Electrical Measurement and Electronic Instruments
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Lecture – 72
Instruments with op-amp based amplifiers – I

Hello. So, in our last class we have learned the most important fact about why we need Electronic Instruments. The fact is that we need high internal resistance for voltmeters and amplification, if we want to measure small voltages or currents. If you recall a couple of weeks back we have we were studying op-amps. And, there we studied a lot of amplifiers right and what does an amplifier do? It takes a voltage small voltage amplifies it.

So, those amplifiers fulfill definitely 1 of the two requirements, which is amplification of small quantity. And, then we can measure it using a normal voltmeter classical electromechanical voltmeter once it is amplified. This amplifier should also satisfy the requirement about the impedance of the measuring instrument. So, let me drop the scheme of measurement in general.

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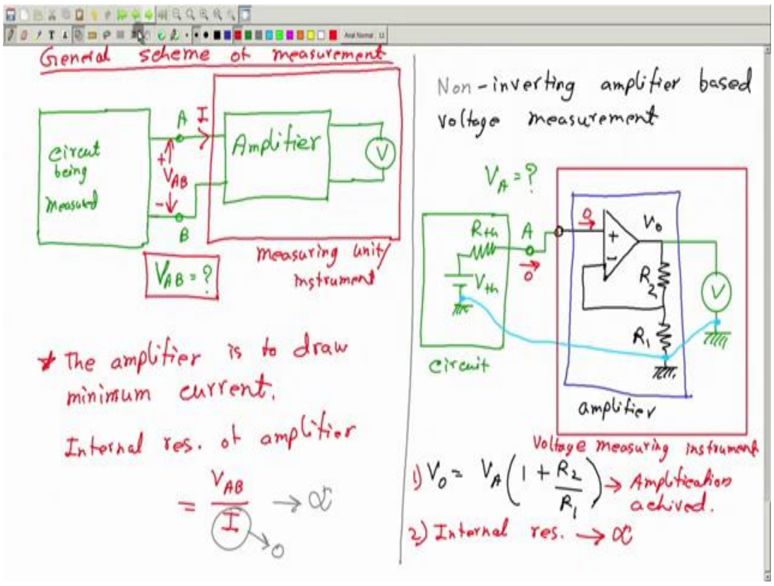

So, see this is a circuit and we have 2 points 2 terminals, where we want to measure a voltage. So, this is a circuit being measured. So, you want to measure this voltage A B V A B. Instead of connecting an ammeter sorry voltmeter directly like this, what we will do is this, we will first take an amplifier. So, we will give this to the amplifier and the output of the amplifier will be connected to a normal voltmeter, this can be a classical electromechanical voltmeter ok.

And, this two together the amplifier and the voltmeter so, this together is my measuring instrument or measuring unit, or instrument ok, which has an amplifier inside and this voltmeter. So, and as I was saying do not ever think electronic instruments mean digital instruments no, this instrument can be an analog PNMS instrument ok. So, this is a general scheme or structure of general scheme of measurement ok, amplify and then measure.

Now, this amplifier should amplify this voltage not only that it should also ensure that less and less amount of current is drawn from this circuit ok. So, the amplifier is to draw minimum current or if possible no current at all ok. So; that means, the internal resistance of amplifier should be how do we define it? We define it by this voltage V A B plus minus call this current I ok, then we define it as V AB/ I as you know and I tends to 0, till study tends to 0 therefore, this quantity tends to infinite. So, we want high internal impedance for the amplifier that is what we need.

Now, let us see whether the amplifiers that we have studied inverting non-inverting difference amplifiers fulfill this requirement or not. So, let us take first and non-inverting amplifier; non inverting amplifier based voltage measurement. How does a non-inverting amplifier loop? So, from the output of the op-amp we take a potential divider and a fraction of this voltage output voltage goes back to the input negative input and here we have the input.

So, this is the amplifier block, this is plus here. So, this is the amplifier and now we have a circuit which we want to probe which we want to measure. So, this is let this be a circuit, which is say equivalent to this, some voltage source Thevenin voltage, Thevenin resistance. So, this is the equivalent circuit. So, this is this voltage call it A. So, we want to measure V A is equal to how much with respect to ground.

So, what we will do, we will simply connect this like this and here we will connect a voltmeter. Normal voltmeter where should be the other terminal of the voltmeter V this should be connected to the ground. When I draw anything like ground in this in such scene similar diagrams, it means it actually means that all these terminals are sorted ok. So, that is what is important. So, all these terminals are actually sorted. If, I do not want to draw this line when I put the common symbol of ground it means they are commonly corrected ok. So, this is the scheme of measurement. Now, we know that if this voltage is R 1 call this R 2 R 1 ok. Then, we know that if this is V A this voltage V o will be how much? V o will be amplified VA (1+ $\frac{R2}{R1}$), which will be measured by this voltmeter this is all we know.

Now, let us take a now important thing important thing is that. So, this is my measuring instrument ok. So, now, this together these two together is my measuring instrument. So, it should fulfill two requirements, number 1 amplification. Do we have amplification, yes there is an amplification so, there is definitely an amplification. So, amplification achieved.

Now, the second requirement is what, high internal impedance for this measuring instrument, this is a voltage measuring instrument right. So, therefore, we need a high internal impedance. Now, how much is the internal impedance of this circuit, ideally, theoretically? Theoretical you know that this current here is 0. So, this current is 0, because no current can go inside the input terminal of an op-amp theoretically. So, this current is therefore, 0. So, this current is definitely also 0 right theoretically practically very small.

Now, if so, how much is the internal impedance of this, this circuit it is this voltage which is VA/0. So, it is very high in finite ok. So, also in internal resistance or impedance is tending to infinite, because this current is tending to 0 2 requirements fulfilled great. Now, now I mean so, we will take a lot of examples so, this what we are discussing now is not a new topic to understand, but this we will take a lot of example to recapitulate and enhance and make our understanding solid ok.

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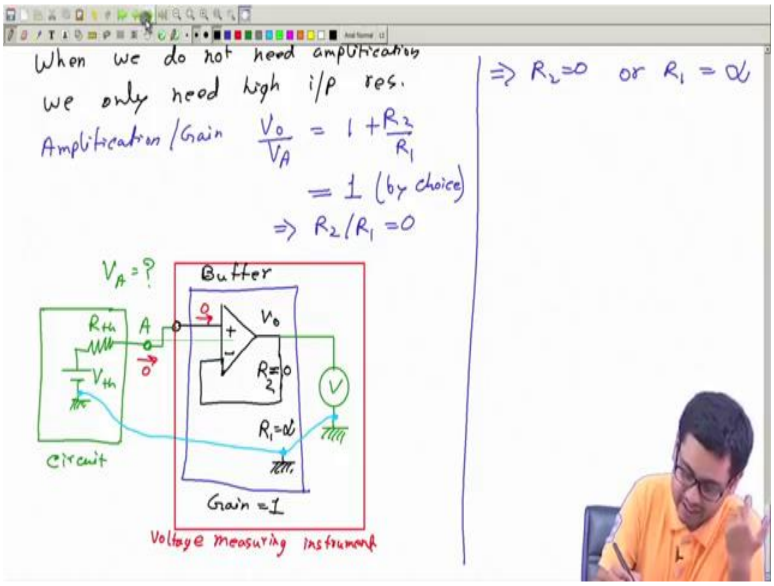

So, let us take case when we do not need say amplification and we only need high input resistance. So, this is a situation, where the voltage to be measured is not small. So, you do not have to amplified, but the circuit that we are probing has high resistance. So, the measuring instruments should also have very high internal resistance. So, this is a situation.

So, what can we do? So, let us take this case. So, we do not need amplification, which will mean, now what was the amplification?

V amplification or gain = $\frac{Vo}{VA}$ = $(1+ \frac{R2}{R1})$

we do not need to amplified. So, how can we do that so; that means, we have to make this term equal to 0 ok. So, implies R 2 / R 1 = 0, this will imply what, either I can take R 2 equal to 0 right or I can take R 1 equal to very large in finite or both I can take both.

So, if so, then what I can do? In this circuit let me make R 2 = 0; R 2 = 0 means I sort it and R 1 is in finite so, this is infinite. In finite means, I simply open it and then this becomes this so, R 1 equal to infinite R 2 = 0 ok. So, then this is an amplifier where the gain is equal to 1. This circuit you probably have seen before this is also called a buffer, this is called a buffer; a buffer means what is a buffer? A buffer is a circuit that copies input voltage from the input to the output without changing.

So, this value is copied here same value we get ok. It copies the input to the output without changing ok. It is not changing because no current is drawn. So, it should give high input in this case in finite input resistance. So, no current is drawn, so, no voltage drop will occur here, but the same voltage will be replicated duplicate it at this point. So, this is an example of buffer. Now, let us take another example. So, let us just keep taking example, this is one example, this is another example, that we take another example amplification.

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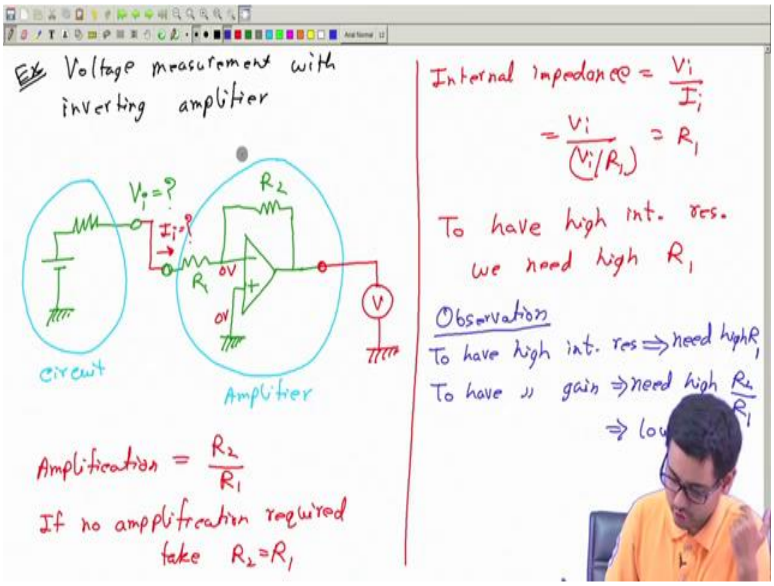

So, our voltage measurement with inverting amplifier ok. So, same thing we have a circuit to probe to measure call this voltage V i, how much is V i ok? Which is same as this voltage when there is nothing connected here? And to measure it we will first use a amplifier this time an inverting amplifier. So, we give negative feedback. So, this is the input of the amplifier, this terminal you know is grounded, ground means all this should be sorted and call this R 2 call this R 1.

So, this is the amplifier block. Now, this is the amplifier to this amplifier we will connect the voltmeter and the input will be connected to this ok. So, this is the circuit amplifier and voltmeter same scheme ok. Now, let us ask how much is the amplification? Do we have any amplification? For this we know it this is equal to R 2 / R 1 we have derived it ok, you can go back and check and if I do not need any amplification I can make R 2 = R 1 ok. So, if no amplification is required, take R 2 = R 1 then the gain will be 1.

So, same voltage will come from here to here. You can in fact, in this circuit even attenuate the voltage you can reduce the voltage if you want by taking R 2 less than R 1 that is also possible. And then internal impedance how much impedance or resistance for this circuit ok. So, for that you have to calculate this current call it I i equal to how much?. I i is equal to how much that is what we have to calculate.

So, this will be equal to V i / I i and this is easy, because we know I mean we know that for this circuit virtual sorting happens. So, therefore, these two remains at same potential. So, this is 0 volt therefore, this is also 0 volt. So, this is 0 this is at V i. So, how much is the current? V i / R 1. So, this is equal to Vi/(V i / R 1) this is equal to R 1 so, this is the resistance.

Now, if you want high internal resistance, what you have to do? You have to take a high value of R 1 ok. To have high internal resistance we need high R 1. Now, there is a; there is a nice observation that we can make here, you see to have high internal resistance, we need high R 1 ok. And to have high gain, if we want a high gain, we need high value of R 2 / R 1 ok.

So, here we need high R 1 here we need high R 2 / R 1, which means low R 1. So, you see this is a complementary requirement right. So, we need a lower 1 if we want high gain and if we want high resistance then we need higher value of R 1. So, this circuit therefore, has a small problem, I mean it is difficult to achieve both the goals, both the requirements together. You may say that I will take both R 1 high as well as I will take R 2 very very high ok.

But, then there will be other problems the I mean bandwidth circuit response etcetera those there will be other and you also know I mean standard a pretty high resistances are not easy to achieve calibrate etcetera, there are other problems ok. So, you cannot do that you take R 1 high and R 2 high high that is not possible ok, that is difficult. So, this has a small problem ok, nice thing to observe. And therefore, later we will see multistage amplification; we will study something like instrumentation amplifier. Let me just also tell you briefly, what we can do?

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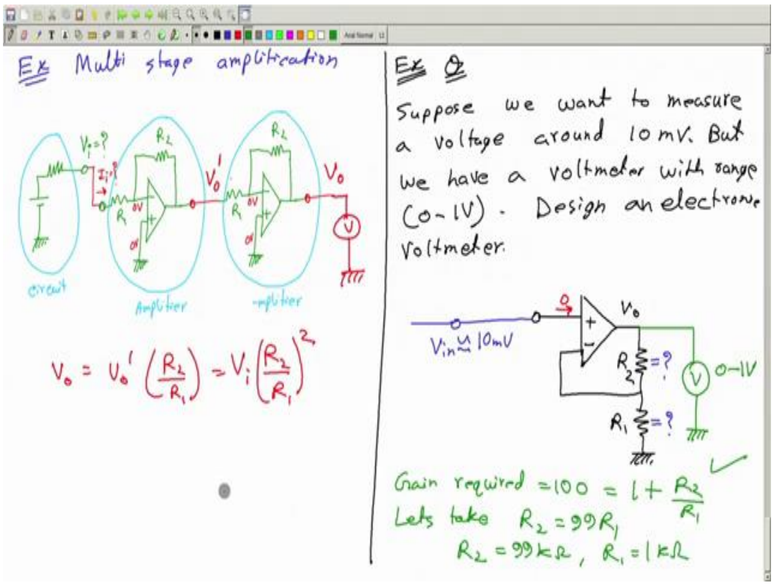

So, example multistage amplification, what we will do is this say ok. So, this is the circuit and what we will do see we will take another amplifier at it is output, this can be you can choose it to be inverting non-inverting whatever you want. So, you can take another of this connect them in cascade. So, this output goes to this input right and then from and then here you can connect the voltmeter.

$$Vo = Vo' \frac{R2}{R1} = Vi \left(\frac{R2}{R1}\right)^2$$

So, with this the gain increases. So, you can increase the gain in this way, you can take R 1 to also to be high, where in that case this gain of 1 amplifier will be low, but you add 2 of them it will be product of 2. So, this way you can go on.

Now, let us take another example or a question. Suppose, we want to measure a voltage around say 10 millivolt, but we have a voltmeter with range 0 to 1 volt. Design a circuit that can do this designer an electronic voltmeter. So, how will you do? So, this is a question which you may get in a exam in practice in real life ok. That this is a voltage we want to measure, but the voltmeter is of this range, you know if I want to measured 10 millivolt with this voltmeter I mean so, this voltmeter has 0 here, 1 volt here. So, 10 millivolt is somewhere here, I if I want to measure this.

So, this is 10 millivolt, if I want to measure the a small voltage, if then the pointer will be somewhere here. And if I make a small mistake or if the pointer is slightly away from it is position due to friction or something ok, then there will be a huge relative error. Because, I mean a small error I mean a small change error out of a small deflection will give you large relative or percentage error.

So, therefore, I cannot measure this voltage directly I have to amplify it. So, what I will do I will simply do this ah. So, I know this is V in which is around 10 millivolt and I have to amplify it to close to 1 volt so; that means, 100 times amplification. So, I need an amplifier which can amplify it 100 times. And, now you choose which type of amplifier you will take inverting, non-inverting. So, if I choose inverting 1 then I also have to deal with how much resistance internal registers I want, let us make it simple. So, I will just take this. So, this I will connect to this.

So, what you are supposed to do if this question is given to you, you have to design this circuit and design means you have to find out the values of all circuit parameters like R 2 should be how much, R 1 should be how much, and here you have to connect the voltmeter whose range is 0 to 1 volt ok. So, how much R 2 will you take, how much R 1 will you take? So, we know we need a 100 time amplification gain required is 100, but gain is given by1+ $\frac{R2}{R1}$. So, we will take. So, let us take R 2 = 99 R 1 and let us let us take R 2 = 99 kilo ohm R 1 equals 1 kilo ohm.

Now, you could have also taken this as 1 ohm and 99 ohm, because it only tells you about the ratio of this 2 does not tell you what should be the exact value of R 1 and R 2 those considerations I mean I can give you more information. So, that you can choose these values, but right now I am not going into that much detail. This is just one example, which will work based on these requirements specified in the question done ok.

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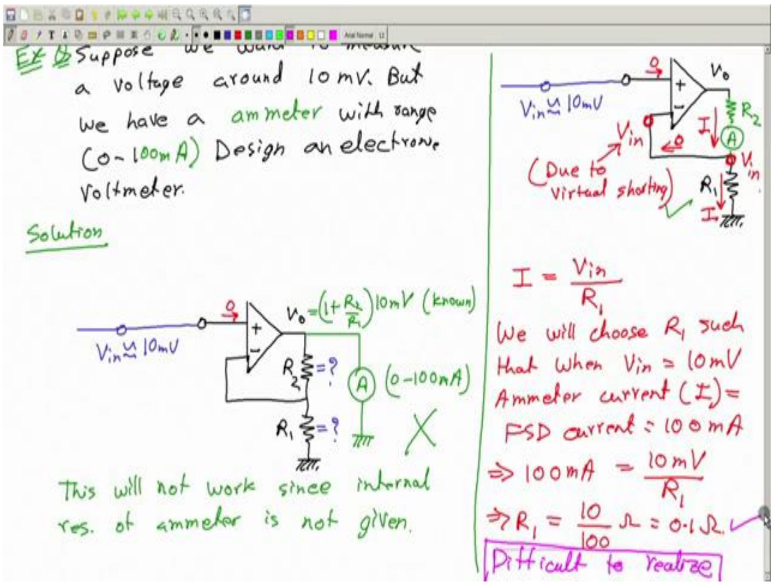

Let us take another example or the question ok. Let me just copy this. Suppose we want to measure a voltage around 10 millivolt, but we have a ammeter with range 0 to 10 to say 100 milliampere design an electronic voltmeter with using this ammeter. So, this time you have to make a voltmeter electronic voltmeter using an ammeter ok. So, if we follow the previous scheme copy so, let us see the solution.

So, this is the voltage we want to measure, this is the amplifier that we have, but this time we do not have a voltmeter we have an ammeter ok. Now, can we just connect an ammeter here? If we connect an ammeter here, then this voltage is 10 millivolt. We can choose proper value of R 1 and R 2, then we can tell this will be how much, this will be 1+ $\frac{R2}{R1}$ times 10 millivolt this can this is known. So, this is unknown quantity ok. This is known because I can choose the value of R 2 and R 1. So, this is a known quantity ok.

So, I know this voltage and the space fake for the ammeter is 0 to 100 milliampere ok. So, if this voltage is known can I tell how much current will flow through this? I cannot unless I know the internal resistance of the ammeter or in an opposite way, if I know how much current is flowing through this by observing the pointer position here. Can, I tell how much is the voltage here or how much is the voltage here, unless I know the internal resistance I cannot tell no ok.

So, this will not work. So, this will not work. Since, internal resistance is not given, internal resistance of ammeter is not given. So, based on the available data I cannot use this circuit.

So, this circuit will not work. Now, let us do a small trick let us play as play with a small trick, what I will do is this? So, this is the circuit, this is the amplifier ok. And what I will do, I will connect the ammeter over here ok.

So, I will connect the ammeter over here. And then I can say for what input how much current will go through it ok, or if I know this current I can tell you how much is this voltage right. So, this circuit will work. Let us see how let us just solve this problem then I think it will be clear. So, this circuit will work ok.

So, you see that this point is that V in right. This point is at V in since this is an basically this is an non inverting amplifier circuit ok. These 2 together you can think just one resistance. So, this is a non-inverting amplifier and in a non-inverting amplifier virtual sorting works, we know that for a non-inverting amplifier virtual sorting works.

So, for using virtual sort the notion of virtual sorting I can say the potential over here will also be V in by virtue of virtual sorting ok, we know that I am not going to repeat that now. So, by virtue of virtual sorting this point will be at this potential so; that means this will also be at V in ok. Now, if this is V in how much current will flow here call this I this current that we call this current here I. So, this current is I. So, how much what can we say about I? I must be then V in / R 1 right.

Now, we will choose R 1 such that when V in is around 10 millivolt I should get full scale deflection and, in this ammeter, ok. So, that is what we want we want as large deflection as possible when the input voltage is applied ok. So, we will choose R 1 such that when V in is 10 millivolt ammeters current ok. Now, the ammeter current is same as I right, this current which is I is also flow here I, because no current can go through this. This current is no is 0, no current can flow through this, through the op amps input terminal. So, same current I flow here as well as here ok.

So, we will choose VR1 such that when V is 10 milli ampere ammeter current, which is given by I is equal to it is full scale deflection FSD current which is how much 100 milli ampere ok. So, therefore, we can write this is equal to 100 milli ampere, this is how much, this is 10 millivolts. And, then I choose R the value of R 1.

And, the value of R1 will be 10 /100; that means this is ohm this is 0.1 ohm ok. This is not a practical number; I mean 0.1 ohm is difficult to achieve I think my calculation is correct

V is 10 milli and I is 100 milli ampere ok. So, this is something difficult to realize, I mean this is difficult to realize an electronic voltmeter with this ammeter, which can measure only 10 millivolt this is difficult to realize.

I just will comment this fact difficult to realize, this is a very small resistance difficult to have a standard 0.1-ohm resistance. This happened to be so, because I just have taken arbitrary numbers out of my mind. So, that is why it has happened ok, calculus unwise this is correct fine, but after this calculation idealized this is difficult to achieve ok, I have to think something else ok.

So, I will conclude this video this class here at this point. And, so, this part or this chapter in our course we will go like this. We will take more and more examples later we will take AC circuits, when we want to measure AC voltage, AC current, we will measure current we will measure resistance etcetera. And we will do it by taking example, numerical example. So, we will make a we will take a lot of practices and that will hopefully make our footing on this on this subject very firm.

Thank you.