Circuits for Analog System Design

Prof. Gunashekaran M K

Center for Electronics Design and Technology

Indian Institute of Science, Bangalore

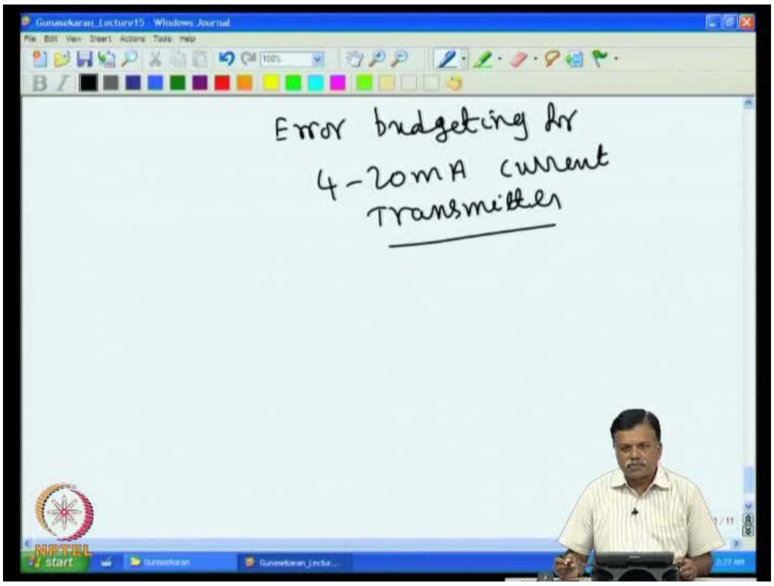
Module No. # 05

Lecture No. # 24

Error budgeting for 4-20mA Current Transmitters

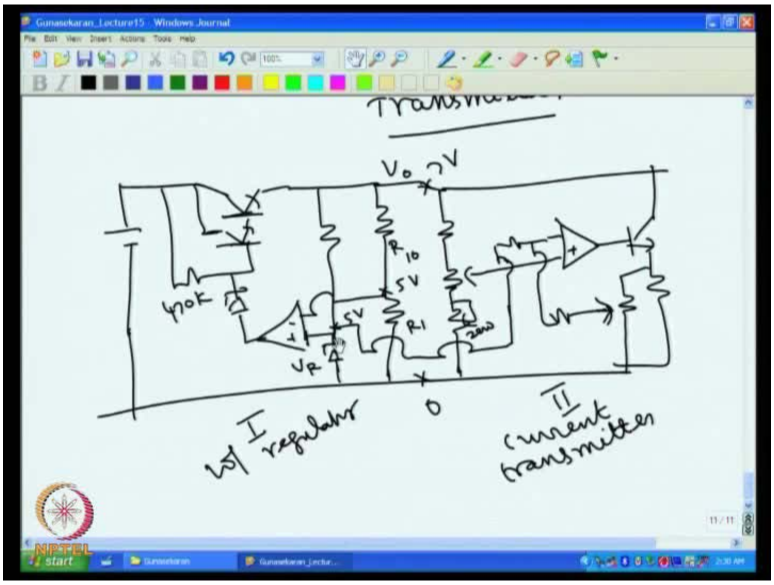
In the last class we had discussed about 4 to 20 milliampere current transmitter that was using a potentiometer we have discussed we at so on how to design a 4-20 milliampere current transmitter and then we also explained how to calculate the various resistance values that is used in the circuit

(Refer Slide Time: 00:52)



Today we continue on that and explain how to do the error budgeting for the same4 to 20 milliampere current transmitter so we will pick up the topic error budgeting for 4-20 milliampere current transmitter because as we discussed earlier error budgeting is an very important aspect analog system circuit design so how we do this error budgeting for this current transmitter

(Refer Slide Time: 01:30)



First let us draw the current transmitter circuit first then we pick up one error after another so here we know we have the voltage source and then we had the regulator that consists of one Darlington pair transistor this we are discussed in the previous class so we had the biasing resistance here and then we had the output so output voltage is taken and then we had the error amplifier for voltage regulator so we had the plus then we had this and then we are connected this so this is our current transmitter voltage regulator part of the current transmitter is this so we had 470 k resistance here and this is Zener to give a startup current for that

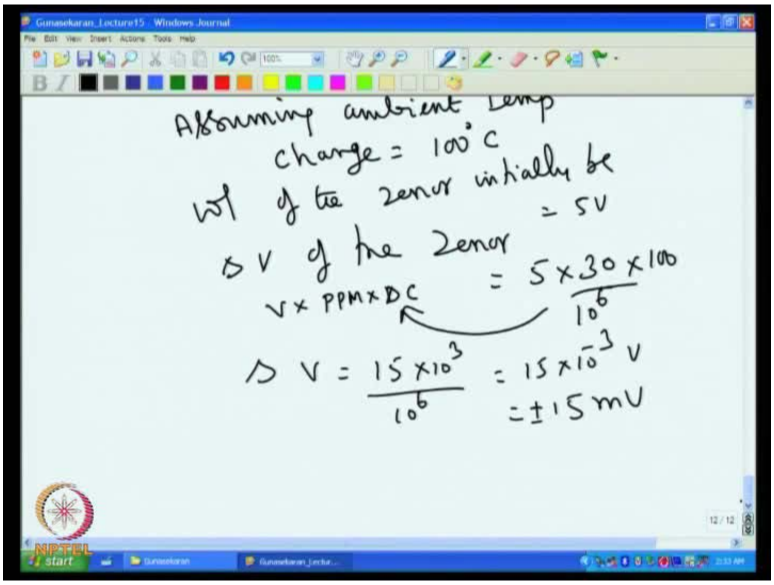
Now then if you draw the other part of the circuit that is transmitter part that is like this we had this and then we had the this is connected to this that is 0 part then we had this that when voltage increases that increase so we had this then we also connected that and this is connected to this

So the second part is the this is the second part is the current transistor part this is the voltage regulator part this is the voltage regulator this is the current transmitter part so typically we get 0 to say 7 volt here fixed and if this 7 volt has to determine by this V reference and this two resistance say R 10 and R 11 so this R 10 R 11 and V reference actually forms this 7 volt because we now voltage at this point is say 5 volt then we want this is to be 5 and then across this voltage across this is 5 volt so the can adjust just R 10 to get whatever voltage you want

Now if you look at the error basically if the V reference changes with temperature then this 5 7 volt will changes because if this increases obviously this point also have to follow that and then this output also have to increase similarly if this resistance and this resistance drifts then also output voltage will change

So if this regulator voltage changes than voltage at this point which as for a given position you had kept the potentiometer point fixed so if this increases then this also will increases that will increase the current through this so first we have to calculate what is the error that is expected or which error expected due to change in the regulated voltage if the regulator voltage changes what will be the current error that is what we have to calculate first

(Refer Slide Time: 05:30)

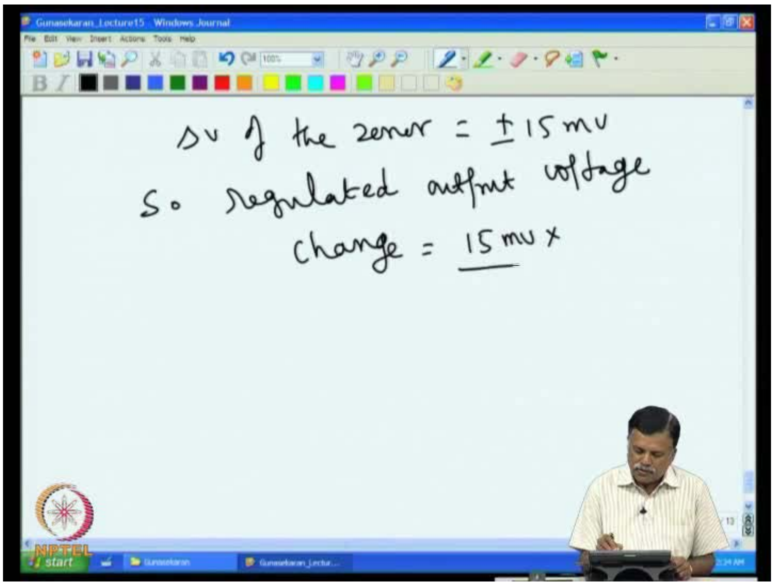


So we take the Zener for example if we are take a typical Zener say LM a 336 is used as Zener diode then if you look at the datasheet of LM 336 the Zener 5 volt Zener the drift is given as 30 PPM for degree C so drift actually for Zener is 30 PPM for degree C

So what is the expected output voltage change if the Zener drifts by 30 PPM per degree C then what is the output voltage change due to the Zener drift so that means first we have to find out what is the voltage change at the Zener end for 100 degree C assuming ambient temperature as ambient temperature change equal to 100 degree C this is required because if you have make the industrial grade equipment and then it has to withstand minus 20 degree to plus 80 degree so maximum temperature changes expected is 100 degree C so we take 100 degree C as a temperature changes

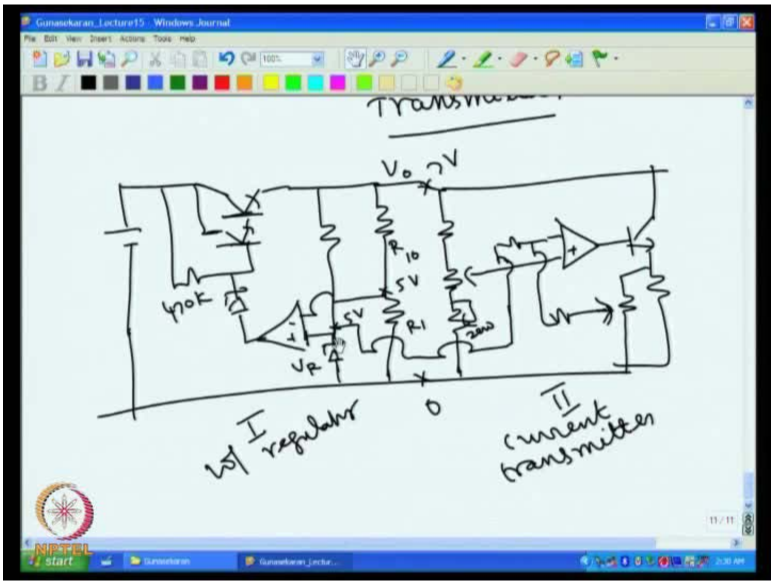
Then so voltage assuming voltage of the Zener initially be 5 volt so delta V of the Zener is equal to change on Zener voltage that will be 5 into 30 PPM that is 10 power 6 in to 100 degree C basically it is a V in to PPM into this delta t that is what we had shown in this

(Refer Slide Time: 07:50)



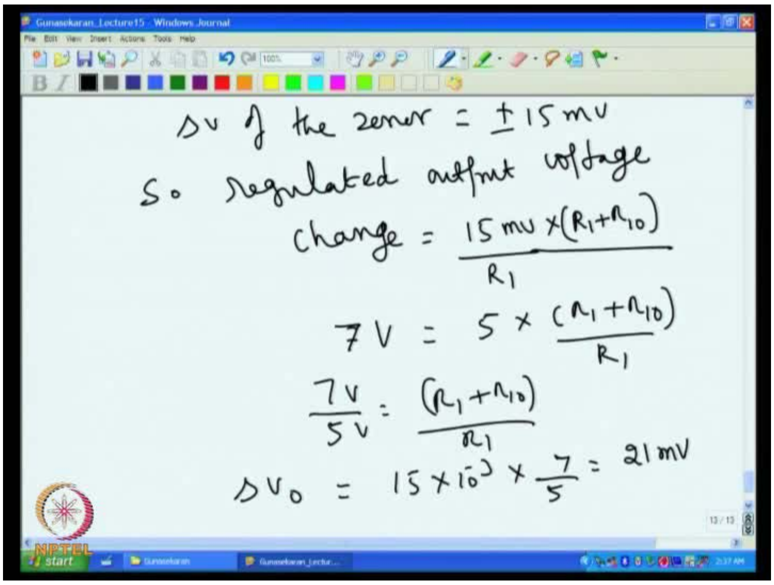
So delta V then it comes that is 15 into 10 power 3 divided by 10 power 6 that is 15 into 10 power minus 3 volt that is 15 millivolt so Zener voltage you will change by plus or minus 15 millivolt for 100 degree temperature change so delta V of the Zener equal to plus or minus 15 millivolt if Zener voltage is 15 millivolt what is the output voltage change at the regulator output

(Refer Slide Time: 01:30)



So regulated output voltage change that is equal to 15 millivolt into 15 millivolt divided by the resistance that we are used here that is in this case I want to go back to it is here I think today’s circuit is somewhere here this is R 1 and this is R 10 so we have to find if this voltage changes by if the Zener voltage changes 15 millivolt this also had to change by 15 millivolt that means 15 millivolt change at occur here then if you now 15 millivolt change here than we can find what is the change here and what is the net change at V naught

(Refer Slide Time: 09:34)

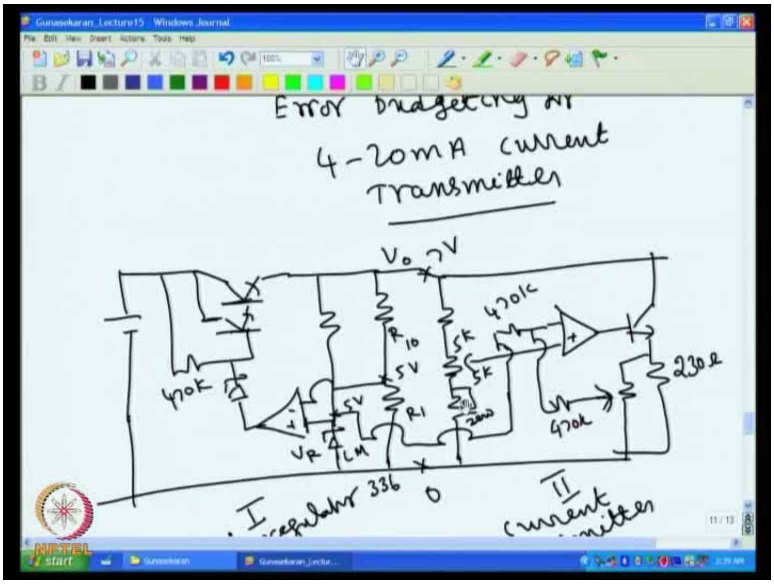


So considering this then we can recalculate R 1 and R 2 are the two resistors now I can write 15 millivolt divided by R 1 into R 1 plus R 10 that is the output voltage change x by change in the output voltage expected that is 15 millivolt divided by R 1 gives you the current change in to R 1 plus R 10 is the resistance so the total resistance so that will be the total change the output voltage

So that if you work out this that will be because we now that this ratio is we are Zener voltage is 5 volt and R 1 and R 10 can be computed because 7 volt is whatever output voltage 7 volts equal to 5 in to R 1 plus R 10 divided by R 1 because we got 7 volt from 5 volt reference that means this ratio we can determine so this ratio will be 7 volt divided by 5 volt that is the R 1 plus R 10 divided by R 1

So substituting this value there this then you will get delta V 0 change that will be we can now we have to substitute here this this we replaced by this 7 by 5 so that actually comes out to be 15 millivolt into 7 by 5 that actually 21 millivolt it comes

(Refer Slide Time: 01:30)

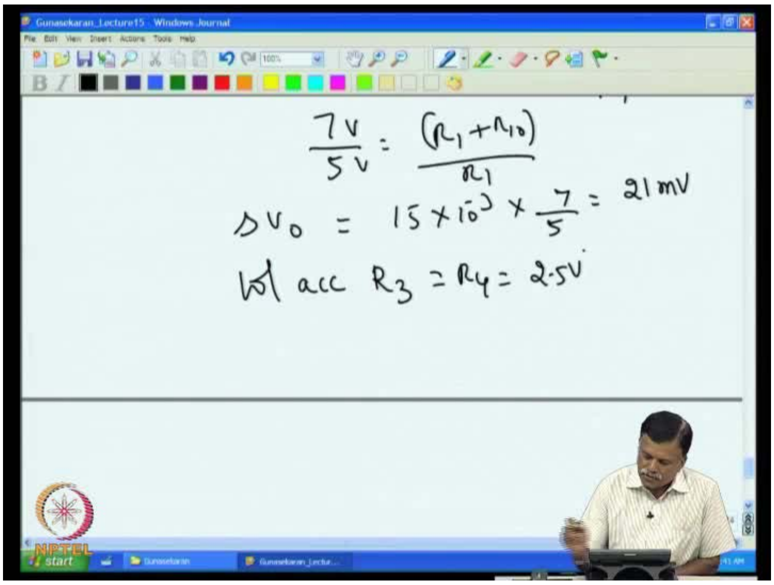


So because of the drift in the Zener the regulated output voltage will change by 21 millivolt so this is the error due to the Zener drift if the if the regulator output will not changes with 21 millivolt then what is the expected change in the output current that we have to calculate that is if you go back to the circuit that we have started today if this voltage changes by 21 millivolt that is what we have got because of the drift in the Zener if this changes by 20 millivolt 21 millivolt then what is the change in current that is expected here

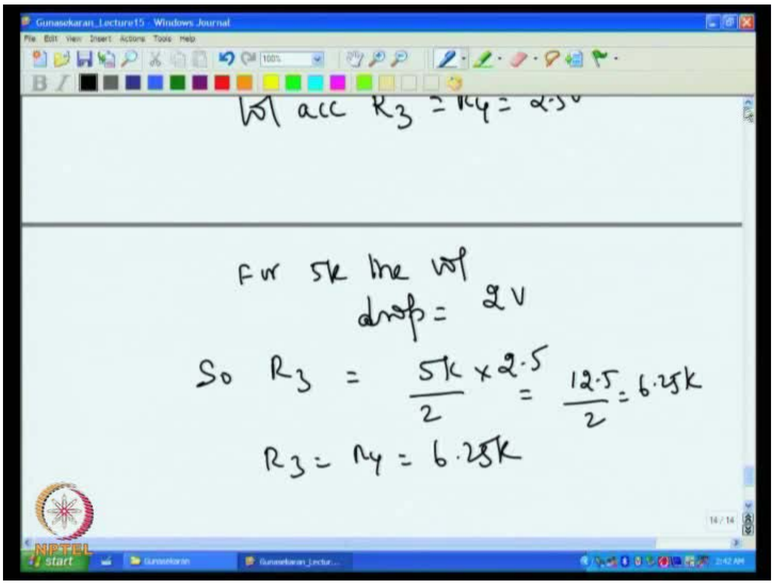
Well if this changes by 21 millivolt then we have to find out the what is change that is expected at this point then if I know the change in voltage at this point than I can find out what is the change in current through this because if you recall our earlier class values that this is taken as the 230 ohms such that value taken and then this was taken as the 5 k than I had to go back and see what was the other values taken you had taken 5 k I will calculate the values this is 235 ohms actually we have not calculated that values that we checked whether it calculated or not

We will write down the values first so this was taken as 470 k this was taken as 470 k and this was taken as 5 k so we had taken 2 volt difference across 5 k at that means we will have then this is taken as this voltage is 5 volt so you got 2.5 so this has to be minimum 2.5 so we have 2 volt design for the potentiometer so 5 k has 2 volt that means 2.5 will be a voltage across this then 2.5 plus 24.5 they produce 7 volt then remaining 2.5 has to be across this volt 2.5 2.5 and 2 that is the voltage across the this for example 2 volt here 2.5 here 2.5 here that is the normal values

(Refer Slide Time: 15:06)



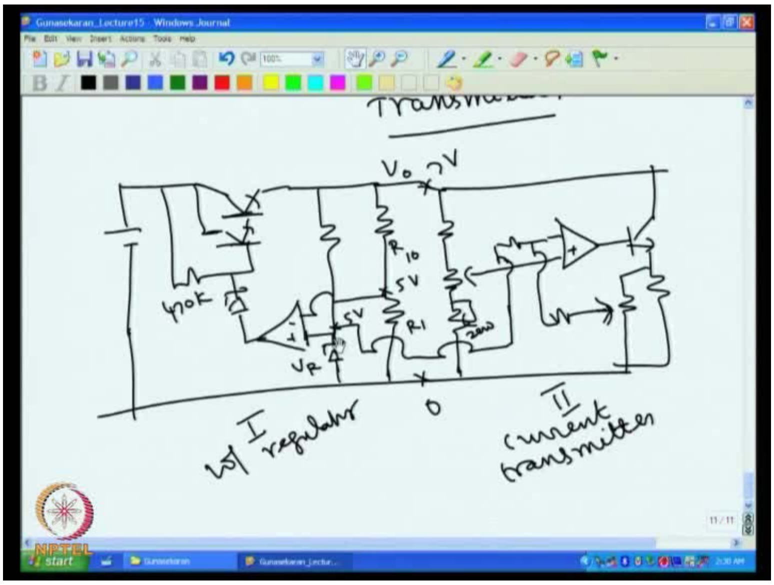
(Refer Slide Time: 15:36)



If you go back to our circuit here I have named them so that is easy to refer so I call this as R 3 this is 0 part as R 4 so we had to find R 3 R 4 that can be recalculated so R voltage across R 3 equal to R 4 equal to 2.5 volt R 3 R 4 is 2.5 volt so we have to find the R 3 and R 4 values because for 2 volt for 5 k the voltage drop is 2 volt

So we can compute what is the required voltage for 2.5 volt required resistance for 2.5 volt so R 3 will have 5 k divided by 2 into 2.5 that comes out to be 12.5 divided by 2 that is 6.25 k so we need R 3 is equal to R 4 6.25 k so R 3 is equal to R 4 will appear to be 6.25 k

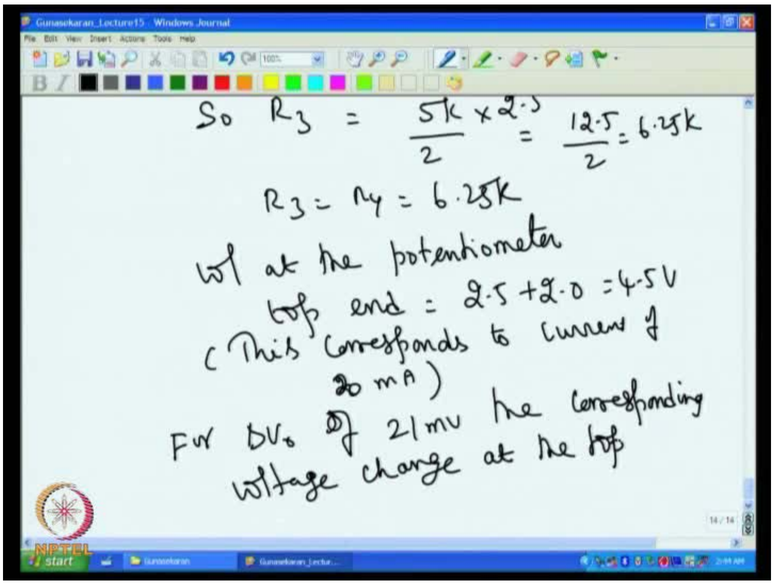
(Refer Slide Time: 01:30)



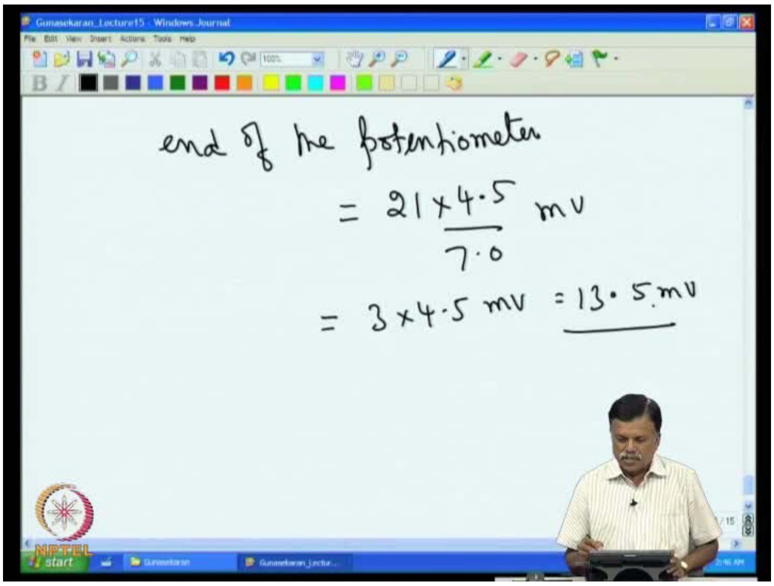
So our interest is that to compute the voltage change at the potentiometer point so if you take this potentiometer assume that it is at the maximum say at 20 milliampere then we know the voltage at this point is 4.5 volt because this is taken as 2.5 voltage across this is 2 so voltage at this point will be 4.5

So at that point what assume that current is 20 millampere now at 4.5 what will be the change because if this voltage is by 20 millivolt that is what we have calculated then what is the expected change at the midpoint now we go back and calculate what is the expected error

(Refer Slide Time: 17:35)



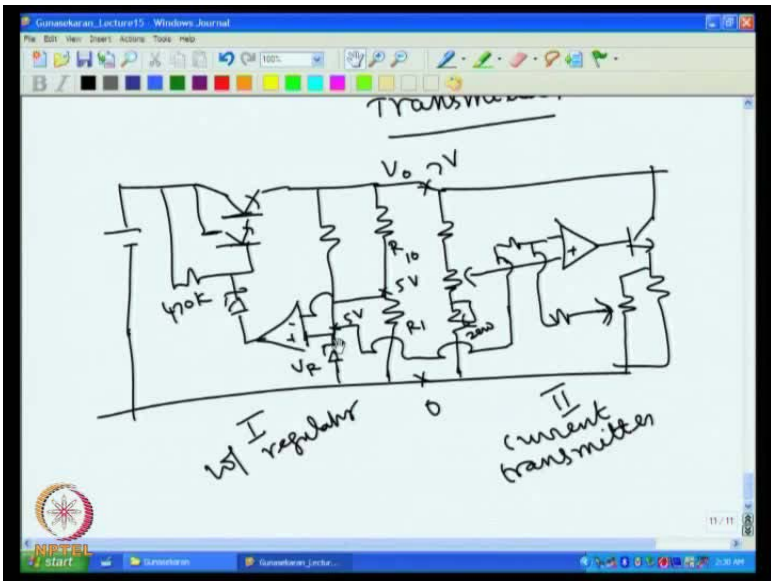
(Refer Slide Time: 18:57)



So we will get the voltage at the potentiometer top end top end is equal to 2.5 plus 2 it is equal to 4.5 volt this corresponds to current of 20 milliampere so voltage here at the potentiometer top in this 4.5 volt and the current is 20 milliampere now if this 7 volt supply voltage changes by 21 millivolt then what is the voltage change at the potentiometer top end for delta V naught of 21 millivolt the corresponding voltage change at the top end of the potentiometer that will be 21 into 4.5 divided by 7 that is the expected change of the top end of the potentiometer because that is the 21 millivolt change at the regulated output voltage

So that if you calculate this that actually comes 3 into 4.5 millivolt that is equal to 13.5 millivolt we have 13.5 millivolt change expected the top end of the potentiometer so that means if the temperature of the Zener changes by 100 degree C then the regulator voltage changes by 21 millivolt that makes a potentiometer top end change by 13.5 millivolt

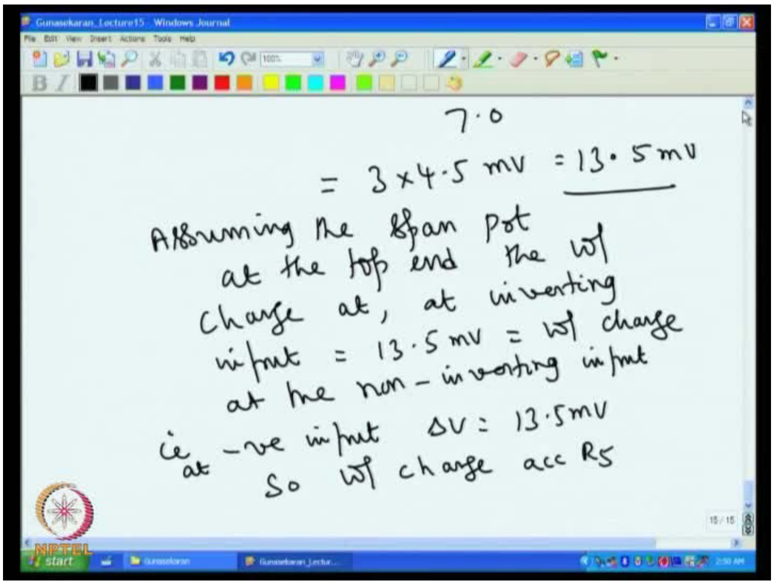
(Refer Slide Time: 01:30)



Now we have to calculate because of the potentiometer top end changing by 13.5 millivolt what is the expected current change in 20 milliampere because if you look back go back to the circuit and see if the thus now we arrived at you know the voltage change at this point is 13.5 millivolt 13.5 millivolt for example if it goes up here then 13.5 millivolt have to go up here that will demand approximately two types voltage because there is a divider of 1 or 2

So 27 millivolt change have to occur here if I assume that this is all most close to the top then 27 millivolt change have to occur at the resistance part here so we name this resistance we name this as R 5 so what is the expected change at R 5 assuming the this potentiometer is also at the top that is the span potentiometer we call this as the span potentiometer

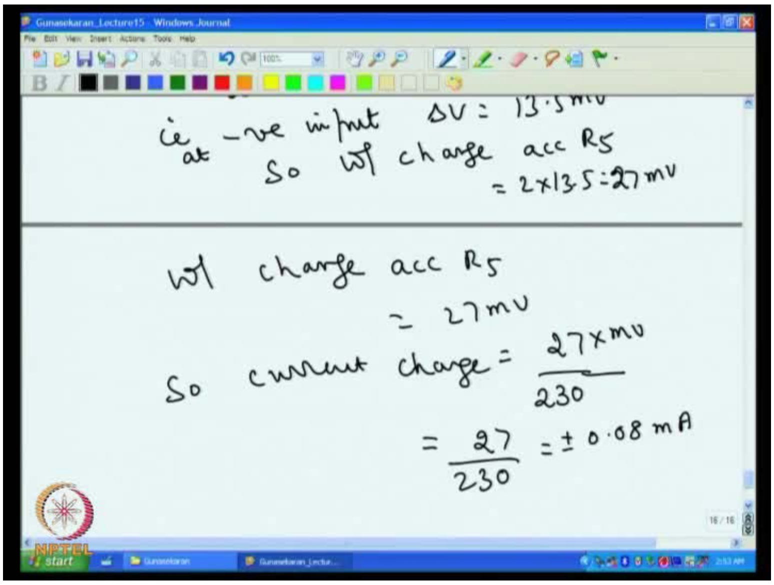
(Refer Slide Time: 21:34)



So assuming the span potentiometer is at the top end at the top end then voltage change at assuming the span pot at the top end the voltage change at inverting input is equal to 13.5 millivolt that is equal to voltage change at the non-inverting input

So the voltage change require expected voltage change at the non-inverting input is 13.5 millivolt so if the 13.5 millivolt that is at negative input delta V equal to 13.5 millivolt so voltage change across R 5 this R 5 is the 235 ohm resistance so voltage at this point what is the expected voltage change that will be twice because we have this and this voltage divided by factor of 2

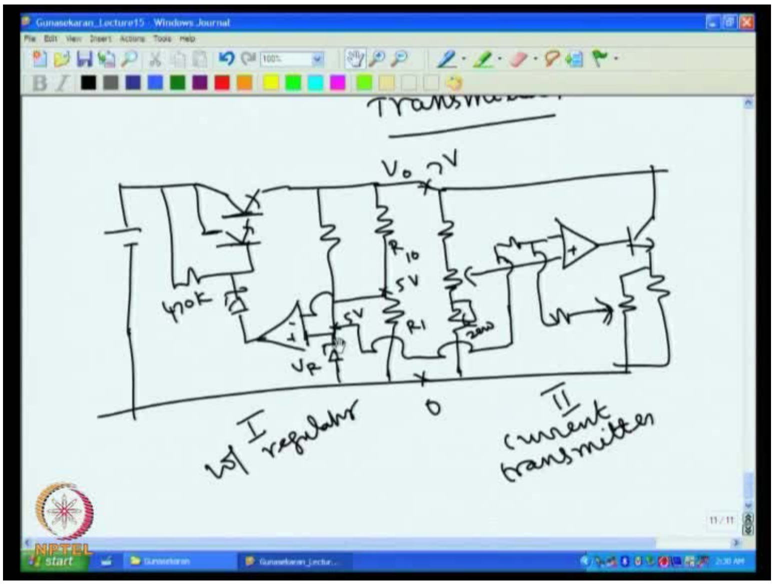
(Refer Slide Time: 24:08)



So voltage change across R 5 will be twice the value so we write voltage change at R 5 equal to 2 into 13.5 that is equal to 27 millivolt voltage change across R 5 is equal to 27 millivolt so delta current change equal to 27 divided by 230 volts that is 230 ohms that actually if you calculate that will come almost if I take that is 27 by 230 I think it goes by 3 roughly it comes about point naught 8 milliamps

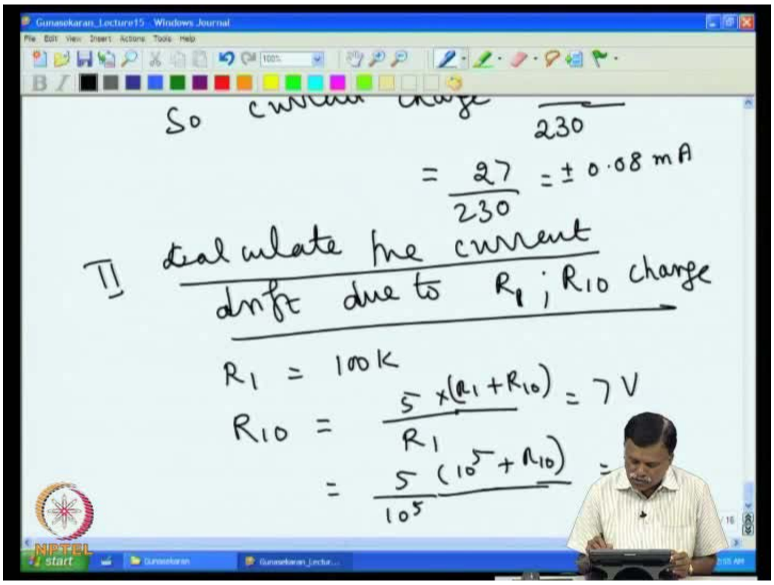
So we have point naught 8 milliampere change in the 20 milliampere current due to the drift of the Zener if the Zener voltage drifts by 30 PPM then you will have a output current error of 0.08 mill ampere since the expected voltage changes plus or minus this current change also plus or minus point naught 8 milliampere this is the current error expected because of the Zener voltage drifts

(Refer Slide Time: 01:30)



Similarly we can calculate the error due to the change in resistance because we are using voltage regulator because of the voltage regulator if this two resistors values change with temperature then however also output voltage will change we already discussed about this we has set if I use a for example a 25 PPM resistors here one can go up one can come down and then we can find out what is the drift in the output voltage so assuming that R 10 R 11 that we already calculated we have to calculate first R 1 and R 10 and then we arrive at what is the expected drift

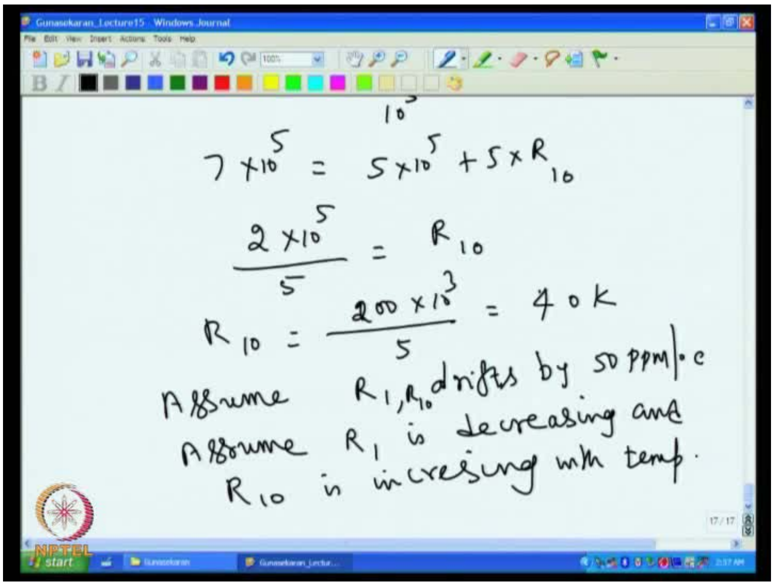
(Refer Slide Time: 26:39)



So assuming R 1 as 100 k we cannot keep low value that low value will consume lot of current so let R 1 be next we calculate the second one is calculate the current drift due to R 1 comma R 10 change that is the thing that we going to calculate

So R 1 equal to 100 k so R 10 is how much because we know the ratio between R 1 and R 10 we already then this one so R 10 is equal to 5 divided by R 1 into R 1 plus R 10 that supposed to be 7 volt

(Refer Slide Time: 27:58)



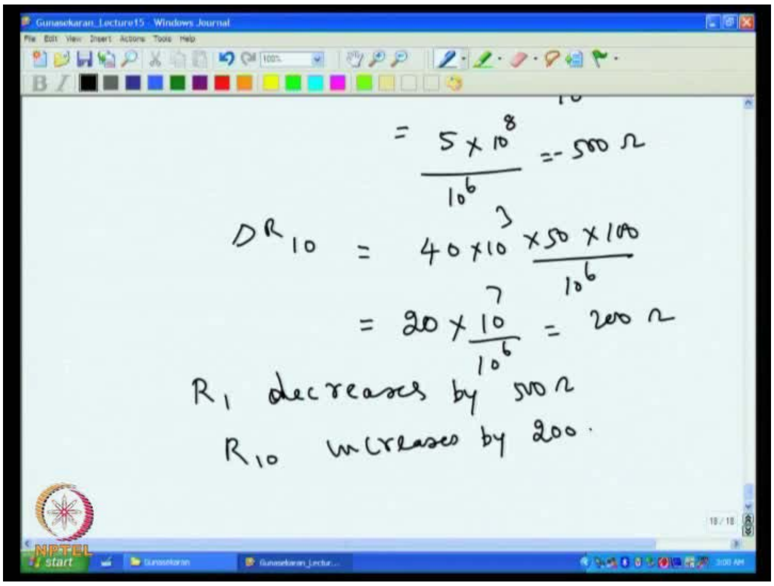
So now R 1 is known so R 10 can be calculated so 5 by 100 k 10 power 5 into 10 power 5 plus R 10 that is equal to 7 volt that is 7 volt is equal to 5 into 10 power 5 that is R 1 plus R 10 divided by 10 power 5

So we had to find out now R 10 in this so that comes 7 into 10 power 5 that actually is become 5 into 10 power 5 plus 5 into R 10 that actually subtracting the 2 into 10 power 5 divided by 5 will become R 10 that comes actually you have 100 k here 200 k that become 200 k 200 into 10 power 3 divided by 5 that is equal to this is R 10 that is equal to 40 k

So if I assume R 1 as 100 k than R 10 comes as 40 k now we fix the drift assuming we are used to say a 50 PPM resistors assume it can be 25 PPM or it can be 10 PPM that depends upon what is the drift that you are looking for here let us assume that we have 50 PPM resist assume R 1 drifts by R 1 comma R 10 drifts by 50 PPM per degree C we have to find out what is the voltage drift

So we have to find what is assuming R 1 is decreasing R 10 is increasing with temperature now you may ask why it is to be like that it can be other way around also that is R 10 can be decrease R 1 can be increasing they can both ways but we had taken here this because both is one will be increasing another case it will be decreasing for the magnitude is same any way we are going to write it as plus or minus so that really does not matter so we can take R 1 is decreasing R 2 is increasing

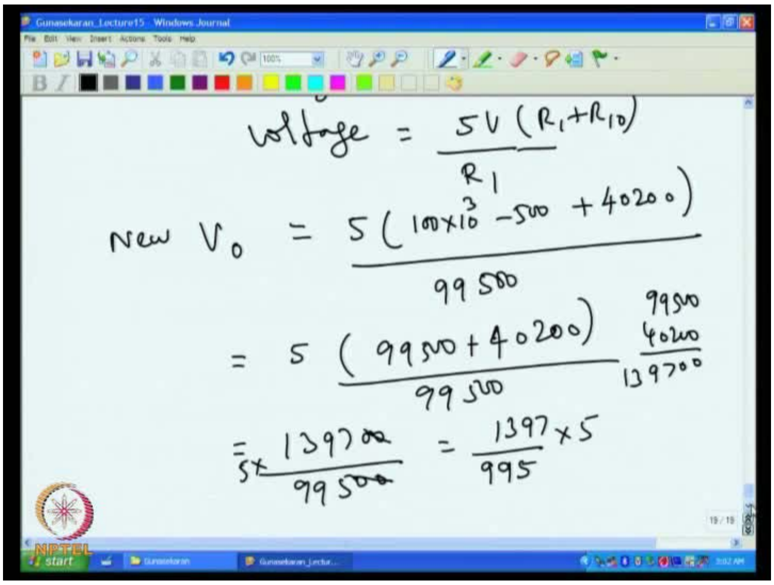
(Refer Slide Time: 30:46)



So if you find what is the delta R change so delta R 1 that delta R 1 will be change delta R 1 is 100 k so 100 k into 50 PPM into 100 degree C so we set it will be decreasing so that will be minus delta will be minus so this works out to be 10 power 4 10 power 5 5 into 10 power 8 100 k because 5 into 10 power 8 divided by 10 power 6 that comes 500 ohms that is R 1 will decreasing by 500 ohms then we can also find out what is the change in R 10 so delta R 10 would be equal to same thing because delta R and 40 k

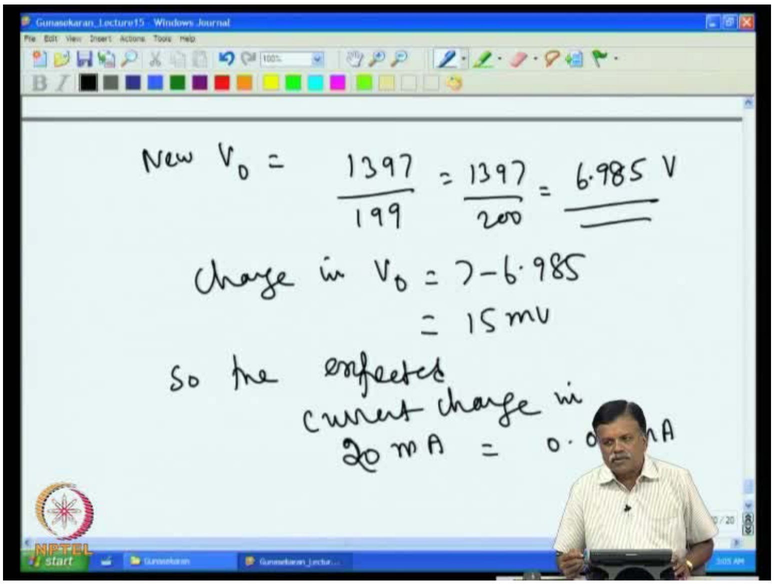
So we have 40 k in the same 50 PPM 100 degree C that comes to 10 power 6 that is the expected change in the resistance that will be 3 4 20 into 2 3 5 3 10 power 7 divided by 10 power 6 that comes out to be 200 ohms

(Refer Slide Time: 32:48)



So delta R will decrease by 500 ohms sorry R 1 will decrease that is nutshell R 1 will decreases by 500 ohms then R 10 increases by 200 ohms so if that is the case what is the regulated voltage change so change in the regulated voltage voltage change would be now you find the new value because we have the old formula 5 volt divided by R 1 in to R 1 plus R 10 now the values are changed so that will be 5 volt 5 into R 1 which actually reduced by this thing 500 ohms so 100 k 100 into 10 power minus 3 minus 500 that is R 1 now plus R 10 are increased by 200 ohms so we have 40200 here that divided by 99500 because 100 k reduced by 500 ohms that is the new voltage so that is the new output volt new V 0 that actually if we simplify that we get 99500 plus 40200 divided by 99500 you will get

(Refer Slide Time: 35:11)



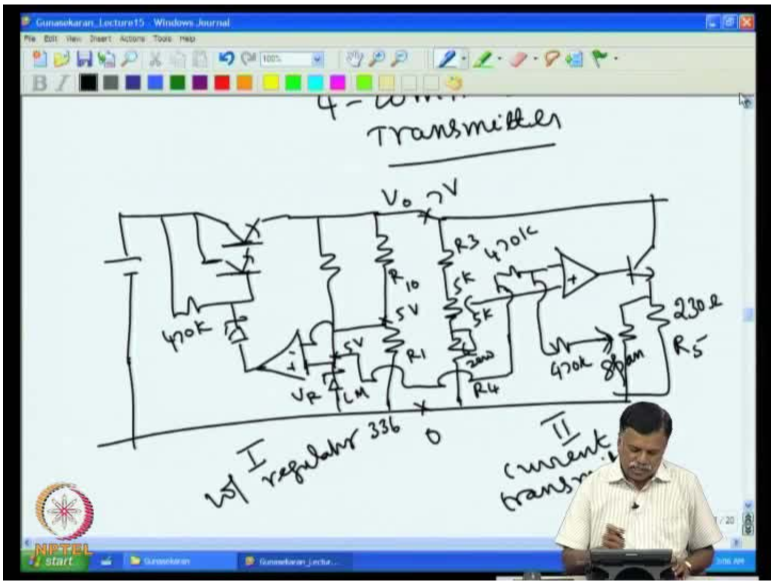
Now that actually if you calculate that you will get 99500 plus 40200 that comes so you will get 139700 divided by 99500 that actually goes off so get of course in to 5 is there so if you simplify further that comes I will write the next step so you will get so new V naught new regulator voltage that will be 35 3 I can remove this I can simplify here itself so I will remove this 5 actually comes 149 that comes 199 actually so I will remove this it will become simple now

So that is actually become 1397 divided by 199 if we make as 200 as this for simplicity I make this as 200 then it become 200 that comes by the net 6.985 volts a new voltage actually had become 6.985 7 volts

So the output voltage are reduced so change in output voltage 6.985 that is equal to 15 millivolt so you will get 15 millivolt change in the regulated voltage and that 15 millivolt change again will produce error in the current that I am not calculating because earlier we have done it for Zener drift of because Zener drift of 13.5 millivolt we have found the current drift now it is since 13.5 millivolt it is 15 millivolt we had a Zener drift of 15 millivolt exactly so Zener was 15 millivolt that 15 millivolt that given as current change of that we have calculated 0.08 milliamps so 15 millivolt change that given you the current change of 0.08 milliampere

So here also the same change will come so the voltage will change this 15 millivolt changes due to resistances drift but the current actually will decrease now so the expected current change into 20 milliampere equal to in 20 milliampere equal to 0.08 milliampere this is same as what your calculated in the previous case

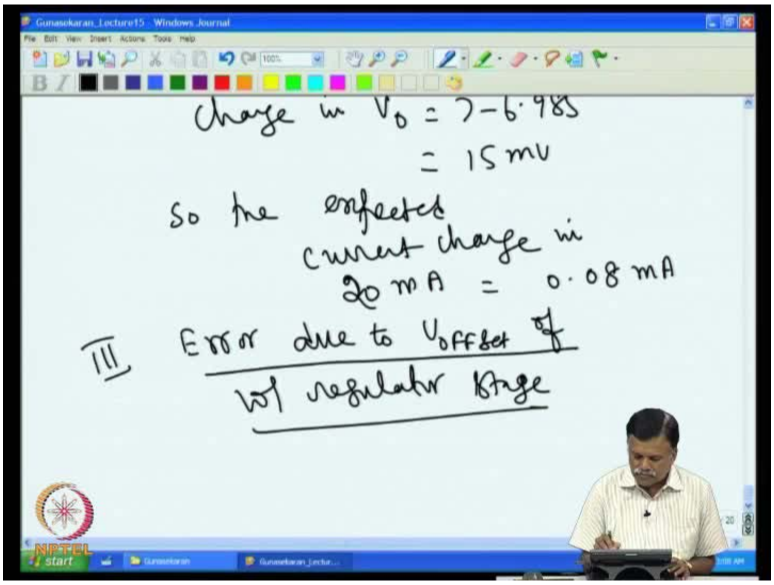
(Refer Slide Time: 01:30)



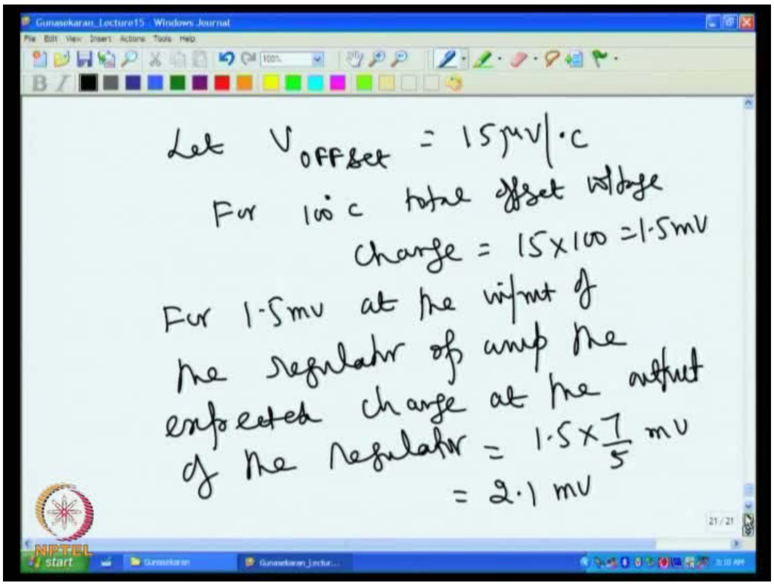
So this is how we have to calculate current change due to the resistance drift we are considered only are the voltage regulated stage we are not consider the resistance change in the current regular as current transmitter part now we look at the other errors in the correct transmitter part because there are not much error there in the voltage regulated part because there only two main contributed as per the voltage regulated part there is one more error possible in the voltage regulated part because if you look at the circuit that we are considered now what is the error due to the Zener drift what is the error due to this and this because of this you got 15 millivolt change here because of this Zener also we got 15 millivolt change of course offset voltage of this op amp can have a drift that will also change the output voltage

So if I use for example simple op amp like LM 324 there will be offset voltage drift of 15 microvolt per degree C so if the offset voltage at drift this to be considered then it assume that the voltage change expected at this point this 15 microvolt per degree C for 100 degree C 1.5 millivolt change is expected here then 1.5 millivolt change is expected here that will make 1.5 into the corresponding multiplications we have to write down 4 millivolt change expected the output that will also make the current to drift

(Refer Slide Time: 40:24)



(Refer Slide Time: 40:55)



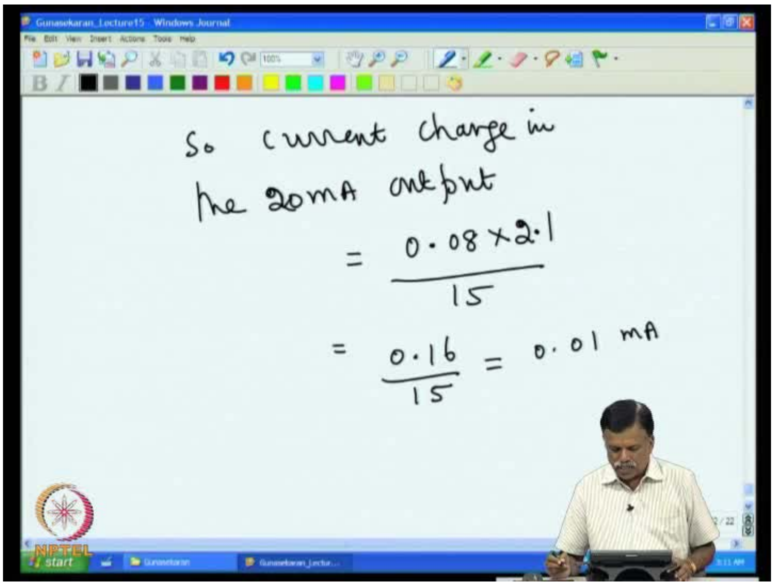
So we can now calculate what is the error due to the offset voltage drift of the op amp that is present in the voltage regulator part of this circuit so next third error of that we calculate would be error due to offset voltage change V offset of voltage regulator part this is the third error that we are going to calculated

So let V offset drifts equal to 15 micro volt per this is a general purpose of op amp that is the figure that we get for most of the general purpose op amp so for 100 degree C total offset voltage change that will be 15 into 100 microvolt 1.5 millivolt so expected have

1.5 millivolt change at the input of the op amp

So then if for 1.5 millivolt change input of the regulator op amp the expected change at the output of the regulator is equal to 1.5 into 7 by 1.5 millivolt into 7 by 5 that is the resistance multiplication factor that is the R 1 and R 10 contributions that actually comes 2.1 millivolt

(Refer Slide Time: 42:59)

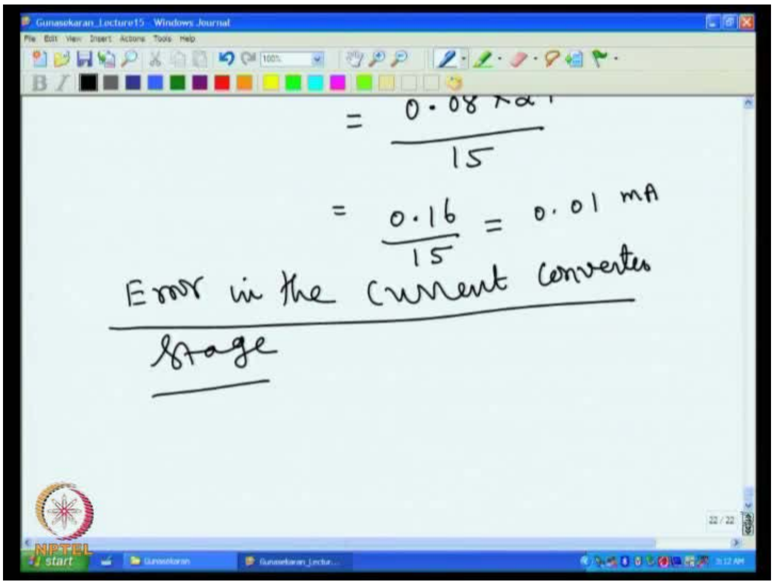


So we will have a 2.5 even millivolt change at the output of the regulator due to the offset voltage drift this are the three errors possible in the voltage regulator stage so corresponding to 2.5 millivolt again your find out the current change at the output of the regulator so current change in the 20 milliampere output because we got for 0.08 milliampere for 15 millivolt so we can also find for 2.1 millivolt that is this that is the expected change so you get 0.16 divided by 15 millivolt that actually comes almost 0.01 milliamps

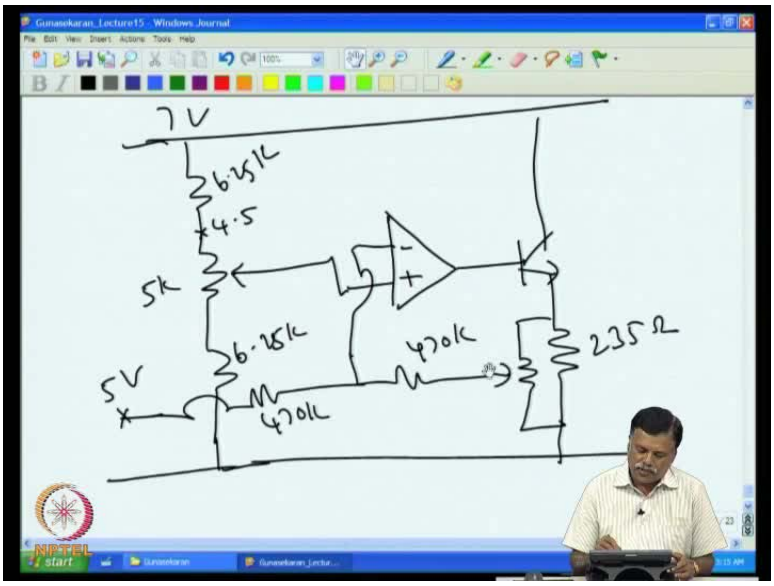
So offset voltage will produce a 10 micro ampere change at the 20 milliampere current this is the small nevertheless we at compute all the errors like this deepening on what is the op amp that we are using

Now we had finished calculating error at the error that is the coming due to the voltage regulator part we have not calculated the error that is expected to come due to the various changes that is expected in the regulator part because if you read all the circuit now the regulator part around the current converted part if I take current converter

(Refer Slide Time: 44:48)



(Refer Slide Time: 45:13)



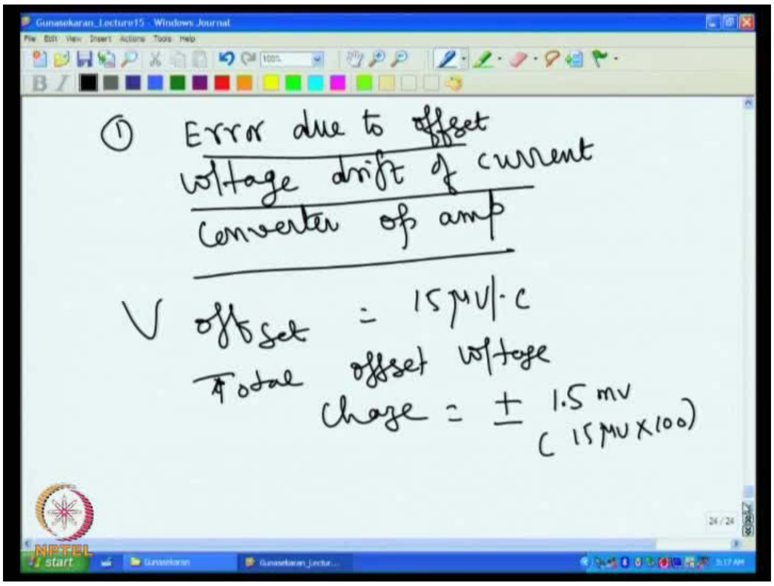
So we around next calculate error in the current converter stage so we at now look at the current converter stage to compute the errors so first we pick up the simple circuit here a current converter looks like this and the span part here and this is regulated to voltage 7 volt which I had set then we had that these resistors this is that 5 k then we had this is given to the reference Zener this is given to 5 volt just 470 k 470 k this is 235 ohms then we had taken a this voltage as 4.5 this was taken as 6 .25 k this also is taken as 6.25 k

So this is the current converter stage now we have to calculate what are the errors involved in this we have to find what are the errors involved and then we had also had to compute that errors in terms of current that is flowing in this circuit now if I take this circuit because we take a simplest one that is offset voltage drift of this operation amplifier if there is well this operational amplifier also will have a offset voltage drift so if this offset voltage drift here then what is the current change here

So the offset voltage change the for example if the same op amp general purpose op amp if I take if we can expect it is 15 micro volt for degree C so for 100 degree C we can say 1.5 millivolt change is expected here this offset voltage if 1.5 millivolt change or 1.5 millivolt change here then also we have to change 1.5 millivolt here if 1.5 millivolt we have to change here then we know 3 millivolt have to change here because 1.5 whenever change will come only if it is twice the change here because we have 1 is to 1 here

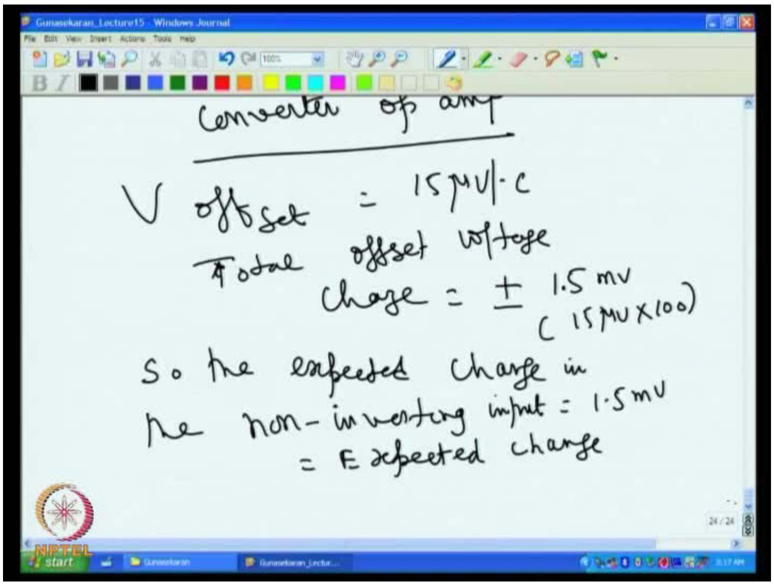
So we have a 3 millivolt change expected here that is 3 millivolt change here then get 3 millivolt change 3 millivolt divided by 235 is the current change that is required that is how you have to calculate the current change so essentially first if you find out what is the offset voltage drift here then same drift is expected here then the drift that is the voltage change that is required find here then the voltage change here expected voltage change here then that once we know the expected change in voltage here then resistance is known the current change can be computed

(Refer Slide Time: 48:14)

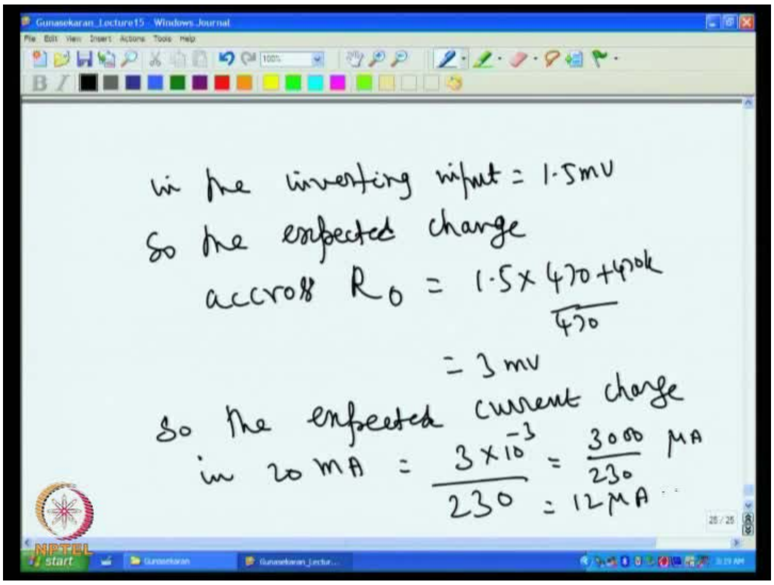


So we go step by step now we are calculating error due to offset voltage drift so that is the first error in the current converter stage so error due to offset voltage drift of current converter op amp that is the error that we are going to calculate offset voltage drifts equal to V offset that is equal to 15 micro volt per degree C so delta total offset voltage change equal to plus or minus 1.5 millivolt this is coming as 15 micro volt into 100 considering 100 degree as a temperature change that is the change expected

(Refer Slide Time: 48:14)



(Refer Slide Time: 50:12)

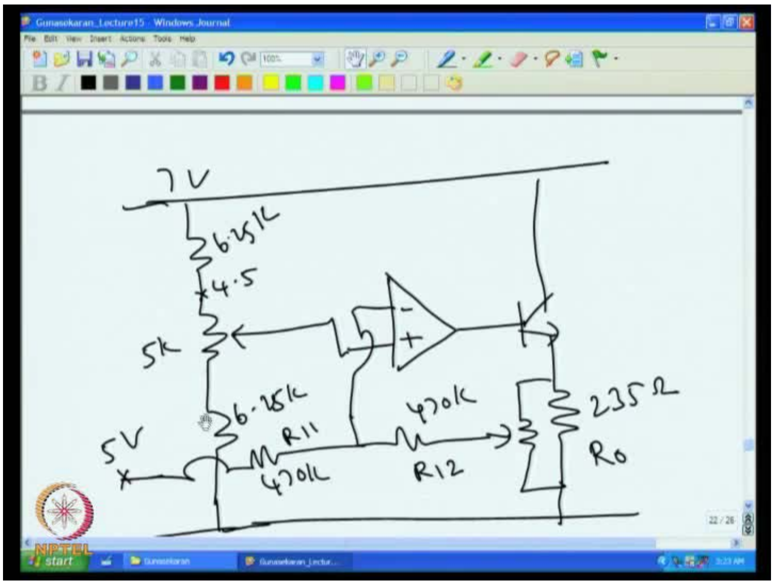


So offset voltage so expected change in the non-inverting input if it is 1.5 millivolt that is equal to expected change in the inverting input as well that is also equal to 1.5 millivolt if the 1.5 millivolt change require then the expected change at the output resistor that is this resistor I name it I think I again named it that is 235 ohms I call it is R 0 so expected change in across R 0

So the expected change across R not that is equal to 1.5 into that 470 k divided by 470 k divided by 470 plus 470 k that is equal to 3 millivolt

So the expected current change in 20 milliampere that is equal to 3 millivolt divided by 230 ohms that is equal to if I convert into micro amps that will be 3000 divided by 230 micro amps roughly I want 12 micro ampere current is expected change due to the offset voltage drift of the current converter stage

(Refer Slide Time: 45:13)



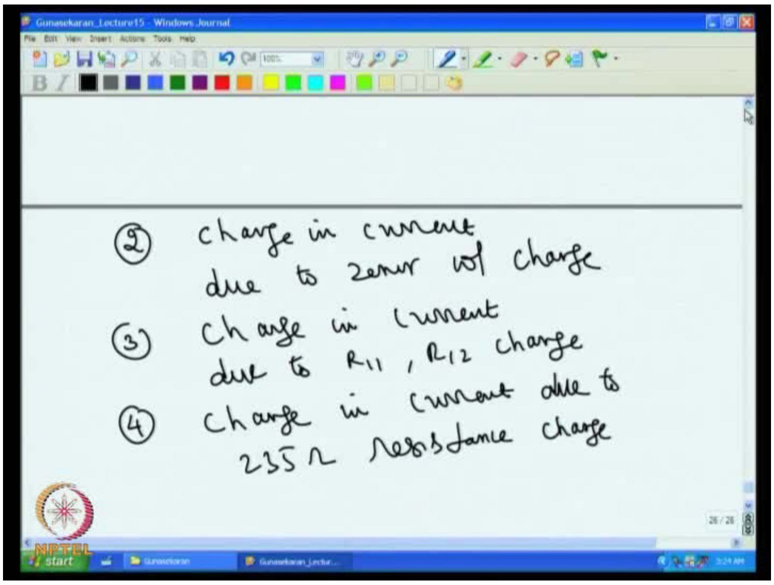
So if there will be error of 10 micro ampere this error of 12 micro ampere because of the offset voltage drift of the second stage this is considerably smaller compared to the other errors now let as pick up the other error one more error thus we are now seen that offset voltage drift of this produces 3 millivolt change here and 3 millivolt change will correspondingly produce 12 micro ampere current change through this next we let find out the what is the error due to the resistance drift as you consider these two resistors this 470 k and 470 k now let us name them actually this is take it as the R 11 and this is R 12 if R 11 and R 12 change with temperature then also output current is expected to change

So we assume one is increasing one is decreasing and we will also take 50 PPM drift so if I take this is going up by 50 PPM and this is coming down by 50 PPM in that case what is the main error now if this voltage is 5 volt then we know that this voltage this voltage at this point divided by this and this so if this resistance goes up this resistance comes down then voltage at this point will not be divided equal because we have taken 5 volt and this is equal to this and then we had taken the null point voltage is 2.5 and it is not going to be 2.5 volt and if this increases this decreases voltage at this point will decrease and that will decrease this current as well so we have to compute that error

Similarly never assumption earlier will assume that this voltage itself increasing by 15 millivolt because the Zener voltage drifts a 15 millivolt and because of the that we will assume that output voltage was changing and this 7 volt change was there and that will change here that will change the current will assume but then if this increase will also increase this and then that will also increase the current so that also we have to calculate that is another error that is left out for a computation

So we have one error left that is because of this resistance and the this resistance to then because of this resistance change this voltage change than voltage will change here that also will change the current through this then more importantly if this resistance changes then if this resistance drifts the temperature then the whole current will change so that also we have to compute similarly this resistance drift this resistance drift also will contribute for the change in voltage here and that will also change the current

(Refer Slide Time: 56:06)



So we have to compute all this errors so first we will list it and then we compute it in the next class so the errors that is to be calculated are so the second error that is to be computed is change in current due to Zener voltage change then we also have to compute change in current due to R 10 R 11 change I think it is R 10 and R 11 R 11 and R 12 change

Then we also have to compute error change in current due to 235 ohm resistance change that is I think we have named it as so these are the errors that we had to compute that we will do it in the next class now if we see this the various error completion is a very important because if we make simply 420 milliampere and assume that the current will not change with temperature that would be wrong now this gives the idea that what is the total change in current expected and which are the parameter which are very critical to reduce the output drift for example if I take the low PPM resistor then we can expect low current change in the output so with this I will stop we will continue in the next class

Thank you