

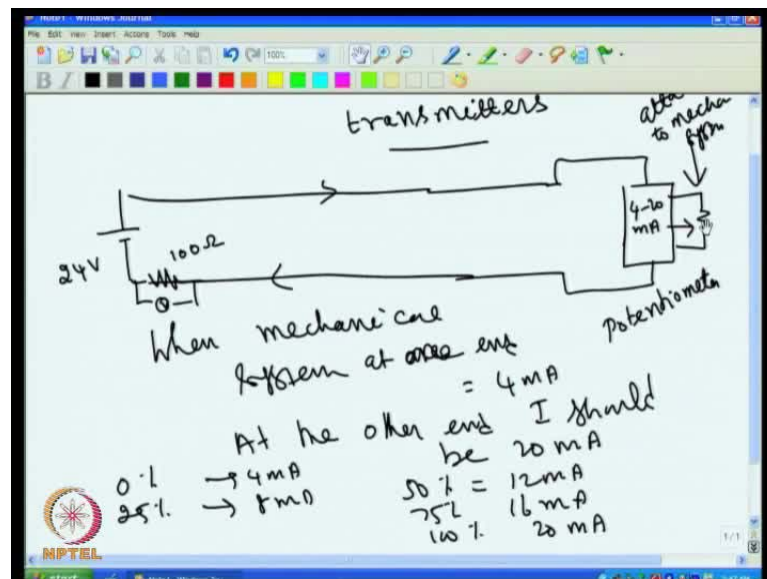
Circuits for Analog System Design
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Lecture No. # 23

4-20 mA Current Transmitter Design

Today, we will discuss 4-20 milliamper current transmitter which is used extensively in analog domain, and then we see how to design the 4-20 milliamper current transmitters for various transducers, and then we also discuss how to do error budgeting for the current transmitters.

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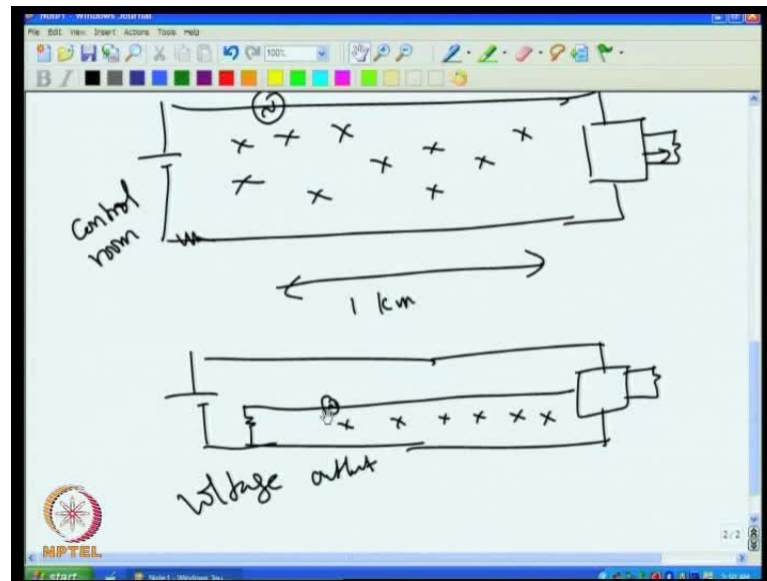
So, this is basically called 4 to 20 milliamper current transmitters; over all, it looks like this; that, normally what is done is, you have a supply like 24 volt supply, normally used in the industry; then, there in two long wires like this; typically, this is in the control room and this is at the site; you have this 4 to 20 milliamper current transmitters. Then, this is **having a** connected to a transducer, say for example, in this case, potentiometer is the transducer; so, what is actually done is, this potentiometer, this is attached to mechanical system, resistances are doubled and mechanical system moves the potentiometer centre point. **actually moves**.

Now, what is required is the mechanical system position to be transmitted as the current, for example, when mechanical system is at one end, then current will be 4 milliampere; and at other end, **at the other end** of the mechanical system, current should be 20 milliampere. So, in the middle, represents the potentiometer's middle; that is, if the mechanical system is in the middle, then the current will be 12 milliampere. So, **obviously, what** it basically varies linearly; if you look at like this, that is, at 0 percent, the mechanicals are 0 percent, current will be 4 milliampere; at 25 percent, of the movement of mechanical system, it will be 8 milliampere; at 50 percent, it will be 12 milliampere; at 75 percent, it will be 16 milliampere; 100 percent, it will be 20 milliampere and that is how normally, it transmits.

Now, if you look at this, this is getting power only from these two wires, because this does not have any power supply by itself. So, whatever power that is required for the operation of the electronics, that is there inside, that is actually divided from this wire only; and then the signal, you know, the signal is here, position of this potentiometer; then the position varies, the resistance value, the voltage across these two points, for example, varies normally at this, is connected to a fixed voltage; so, voltage across this varies. According to the **voltage**, current in this, it will be varying like this, you know, at 0 percent will be 4 milliampere and so on, it is adjusted like that.

Now, this is a **very** classical system and it is used extensively even today. Now, this is called advantage; this is called two wire system because the only two wires are used to carry the power and the same two wires are used to carry the signal; know, actually, what they do is, in actual use, to know the signal position, they connect one resistance here and then measure the voltage across this measure. Voltage across this, gives you the position information **if the**, for example, if it is 100 ohm resistance, they normally connect up to 600 ohms; the 100 ohm resistance, and if I get, if there is a 4 milliampere current through this, for example, 4 milliampere current through this, then you will get 0.4 volt, indicating this at 0 percent; if it is 12 milliampere through this, then it will be 1.2 volt indicating, you know, this will be 1.2 volt, indicating that the mechanical system is at 50 percent - the halfway through.

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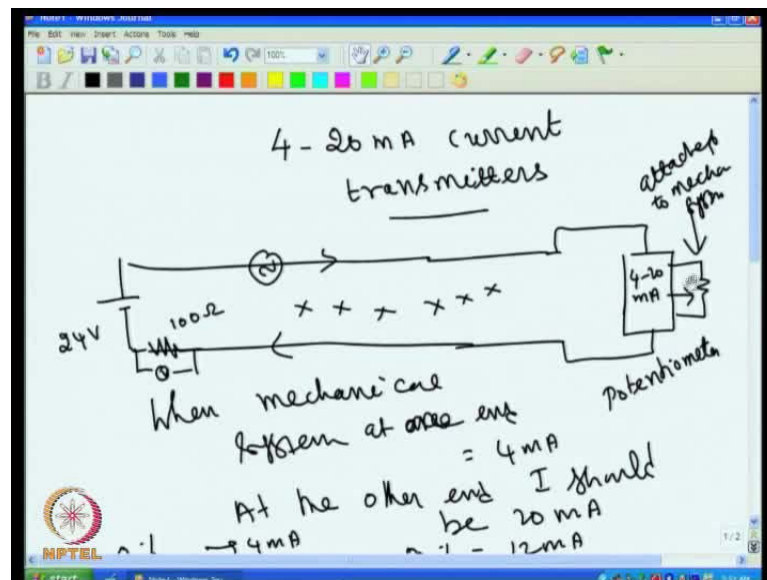


Like that normally, it is done. Now, why this system is very popular and then why it is still used, what is the basic reason for this? Actually, this system is used early, because this is not known for noise, for example, if I take the system, because normally, this will be in the control room, in process control industry, this will be in a control room; and this is actually, this mechanical system will be in the field, maybe the distance between these two can be up to 1 kilometer. Now, what happens is, you see **the** this wire is actually route at per kilometer long, there are two problems are associated with that; normally, of course, they put a resistance here and to know the current that is flowing through that, which acting as a signal. Now, if you see this loop, as an enormous amount of loop area, if you take, you know - this loop area.

Now, we know that you know, there is a change in magnetic field in this loop; there will be induced voltage in this loop, noise induced voltage, so, the change in magnetic field in this loop will induce the voltage like this; that actually should not influence this signal, that is the aim, for example, instead of having a current signal like this, if it have been a voltage output like,, for example - if I send the voltage output, then what happens? You have this, then I have a system like this, potentiometer is connected to this, then I send the voltage output to the back, and I put our resistance here, and measure; this is the voltage output; if it is the voltage output like this, problem is that, you see there is enormous amount of loop here in this area.

So, this will be sending some voltage, and that is supposed to get here, you know, suppose, if this **sends** 1 volt and you expect it to get 1 volt, leave alone the loss that is taking place in the wire and so on, but the voltage induced in this loop due to change in magnetic field externally, **the** there is a magnetic field and that there is a change in magnetic field, then you will have induced voltage in this. This induced voltage will appear along with this; so if this is sending 1 volt here; this is sending 1 volt but where else you will get 1 volt plus the noise is what? That we expect to get; and that sometimes, this noise will much **much** higher than this signal; if we are considering 1 kilo meter long wire, where in, you know, other wires are carrying current, and they all will be producing magnetic field and you will have enormous noise voltage induced.

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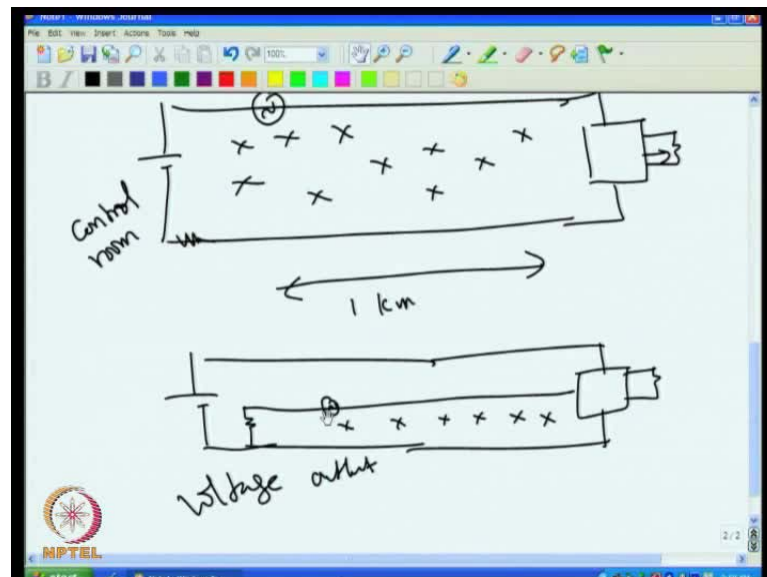


So, if we use a voltage transmitter system, then this is **prone** for noise; whereas, if you go back to our system, that is, a current transmitter; you go back, our current transmitter, that is, in this case, what happens? If there is a noise voltage induced in this, that will induce the voltage in this; but this voltage, **this voltage**, will have no influence on the current of this; because this current transmitter, see, make sure that only the current that is required, 4 milliamperes means 4 milliamperes load will be flowing; **and**, this current, depends only on this, position of this, and not depends on what is voltage across what it is received, because voltage across this can change either, because of this change, or because of the resistance change, or because of the induced voltage change - all these

things, for all these things, this current transmitter not going to respond. If you make sure the current is always constant and that depends only upon the potentiometer value.

So, if I use 4-20 milliampere current transmitter, or for that matter, any current transmitter that is not noise prone, is one of the biggest advantage other than **other advantages** that you get because, it has only two wires and so on. But more than that, the pickup issue is greatly reduced because of this current transmitter and that is why these 4-20 milliampere current transmitters are used, even today, in the industry. And, there is no alternate for this, **really**, from the noise point of view.

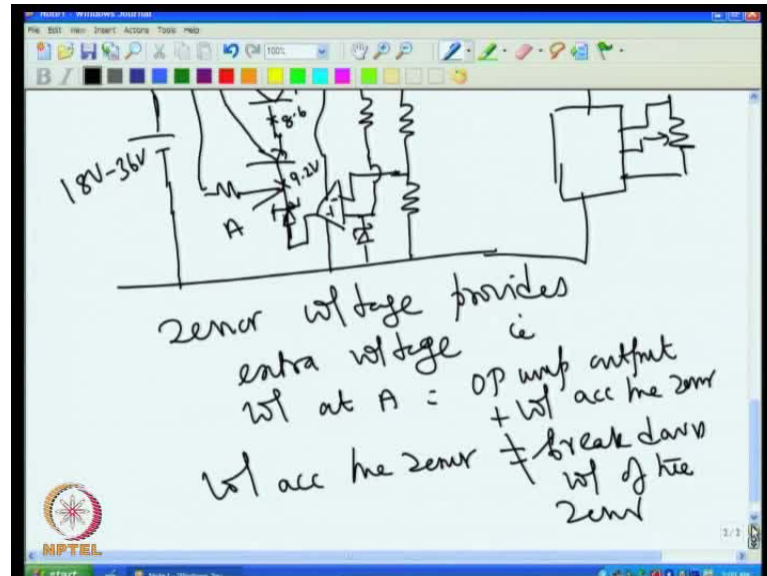
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So, this is the back ground of this 4-20 milliampere of current transmitter. Let us see how to design the system because as a **said**, you know, this current transmitter what we are designing here, you know, should send a current through this; that is, the same current comes and same current goes here; and that current should be independent of **what is** whatever the voltage across this, that is, within the limit; and then, it also should be dependent of the noise induced voltage and that should vary with this; and then, for this unit, minimum current is 4 milliampere, we said it is a 4-20 milliampere system. So, when the system is in the lowest, the current in this will be 4 milliampere so, obviously, this should not consume more current; this should not consume more than 4 milliampere current; and even, whatever current it consumes, that should be constant, again its

temperatures and other parameter variation, so that, the current does not change for other variations, only this variation should change the current in this.

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So, we will make sure that - you know - we design a system, such that, this takes only less current and the voltage across this changes will not have any effect on the current that is flowing. So, considering that, let us see how to design the system. Normally, if you see, the expected variation, this supply variation, we set normally 24 volt, but very often, it varies from 18 to 36 volt in the industry. So, this variation also should be taken care, plus the noise pickup also should not create in any problem so, if I make a system, then what we have to do is, we make a voltage regulator first and then voltage regulator should our regulator voltage should be used to make a current source so that, current in the loop varies depending upon the position of the potentiometer; because, in this example, we have taken potentiometer as the transducer here, for the position.

So, I take this, then how will I make a voltage regulator? For example, if I take our classical voltage regulator, one possibility is - I can have this. So, I can have a regulator, so I put one darlington here, then I put one darlington so that, and this base current is very small; then, if may output voltage regulator is this; then I have to divide the regulator voltage, output voltage, then I feed this to a error amplifier; so, error amplifier is connected here; then this is supposed to be connected to a reference voltage, I will connect a reference; so, it is the simple voltage regulator, but there is a small change.

What I do is, then, there are various ways of obtaining this; I put one Zener here, connect this, then I connect one resistance here, this I connect to this.

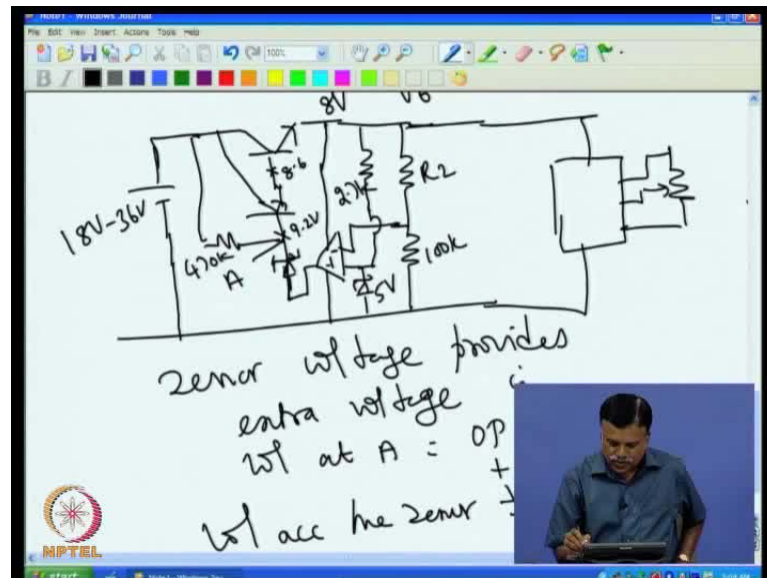
Now, this is the voltage regulator, that was some supply for this, I connect this to ground and the supply plus input, I connect to the output, **connect to the output**. This is the typical voltage regulator used in the 4 to 20 milliampere current transmitter, this voltage regulates the output, that is, **the** this is the output of this.

This will be fit to a current transmitter; I will show you this, what to do is, in actual case, we will put a current transmitter here, and that will be followed by this regulator voltage; then, we will have our potentiometer connected here. When the position varies, the current drawn by this varies; and so, it is the current that is coming from here; so, the total current that is going will be current consumed by this, and the current consumed by this plus current driven due to this; so, we have first voltage regulator part, then we have the current transmitter part. So, first let us concentrate on the voltage regulator part, then we will come to this current transmitter part.

Now, if you take the voltage regulator part, this is the reference voltage, and output is actually divided by the voltage divider, and the fraction of the output voltage is given to the minus supply.

Now, for example, **if I** the one important difference is, the supply for this op-amp is coming from the output. So, the supply is coming from the output, now, **if I** for example, **we want 8 volt output voltage**, output of regulator voltage of 8 volt, we want 8 volt here, I know that I have to get 8.6 at this point, because the base entry is 0.6; then this has to be 9.2 volt; if the base should be 9.2, for example, in normal case, we do not use this Zener so, we do not remove this Zener. So, then in normal case, we do not put the Zener so, if I do not put the Zener, for example, then **directly** connect; then, if I want 9.2 here and if this is, you know, if the supply voltage for the op-amp is only 8, then there is no way you can get 9.2 here, because the output will be less than the supply only.

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So, obviously, to get 8 volt, we need 9.2 here, and that is not for that, means, this area, it will not work. To solve that problem only, here, put this Zener diode here; now, the Zener diode is kept here; now, **the and then** we have a small resistance, is very high value resistance, that resistance will be very high value, that is connected between this and this. So, what happens is, **initially**, even if there is a current, **if the** flow is like this, then there will be small voltage drop across this; so, essentially, this will not go to 0; and then, if there is small current through this, voltage at this point will be output voltage plus whatever voltage drop across there in the Zener; it may not be full break down voltage of the Zener, but nevertheless, some voltage drop is there.

So, voltage at this point is output voltage plus the voltage across this Zener, that means, we can get voltage at this point, higher than the op-amp output, by adding this Zener; that is the trick that we have done in this case, to get, you know, regulated 8 volt output, 8 volt. And then, regulator voltage also, it **would** supply voltage with op-amp also, we could operate at 8 volt; that extra boost that is required, is coming from this Zener; this is a very important thing. So, essentially, the Zener voltage provides extra voltage, that is, say, **we have called this is as A**. So, voltage at A is equal to op-amp output plus voltage across the Zener; but voltage across the Zener will not be break down voltage. Zener is not equal to break down of the Zener break down voltage **break down**.

Some voltage requires that, solve to make the system to start; so, that is why we have done it, we have added this Zener; but when you ask why did you take this op-amps supply, for example, you may ask - why did you take op-amps supply from here? You will op-amps supply, you may say - you connect it to the input. For example, you may connect the op-amps supply to the input, instead of here, we can also connect like this; you can connect like this; now, if I do like this, then obviously, what happens? You... that is, I will connect the op-amps supply here; then, the supply of the op-amps is much higher than what is required here, because this will be around 18 volt or so, and on getting 8 volt, it is not a problem, and then you can remove this, directly connect, and even this is not required; so, it will work in the normal way.

But then, if you do this, then the supply voltage changes here and the we see it, you know, then the supply voltage changes here; then the current consumed by the whole circuit should not change; the current flowing in this line should only vary because of this. So, that is why we are not connecting the supply for the op-amp here; so, we connect the regulator output, because the regulator voltage is always constant irrespective of what is there at the input, so, the current consumed by op-amps also will be constant; that is why we are connecting this, this we are connecting it there, we connecting it here.

But once you connect this, we need the extra boost, that is given by the Zener; that is why, this configuration is used for this voltage regulator. Because of this, the current consumed by this, this is constant; because, you know, the voltage at this point is constant so, current consumed by this is constant; since this voltage is constant, current consumed by this also constant; these two resistances are constant so, current consumed by this also constant. And, we keep this one very large value 470 k, one make like that, because, we need only 20 milliamperes here; so, obviously, this base current is very small so, this current, very small current is enough. So, we will have a large resistance here, that is, that makes that, even if this voltage changes, the current change here is very small and that will not affect the system performance very much; that is why we put here high resistance like 470 k and then make this regulator.

The working of the regulator is a straight forward like our simple regulator, which we have discussed. For example, if the we want to keep at 8, I put this one, say 5 volt Zener here, 5 volt Zener here; then, I know that I need, say 1 milliamperes current, through this

so, I need about 3 k, I can put 2.7 k resistance here; 2.7 k then, if it is 5 volt I want, say, if I put here 100 k and we want current through this very small, so I put 100 k; then the voltage across this will be 5 volt, then, if I want 8 volt, then I can select this one R 2, such that, why you get 8 volt that formula is very simple, because voltage across 100 k is 5.

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$$V_{out} \text{ acc } 100k = 5V$$

$$\text{So output } V_{out} = \frac{5V \times (100k + x)}{100k}$$

$$x \text{ can be calculate} = 8$$

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The circuit diagram shows a 18V-36V source connected to a 470k resistor (labeled 'A'). This is followed by a Zener diode (5.1V) and a 2.7k resistor. The output voltage is labeled V_o . A 100k resistor is connected to ground. A Zener diode (5.1V) is also shown in parallel with the 100k resistor. The text below the diagram reads:

Zener voltage provided
 extra voltage
 $V_{out} \text{ at A} = 0V$

So, that I can calculate; voltage across 100 k is equal to 5 volt so, output voltage is 5 volt divided by 100 k into 100 k plus x. So, that is suppose to be kept 8 volt so, the x can be

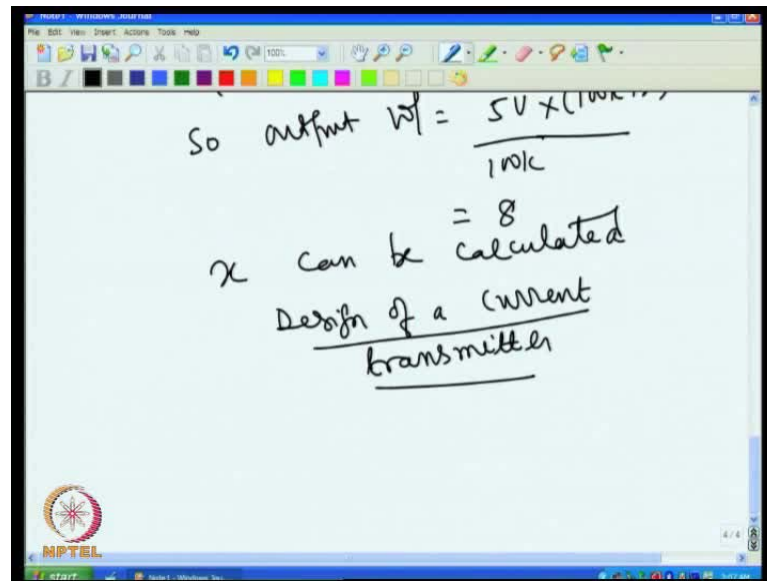
determined, the value of the x can be calculated. So, you can get any voltage you want; in this case, we set this one to 8 volt, we set R_2 for 8 volt using the formula that I have discussed.

So, if this is always sitting at 5 so, in case, if the output goes more than 8, then this point will go more than 5; then, if this goes more than 5, then this voltage will come down because, minus going up so, this will come down; if this comes down, this will also will come down and so, thus, this also will come down. So, in case, it goes below 8, then this will, this point will go below 5 volt - this is lower than 5 and this is 5 - output will go high then, this also will go high and output also will increase.

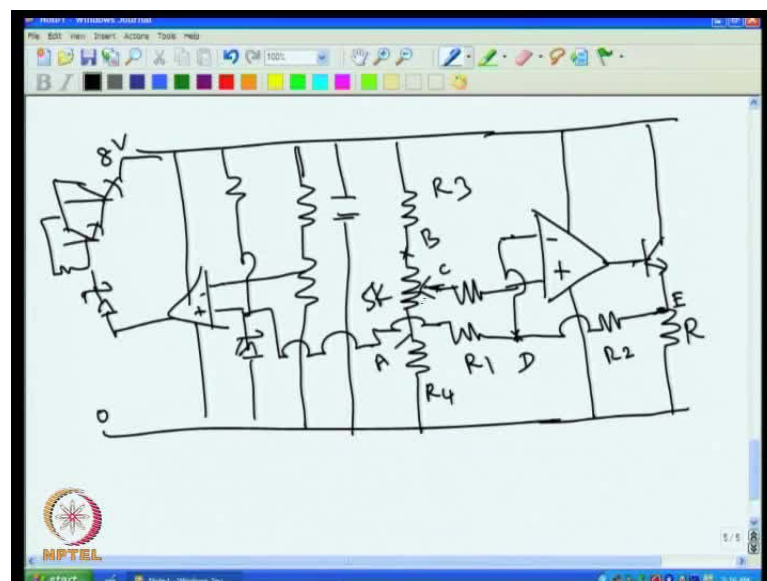
So, essentially, if I am keeping this at 5, this also comes at 5; and that is how the regulation is done, and the circuit regulation **provides you**, provides a circuit 5 volt, and then, we know that avoid oscillation, we have to connect the capacitor here; that small capacitors can be connected across this so that, no oscillation comes in. So, normally, we put one capacitor here, but here, we come to electrolytic capacitors, because it is a 4-20 milliamper system and if the electrolytic capacitors, after sometimes, if it leaks, then the current drawn by this will upset the other current in the unit; that will create a problem. So, normally, we put a small value 1 μ f, 5 μ f, like that and not very high value, to avoid oscillations.

So, this is the voltage regulator pot of this. What of this current transmitter? Now, we can go **at** and see how to design the next pot, that is, this current transmitters pot; because, the current that is flowing here, **returns** here, and that comes here; where in actual use, there will be using the one resistance here and measure the current, and that current should give the position information corresponding to this potentiometer. So, we have to design now, since the voltage across this is now constant, this resists the constant voltage; now, this current transmitter can be designed easily. Let us see how to design this current transmitter.

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So, design of a current transmitter: so, let us start using the circuit like this, for example, I have this regulator voltage which is coming from the regulator, say, that is 0 to 8 volt; what I do is, I will have to connect the potentiometer know, so, I have this, I have this; if you want, you can retain this circuit also, this side, **that is, your...** Here is the Zener diode, connect this reference and then bias in the Zener like this; now, here, we put the current; now, this is the regulator pot and then, we also said, we put one capacitor here. Now, I put the current transmitter, for that, I take one operational amplifier; then, what I do is, I will also connect one **transistor** here; I **get** put the potentiometer. Now, what I do

is, I put this, this is the potentiometer, **this is** when the mechanical system moves, **this** by this, centre tap of the potentiometer actually moves.

So, the mechanical system at one end, potentiometer will be here, at this end, making conduct here; when the mechanical system at other end, then the wiper moves and makes the conduct at this point. So, if it is halfway, then the potentiometer will be, at the centre point will be, at halfway point of this potentiometer. Normally, for example, we use this 5 k pot actually; so, essentially, what is happening is, when the mechanical system moves, the voltage across this, there is centre tap to this ground, **with respect to ground**, if you take, that voltage actually varies.

Now, invariably, for example, this supply for this, also can be obtained normally, when the same, **this** thing, whether it is a regulator voltage; supply for this also can be from the same. Normally, what is done is, you can have a system where this, this and this, for example, 4 op-amps are there in once single chip so that, you know, if you give a supply to this one, that automatically other one comes and we also need not look for the second op-amp; the same package 4 op-amps **are there**, one or second one can be used for this purpose.

So, in a simpler system like this, you can take the op-amp; **now, this and then** we are designed now, if this voltage varies, current through this should vary linearly; this is at one end, we have to make sure that the current, the total current that is flowing here, **the** all this current put together plus this current, all put together should be 4 milliamperes; then, the potentiometer moves to other end, that is, at this point; then, all this current plus current flowing here should make it up to 20 milliamperes, that is what we have to do; and then, the exact circuit design is to be carried out for that.

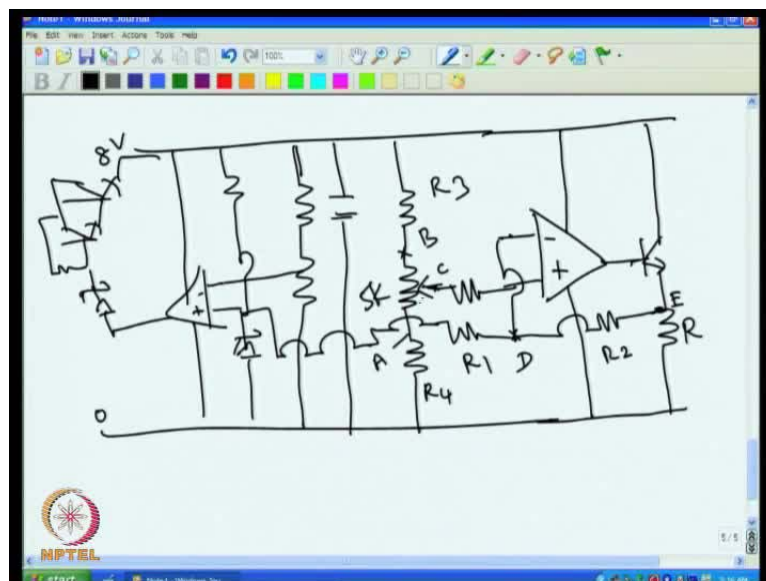
So, what you can do is, we can connect, **that will increase in this**, to increase the voltage here. So, obviously, we have to connect this, this output of the potentiometer to plus terminal so that, when this increases, output increases; but then we also want to make sure that the current does not go very high so, we give the feedback – here, I put this, connect it to this. Now, this voltage, whatever current that is flowing, develops the voltage across this **voltage across this**; if more current flows, you will get more voltage, then you will also get more voltage; the voltage more, this voltage will come down and this current also will come down; essentially, our idea is whatever voltage is there, here

the same voltage will come here. So, if I give more voltage, then I get more voltage here; and then, I also have to get more voltage that automatically more current will flow.

So, if I increase this, then I will find that current is also, through this also, increasing. Now, only one small problem in this, is that, you know, we have to make sure that when this is at one end, for example, if it is at one end, you will get 4 milliamperes, but already, you have around 3 milliamperes current is flowing; here some current, here some current and then, the op-amp takes some current; with all that, some 3 milliamperes flowing so, when potentiometer is one end here, then you need a balance of 1 milliamperes current because, if already 3 milliamperes is going, that to make it 4, I **get** to send only 1 milliamperes current.

Then, when it is at the other end, the current has to go to 17 milliamperes, because, already 3 is there, the current through this has become 17, then it will go to other end; but we know that, we are operating in the operational amplifier in a single supply, we are operating in a single supply, then there is a limitation, that, input of the op-amp should not go below certain level; and, if it goes below certain level, then the op-amp will not work, for example, if we take 741 - if we operate in a single supply, then I need a minimum of 2 volts at the input, then this would be kept to 2 volts.

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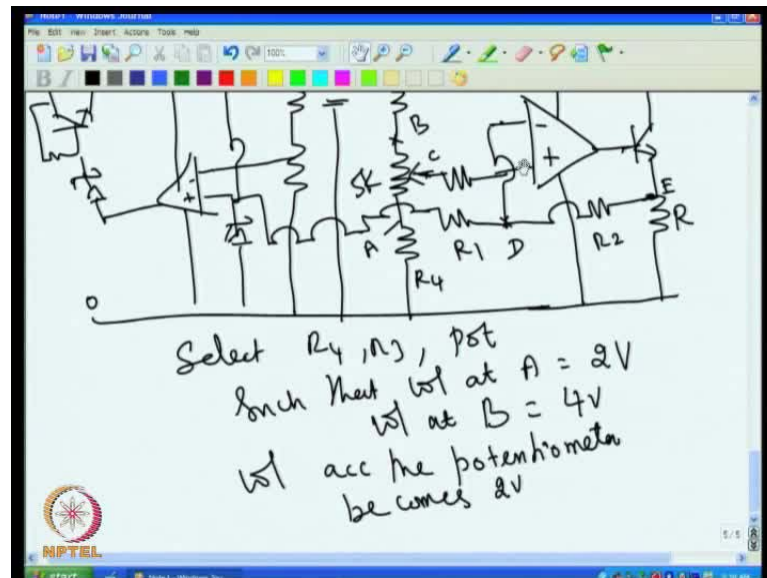
And similarly, the **top** should not go very high; they may supply 8 volts. This will be better limited to 7 volts so, if it is 2 volts, this will be, **this** set will be normally 7 volts so,

only you get 1 is to 3 variation in voltage; but current variation required would be around 1 is to 1 milliampere to 17 milliampere, that is, when input is around 2 volt, we need 1 milliampere current; when the input is around 5 volt, we need current of 17 milliampere, that is **the** roughly, you know, 2.5 time variation voltage that vary the current 1 is to 17, that means, it becomes a non-linear variation and that is not acceptable. It has to vary linearly with the position here.

So, to tackle that issue, we can do a simple change. What you do is, I take this voltage, put one resistance, connect this here; by connecting like this, that problem is solved. For example, I take this one as R_1 , this R_2 , this is the main resistance that is R ; so, by suitably selecting R , that is, **this resistance** this resistance, then $R_2 R_1$ we can make it, such that, when the potentiometer is at this point, it is **current** total current is 4 milliampere. Potentiometer at other end, the total current is 20 milliampere.

Now, how to select this R_1 and R_2 ? Because, assume that, I will mark the points now, for example, assume this is A, this is B, this point is C, and then this junction is D and this is E, this point is E so, let us mark this points. Now, for example, when the centre tap is at A, and now, potentiometer, **that** the mechanical system, it is at A; we need to know, this op-amp to work, assume that 2 volt, then I have to select, you know, this resistance **known** so, I can select this resistance A, I will take this is $R_3 R_4$; so, R_3 and R_4 , I can select $R_3 R_4$ and this like a pot; all these three can be selected in such a way that voltage at A is 2.

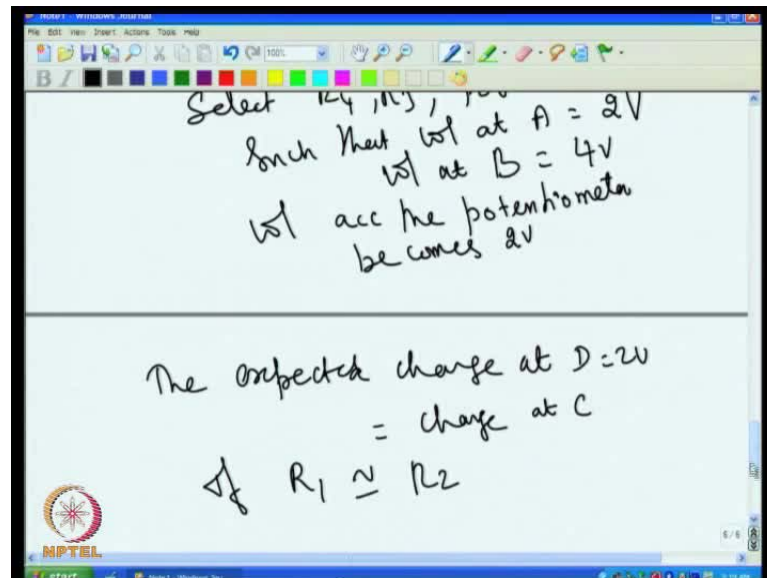
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So, what you do is, select R_4, R_3 and pot, such that, voltage at A is equal 2 volt; that can be done by varying the value of R_4 and R_3 ; and make sure that you know this resistance value is not very small, because this resistance value, very small, then large current will flow and **that itself will take...** If it takes more than 4 milliamperes, then the whole purpose will be lost. We can keep away 0.5 milliamperes to 1 milliamperes current for this, that is, practical value, but we can adjust this, of course, we know this is 8 volt. So, it is not difficult to calculate what is the value required for R_4 , because this is known as 5 k.

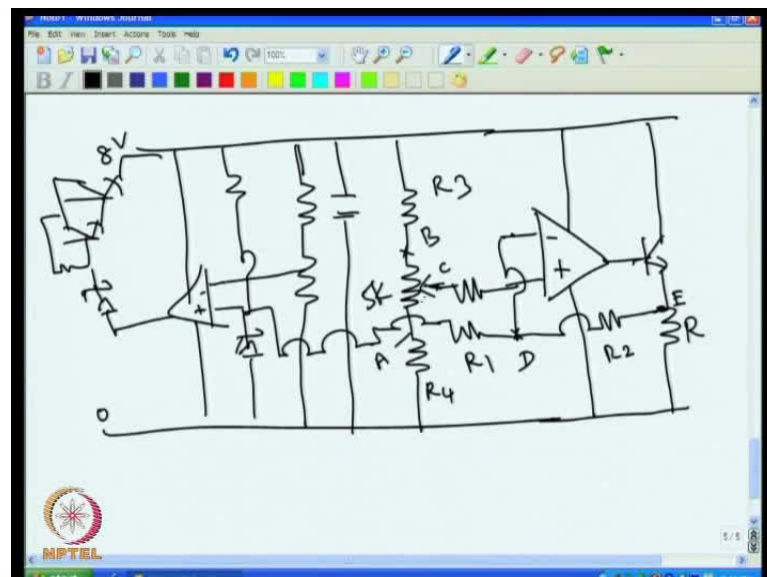
So, one can select R_4 , that normally, we also have to consider, if this voltage variation is, say, if this is 2 volt, and if I keep this one at 4 volt, for example, I can keep, that is, **B** A at 2 volt, then voltage at B is equal to 4 volt so, the voltage across the potentiometer becomes 2 volt. So, that means, if I keep this one at 2 volt, and this is at 4 volt, then I know that when potentiometer is varied, a voltage at this point varies by 2 volt, **voltage at this point varies by 2 volt; If voltage at this point varies by 2 volt then, this also have to be varied by 2 volt,** because this and this are always following each other. So, if this is at 2 volt, we know that this is at 2 volt; if this goes and reaches B , then **this will, plus symbol** plus input will go to 4 volt and automatically, D also have to go to 4 volt.

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So, that means, the expected change at D will be again 2 volt, because C is changing by 2 volt so, D also expected to change 2 volt; so, next to this, the expected change at, that is, a change at D equal to 2 volt, that is, equal to change at C, and that is potentiometer change.

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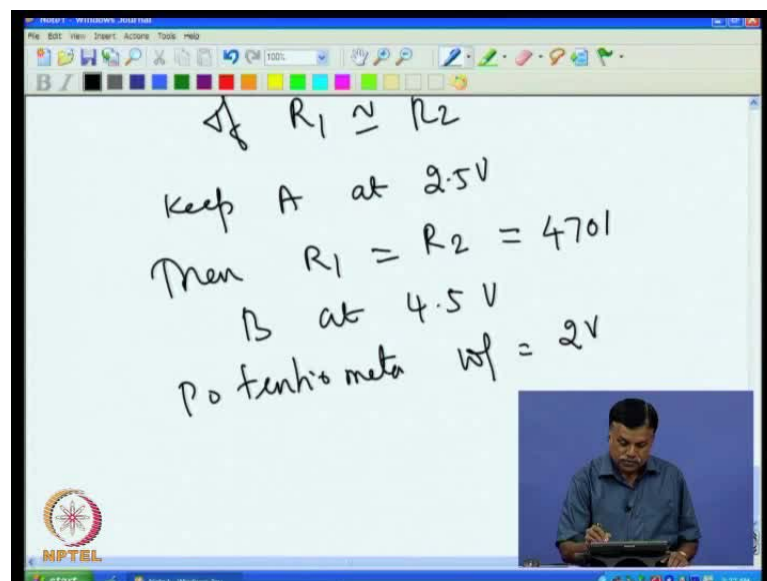


So, if D have to change by 2 volt then, if I take R 1 R 2 are equal, if R 1 equal to R 2, if R 1 is nearly equal to R 2, then, to get 2 volt change to get 2 volt change, to get 2 volt change here, if these are equal; we know that this point have to change to 4 volt, if 4 volt

change occurs here, you will get half the change occurs here. So, we need to get 4 volt change here. Now, the 4 volt change has to take place means, here, it has to change to 4.6 so, we have 8 volt supply so, 4 volt change is always possible; so, we can keep 2 volt change across this; but, if I keep too much change, for example, if I take 4 volt change, if I drop 4 volt across this, then here, I have to change, here, change will be 4 volt and here, change will 4 volt then here, at change, you need a change of 8 volt at this point, that is, 8 volt change across this; that is not possible. So, **the** our assumption of, you know, 2 volt change that is required here, is perfectly all right, because that will able to change 4 volt here and that is what required.

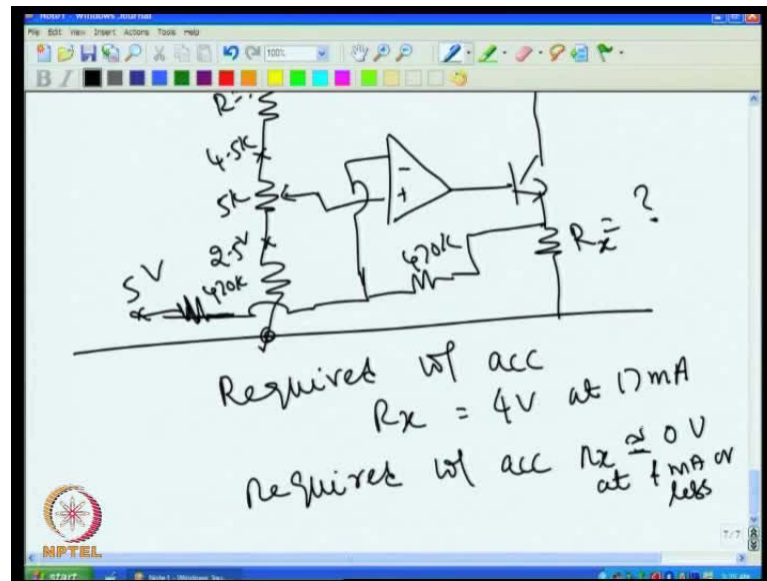
So, what actually can be now done is, since this is 5 volt Zener, we have taken - 5 volt Zener; if I make $R_1 = R_2$ equal, then I will get 2.5; so, **this of** that means, 4 milliampere, we need almost about 1 milliampere, almost negligible current; I can make sure that this is also, you know, when at A, A also I can keep it say 2.5 volt so, if I keep A at 2.5 so, what I do is, now readjust this.

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So, keep A at 2.5 volt, then R_1 can be kept equal to R_2 ; of course, I can keep B. B at 4.5 volt, that is, it makes a potentiometer voltage becomes 2 volt, then voltage equal to 2 volt. So, 2 volt any way we will call for 4 volt change at the output; that can be easily achieved.

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So, I keep R_1 R_2 equal so, I **make it the set** make the current small; I keep this 100k or 470 k, for example, I can keep R_1 equal to R_2 equal to 470 k so, if I draw the circuit now, that current transmitter part it looks like this; you have this, then I have this potentiometer, then this point is kept at 2.5. Then this is a 5k so, this automatically, I have to keep with 4.5 k, that, **I can select this resistance**, I can select this resistance; then we have to put this one to plus, then we have to **minus**; minus, actually one end we have two resistances, this is given to 5 volt reference, I have this resistance connect this, other resistance here, and then, say, **put** we said we will take 470 k so, this and this, we will take 470 k.

So, normally, this is 5 and this will come to 2.5 so, when it is at this end, then almost no current flows. We will see how to tackle these small differences, we will give 0 and span adjustment to take care of this **is** small changes. So, I can do this, and this is connected to this; now, only thing that is to be designed, is this resistance value R or R_x - what is the value that we have to select for R_x ? Because we know, when roughly about 17 milliamper current is flowing, we need to develop about 4 volt. So, we will develop 4 volt so, we need required voltage is 4 volt; so, required voltage across R_x is 4 volt, **at 17 milliamper current**, at 17 milliamper current; and of course, required voltage across R_x equal to almost 0 volt or very small voltage, at equal to 0 volt at about 1 milliamper current, say, it can very small, that I can adjust nearly equal to 0 volt at 1 milliamper or less. Now, this is small voltage can be taken care easily; that, I will show you little later.

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Handwritten calculation on a whiteboard:

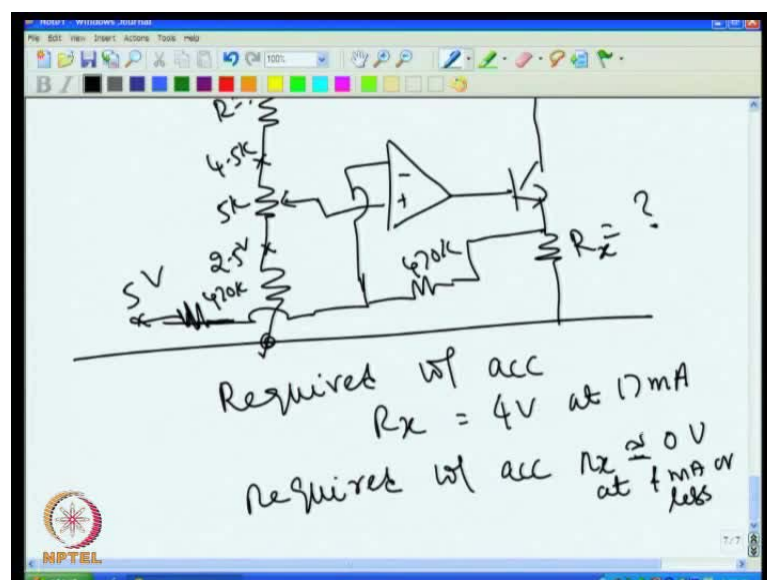
$$R_x \times 17 \text{ mA} = 4 \text{ V}$$
$$R_x = \frac{4 \text{ V}}{17} = \frac{4 \text{ mV}}{17} = \underline{\underline{235 \Omega}}$$

60

The whiteboard also features a small video inset of a man speaking and the MPTEL logo in the bottom left corner.

So, all the time to concentrate at this point, is that - how much resistance have to put to produce the 17 volt for 17 milliampere, 4 volt at 17 milliampere? So, the R_x into 17 milliampere is supposed to give me roughly 4 volt, so that, you can find R_x very easily by taking this; that actually, if you take this 34, you will have 6 3 9 0 so, you will get 2 for 35 ohms so, that is the approximately the resistance that is required for R_x .

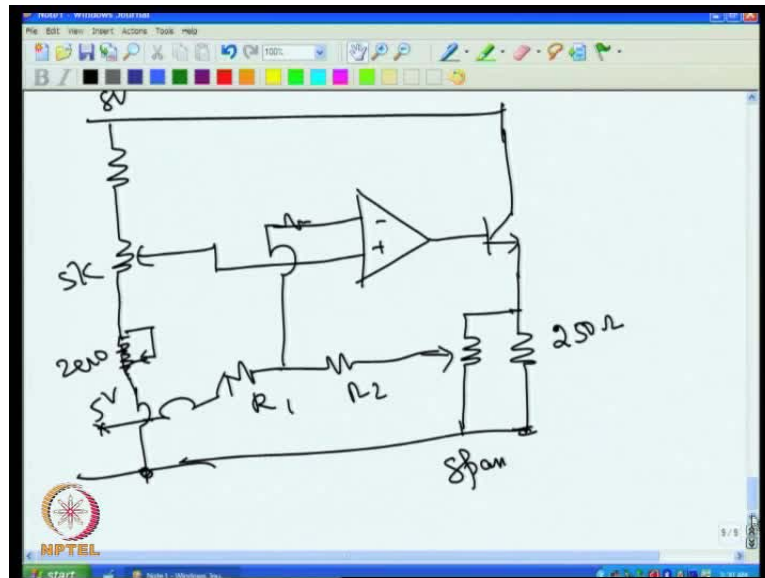
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So, if I put this R_x here, around 235 ohms, then, more or less the circuit design; but it is not perfect, because we said, you know, when 1 milliampere is flowing, this output is

235 millivolt; that may not exactly match, because this is giving the voltage at this point is 5, voltage at this point is 5 and if this is kept at 2.5, at 5 it will come 2.5 here; at the time, if 1 milliampere goes, then you will have 235 millivolt, half of that will come here, but then, you know, that fractions may not match exactly to make 4 milliampere.

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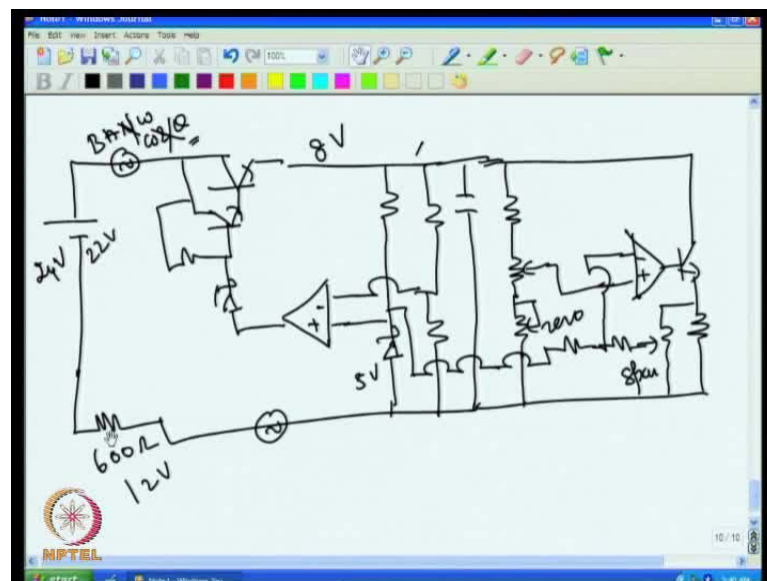
So, what we normally done is, we will to take care of this fractions; we will have adjustments, 0 and span adjustment is provided; so, what we do is, now, the current transmitter circuit can be modified like this. So, we take this, then we put one potentiometer here, that is connected here, we call this as a span potentiometer; this can be 235 or even it can be little higher so, it may be 250 ohms or so, we can be connected, that extra thing can be taken care by this potentiometer.

So, this your 8 volt line, that regulator voltage. So, you will have potentiometer, and then ground here, and then you have this, that can be connected to plus, and then minus voltage is coming here; that actually, you have this, this is there; now, one thing can be done, we can connect this one to 5 volt, then we can also have a position to vary this voltage or even we can vary this resistance a little bit as a 0 variation.

For example, I can have this variation, this resistance can be varied, I redraw this, everything is gone. So, I redraw this so, what I do, I have this so, that is the 0 pot that is connected to 5 volt so, this is kept same, R 1 R 2 are same, and then this is the potentiometer that is connected to this A. This we call 0 pot; so, normally, what is done

is, you know, the potentiometer, this, that is, this potentiometer is kept at one end, then adjust 0 to get totally 4 milliampere here, then they move the potentiometer to this end; then, adjust the span pot to get 20 milliampere in the whole system where this current plus; all other current put together, it becomes 20 milliampere. So, then again, you come back to this end, adjust this to get 0, then go back to other end, adjust this to get 20 milliampere; the span and 0 adjustment is provided to make sure that, in other end, exactly current 20 milliampere; at one end, it becomes exactly 4 milliampere.

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So, this is the 4-20 milliampere current transmitter is designed; and then, this is used as a current transmitter. Now, if you look at the entire circuit in one go, that looks like this, that is, you have a supply, say 24 volt, then we have our sensing resistance here, then the first input pot will be here, voltage regulator so, that is done like this; then this resistance is used, then we have a voltage regulator so, this gives you 5 volt, then output is sensed potly then use the Zener. Suppose, the voltage which I already discussed, then I put the one small capacitor to avoid the oscillations, then you have our current transmitter connected at here; put's span pot, then you will have minus; plus here, our potentiometer is connected, our 0 pot is connected here so, you connect this ground, then the potentiometer end connected to plus input; then, we will have this two resistance are connected here, and this goes to 5 volt reference, that is, the complete circuit diagram of the 4 to 20 milliampere current transmitters.

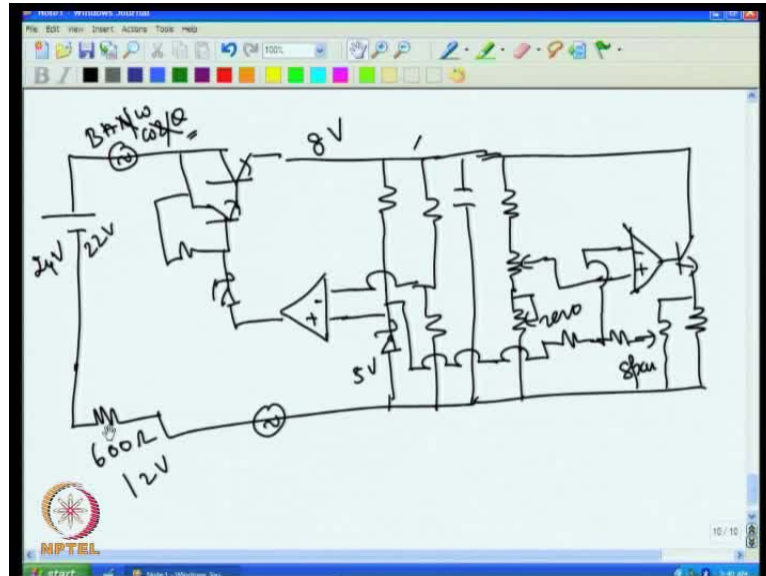
So, what we have done is, we have a voltage regulator pot here, voltage regulator pot. So, that makes sure that voltage across this is constant, then the potentiometer system moves; voltage at this point varies, if it increases the voltage increases, then we know that if the voltage goes up, this voltage also has to go up. Now, if this is not going up, if this alone increases, then this will be less and this will be more. So, output will go high and the current will increase; through this, the current increases; this voltage will increase and automatically, this also will increase so that, if this increases, this also increases so, that way, as long as I move this, this also will correspondingly follow. This voltage, if this voltage increases, this also will follow; this, that is minus input will follow the plus input by increasing the current through this, because if the current is not increasing, then the this voltage will be less compared to this. Then, automatically, this is high output will go high, more current will go. In case if the current goes very high, then this voltage will increase and this voltage will go up. This voltage goes higher than this, that is, inverting input goes higher than the non-inverting input, then output will come down; then the current also will come down; this way, the current through this is controlled by the fact that this voltage has to be equal to this voltage. By this fact, the current is continuously regulated and the current that is flowing through this, depends only upon the position of this.

This current, of course, is same as this current, because the current flowing through this, plus current flowing through this, which is constant; then some current is flowing, that is also constant; **some current is flowing that is also constant** since, all the other currents are constant and this is the only variable so, once you vary this, this current changes; so, one can adjust 4 in 20 milliamperes by adjusting this 0 pot. For example, this is 0 pot, this is a span pot; one can adjust the 0 pot to get 4 milliamperes when the potentiometer is at one end; and then, the potentiometer at the other end can adjust the span pot to get 20 milliamperes; by repeatedly adjusting 0 and span a few times, one can make this 4 to 20 milliamperes current transmitter for the potentiometer.

Now, if we recollect our earlier discussion that the current flowing through this should only depend upon this potentiometer variation, it should not depend upon this supply variation or this load changes; because up to 600 ohms, **the may put this so...** for example, we put 600 ohms or 100 ohms then, whatever current is there, that should remain. Suddenly, remove this 600 ohms, put 100 ohms, then also same current should flow,

because that will be definitely assumed, because we are keeping, we have only 8 volt and this is 24 volt. Even if, **the even if**, this voltage, say, goes to 22 volt, and even 20 milliamperes current, which is maximum, this will develop 12 volt only.

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So, out of 22 volt, 12 volt where gone across this so, we have 10 volt left so, 10 volt we are leading 2 volt for resistance; we are, **getting only**, regulating only 8 volt so, only if the voltage goes less than 22 volt or the resistance goes more 600 ohm, only the output will not be maintain 8 volt once output is not maintain 8 volt, then, if this decreases, then this also will decrease; the current also will decrease and the 4-20 milliamperes current will not be valid and it will not be maintained.

So, as long as this is not going below 22 volt, it is similarly, if I put 100 ohm, that is no problem, because 100 ohm will create only 100 into 20 milliamperes, we will give only 0.2 volt; so, 22 minus 0.2 that will get almost 21 volt here, and that easily gives 8 volt; so, even if you shift also, you will get same 21 milliamperes only flowing that current will not get affected. So, current will not get affected because of this change **or because of this change**. Then, all the other currents are actually get constant so, they are not going to change; so, current will remain constant, then other discussion is, what happened to the noise pick up? Suppose, if this is, we set **the** this loop area, is very long in; normally, we keep this is about a kilometre long, then the change in magnetic field will induce the voltage; that should not create the problem so, that what happens is, that voltage I

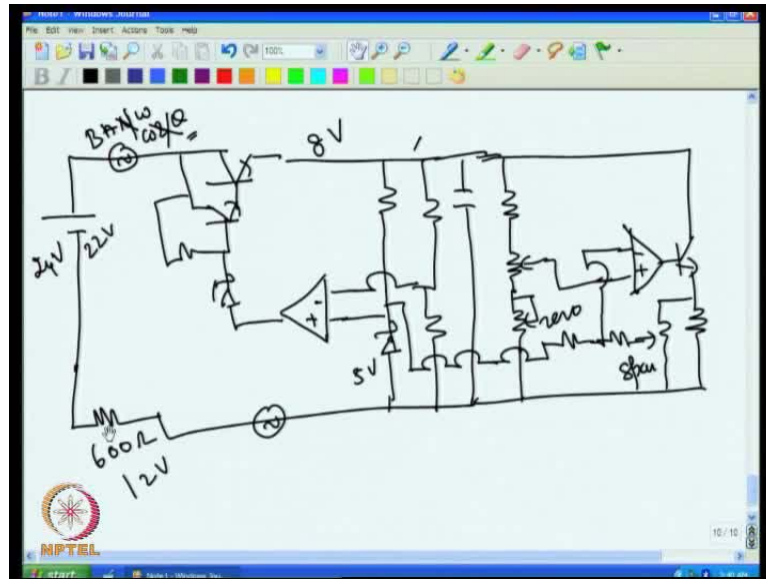
represents like this, because that will be in series with this, and that is actually $BAN \omega \cos \theta$, where B is the external magnetic field, A is the area of the loop and in this case, N is 1 number of turns that, N is 1 so, I remove that; ω is the frequency of applied magnetic field, $\cos \theta$ is the angle of orientation between the field and the loop; for normal purpose, I keep that as 1.

So, induced voltage is actually this, that voltage comes in series with the applied 24 volt, if it comes in series with the applied 24 volt, then actually, what really happens is, the circuit, that is, this voltage regulator really, this is not the 24 volt that is supplied voltage supplied voltage plus or minus this AC voltage, is what is coming. Suppose, even if the pickup voltage due to the magnetic field is 1 volt, that is, 1 volt AC is 50 hertz, then you have 24 volt plus or minus 1 volt; what is appearing here? But nevertheless, the voltage change at this point will not change the output voltage because, the frequency response of this operational amplifier is more than 50 hertz, is much higher; so, as long as the noise frequency is much lower than the frequency response of this operational amplifier, whatever change that is coming here, if this increases, then this voltage will increase; and this will increase automatically, this voltage will decrease, this decrease and this will decrease.

So, even it has a 50 hertz AC, all that it is doing dynamically, is adjust 50 hertz field and you will get only 80 volt here; and no AC current will be present here; because, any small increase, any increase in voltage at this point due to the noise that is present here, will increase this; and automatically, that will pull it back. So, this is, this is, faster than 50 hertz, or it is essential to remove the noise, that is, the frequency response of this loop should be much higher than the noise pick up; then, the noise pick up the output voltage, this 8 volt, will not have any AC comet and this 8 volt will remain constant.

So, the noise voltage will not create any problem in the circuit, because, if there is no noise voltage here, this is correct; and this is correct, of course, you may have noise voltage induced this pot of the loop. For example, here, now, this also that it have the current like this only, but then we know that this, as long as this voltage is not changing, this current also will not be changing. So, external noise will not, will have no effect on the current; that is why, this current transmitter is used and also only two wires are used.

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So, in practical usage, we find that there is no problem because of the noise; and we need not put too many wires because, the wires have to be long so, too many wires will cost more money and so, that problem all solved; and then, noise pickup is not there and even the small change in the voltage of this, and even load change or the wire resistance change also will have no effect on the signal here. That is how this 4-20 milliamperes current transmitters are made, and it is used in the industry.

So, with this, I will stop this lecture; so, next class we will see how to make an error budget for this circuit. Thank you.