you can see on the breadboard, right. So, he has applied the signal to the input of the differential amp of the instrumentation amplifier, alright?

Now, when we have applies input we had to check the output, that is what we had to do in the experiment we had to apply the input ok. So, there is only one input he has applied, now he is checking the second input, second input again with the oscilloscope. So, you can see in the oscilloscope, you can see in the oscilloscope, yes, and you can if you if you focus it is around 2 volts, 2 volts peak to peak, right? 2 volts peak to peak ok.

Now again you go back to a breadboard please, and he is connecting the second to the instrumentation amplifier, ground to ground, now we have applied voltage V 1 and voltage V 2, right. And we will measure the voltage at the outputs we have applied voltage V 1 we applied voltage V 2.

Now, we are measuring the output of the instrumentation amplifier, alright. So, this is in this configuration, you understand neglect this Wheatstone bridge for now just understand the voltage directly applied at the buffer V 1 V 2, output voltage V out. So, we are measuring V out, V 1 if you see here what is V 1, 1 volt V 2, 2 volts V out we had to measure from that we will say V out 2 minus 1 is one, right? what is V out let us see what is V out. So, if you see again the circuit, you see again the circuit. You will see that he has connected the output of the instrumentation amplifier to the oscilloscope. So, if you see the oscilloscope, you will see the result you will see the result. And if you see the output is 1.04 volts, output is 1.04 volts, right?

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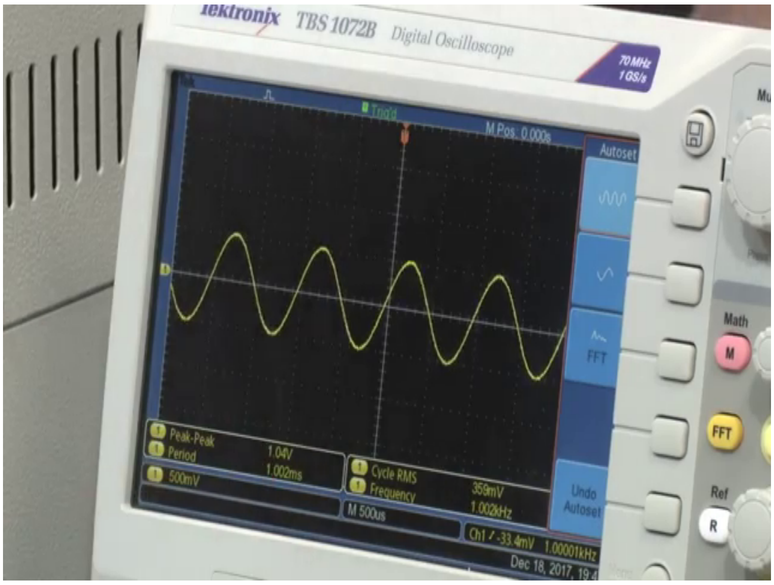


So, let us write down output on the screen, we will write output as 1.04 volts. So, I write 1.04 divided by 2 minus 1 or 1 minus 2, this is equal to 1.04. So, my gain that I have calculated is nothing but 1.04, alright? So, this is how you can use the instrumentation amplifier with buffer with buffer, right? Now what will happen if I directly connect the potential divider output? And see what is the voltage difference between V 1 and V 2. So, he if I measure voltage here, if I am measure voltage here, and then what I will do? First I will mode whether voltage here, and then second, I will voltage measure voltage at V out, alright?

So, first I am measuring the voltage, at the output of the Wheatstone bridge or the output of the Wheatstone bridge. So, I had to apply voltage across the Wheatstone bridge, and if the Wheatstone bridge is properly tuned then my output voltage would be 0, right? Output voltage would be 0. So, if you see again what he is trying to connect he is trying to connect the Wheatstone bridge with the supply voltage.

And we should expect the output to be 0 volts. So, he is applying supply voltage across the Wheatstone bridge, and the voltage is you can see here voltage is about 5 volts, 5 volts ok, and then he has to measure the voltage, at the output of the Wheatstone bridge and the voltage should be close to 0. So, let us see he is measuring the output voltage. And you can see the voltage is close to 5.4 millivolts, right 5.4 millivolts.

Now, if this voltage he applies to the buffer one 5.5 4 millivolts across the buffer, 2 buffers. And he is measuring the output, final output at the output of the instrumentation amplifier, the output of the instrumentation amplifier. Then what we are able to find out the output of the instrumentation amplifier is you can see what is it 42.6 millivolts, 42.6 millivolts, right.

So, there is a difference, isn't it? There is a difference, and that difference why there is a difference find it out. always I will not give you all the answers to all the things that we are doings you try to find it out, by yourself why there is a difference when we measure, the value here why there was the difference when we measure the value at the output of the Wheatstone bridge, alright? That is your kind of homework, right? I do not like to give homework.

Because I do not believe in homeworks, I believe in actual thing and I believe that student will do homework, if they really want to study, right? You cannot be forced to attend a lecture you cannot be forced to do the homework, you cannot be forced to do the assignments, you should do it by yourself, right? It is your will your zeal to learn, if you do it, you will learn more if you do not do it, it is yeah.

So, so what is the circuit here what is the circuit you see connect the circuit as shown in figure when we have completed let us complete our clearly see, what we are done? Here R 2 is short circuit R 1 is infinite or open circuit, right? These we are consider, why, because if you see earlier part here, right? Here what we have seen? Here we have R 2 R 1, right? Here we have R 2 and we have R 1. And this R 2 and R 1 was having an effect on the overall voltage V out, correct?

Now, in the experiment, what we are done? We are considered as R 1 equals to infinite or open circuit and R 2 short circuit, correct? So, you see here there is no R 1 and R 2. Here can you find R 1 and R 2, there is no R 1 and R 2, right? Now apply 1-volt peak to peak sine wave at one kilohertz V 1 2 volts peak to peak sine wave at one kilohertz V 2. So, apply one V 1 here V 2 here, observe V out and note down the peak to peak voltage we have done that experiment, repeat the experiment for higher and lower amplitudes, and note down the observation. So, we have not seen higher and lower amplitude, but we have actually seen the voltage when we applied directly to the input V 1 and V 2, and we have seen that when it is connected through the potential divider or Wheatstone bridge, what is the V out, right, this we have seen.

So, let us quickly see, if we if we change the voltage; that means, that if we lower the amplitude, lower the voltage what will happen. So, right now what we applied we applied 1 volt at the V 1 2 volts at V 2.

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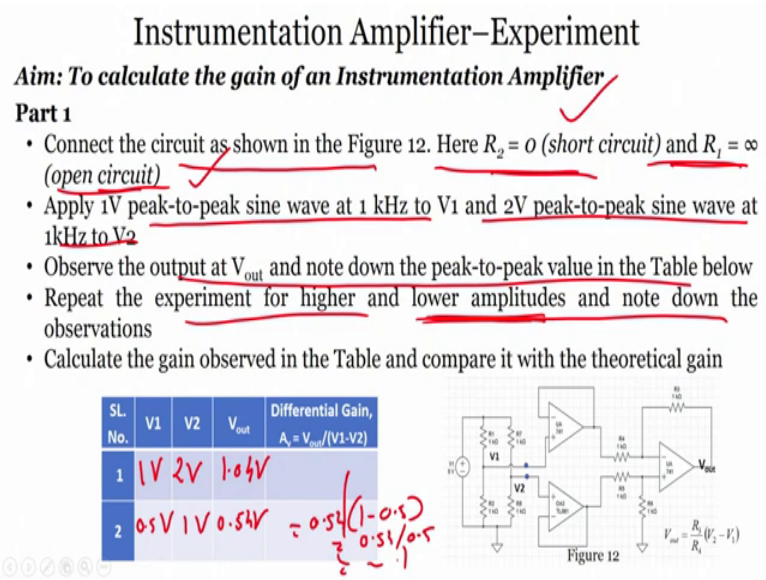


Now let us apply to 0.5 volts at V 1 and 1 volt at V 2, right? So, you see in function generator he is right now applying 0.5 volts in channel 1, and 1 volt in channel 2. What will happen? If I apply 0.5 volt in channel one and 1 volt in channel 2, what do you expect what will happen? V out what will be V out? So, I am applying directly V 1 and V 2 to the buffer, alright? Applying directly V 1 and V 2 to the buffer.

Again, he has to he is checking which one is channel one which one is channel 2 not exactly is he doing that, no, what he is checking he is checking the signal in the oscilloscope to confirm that there is 1-volt peak to peak and there is 0.5 volts peak to peak. So, once he confirms his experiment, you can see the oscilloscope please yes. So, he can see 5.5 volts from channel 2.

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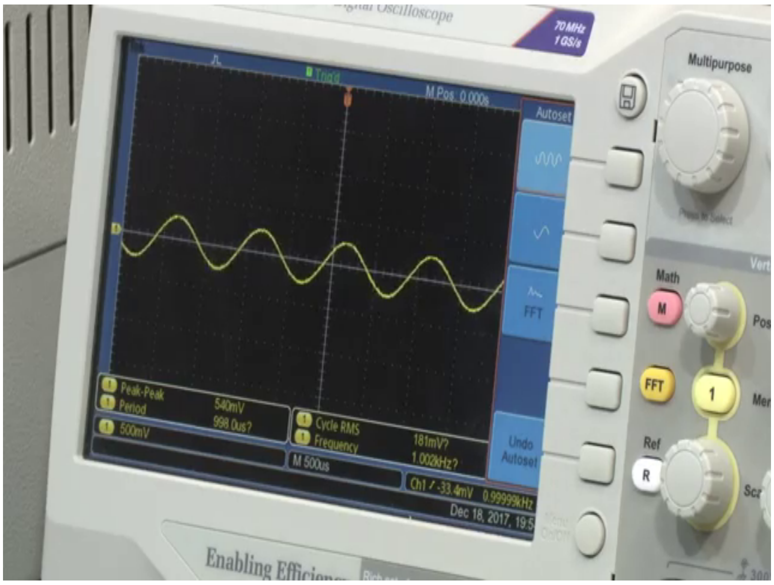


Student: Channel 1.

Or a 0.5 volts in channel 1. 0.5 volts in channel 1. And then he has to also see 1 volts in channel 2. So, let us first connect channel 1 to V 1 channel 1 to V 1, alright? And now he has to check 1 volts in channel 2 1 volts that we are applying to channel 2. So, again he will take a probe from function generator which is right now doing. And he is connecting the probe through the oscilloscope, to again check whether it is 1-volt peak to peak.

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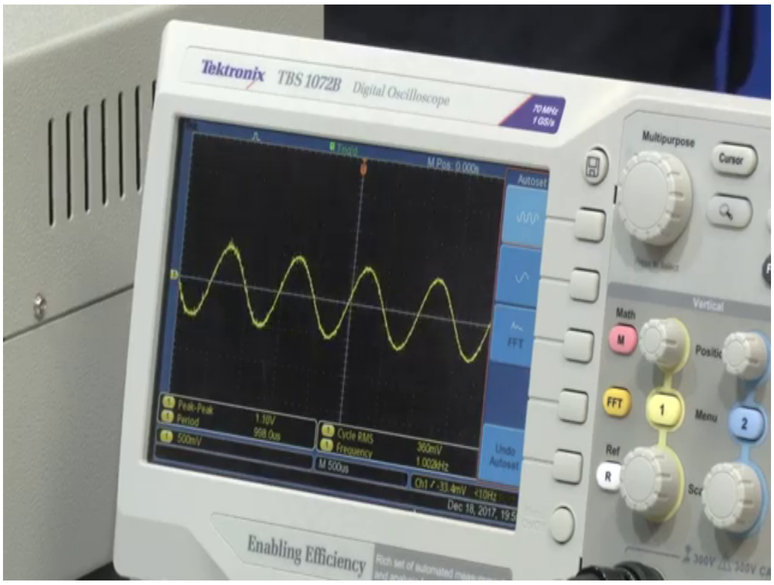

He has to check whether the function generator he has applied 1 volt, is it 1 volt or not he has to check it on the oscilloscope. So, if you see it is 1.04-volt peak to peak, alright? Peak to peak.

Now, he will apply this signal to the V 2 to V 2. See is applying it to V 2 as you can see. So, he you had to make sure that the ground is ground connected with the ground, and signal to the signal, and when you applied V 1 and V 2 what is output? Output here to connect to the output of the instrumentation amplifier, and measure the signal in the oscilloscope. So, see when he connects it, you can see the signal in the oscilloscope, the output is if you focus on the oscilloscope, you will see.

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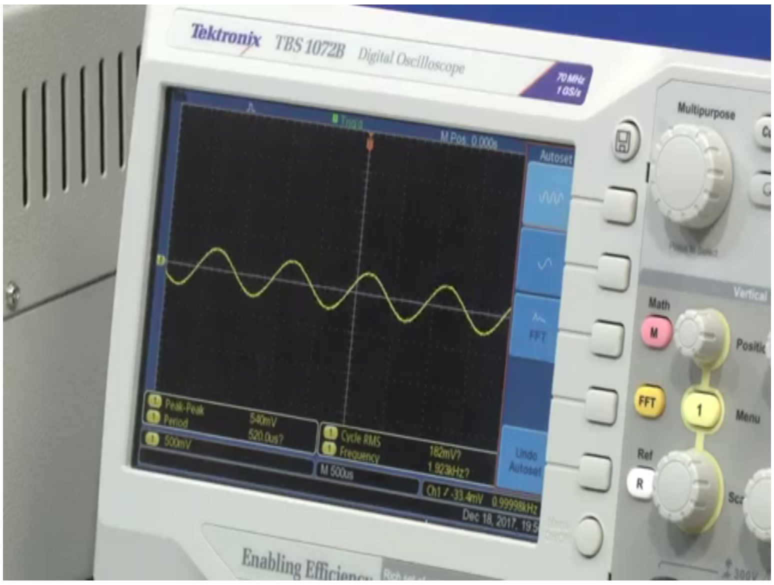


540 millivolts, 540 millivolts so, earlier when we were looking at the output was close to 1.04 volts, here it is 540 millivolts or 0.54 volts, right? So, what will be the output? What was expected output by expected out 0.5, because the gain here we have kept as 1, right, the gain is 1. So, if gain is 1; that means, that my output V out let us see 0.54 divided by 1 minus 0.5 which is nothing but 0.54.

Student: 5 point.

Yeah divided by sorry, divided by 0.5, right? So, 0.54 divided by 1 minus 0.5 or 0.54 divided by 0.5. This is close to 1. So, the this is how you can measure the gain of the instrumentation amplifier. Very important experiment, very important circuit, you have to understand instrumentation amplifier because it is used in large number of circuits, large number of circuits, alright. So, understand this now, let us see the part 2 of the instrumentation amplifier, which is the last circuit for this particular module.

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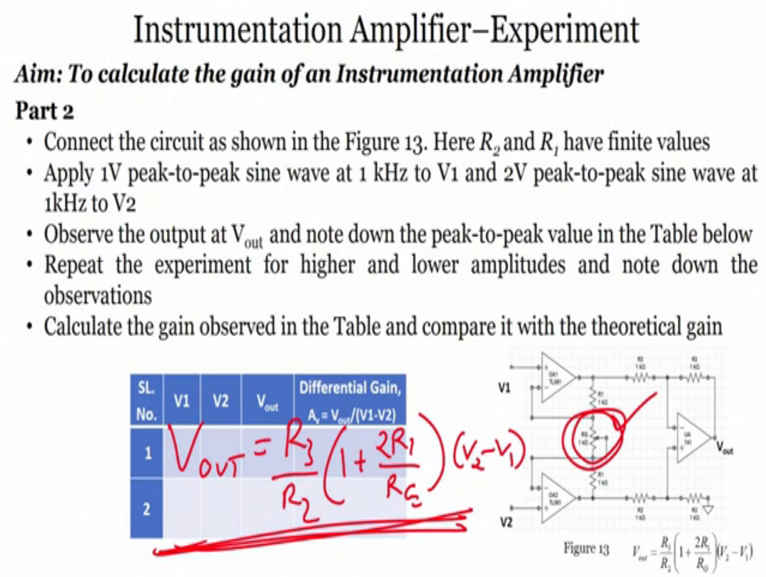


And here we had to again calculate the gain of an instrumentation amplifier, but here if you see there is a slight change that we have made. What is the slight change? The slight changes here we are consider the same circuit which we have used to understand the theory, right? Which is that you have here R 1 have here R 1, you have your R 1, and instead of R 2, you have your R g, you have your R g.

So, what is the formula, if you remember the formula would be V out, V out equals to here, you see here, right? So, here is nothing but R 3 by R 2, right? Into what is this one? This formula for this one you have seen, right? 1 plus 2 times R 1 by R g into V 2 minus V 1, correct? So, this is the formula that comes into effect, if we are going to use this circuit, alright. The advantage here is you can change the gain, you can change the gain by changing the part, what is part what is potentiometer, alright? Are variable resistor right.

If those for those people who do not know how the potentiometer looks like the is in the next circuit, you will be able to see how potentiometer looks like. like I said do not feel that, and the beauty of this NPTEL is that you really do not have to feel embarrassed, had there is no nope no person around you, who can who can tell whether you know or not. If you have that mentality, first of all I see, I tell, I told you very clearly that a lot of things we do not know. And if we are in class and if we ask right; that means, you are curious it is not that you do not know and everybody knows. So, do not feel that when you ask a question; that means, you are the only guy or a only girl in the class that does not know the answer, or they do not understand the things right. In fact, I take it in a different way if my student ask me question; that means, their student this curious, right, you curious to understand curious to learn the things.

So, the point is for those people who do not know how a potentiometer looks like, or how a variable resistor looks like. Now we will see in the next circuit, soon once I once I complete the this light. So, what we had to do? We had to connect the circuit as shown in figure, alright? We have connected, now what? Now what to do? Now here resistors R 2 and R 1 have finite values ok, R 2 and R 1 have finite values. R 1 is 1 kilo ohm, R 2 is 1 kilo ohm ok. Apply 1 volts peak to peak sine wave at one kilohertz.

So, actually you see we can also say sub R 2 and R 1, we also have here R 2 and R 3, R 2 and R 3 also has the same value. So, do not worry about finite values or not, do not do not really bother about this, right? apply 1-volt peak to peak a sine wave at one kilohertz to V 1 2 volts to V 2 observe V out and note down the peak to peak values in table below. So, this is the same circuit if you remember, right? the only difference here is that, we have now considered the this particular resistors, set of resistors, and that is why the formula is little bit changed. Calculate the gain observed in table and compared with the theoretical gain.

So, let us see if I apply voltage between 2 bet between the 2 to one of the buffer voltage 1 2 buffer 1 voltage 2 buffer 2, buffer is not a voltage follower, what will be the output V out, alright? So, let us see, again you can see so, please disconnect the see the breadboard. you see if you can look at the breadboard, now he disconnecting the previous circuit, he is disconnecting the previous circuit, which in which we have used buffer without the R 2 and R 1 or R g and R 1, alright? There was no feedback if we have seen ok. And now he is bringing a circuit so, it is similar circuit, except that there is R 1 and R g.

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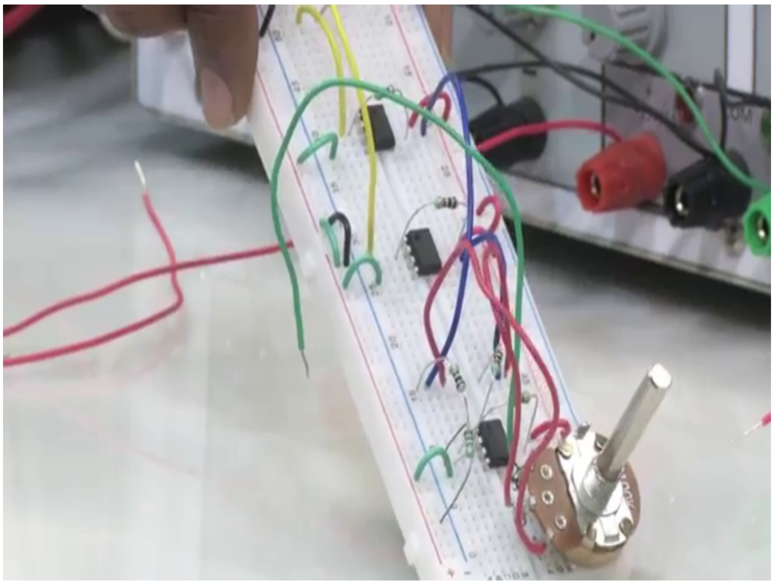

So, can you see and for those people who do not know, right I told you this is the potentiometer, alright? This is the potentiometer, it is called pot, p o t, pot and a value here is written 100 k. If you can see, I do not know whether you can see or not ah, yeah 100 k, right. So, this is 100 k pot there are 3 terminals in the potentiometer here, 3 terminals are there, right, and you can you can use the 2 terminals and the third terminal you can around it, or 2 terminals you can short and one terminal can even use it. If you go to YouTube, and see how the pot can be operated, you will be able to see. It looks like this you can if you change this knob the resistance value changes, alright?

If I change this knob the resistance value changes. I can use it clockwise and anti-clockwise. Do not try to go beyond it is capacity. So, once it is mood, you know, know equipment requires too much of force brutal force. This is all electronic equipment, there is no mechanical this is not a workshop.

So, do not apply extra brutal force to any electronic equipment, right. You had to turn it clockwise, you had to turn it anti clockwise to change the resistance. Now what he is doing? He is he is trying to measure the resistance of the potentiometer, and you can see the resistance here, on the multimeter, you see you can change it 4, 419 kilo ohms 62 kilo ohm 63.6 kilo ohm 67. So, he is turning the knob and you can see the change in resistance, right. So, this is called a potentiometer, alright, ok, anyway.

So, let us now adjust the value of the potentiometer, and apply the voltage V 1 and V 2, which we have already set in the function generator, which we have already set in the function generator to the instrumentation amplifier. Again, understand that whenever you want to measure the resistance of the potentiometer. It cannot be connected to the circuit, you need to disconnect the potentiometer. Because then other parameters will come into effect, and you will not get the actual resistance, alright?

So, whenever you want to measure a potentiometer, please, disconnect it from the circuit. If you see now he has disconnected from the circuit. I thought earlier that it was disconnected, but now he has disconnected. So, you can see now change in the resistance values, right, if he sees it is changing 2.2, 2.4 2 point. Because how it can be more than 600 when the when the maximum well maximum kilo ohm or maximum range is up to 100 kilo ohms? You cannot exceed 100 kilo ohms, right.

So, we are connecting now volt potentiometer, as shown in the circuit, if you see the circuit on the screen he is connecting the potentiometer as shown in the circuit. and he is also connecting resistors R 1, like you see in the circuit. And then he has already prepared this time he has prepared, alright? This particular circuit which is here right; so, what he is trying is just trying to connect the potentiometer as you see on the circuit.

Now, he has already connected, now he will apply the signal voltage, he has already we have seen in the previous experiment 1 volts.

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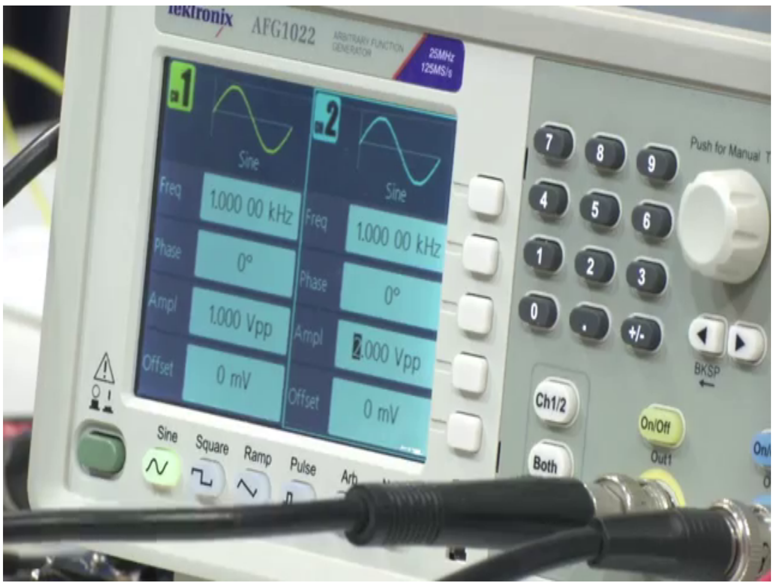

And now you can see here, the signal from the channel one is 1-volt peak to peak is channel, 1 yeah and now connect with channel 2 please. And let us see both the channels together, let us see both the channels together, yes. So, channel 2 applied some different voltage ok. So, you can see channel one is 1-volt channel 2 is 2 volts. This is we are applying to the instrumentation amplifier at the input, can you please connect it? 1 volt at one input 2 volts add another input, and now we are trying to measure the output, alright? We are trying to measure the output of the instrumentation amplifier.

We can measure the output by connecting the output of the instrumentation amplifier to the oscilloscope. When we try to do that then let us see, let us see what is the output? Do not forget to apply the bias voltage to the operation amplifier circuits. So, we had apply plus 15 minus 15 right,? Ground to ground, alright, turn on the DC power supply, yes, plus 15 minus 15 is given. Now he is connecting the output of the instrumentation amplifier with the oscilloscope. And once he connects it, we can see the output of the instrumentation amplifier on the oscilloscope, alright? So, ground he needs to connect it ok, can you just, alright?

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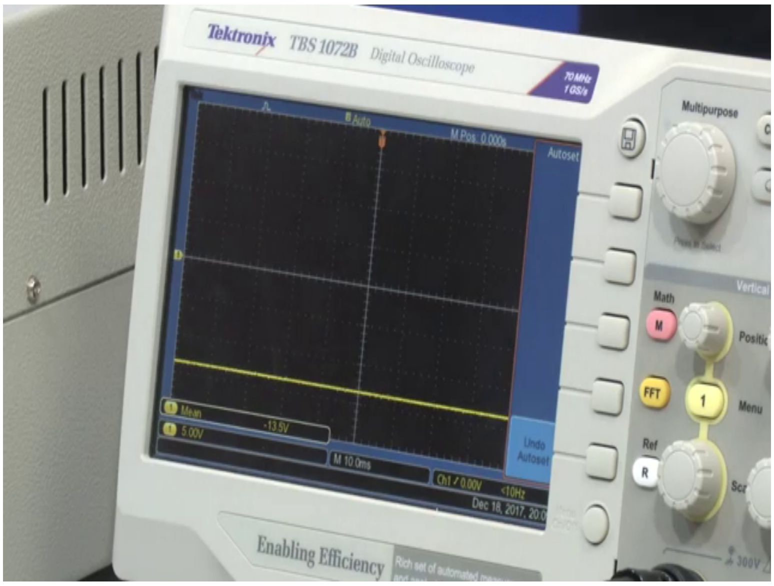


So, what is that what we see? Minus 13.4 volts, minus 13.4 volts is the output of this particular instrumentation amplifier, right ah? So, again I said it depends on the feedback resistors, it depends on the 1 plus 2 R 1 by R g. So, when you put all the values together, you will find that the output voltage would be close to what we got in the in the experiments. And you can also understand that, we can change the gain. Because, here the gain is extremely high why because we have change the potentiometer. You see here potentiometer, the gain is extremely high, and that is why you can see that the output is minus 13.4 which is very close to your biasing voltage. If we reduce the gain, so, can we reduce the gain and see if there is a change. So, what will happen if we reduce the gain? If we reduce the gain, then we will see, we will able to see the change in the voltage. But for now, it is fine. Do not worry about it for now let us just understand that, if you use the differential amplifier in this particular configuration along with the buffer a big it makes the instrumentation amplifier.

So, if you use differential amplifier with buffer makes instrumentation amplifier, if you use this particular circuit, then it will help to have different gain you can change the gain, if you have the previous circuit, here you do not have any control on changing the gain except value of R 3 and R 4. Except value of R 3 and R 4. The role of this buffer is to reduce the loading the role of this buffer the role of this buffer is to reduce the loading effect.

So now what we understood is that when we use instrumentation amplifier, right? it is nothing but a combination of your differential amplifier, and your voltage follower or voltage buffer. So, from this set of experiments, let us see the final slide and final slide today is another quote from Dean Kamen, which he says that every, every once in a while, a new technology and own problem and a big idea turn into an innovation. You see once in while generally when we do research, right, it is called researching the things which already searched.

So, ah, but while doing a research, while we are trying to understand the problem, and we dig into the problem, we can find old problems and we can understand whether they can find a solution to this problem. Sometimes, this finding solution of the existing problems will result in an innovation, right. So, always try to see the problems around you along with like I said I strongly believe that when you learn electronics, excellent when you learn any other subject excellent, but try to see and be kind to other people be kind to other humans fellow humans, because I believe that you know that you can be a good scientist ah, but if you are not good human it is not useful, right.

So, be a good human and if you are good human you can be an excellent scientist you can be an excellent engineer. So, with that particular quote of Dean Kamen, what why I think is, let us recall quickly in this particular module, which is the instrumentation amplifier here, we have used nothing but differential amplifier, we have used a buffer, then we have seen a Wheatstone bridge, a Wheatstone bridge buffer, instrument differential amplifier together or x cap Wheatstone bridge becomes your instrumentation amplifier, alright.

And then we can change the gain of an instrumentation amplifier by changing the value of R g which is a potentiometer you guys have seen, if you if you do not understand, I will just take it out from the supply which is here. And if you can just switch it off and take it out please potentiometer. So, that we can quickly see once again, yeah.

So, yes so, if you see in my hand this is a potentiometer, is the potentiometer in my hand, right? And what we can do is, we can change it, we can change we see I am twisting it, right? You can and this maximum. I will not force more than this, alright? See slowly I am turning it until it reaches to a one point, beyond this point, I can, I cannot turn it. I should not turn it, right, I cannot and I should not, alright. This is the potentiometer clockwise anti clockwise, clockwise anti clockwise.

There are 3 terminals here you can see here, right, and you can you can use potentiometer to change the resistance from 0 to 100 kilo ohm. 0 again is a ideal values so, extremely low 200 kilo ohm. That depends on the type of potentiometer, you get the one that I have is about 100 kilo ohms, right. So, using the potentiometer, you can change the voltage, you can even change the gain of the instrumentation amplifier, alright. So, in next class, in next modules we will see other application of operational amplifier.

Till then, you kind of keep understanding keep reading the lectures notes, keep understanding reading the theory that we have said it, because most of the things that I am teaching now in this particular classes are related to theory classes, alright. So, try to try to keep yourself up to date by reading the things which you have already studied in this particular course. With that you take care, and I will see you in next module.

Thank you.