Circuits for Analog System Design

Prof. Gunashekaran M K

Center for Electronics Design and Technology

Indian Institute of Science, Bangalore

Module No. # 03

Lecture No. # 07

Short Circuit Protection for Linear Power Supply

In the previous class, we were discussing about use of operational amplifier, and then I was explaining you what is the linear voltage regulator out of in a regulator output voltage from under (( )) voltage. In that connection, we have discussed about how to design a transformer, and how to design a heat sink, and then also I explained in detail how the regulator is working.

So, for this is good, now there is one more aspect we have to discussed in the voltage regulator, that is how to give a short circuit protection, because the short circuit protection are will be used in analog circuit at very many places, not only in the voltage regulator, even at other places that you will see as we proceed.

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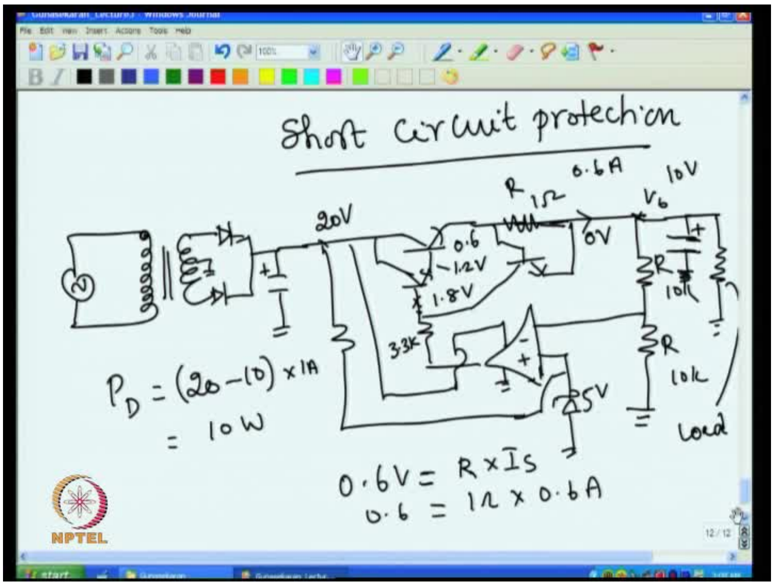

So, we will discuss now about how to provide a short circuit protection. So, our topic today is short circuit protection. Now, let us see our circuit that we have discussed so far, the derivator circuit; that is we have the input AC, and then we had this through this step down transformer, we are rectified that into DC, then the unregulated DC is obtained here and that is regulated through the use of transistor, series pass transistors this is called. Then, you have the output voltage that all over is here, that is feed back to the… We had this operational amplifier, so the operational amplifier had given the output and then this point is given a feedback.

So, this is the regulator circuit that we are seen so far. So, essentially you give an unregulated voltage at this point and get a regulator voltage at this point, and this is reference voltage and this is the feedback point (Refer Slide Time: 02:25).

Now, we can get whatever voltage we want, for example, if this is 5 volt here, and if I put here R and here R, say 10 k, 10 k and then I will get 10 volt regulator, this is what we are discussed so far. And then, of course, I have also told you that we at have one large capacitor to be connected at this point to ground, this is to avoid oscillations, so this normally analytical capacitor and then the load are connected here and this is the load (Refer Slide Time: 03:05).

Now, in this circuit, suppose if I connect a load, say 10 volt is here, and if I connect 10 ohm, then 1 ampere current will be flowing here. So, you will have 1 ampere current coming on that 1 ampere current, will be flowing through this transistor and then it will flowing through this (Refer Slide Time: 03:15).

Suppose, the output voltage is 10 volt and the input here is a say 20 volt, because it has to be more than 10. Now, if this is 20 volt, and this is 10 volt, then you have 10 volt across this transistor; the series pass transistor will have 10 volt and the other 10 volt is here.

Now, if load is 1 ampere current, then 1 ampere current flow through this and then 10 volt is present across this transistor, then the power dissipation on this transistor is power dissipation on this transistor, is 20 minus 10 that is the voltage divided into 1 ampere that will be 10 watts.

So, where we said 10 watts of power dissipation, and we have to shown last time that how to design the heat sink, so that junction temperature is kept within the limit. Now, what happens if I short circuit the load? Suppose, if the load short circuit means, it is of

10 ohms, I put as 0 ohms, then obviously if supposed to be 10 volt, then infinite current have to go, or other way round large current flows through this transistor. And then, if this is 0, if this voltage is 0 and then if this is 20, then 20 volt across this. And enormous current flowing through this will heat the transient and the transistor gets destroyed immediately.

So, if there is a short circuit, automatically this transistor goes bad, this is because if this is 0, this becomes 0 and this is 5, immediately output of the op amp goes very high and then the output goes high, rise to high current. And since, this is 0, and high current is flowing through this, when you get enormous high voltage of dissipation here, and this transistor goes bad.

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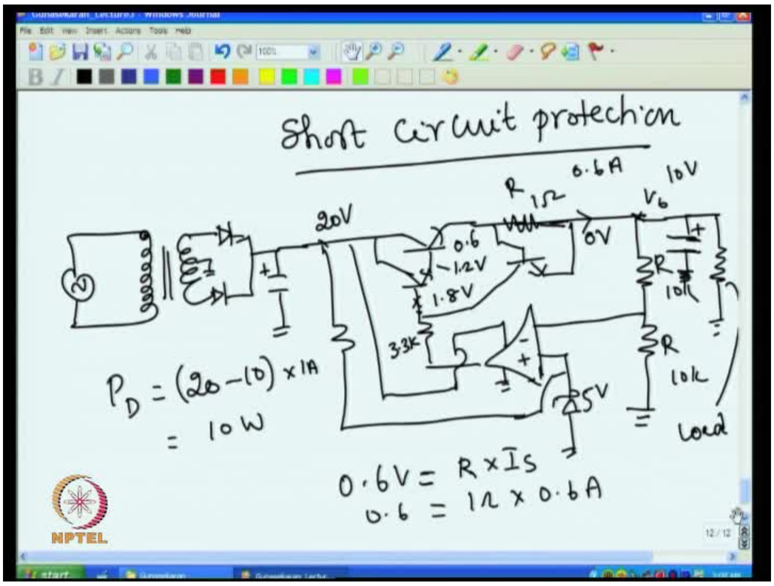

So, we had to provide short circuit protection, in sense that even if there is a short, the transistor would not go back. So, what is that we can do for that? Now, what is done is we had one series resistance here, now if I had a series resistance across this, then whatever current that is flowing through this will develop a voltage across this. So, voltage across this is this R into the current what that is flowing through this. Now, to this, what I have is a ladder transistor here, connect this, connect this and then connect the transistor here (Refer Slide Time: 05:20).

Now, this transistor and that is a this resistor and this transistor put together, this was short circuit protection. And even if you start this now, this transistor will not go back and there will not be large participation across this that is achieved using this resistors and this transistor. Let us see that how this works?

Now, as I said, you know the current that is flowing through this produce a voltage. If this voltage - the voltage across this resistance is same as voltage across this base and emitter of this transistor, so we know that base and emitter of the transistor voltage exceed 0.6, there is a 0.6 voltage and then we can say the appreciable current is flowing in the collector.

So, if more current flows through this, we know obviously there will be more voltage drop, and if the voltage access more than 0.6, that is then the base emitter voltage access 0.6, and this transistor start conducting, so current will be start at flowing. So, that current essentially comes from here and through this and then it goes here to this point. Suppose if it is grounded, then the current actually goes through this.

Now, the problem is that you have ordinarily, suppose if I do not connect this, short circuit protection is not there, then this current is only the base current and the base current is negligible, you know, this current what is flowing is negligible current, that is the base current, that is supposed to flow and that is very small. So, normally very small current is flowing, and there is no voltage drop across this resistance. So, there is no problem because of this resistance on this circuit, it works normally.

However, when the short circuit occurs, then the current flows through this, now there is a current that is flowing through this and there will be a current through this. And there will be a voltage drop, because this current will be high, because suppose large current flows, and if this is voltage start increasing here, then more current will be increasing.

Now, the question is how much current will flow? Because this voltage cannot go more than 0.6, because if it is goes 0.7, then enormous large current will flow through this and large current will flow here and that will develop a large voltage across this and that make this voltage at this point less. Because, once short occurs, this op amp, this voltage goes to 0, and this is already high, and this puts high voltage, where high voltage is normally depends on what is the supply that is given to this, normally the supply given to this is this.

So, in this case, it is 20 volt from short occurs, this puts voltage at this point, tends to 20 and then voltage at this point depends upon what is the current that is flowing through this and into this resistance. So, there is a voltage drop across this, and then this 20 will not appear as it is at this point. If there is a 10 volt drop, then near 20 volt, you will get only 10 volt here, but then if it is 10 volt, you needed this will be 9.4, and this will be 8.8, but then 8.8 and this point is 0, then the voltage difference so high, there is heavy current will go through this and then further large voltage drop will occur.

So, eventually what happens is this point will sit at 0.6, this will sit at 1.2 and this will sit at 1.8. So, essentially in actual case, this will go to 0.6, this will go to 1.2 volt and this point will go to 1.8 volt.

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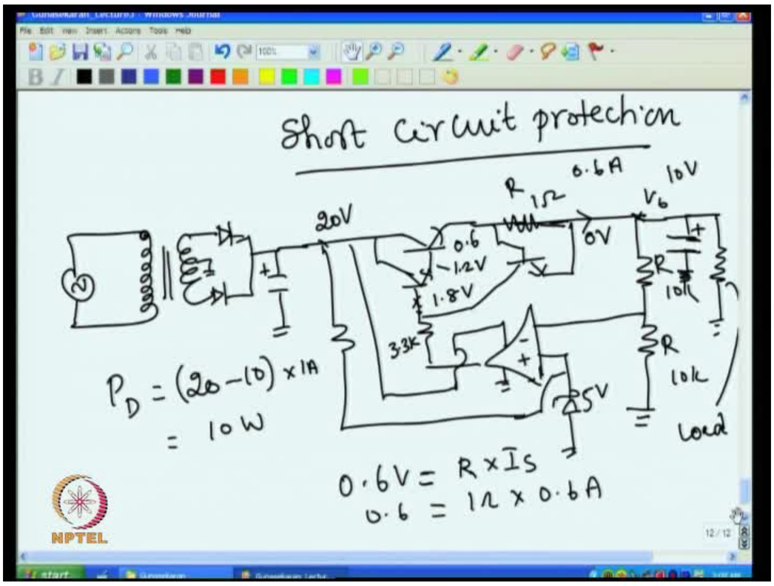

So, one short occurs, I have connect at this, so voltage at this point goes to 1.8 volt and this sits at 0.8, so this is 20, then obviously it depending upon this resistance the current flows, assume that this I had put say 3.3 k, then 1.8 here and 20 volt here, that will give me about 18 volt, 18 by 3.3 k, here around 6 milliampere current will flow through this.

So, you will have 6 milliampere current is going through this, and this sitting at 1.8, and this sitting at 0.6. Now, if you look at how much current that is flowing through this, now this is at 0.6, this is at 0, then the suppose if I put 1 ohm resistance here, then obviously to get 0.6 here, 0.6 ampere have to go through this, so this is 0 volt, and this is 0.6, and this 1 ohm, so the current is flowing through this is only 0.6 ampere.

That means even if I short circuit this, the current through this cannot be more than 0.6 ampere. So, that the current is limited to 0.6 ampere that is because of this resistance. So, eventually what really means is the I short circuit current is actually R into I s, actually is given by 0.6, because 0.6 is what it can come and that should be equal to R into I s. So, if I put R as 1 ohm, then 0.6 volt to come, then I s have go to 0.6 amps.

So, I can select R to get whatever current short circuit current that I will required, because in the normal operation, in the sense, if I put for example 1 ohm, then even in the normal operation, if the current goes more, and if you get 0.6, then this start conducting and it will get into current limiting more. So, if I put 1 ohm, then I can take only 0.6 ampere maximum in this case.

Now, this is a celebrated short circuit protection, because this is a full proof arrangement, and as long as you have this, and if the transistor heat sink, and the transistor rating is correctly selected, even will be short circuit, it never goes back, because this acts very rapidly, and it is a celebrated short circuit protection, everywhere it is used extensively. And it is a must for any voltage regulator, otherwise invariably this transistor goes back under the short circuit conditions.

One can select the different variation of resistance to get different amount of short circuit current, but there is one issue on this, you know, this we called the normal short circuit protection, there is one difficulty even with this. Now, for example, if this is 20 volt, if I if its is short circuit and I limited the current to 0.6 ampere by using 1 ohm here, in that case, under short circuit condition, you will have at this point 0.6 volt, at this point 20 volt and then 0.6 ampere going through this. So, roughly you have 20 volt across this transistor, and then 0.6 ampere going through that, so power loss across this will be 20 into 0.6, there is around 12 volt of heat dissipation will occur across this transistor.

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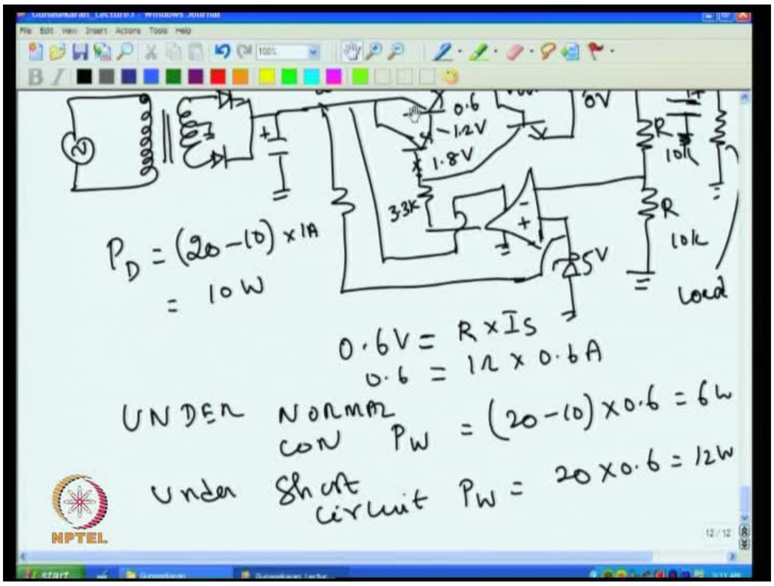

But then if you see the normally the working case, you know, if short circuit is not there, you will find that the 0.6 ampere is going, at that time this is around… 10 volt is here and around 10 volt here and 20 volt here, you have only 10 volt drop across this. So, 10 volt drop, and then 0.6 ampere current is what is the normal conditions. So, if you write like this, under normal condition power dissipation actually is 20 minus 10 into 0.6 that is 10 into 6 watt under short circuit. Under short circuit power dissipation, actually it comes full 20 into 0.6 that comes 12 volt.

You see the point here, that and the short circuit even though we are limited, the current that is flowing through this, but power dissipation is large, and this can go extremely high, because if the voltage high current regulator is made at the voltage is high. But more important is, we would design our heat sink for normal heat dissipation that is you know per 6 watt, but now we find that when the short circuit condition 12 watt is there. And if short circuit is left like there for long time, then this transistor dissipate 12 watt and the junction temperature will go much higher than what was calculated, because we would have calculated the heat sink for only 6 watt, and we would applied the heat sink for 6 watt. And for correspondingly the junction temperature would have been lower, but now if it is goes dissipate 12 watt, the junction temperature can go high and the transistor can go bad.

So, to avoid this, what we can do is we had to make a circuit such that the power dissipation is same even under normal conditions that is 6 watt, and even on the short circuit conditions, the power dissipation is should not go to 12 watt, it should be made 6 watt. Then, the same heat sink what we had designed under normal working condition can be utilized, and even if short circuit is left for long time, this chances have will not go back, so it is essential, otherwise I have designed a heat sink for 12 watt, even though in the normal condition the 6 watt heat is only dissipated in the transistor. But then, this designing heat sink for 12 watt is a waste, because it will be very big and it is not necessary one can make such that under short circuit condition also, only 6 watt heat is dissipated and that is very much essential to reduce the cost and size of the unit.

So, how to change this, because we want to make sure that not only current limited, under short circuit condition only a lower voltage cannot full heat dissipate lower watt heat is dissipated. Now, for doing that what we had do is, see normal current, you know, when the short circuit is not there, I want 0.6 ampere have to go. When short occurs, I know more heat is dissipated, so only of reducing the heat, it would be reduce in the current limit, it do not limit at 0.6 ampere, it is limited much lower than 0.6. For example, when short occurs, I should make sure that the current limiting takes place as soon as 0.3 ampere flows through this, in that case 20 into 0.3 ampere will give me only 6 watt of dissipation, but as long as short is not there, when output is a 10 volt, then the current limit should not coming into the picture, have to be 0.6 ampere, so that is to be achieved. That can be achieved by slightly modifying the circuit in the following manner.

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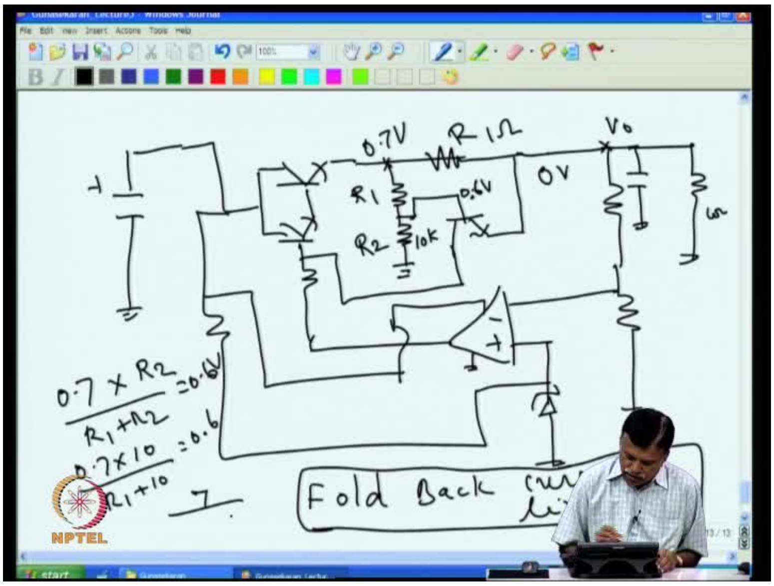

So, we can do that by modifying the circuit, so what I do is I will start the discussion from these capacitors. So, we have an input capacitor here, and then we had this series pass transistor, and then we had our output resistance that I put it here and then our output is here. This is our output point, and this is our load, take this, so this is the feedback for… and I put the regulator here. So, that is to be biased, so that I can do this, then this. And you know this is ground at here, and then we give a supply to the op amp like this.

Now, what I do is I will connect the short circuit photo resist transistor, but not directly I divide this voltage and operate this. I am connecting the short circuit protection, now this as usual to this and base will be connected to this.

Actually, we had in earlier case only this resistance and these transistors for short circuit protection. Now, we added these two resistors extra and terminated the base to the midpoint of this. And once you do this, we assume see that this circuit gives me the protection, the sense that one short occurs, then the current is limited at lower current, there is a in our earlier example, the normal current was 0.6 ampere, now I want limit this to 0.3 ampere that work is done by this and that to happens because of this voltage divider. This is a remarkable circuit, because one needs not unnecessarily over design the heat sink for the regulator because of this element. This is actually classically called fold back current limiting; this is called fold back current limiting.

That idea is a normal current should be much higher and short circuit current should be much lower that will make that heat dissipation on this transistor is same under the short circuit conditions as well as under regular work conditions. Definitely under short circuit condition, this should not go higher than the regular things, so we can avoid designing a weaker heat sink that is the idea of this.

Now, the question is how it is working? Now, we will name this resistors; this is R, I will put this is R 1 and this is R 2. See, the working is not very complex, because many people struggle a lot in understanding how this is working, and then invariably in student community this is a tricky issue, and very often student come and ask me how it is working and so on.

So, it is nothing difficult unit to understand, if you follow this carefully you can understand quite easily. See, the basic concept is that the base and emitter voltage if it exceeds more than 0.6 that will be conducting and then current limiting will take place immediately.

So, the question is when the voltage difference will be 0.6? Now, see under short circuit conduction what happens. Under short circuit condition, this voltage becomes 0, that means current limiting will take place ones this voltage goes to 0.6 volt, because under short circuit, this is 0 volt, so obviously ones it goes to 0.6, the current limiting should take place. So, when this will become 0.6? If this has to become 0.6, obviously this has to go more than 0.6, because whatever voltage is here, it is divided in this two and that voltage will appearing here; that means this has to go more than 0.6.

Assume that this goes to 1.2 volt, this goes to 1 point only, when it goes to 1.2, this comes to 0.6 that means what it put equal resistance, then 1.2 comes, then this will go to 0.6. Suppose that means I need 1.2 volt drop across this, if it is 1 ohm, suppose if I put this as 1 ohm resistance, then 1.1 ampere current flows through this, you will get 1.2 volt here that will give you 0.6, then the current limiting will take place at 1.2 ampere.

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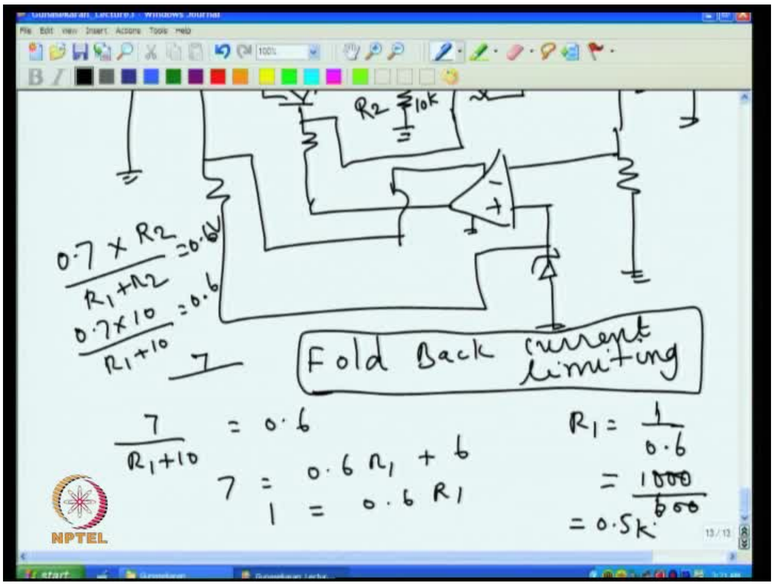

Or I can also do like this, you know, I want only 0.6, I can select not equal resistance here, I will not put equal resistance here and here, I put this values smaller, this values larger such a way that this is not 1.2, I can get 0.6 when this is say 0.9 or I can make it even at 0.7 volt when it is 0.7, here I will get 0.6. All that require is I have to select this resistance, for example, if I put here 10 k to get 0.7 what is the resistance value of R 1 that require? So, 0.7 into R 2 divided by R 1 plus R 2 supposed to be 0.6 volt, because I want at 0.7 the current limiting should take place when short circuit occurs. That means I would not limit the current at the 0.7 ampere at short circuit.

Now, in that case, what is the…. if I take R 2 as 10 k, then the I need 0.7 into 10 k divided by R 1 plus 10 that is equal to 0.6. Now, we can find out R 1 and then R 1 roughly will come around the 1 k, because if you calculate this back you will get 0.7 volt at the top and then down, actually you will get this. So, if you redraw this one that is 7 divided by R 1 plus 10 becomes 0.6. So, we can write 7 equal to 0.6 R 1 plus 6, so that will give you 1, will be equal to 0.6 R 1. So that will give you R 1, will be equal to 1 divided by 0.6. That is in kilo ohms, because we are taken everything in kilo ohms, so 0.6 R 1, so R 1 will be 1 by 0.6 that will be 1000 divided by… if I taking ohms so that I will… If I multiplied by kilo ohms so that becomes 1000 and that becomes 600.

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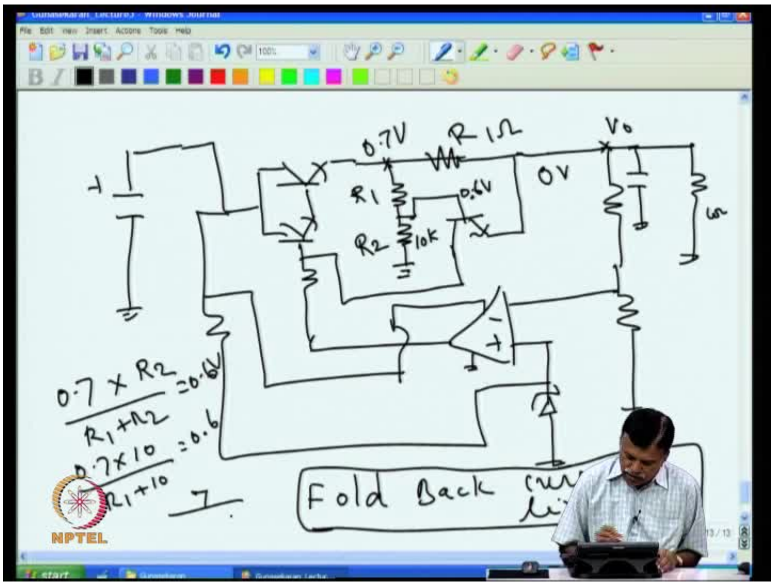

So that actually gives you roughly 0.5 k, so you will get R 1 actually comes out to be around 0.5. We finds that if I put 10 k here, then roughly R 1 comes to be around 0.5 kilos ohms at this point. So, if I put 0.5 k here, then 0.7 volt here, it will give me 0.6 here and that will limit the current. That means under short circuit conditions, when 0.7 ampere is flowing through this, you will get 0.7 here and then 0.6 volt here and then current limiting will take place at that time; that means at 0.7 ampere current limiting will be taking place. But then, see under normal working conditions, that when it is not short, then you will have at this point 10 volt, so at this it is not going to 0 volt and at normal condition this going to be 10 volt.

So, if this is 10 volt, and if want current limiting to take place, this point have to go to 10.6. Only when this goes to 10.6, current limiting will take place, because this is 10, so this only when it is going to 10 point, current limiting takes place. If it has to go to 10.6, this has to go if this point has to 10.6; I do not know this has to be more than 10.6.

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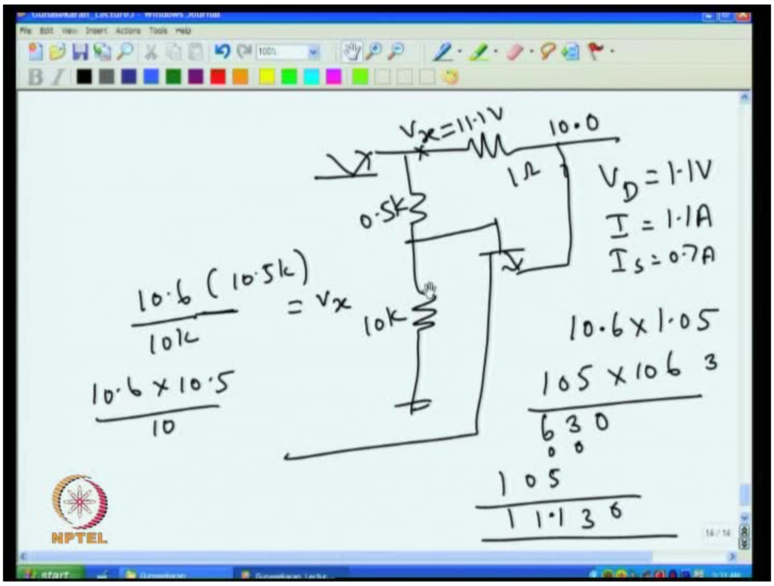

Now, what is the voltage required at this point? Now, if you calculate, if this is 10.6, and that is across 10 k, then what is the voltage across the other resistance? Now, we can go to next page and see, so essentially if I draw only that short circuit path alone, that circuit looks like this. And if I have… that goes to connecter, and that goes here, that is connect it here, so this is 10 volt, this has to come to 10.6, and we are said this 10 k, and this is 0.5 k we had taken. So, what is the voltage required at this point to get 10.6?

So, the voltage across this if I take that is 10.6, so you have 10.6 divided by 10 k into 10.5 k, that is the voltage, that is the v x, that is v x. So, if you calculate this, that comes to be 10.6 into 10.5 divided by 10. So, if you calculate this, we will end up in having, for example, this 10.6 into this revision if we remove, 1.05 will be coming. That will make, this go to, I can multiply this, so we can see, if you multiply this, you will end up in getting, so you get, 0s here, and simplifying, that actually you will find that there is something wrong here, 10.6 into 1.05 1 naught 5, so you get 33, 6, and you will get, I have to move this out, there is a mistake here to move this outside, so you will get 5, I am get 6. So, I remove this again, so you will have, this is 501, so that comes a 3 1 1 1. So, we will have 11.1 volt supposed to come here that essentially means this will be equal to 11.1 volt.

That means, only when 11.1 comes you will get 10.6. Now, you find that difference between these two points for short circuit condition, you know, the difference between these two points is 1.1 volt. In the earlier case, it was only 0.7 volt, now you need 1.1 volt that means if I have taken 1 ohm resistance in our example, we have taken 1 ohm and then current limiting a short circuit condition took place at 0.7 ampere.

Now, if I take the same 1 ohm here, then to get 1.1 volt difference, because this is a 10, and this is 11.1, to get the v difference of 1.1 volt, I need current of 1.1 amps. That means on a normal condition this limits the current at 1.1 ampere, under a short circuit condition it limits the current at 0.7 amps that is what we had seen in the earlier workout. So the that means under short circuit condition, we can limit much lower current, then what is available under normal working condition?

Now, this is possible because we because of this voltage division, if I keep this resistance larger, than even I can make this ratio much larger, because I can make it 1 is to half by selecting this resistance suitably, that you can work out and see how to select for different amount of current.

So, essentially by selecting these two resistances, one can get different current for short circuit and different current for normal working, this is very important. If you do that than one can limit the current at whatever rates that is required, whatever current that is required for short circuit and whatever is the normal current that is required for normal working.

So, this about fold back current limiting, you work out for different resistance, you will get the idea of how to reduce the current under short circuit conditions, but actually the basic principle of working is like this. The voltage that is there across this resistor, voltage across there this resistor under normal working, because an normal working conditions you have 10 volt, and that 10 volt also will be refluxed here, that 10 volt is divided between these two resistors.

So, there is some voltage drop across this under the normal work condition, that is working as a reverse biased for this, because this is 10, and if this is in the normal loop, for example, if there is no current, if there is no current, and this is not going to be a 10, because if this is a normal current, there is no current. If this is 10, this also 10 and this is not going to be 10, this going to be around 9.5 volt; voltage at this point going to be 9.5, this is 10 that means this is 9.5, this terminal, this is already reverse biased.

So, voltage across this transistor, even if I take the voltage across this transistor in the normal working conditions applies a reverse voltage, so under short circuit condition there is the voltage across this is very small, because the 10 volt at disappear and here also it disappear, so there is no voltage across this under short circuit condition due to this 10 volt. The net result is, under normal working condition you have this transistor reverse biased and that reverse biased disappear movement is short circuit. So, it limits that much lower current that is the threads of issues if you forget about the mathematics beyond this, because if you mathematically remember, it is very difficult to design the circuit.

So, if we remember as a reverse bias, and following this example, it will be very clear that fold back current limiting works depending upon the voltage across this. So, one can alter these two resistances to get the required short circuit current. So, this is about short circuit protection given to the voltage regulator, now we had made a long journey in the voltage regulator, because our idea was how to use the operational amplifier as an error amplifier in the voltage regulator.

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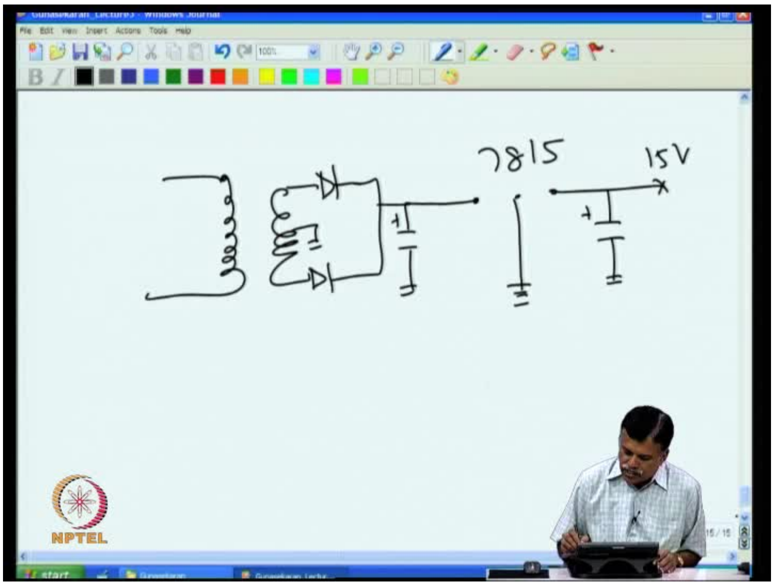

Now, these are available as a, three pin regulators available in the market today, which has all built in protection what I had discussed so far that is, for example, all that user decide that you can have the suitable transformer, which I have discussed how to select, so I have the rectifier, and then I have the suitable capacitor, I told you how to override the transformer, and how to select this capacitor, all that you do is you put this regulator here.

And that regulator, for example, I connect these two ground, for example 7815 there, and then you will get an output voltage at this 0.15 volt. And this unit, there is the short circuit protection what I had discussed, some of they have fold back, some of they have the simple short circuit protection and some of they have short circuit protection plus sensing the temperature and setting down all that. Of course, the heat sink to be design, as I discussed in the circuit and transformer also is design as I discussed. May be you will say, on this operational amplifier, and the circuit that went along with that in the revision, that is already built-in in this. Of course, what discussion that we are had according how to design a voltage regulator will be useful at very many places, even though you are not using that type of regulators right now.

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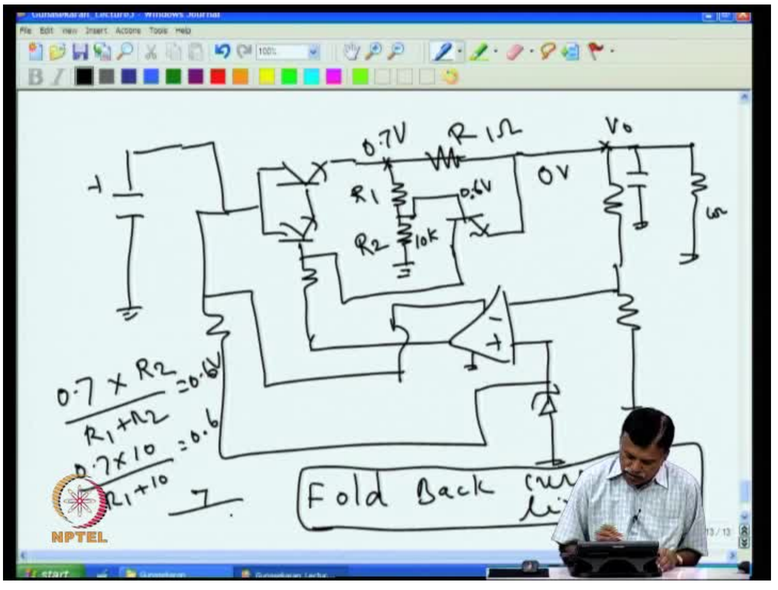

For example, you want to is high voltage regulator, then one must have a circuit which I have discussed earlier, for example, if you want make 100 volt regulator supply, then you would not be getting this 7815 regulated for 100 volt, in that case we had to design a new circuit that actually goes like this. For example, the existing whatever the circuit we are discussed, when at work for 100 volt, because the op-amp cannot give more than 15, because if I see the circuit which we are discussed so far, results if we take this, voltage of this point has to be more than output voltage. Suppose if you want output 15 volt, then

I know this can go up to 15.6 like that, and this has go to 16.2 and 16.8, this has to go to 16. If you want 100 volt here, then this has to go to 100 volt or more than 100 volt, and that mean this has to be more than 100 volt, and you will not get op amp for 100 volt. So, this circuit will not be useful for high voltage application. Of course, this can be straightly modified to make it work for high voltage and that modification I can show to you now.

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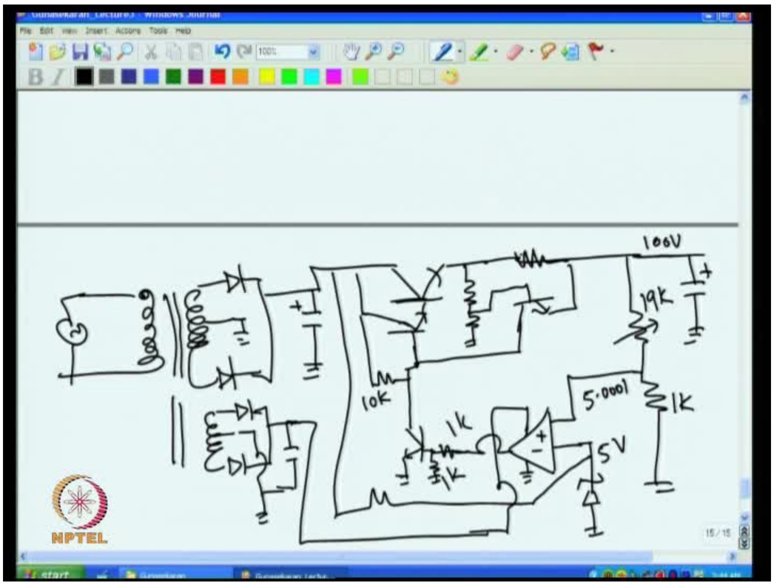

So, what can we do is, for high voltage, we can change the conversion like this, we have the transformer and we have the rectifier. Of course, the transformer to be of… Now, if we want high 100 volt, then we need to have at least 140 volt and 150 volt depending upon up to what input voltage you have to get, 100 volt output, depending on that you can select that discussion, is a same as what we have discussed in earlier. So, I put here the rectifier and filter arrangement, and then similar arrangement I give you with what you are discussed so for that with this serious parse transistor and one Darlington to boost the current; this is similar to what we are discussed so far. Then output also you have, if you want you can prove a short circuit protection, because this short circuit protection is the most in all cases. So, we will give a simple short circuit protection here, whether high voltage or low voltage that remain same, so I will put a short circuit protection and connect to the base.

Then, you get output; output again I have to put a capacitor to avoid oscillations, this we discussed little later. Now, I will take the output and same way I will also give a feedback by taking the part of the output and then give it to the operational amplifier. Here is the change, you will give… Now, to plus input this… and then minus input I give the reference.

Then, supply for this op-amp cannot come from this, (( )) because op-amp cannot take the 100 volt supply, so I put one more rectifier and filter. And this ground is same as this ground, but only thing is this is the only a small voltage, 15 volt secondary, this is 100 volt secondary, so we will get 15 to 20 volt only at this point, not high voltage. This voltage you can give it to operational amplifier supply, so I give this to the operational amplifier supply.

So, operational amplifier now gets, it is (( )) because you cannot give 100 volt to this. Now, what I do? I will connect this fellow, the output. So, if I connect directly to the output like what we are done earlier, it will not work, because this supply voltage what we have is only 20 volt, and this cannot go more than 20, in the sense that invoke if the supply is 20, then this cannot go more than 20. So, if I connect this here, then this output it can go 20, not more than 20, because if this itself 20, then you have to go 20 here, 19.4 here, and 18.8 only maximum possible, but we want 100 volt. So, we cannot connect this directly to get high voltage output here.

Now, what we will do is we want high voltage, so what I can do is I do not give this directly to the output, I give it to example, I can have a transistor arrangement here, then connect this to the collector and put this transistor here, resistance here.

Now, this works as a high voltage regulator, what you have done is instead of connecting the output to the base of the this transistor, we have connected this output through this transistors and this resistance arrangement such that you will get high voltage at this point and that is transmitted here. Of course, if the voltage goes high, then this goes high, then this will go high, and then if it goes high, then the current will flow more and this current also will be flow more. So, more current flowing here will reduce the voltage at this point that will reduce the voltage at this point that is how it regulates, so if the suppose the voltage goes to low at this point, then this is low, this is high, so output goes to 0, because the minus is higher, to suppose to go minus, we have no minus supply, so output goes to 0. And if it goes to 0, the no current flows through this, the no current flows through this.

No current flowing through this, there would not be any voltage drop across this. If there is no voltage drop, then this voltage goes high and then output goes high. So, essentially if the voltage goes high, then immediately this conducts more and brings down this voltage and output comes down. If the output goes too low, then this goes low and then less conduction, and less conduction here, and this voltage goes high and output goes high that is how it regulates.

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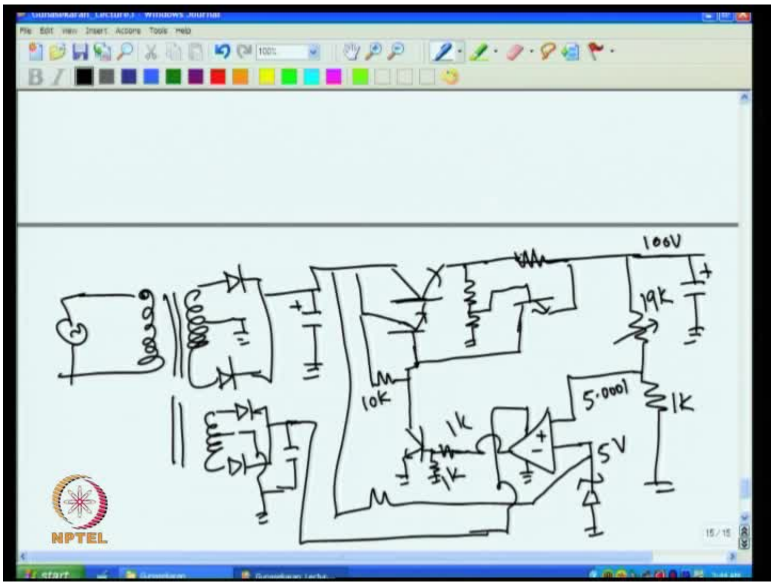

So, the regulation is a similar to what we have discussed, only things we are new common that is this, this; that is this resistance, this resistance, this transistor and this resistor come extra, so that we will able to regulated at the get high voltage. What really happening is, this is acting as a another amplifier to amplify the voltage, for example, if this voltage increases, essentially more current flows through this, and then more current through this and voltage at this point comes down.

Similarly, if the voltage comes down here, automatically the voltage increases here. Of course, we can by so by varying a small voltage, we able to vary large voltage here, for example, if the resistance of a put here is a 10 k, then 1 milliampere current flows through this, you will have a 10 volt drop. That means whatever voltage is here, 150 is there, then 10 gone here, means you will get 140 here. You want bring out the 100 here, then I have send the 5 milliampere current ampere, if this for example, if this point is a 150, and if I want to bring this one to 100, then 5 milliampere current have to go through this. For that 5 milliampere discover voltage have to increase, that is why the small increasing voltage will increase the current here, and that will increase the current here and that will reduce the voltage.

So, small change can being a large change at this point, that is what happening, then that also changes here and you will able to get change here. So, anyway, if the voltage at this point is kept at 5, and this way also will remain at 5 only, which will be the difference, it will not be exactly 5, it will be you know, this has to be positive, so it will go little more than 5.

So, for example, to make this to conduct, if I put for example, I put here 1 k and 1 k, I know this has to comes to 0.6, this has to be around 1.2, it has to be 1.2, then the difference required is 1.2 divided by the open loop gain, because if I want to 1.2, 1.2 divided by open loop gain which is very high 20000, then I need only a point 1 millivolt difference, so this goes roughly 5.0001. So, it goes little higher, and that raise if the voltage goes little more, then more voltage will come here, and then it will conduct more current, then the more current here, and it will reduces this voltage and output also comes down.

So, eventually, if I keep this one at 5 volt, this will also come to 5 volt. And according to the ratio of these two resistors, the output is determined. For example, if I want 100 volt, then what will I do is if I take here 1 k, and if I put 19 k here, I know across this 5 volt, across this 95 volt, because 1 k is 5 volt means, 19 k is the 95 volt, so 5 plus 95 will give me at this point 100 volt.

So, will have 5 volt here, so 5 volt across this, and then you will have 95 volt across this and you will get the 100 volt at this point. So, you can similar to earlier case, you can vary this resistance and the get the variable voltage at this point. This is having the high voltage, (( )) the short circuit protection is controlled by this; this is same as what we had discussed earlier. We can also provide fold back and limiting even to this, so far that is what we will do, we do same thing, will remove this, then put the voltage re arrangement here, and connect this with here, then it gives you fold back current limiting that we had discussed earlier.

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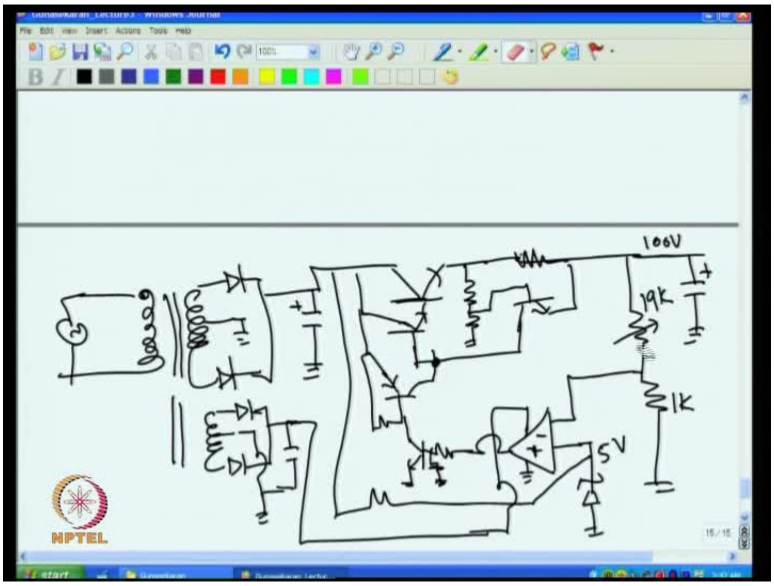

So, this is a configuration for high voltage, and of course there are few other configuration also can be used for a high voltage regulations and this is one of them. For example, I can modify this and get a different circuit for high voltage, I show you one such a modification, what you do is even I can get high voltage, remove this flow, this circuit. Now, I can do one thing, I can put one NPN transistor here, put one resistance here, connect the collector here and then connect this. Of course, I have to connect the transistor here, the same circuit connects this.

This also works well, this also gives you the high voltage regulation, what you have done is we have removed that… these resistors directly connected. Now, we have connected through here PNP transistor this; this has several advantage over previous circuit, because if this voltage, if voltage at this point goes up, then more current goes here, then more current goes through this.

The more current will produce a more voltage drop across this, and that will put a more voltage at this point, for that I once voltage across this goes more than 0.6, this will be start conducting. So, essentially this voltage increases, then you will have increased current through this, because this base current is increasing, that will increase the collector current here, that collector current in virtually comes from here. So, essentially you will have more voltage current flowing here, is a more voltage drop.

If the voltage across this goes more than 0.6, then you will have more voltage at this point. So, increasing voltage increases this voltage and increases that voltage at this point. That increase voltage here, that will increase here, and then that will increase this, and further increase this, so it will go into positive feedback. So, if I use this circuit, all that I do is I will change this, you know, instead of minus I put plus; minus there and then put plus here.

So, now if the voltage goes up here, if voltage at this point goes up, then this voltage also goes up that will make this to decrease. The decrease in voltage will decrease this current that will decrease this current. So, that if the voltage decreases here, voltage across this also decreases, that means you were reduced the base emitter voltage of this. The base emitter voltage decreases, obviously this voltage will decrease and then this voltage also will decrease, so that is how it is acting as a negative feedback.

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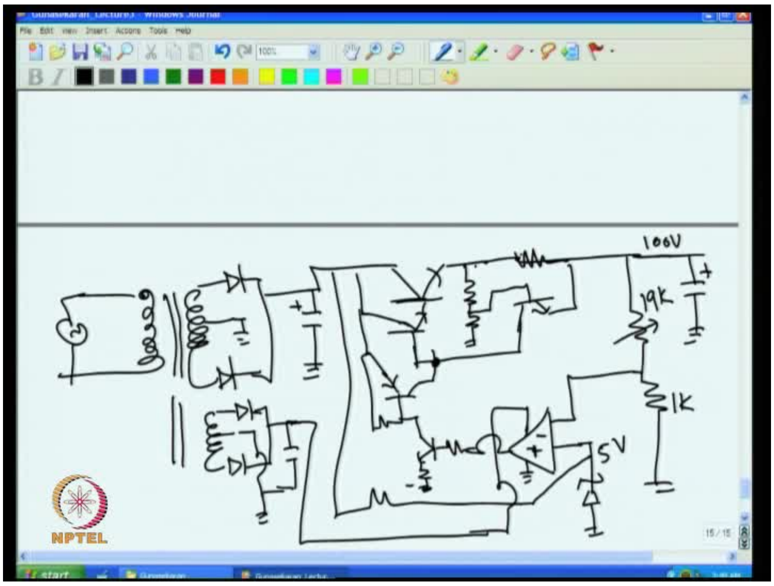

So, if you said at 5 here, these are eventually will come at 5 and depending upon this resistance ratio, you will get your output voltage. So, you can also have this kind of configuration for voltage regulator, of course you will soon find that it is useful if I put one small series resistance here, do it rather than do need for example, I can modify this circuit further to get much better regulation, like I can have this, I can put one resistance here, and ground it and connect this and connect this.

In fact, this circuit was much better, because if the increasing voltage will increase the current here that will increase this voltage. So, this voltage across this acts as a negative feedback, so the gain is controlled tightly, because if so on increase, if we increase the current here, that will increase the voltage enormously here and this voltage cannot go more than 0.6. So, to control the gain we can add an emitter resistance, and make it work and it works in a controlled fashion.

So, this circuit also works nicely for high voltage application, in fact this is better than other two circuits. Reason for that you can see, because in this case, if the power supply for this is not reached first, for example, if the power supply for this reached not reached first, then this voltage would not be there. If this voltage not… there is no conduction will take place, if no conduction is there, no voltage drop across this that will make 0 volt appear here and 0 volt here. That means, unless the power supply arrives at this, there would not be any output voltage. This is not the case in the other circuit, which you can see quickly, for example, if you see the earlier circuit, our high voltage circuit what you have seen, I thing we were removed that. For example, in the high voltage circuit of other circuit, there is you know without this for example our old circuit…. We get put this resistance directly here, and then connected this here and then we were modified this.

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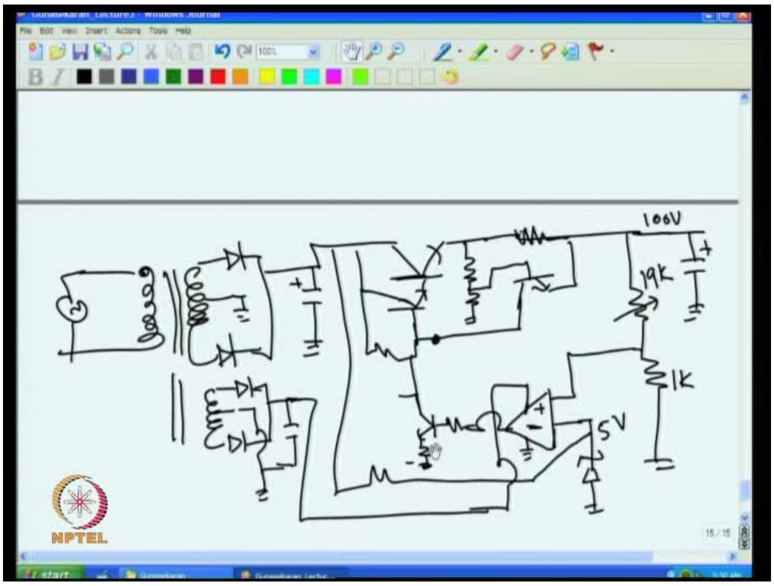

Namely this was we had this, this is plus and this is minus, this circuit, if there if supply for this comes late compared to this, that is if this supply comes first, and this supply comes late, then you will find that when there is no voltage is here, 0 here, then no conduction takes place here and this voltage will be high, because there is no current through, this voltage will be high and output will go high.

That means, initially you will get a high voltage output, and then it will set will to the regulated voltage in this case, whereas the second circuit what I had shown that problem is not there. So, the spike problem is avoided by adding one more transistor there, which I had shown earlier.

So, this is what we had seen in the voltage regulated circuit, that is for low voltage, how to uses, how to connect the circuit, how to connect the op amp, for high voltage how to connect the op amp and the transistor. And then also discussed about the current limiting, both normal current limiting and the fold back current limiting. Then I have also discussed about the heat sink design and that transformer design, this completes the complete design of voltage regulator.

I think you might be understood now that voltage regulator itself has lot of things that has to be learned like how to design a transformer, how to design a heat sink, how to design a closed loop, then how to avoid the spike and so on, many things we were learnt. And we will use these concepts in the coming weeks, in the coming lectures, in the analog circuit design course. We will see in the next week; thank you.