Integrated Circuits, MOSFETs, OP-Amps and their Applications

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Lecture - 41
Experiment Op-Amp Characteristics Input Bias Current

Welcome to this module. Yesterday, in the last module actually we have recorded few of the equipment, right how to operate this equipment? And I have shown you the breadboard devices and the details about the equipment, right. So, just quickly let us recall the equipment where DC power supply, frequency generator, we had oscilloscopes, one was CRO, one was digital oscilloscope. In DC power supply we have seen how we can change the voltage, right. And how we can apply plus minus 15 volts if there is a facility within the DC power supply, it was a linear regulated power supply.

Then we have seen some discrete components and finally, we have seen a breadboard. So, today's class or this lecture is focused on the application. So, application of what? First we should start understanding what we have learned in the theory class; that is, understanding the characteristics of an operational amplifier.

So, if you remember, in the in the theory class we have seen, several characteristics of an operational amplifier. And the today's class is on how to measure those characteristics. So, let us see what are the characteristics of the operational amplifier, and then when the when the after 1 or 2 slides, you will see that once you once you again refresh what you have been learning in theory then we will start the experiment, alright.

So, let us see the screen. So, as you see that this particular lecture is focused on experiments on understanding op amp characteristics. So, we will see today what are input bias voltage input offset current input offset voltage, input and output voltage range. These are the things that we are focusing today. So, like I said and I have taught you in my theory class.

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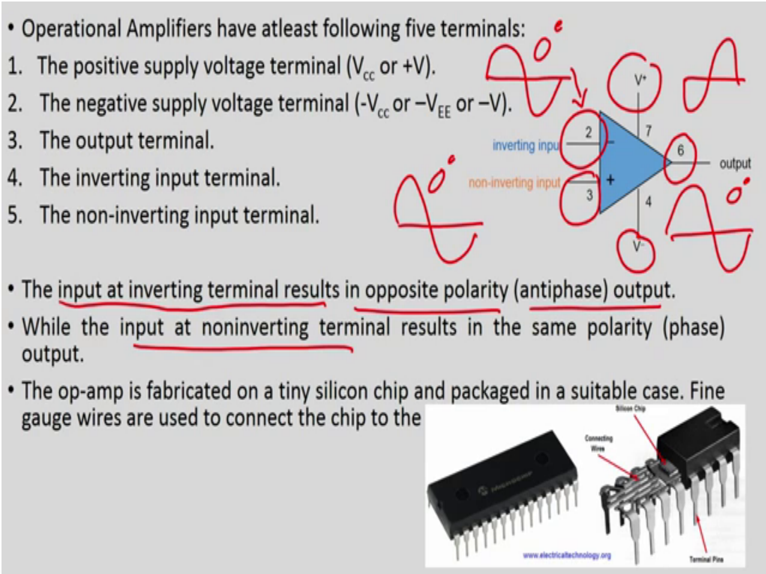

That is, what are the operational amplifiers, and what are the main pins in the operational amplifier.

So, if you remember the operation amplifier we have discussed, there are 5 main pins of course, there 7 pin op amp. It depends on what kind of IC you have. It is single op amp or it is a dual op amp or it is in quad op amp. So, we are talking about just a single op amp. If you take a single of op amp, then as you seen see on the screen the there are 7 terminals 2, 3, 4, 6, 7 which are which are used and 1 and 5 are other terminals. 1 5 and 8, that are used for some other purposes which we have already discussed.

So, let us quickly see the positive supply voltage terminal, that is this one, right. V plus then we have second negative supply voltage terminal minus Vcc which is this one. Then we have the output terminal which is 0.6. Then we have the inverting input terminal. Number 2 and we had non-inverting input terminal number 3, right. So, this we all remember correct.

Now, the input at the inverting terminals result in opposite polarity; that means, that we have seen that if I apply a voltage, right which let us say this polar this phase. And I say this is 0 degree, if I apply voltage at input 2 that is inverting terminal, what we can see we can see a voltage the output with a phase change, right. So, opposite polarity or anti phase output when you have inverting input at the inverting terminal, right this we all remember.

What was next? The input at non-inverting terminal; that means, at terminal 3 if I again apply our signal, right. When I assume that this is a 0-degree phase, then at the output I will have no phase shift. So, what is no phase shift it is a 0 degree, right. Again, we have seen in the theory class how we can understand what are the phases, right. I have taken the example of a circle, but if you do not remember let me just quickly tell you how we can measure the phase, or what do you mean by 0 degree what you mean by 180 degree, and what you mean by 360 degree.

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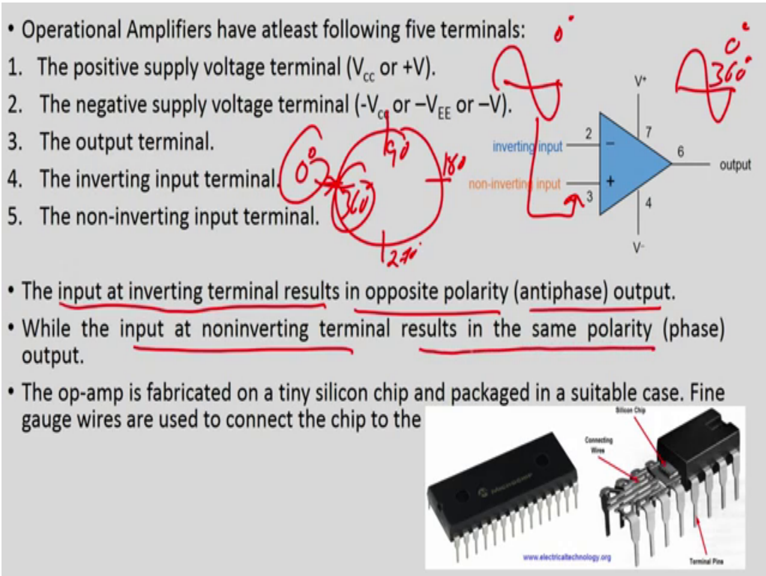

So, you see, let us assume a circle um, and what is if this is the point? I said this is 0, right. What is this? What is this? What is this? And coming back to the same point, right. See if I consider this one this will be 90, right. If I consider this one this will be 180. If I consider this one, 270 if I consider this one, 360 degree; that means, 360 degree and 0 degree is the same thing; that means that, if I have a signal here I see the output here and the signal is applied to terminal number 3, then this is 0-degree phase this is also 0-degree phase or 360-degree phase shift, it means same thing, right. You says is 0 degree or 360 degree it is the same thing so, there is no phase shift.

So, we can also say in the output results in the same polarity right. So, this way this very easy to understand. So, let us move to the second point which is the op-amp fabrication. We have also seen in detail how the MOSFET is fabricated, isn't it? And what are the process flow, the op-amp is fabricated on tiny silicon chip, right. We have seen this and it is packaged. So, this is the silicon chip, right we all remember this, and then fine gauge wires are used to connect this chip to the this final terminal pins. these are connecting wires that are connected heat to the silicon chip, which is connected to the terminal pins. And finally, this whole device is packaged, this is a packaged device right. So, it is a packaged in a suitable case.

Now, why we are kind of repeating this thing? Because that I am sure that you know you are refreshing your lecture notes, but if you do not remember, or you have forgot something, it is easy to see in this particular lecture what things we have already studied.

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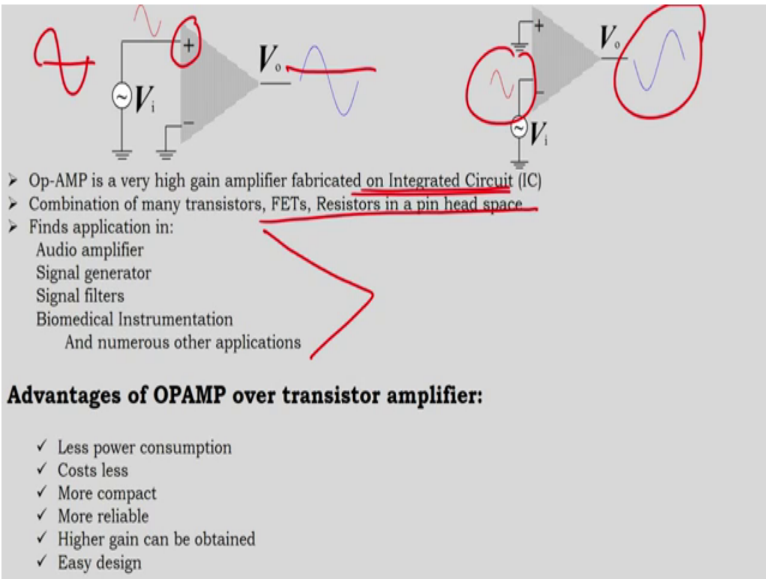

Ah so, let us go to the next slide, now this is the same thing that we were discussing, that if I apply a voltage at the input, right. And the output will be 180-degree phase shift, which is my if it is a non-inverting terminal, this is non-inverting terminal, right. Signal is applied to the non-inverting terminal. Then my signal is like this output is also similar which you see here which is without any phase shift. But if I apply my input signal to the inverting terminal, my output would be 180-degree phase shift. So, this we already discussed in last slide.

Op amp is a very high gain amplifier fabricated on integrated circuit, right. That we know combination of many transistors FET resistors in a pin side pin head size space. Now we also know that recently when we talk about op amps, it has billions of transistors, but all are MOSFETs, right. Very few or almost none uses the bjt technology anymore, most of the op amps you will see the circuit within it would be of a MOSFET. MOSFET is nothing but metal oxide semiconductor field effect transistors. So, that is why we are saying as many transistors including FET's resistors.

It finds application again if you remember what are the application, audio amplifier signal generator signal filters, right. It is also used in biomedical instrumentation and numerous other application now what are the advantages of op amp we already know, right. The advantages of op amps are it is low cost, right less power consumption, more compact, more reliable, high gain and easy design. So, this we know, how it is related to our today’s experiment.

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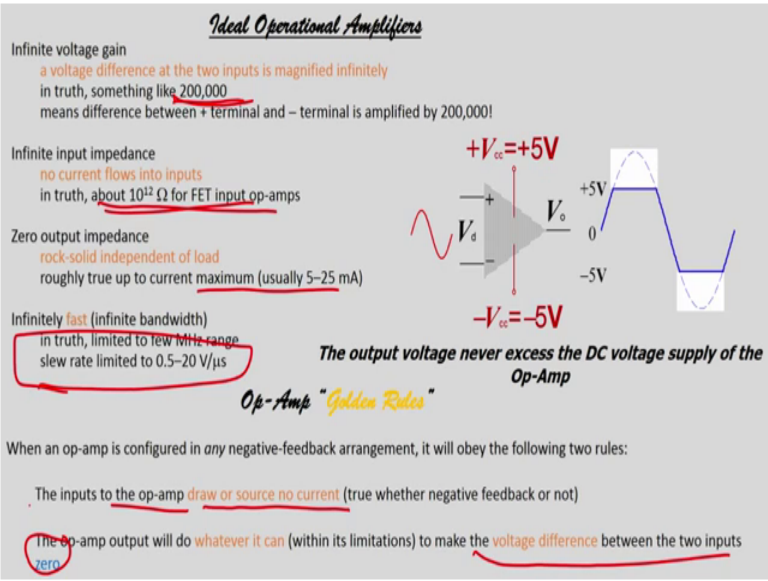

Today’s experiment is on understanding the characteristics of op amp. So, what are the characteristics? A few of the characteristics of an ideal operational amplifier. When we say ideal; that means, that everything that we think, right is there for example, if you take ideal person. Ideal person would not have any kind of negative things, right is a godly. So, same thing when you talk about ideal op amp, it would have infinite voltage gain, it would have infinite input impedance, it would have 0 in output impedance, it will have infinite fast.

But we rarely find a person who has who is ideal, right. Same way we cannot also find operation amplifier or IC which is ideal. So, we cannot have the characteristics that we really want in an operational amplifier. But we will have a practical operation, amplifier with some characteristics which are not really ideal, but close to ideal ok.

So, what are those characteristics like I said if you take a ideal operational amplifier, then you have infinite of voltage gain we will see, but practical operation amplifier it would be somewhere around this value, in input impedance is infinite. So, we will we understand what is input impedance, right. And we will see the input impedance of an practical op amp is around 10 to the power 12 ohms 0 output impedance. But in true the output impedance is not 0, it is low. then we have infinitely fast; that means, that it is superfast, but it is not possible, we will see slew rate in this particular experiment, and we will understand and measure the slew rate. And we will see it is somewhere falling between 0.5 and 20 micro, 20 volts per microsecond.

So, these are the ideal characteristics of an ideal operational amplifier. But we are not going to use an ideal operational amplifier, because we do not have ideal operational amplifier. So, what we have? We have a practical op amp, we have IC that I have already shown it to you in the lecture notes.

Now, we have also seen 2 golden rules, isn't it? So, first is the input to the op amp draw or source no current; that means, that the input terminals will draw or source, no current there will be no current drawn from the input terminals, that is first rule. second is, the op amp will do whatever it can to make the voltage difference between the input 0. This is also we have studied in detail, right in lecture notes that, these are the 2 golden rules that we have to remember. that one is the inputs draw or source no current, and second the voltage difference between 2 input is 0. So, I am sure all of us remember this thing, right.

Ah if you do not remember do not worry that is why I am kind of repeating the things that you have already been studying in the theory class.

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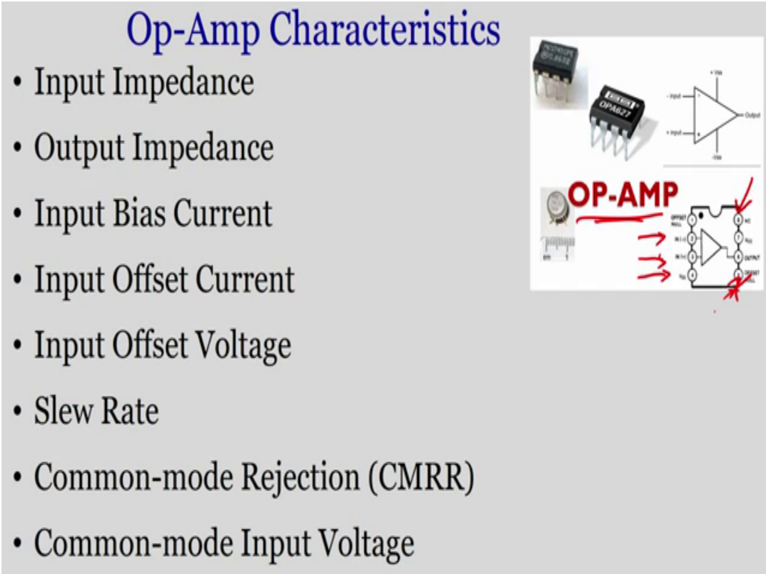

Let us see the op amp characteristics. So, these are the characteristics of an operational amplifier, this is an op-amp like we see here, right. We have seen the IC from one which is offset null, right 2 inverting 3 non-inverting Vee, right 8 is not connected.

Now, the question to you guys is what is a role of pin number 8, right. If it is nc that is not connected right, but what is the role why it is there if it is it useful, or what is the purpose? So, that is the kind of question for you. So, find it out what is the role of pin number 8, alright. Then we have pin number 7 4 plus Vcc 6 for output 5 for offset null, this everything we have seen in the theory class, right what is the role of each pin.

So, today we will check several things in the in the experiment starting with the input impedance, output impedance, input bias current, input offset current, input offset voltage, slew rate, common mode rejection ratio, common mode input voltage so, several things are there right.

Ah so, if you see the first one that we will be discussing is the input impedance. Input impedance would be extremely high in case of ideal operational amplifier. or in case of or you can say it is it is input impedance is infinitely high. But if you if you take operational amplifier which is a practical op amp, right. Which is, right. In my hand here, that we have seen yesterday or I can keep it here. So, it can be focused easily, right this one.

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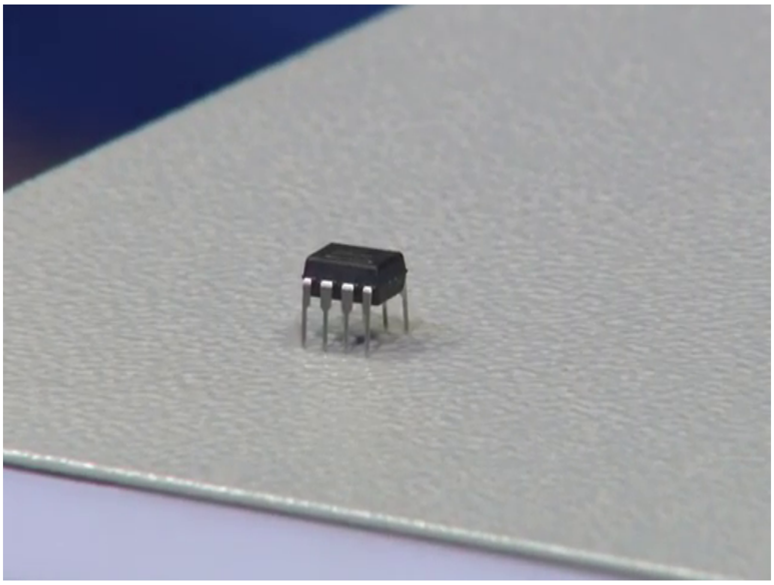

Then we will see it as a extremely high input impedance. Same way the output impedance for ideal op amp would be 0, but if you see in the practical operation amplifier, this operation amplifier, then you will see that the output op amp is not 0, but close to 0, alright. Then we will see infinite gain, we will in this particular operation amplifier the gain will not be infinite that we will see today.

So, let us see one by one, alright. Let us see one by one, the first one that is your input impedance.

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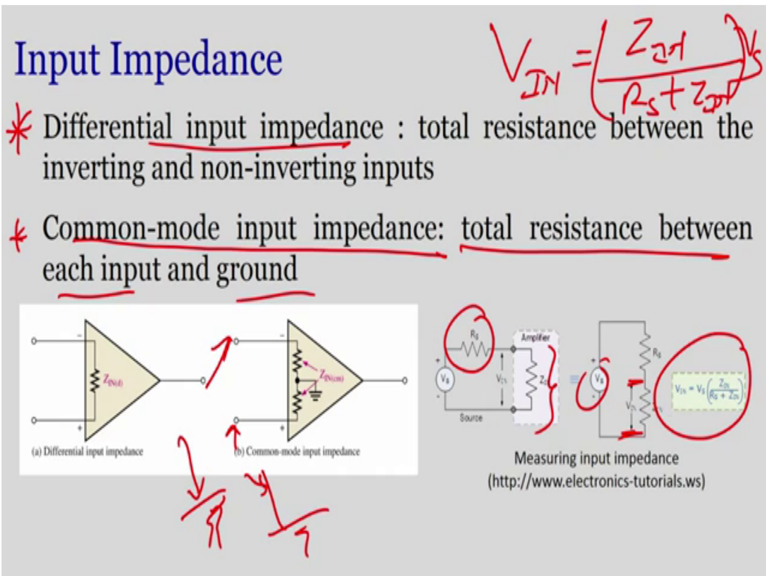

So, what is input impedance and what kind of input impedance are there, first one is your differential input impedance. What is differential input impedance? Differential input impedance is total resistance between inverting and non-inverting terminal; that means, what is the difference; what is the difference between inverting and non-inverting terminal that will be your differential input impedance.

What is the common mode input impedance? Common mode input impedance is nothing but total resistance between each input and ground; that means, the resistance between this and ground or between non-inverting terminal and ground the resistance between it. So, what is the resistance between this and ground? What is the resistance between this terminal and ground, right. This terminal and this terminal or this terminal and ground. So, that will be your common mode input impedance.

One is your differential input impedance, another one is your common mode input impedance alright. So, remember this terms, if you see this circuit we have taken the circuit from electronic tutorials we have if you see here there is a signal V s, right. Then the resistance is because of the source. So, V s is the source or resistance is Rs, this is the input impedance of the amplifier Z in. So, if you draw equivalent circuit we will have r s and Z in series, if you want to measure the voltage V in this terminal which you see here, then what formula you have? You have formula which is V in, V in equals to V in equals to what? This is Z in or Z in upon Rs or divided by Rs plus Z in into what source voltage V s, this is V s right.

So, this is what is the formula for your equivalent circuit which we have written here, alright. Now this is very easy, because this is nothing but a potential divider voltage divider circuit. So, when you want to measure a voltage across Z in, you have Z in Rs plus Z in into vs it is very easy, right.

So now let us see the output impedance, input impedance we have seen now let us see the next slide, next slide let me just remove these things ok. So, we go to the next slide, what is the next slide?.

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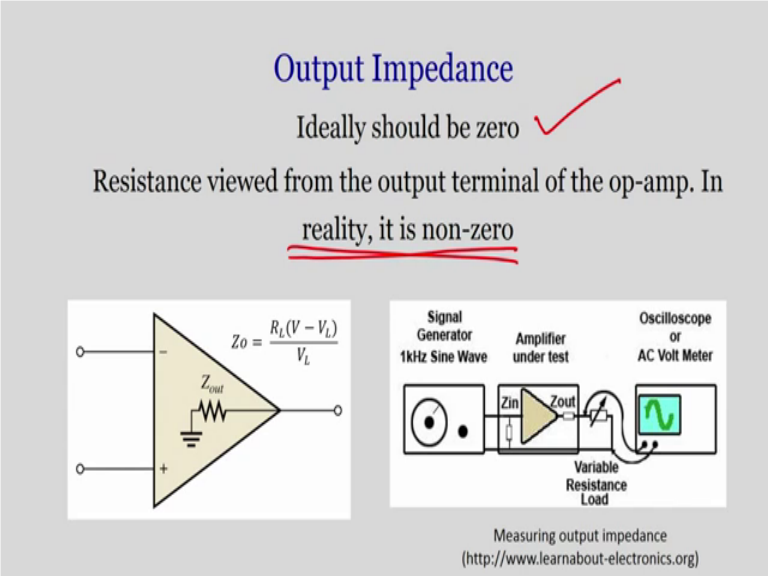

The next slide is a output impedance. So, if you again see output impedance, output impedance ideally it should be 0, right. We have seen ideally it should be 0, resistance viewed from the output terminal to the operation amplifier; that is resistance from the output terminal of the operational amplifier. In reality, it is non-zero is reality is non-zero or extremely small. So, this is an equivalent circuit for measuring the output impedance, you can clearly see there is a signal generator is the amplifier, and there is a oscilloscope or voltmeter.

Same way we will see today, there is a signal generator signal, generator is nothing but a function generator. We have seen in the last modules what is function generator, right. Then we have seen what is oscilloscopes, or we have also seen how we can measure the ac voltage, right. so, depending on the load, if we vary the load we will see the change in the signal at the output of the operational amplifier. So, this is about the output impedance.

Now, let us go to the next one next slide, which is your effect of bias current.

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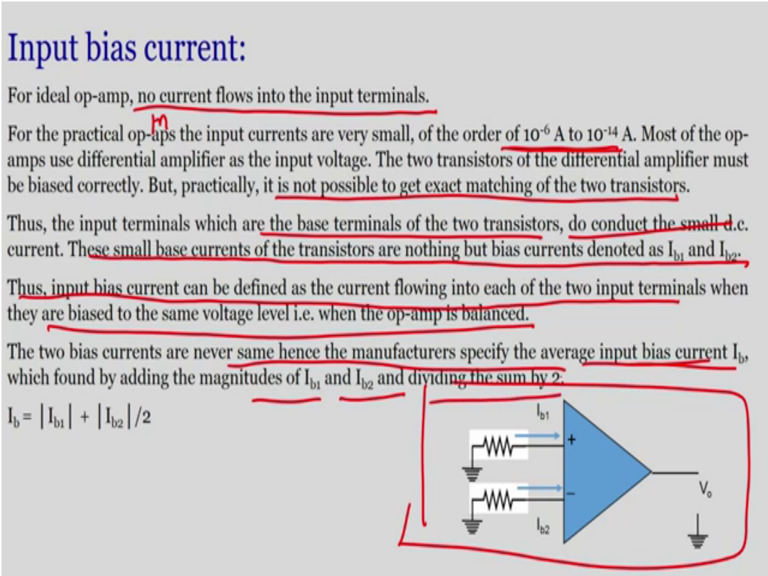

Now we have already seen the effect of bias current, or what is the bias current and how it can be used right. So, again this circuit is taken from all about circuits dot com, this particular circuit that you see here, right.

Ah so, let us consider the effect of bias currents, if you could take a non-inverting amplifier, non-inverting unity gain amplifier. We have seen what is unity gain amplifier in the lecture notes, right. Driven from a source impedance of one mega ohm, if I B is 10 nanoampere, it will introduce an additional 10 millivolts of error. It is very easy to understand this thing, right. This degree of error is not trivial in any system so, this is first point.

Now, bias current is a problem of the operation amplifier because it flows in external impedances and produces voltage which adds to system error, to reduce the system error or the bias current when it flows in the external impedances, right it produces voltage; that means, it will cause a error. So, how we can reduce this error; so, it is very important term in terminology to understand what is the bias current, alright.

Ah so, if the designer forgets simply forgets about I B, if the circuit designer he forgets about the I B, and uses just a capacitive coupling the circuit would not work properly, right. So, we will see in detail what exactly this bias current and what are the input offset current input bias current and so on and so forth in the in the following slides.

Let us see first is input bias current ok. So, you understand this circuit, right. Understand this look at the circuit in detail um. Now let us see what is it. For ideal operational amplifier we know, right there are golden rules the golden rule is that no current flows into the input terminals, no current flows into the input terminals, right. We have we know this for the practical operation amplifiers, right. op amps, a o p a m p s is a mistake here. Op amps the input currents are very small of order of 10 is to minus 6 to 10 is to minus 14 ampere.

A most of the operational amplifier use differential amplifier as the input voltage the 2 transistor of the differential amplifier must be biased correctly, but practically it is not possible to exact match exact matching of 2 transistors. So, what does it say, right? What it say let us see again. The practical op amps have input currents which are extremely small order of minus 6 minus 14 ampere, right.

However most of the op amps uses the differential amplifier. So, if you are using differential amplifier, the 2 transistors in the differential amplifier should be matching. If they do not match, then there will be some change in the output right. So, if the transistors are not matching it does not match then we cannot bias the transistors or differential amplifier correctly. So, for what to do that? So, we cannot do anything regarding the matching of the 2 transistors, but there is another way or another solution to do that is the input terminals which are the base terminal transistors do not current small DC, this small base currents of the transistors nothing but the bias currents I B 1 and I B 2.

What I said? See, the input terminals which are the base terminals of 2 transistor. So, when we see differential amplifier op amp and differential amplifier within the op amp there are transistors. And this transistors conduct, the current a small DC current which are the base currents or through the base terminals of the transistors. And this small base currents are nothing but we call them as a input bias current or we can say I B 1 and I B 2, why I B 1 and B 2? Because the differential amplifier we have a 2 different transistors in the differential amplifier.

Now, thus, how you can define input bias current? Input bias current can be defined as the current flowing into each of the 2 input terminals, each of the 2 input terminals, when they are biased to the same voltage level when the op-amp is balanced; that means, that when you balance your operational amplifier, right. When you balance your amplifier, then you will find that there is a small amount of current flowing into the 2 input terminals. That small amount of current when you have biased your op amp, right. When you balanced your op amp, not bias balance, your op amp, then the small amount of current that you find, right. Flowing into the input terminals is called the input bias current, but sometimes it is difficult to understand until we really perform the experiment.

So, we will see the experiment of how we can calculate the input bias current, alright. the 2 input 2 bias currents are never same, hence the manufacturer specifies the average input bias current, right. Which is which can be found by adding the magnitudes of I B one and I B 2 and dividing by sum of 2.

So, let us quickly see what is what is the input bias current, once again input bias current like we say is due to non-matching of 2 transistors. One, now the 2 bias currents that we get are never same, right. That is why when we get the operational amplifier, the manufacturers already give us the formula of finding the input bias current, how? By adding the magnitudes of I B one I B 2 and dividing the sum by 2, this is the formula that you have to remember, when you take a example of an input bias current, right. It is easy to remember.

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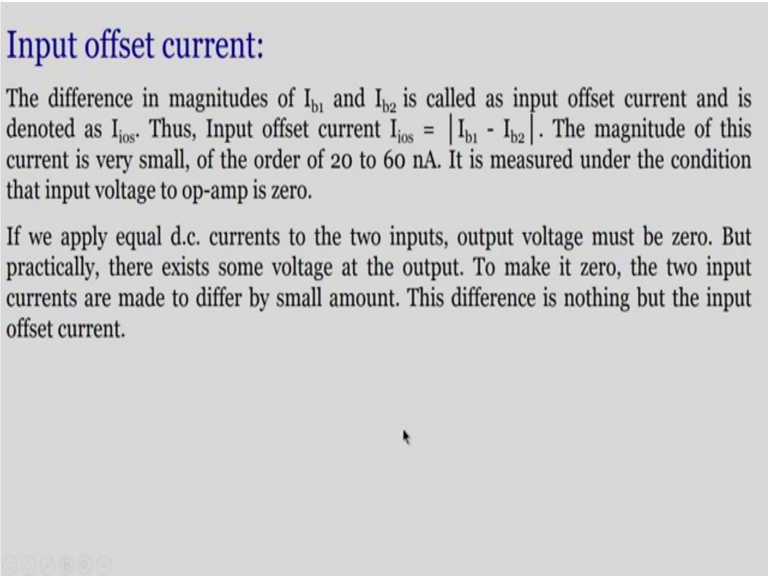

Now, if I say input bias current, then we have input offset current as well. So, before we go to input of sir current, let us see the input bias current in terms of the experiment alright. So, we will start with input bias current we will go to another characteristics in a short while.

But let us first now complete the experiment for input bias current. So, I will request my teaching assistant, you already know him Sitaram who was us with us in the last lectures right. So, can you please come and connect the circuit? So, now we focus how he is connecting the operational amplifier with the things that we have on the table which is our if you remember, what is this is your function generator, this is your DC supply, right. Linear DC regulator supply, and this is your oscilloscope, digital oscilloscope.

So, he will be connecting the breadboard along with the operational amplifier, and a resistors like you have seen in the in the slide. So, if we quickly see the slide these are the resistors, isn't it? 1 and 2 right. So, we are going to we are going to perform the experiment to understand what is the input bias current for the operational amplifier that is 741. So, I am sure that he is using 741, alright.

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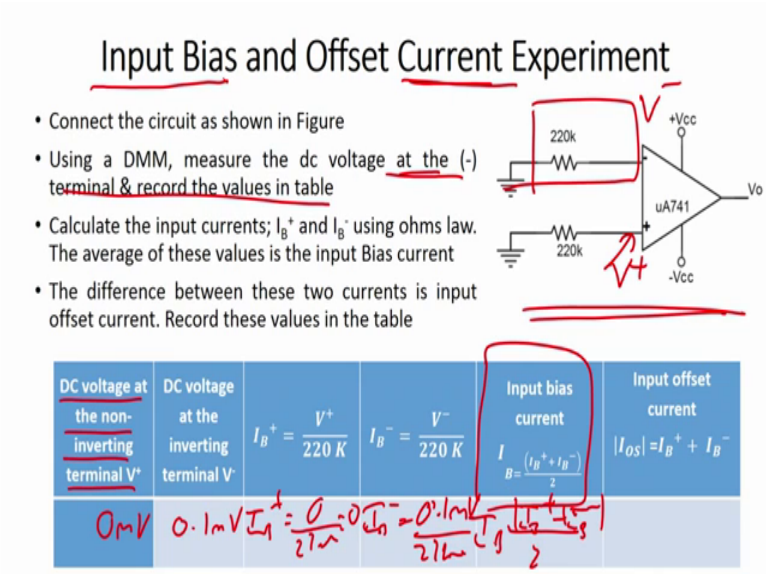

So, let us see how to how to connect this particular circuit and how to measure the characteristics ok, alright. So, let us see this particular slide first, by the time he repairs the circuit and then we go on the circuit. So, the slide shows input bias and offset current.

We will just consider, right now input bias current, then we will see what is input offset current, and then we will come back to the table, alright.

So, here we have to measure input bias current right. So, this is experiment for input bias current. So, what is the table shown here. So, let us see here connect the circuit as shown in figure, this figure is already shown, you have to connect the circuit exactly like a figure. So, if you are somewhere in your university, right. Where you have op-amp and if you have the resistors with DC power supply, then you can perform the experiment quickly, right. You just need multimeter you just need DC power supply and then you can measure this input bias current quickly, right.

You can also do it at home, this is very easy experiment. It does not really require high end technology or you know extraordinary facility. This experiment we can do even at home, alright. So, what is that use a digital multimeter measure the DC voltage at inverting terminal and record the values in the table; that means, that we have to measure the voltage at inverting terminal, and we have to record the value.

How? So, one is at inverting terminal one is a non-inverting terminal. You see, DC voltage if you see the stable, if you see the table DC voltage at the non-inverting terminal V plus. We have to measure the DC voltage at non-inverting terminal, we put the value here, DC voltage inverting terminal measure here, and put the value here. Then we can have I B plus, I B plus is nothing but this V plus divided by 220 k I B minus I B minus is V minus right. So, here will be V plus here will be V minus. So, V minus, right divide by 220 k, there will be your I B plus and I B minus.

We already know the input bias current formula input bias current is I B equals to mode of I B plus I B minus divide by 2 right. So, we will see this experiment, let us see the same circuit he has attached, and I will show it to you how he has attached on the breadboard, and then we come back to the to the screen alright so, let us see the circuit.

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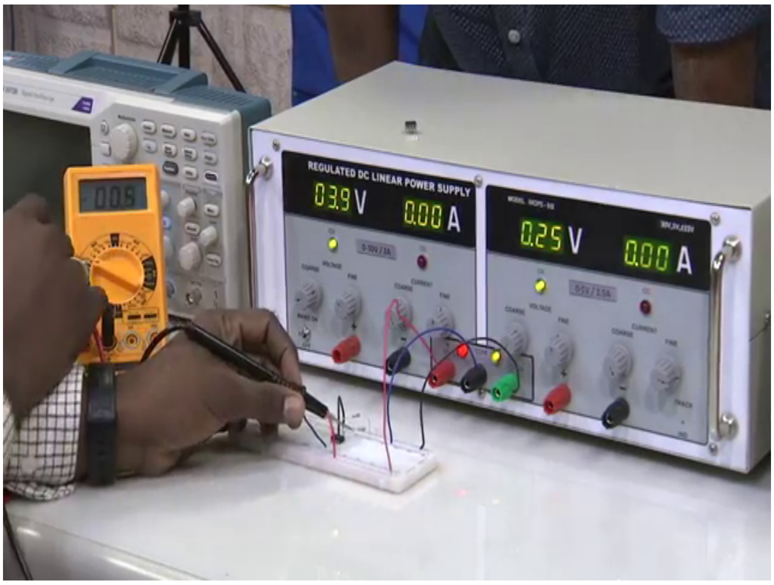

Yeah so, if you see here, right what do you see? You have applied here where are the bias voltage bias voltage is here, you see the red pin and black pin in the center in the center red pin, right in green pin, right. This way green pin these are plus minus 15 voltage, plus minus 15 volts given to the operation amplifier operational affair is, right over here in the center, right is in the center.

Then we have connected 2 resistors, can you see 2 resistors? We have connected 2 resistors, right. yes so, these 2 resistors are the resistors connected to inverting and non-inverting terminal of the operational amplifier, correct? Then we have to now measure the voltage at the inverting terminal, and then we have to measure the voltage at the non-inverting terminal, alright.

So, what is the voltage at inverting terminal let us see, let us see what is the voltage at non-inverting terminal if I have a multimeter yesterday we all know, right. We can use the multimeter and we keep the multimeter at the DC voltage, DC voltage, now let us see what voltage we get at the inverting terminal.

So now you have to understand when you take operational amplifier, when you take an operational amplifier, I will show it to you here. there is a small dot there is a small dot you see. So, guys when you see, close you will see a dot which is here, right here. This is pin number one, it is easy to understand. It is easy to understand which is pin number one, alright and which is pin number 8. So, pin number 1, 2, 3, 4, 5, 6, 7, 8 so, in that particular sense, when we connect the IC to the breadboard, we know what is pin number one what is pin number 2, alright.

So, he has connected now let us focus on the breadboard, he has connected the integrated circuit which is 741, right. With the resistors at the input terminal inverting terminal and non-inverting terminal. Now we are measuring the voltage at inverting terminal, then we will measure the voltage at non-inverting. So, let us first see voltage at non-inverting terminal, voltage at the inverting terminal 0.1, right. 0.1 millivolts, 0.1 millivolts, let us see at non-inverting terminal. 0.1 millivolts 0 it is 0 ok, good alright. So, we have 2 values, right. We have 2 values.

Ah so, let us go back to the screen, let us go back to the screen. Now what we measure at inverting terminal? 0.1 millivolts, and invert non- inverting terminal 0 millivolts, right. From there, we can put this equation I B plus, right. V plus V plus is 0 divided by 220 k, right. Which is equals to 0, then I B minus, I B minus equals to 0.1 millivolts by 220 k, right?

So, we will get another value here, then we put the value of I B plus, I B minus divided by 2, that will be your input bias current, you got it? Again, you concentrate on this table, once again, let us see um, what we have found? We have found the current or the voltage at the in first we have connected this circuit. This circuit was there on the breadboard, where you have seen 220 k resistors connected to the inverting and non-inverting terminal.

Then we have applied plus Vcc, right and minus Vcc or Vee to the pin number 7 and 4, right. Then we have grounded this resistor. Now we have measured the voltage as non-inverting terminal, we have measured the voltage at inverting terminal. So, from here we can write whatever the voltage we measured in this column, at non-inverting terminal whatever voltage we have measured here in the in terminal which is inverting, then we can put this voltage in this particular equation which is your I B plus.

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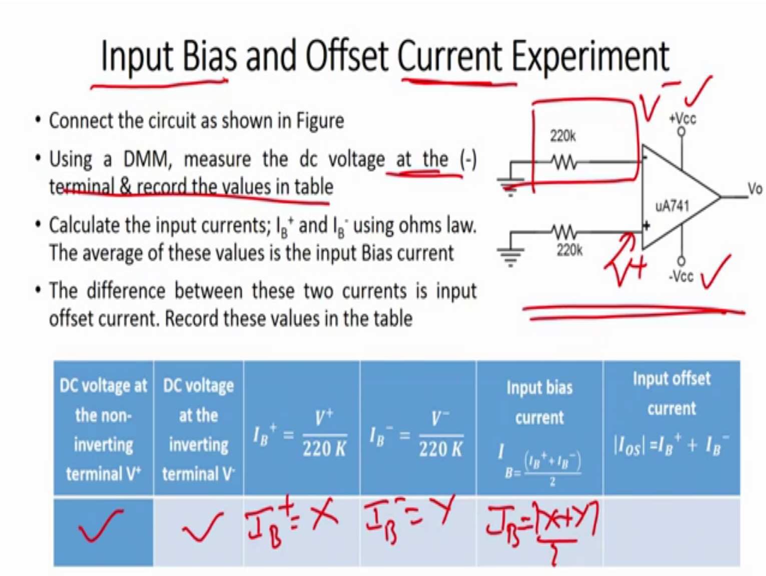

From there you will get your value of I B plus, right. Let us say the value is x, then from this voltage which is inverting terminal you get I B minus which is equals to let us say y. So, what will be your I B? Input bias current is I B equals to x plus y by 2, we can write mod, right. This is how we can measure the input bias current. So, easy extremely easy, isn't it?

So now, in the next module, let us see how you can measure the input offset current, alright? Now let us see input offset current so, we stop here.