Circuits for Analog System Design
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Lecture No. # 13
Short Circuit Protection of Power MOSFET

Today, we will talk about other applications of the transistors, because so far we had discussed how to use the transistor for a temperature compensation, how to use the transistor to drive the load, etcetera, we had discussed. Today, we will look into the linear power supply and see how to use the transistors in series and parallel, to push the power and then to push the voltage requirement. Similarly, we also discussed about how to use the MOSFET today, instead of transistor in different applications, like linear power supply and so on.

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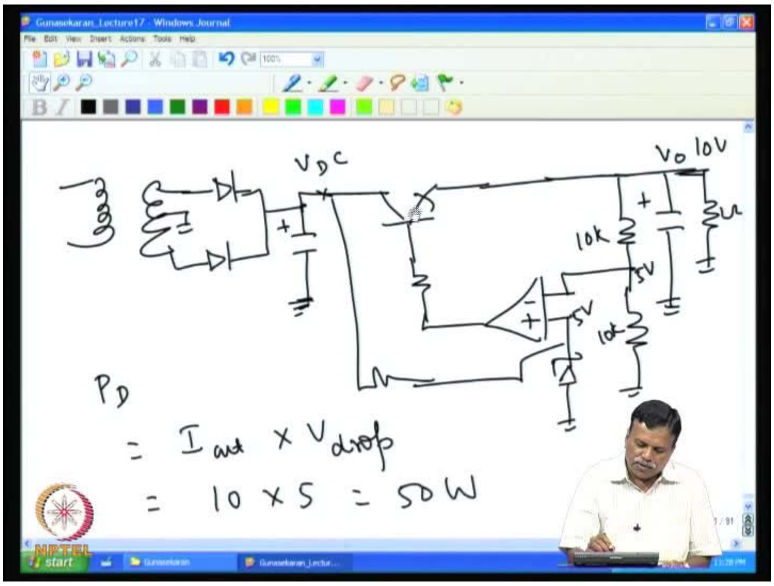

So, first let us take how to use the transistors in parallel; so, transistors in parallel. Because, if you want to increase the power capacity, then it is essential to increase the put the transistors in parallel. Let us take a typical linear power supply and then see how we can do this.

So, in a typical linear power supply, we have the transformer and then the rectified voltage of the transformer - we had taken this; so, we have rectified voltage of the transformer is coming here and that actually we want regulate (Refer Slide Time: 01.35).

So, this we already discussed, so we get unregulated D C here. And then, to regulate this we had put an error amplifier and we had given the feedback and this is connected to reference voltage and then we have connected this output to this (Refer Slide Time: 02.17). And then we invariably connect the output to one capacitor to avoid oscillations. So, this is coming as a V output.

This is a typical voltage regulator that is used in regulating the linear voltage - in regulating the DC voltage. So, the unregulated DC voltage whatever is here that appears as a regulated voltage at this point (Refer slide Time: 02.51).

Now, that is regulated against the reference voltage; for example, the reference voltage is 5, then we know this also has to be 5; for example, if these voltages are resistances are equal, if it is 10 K and 10 K we put, then if this is 5 volt, then we know this has to come to 5 volt (Refer Slide Time: 03.03). If this point goes more than 5, then automatically output comes down and then that is followed here, this output comes down and then this output also comes down (Refer Slide Time: 03.19). If this voltage goes down, if this also goes down below 5 volt, then this voltage goes up and output also goes up. That is how it is regulating. This we had already discussed in our earlier class.

Now, our focus here is how to select this transistor, how to use them in parallel. For example, if I want to use for a high power, for example, if I want output load here, so suppose, in this case if it is 10 volt here and if I put 1 ohm resistance, I need to have 10 ampere current flowing through this; now, the 10 ampere current have to go through this transistor (Refer Slide Time: 03.50).

Then, power dissipation on this transistor would be - power dissipation would be - that, I output into voltage drop - voltage drop across the transistor; so, if this is output, if input says 15 volt, if the output is 10 volt, then you have 5 volt across this and 10 ampere current flowing, it will create a 50 watts dissipation (Refer Slide Time: 04.27). So, this will be 10 ampere and 5 volt drop that will give you 50 watts dissipation. We already seen earlier, that kind of power dissipation will take the junction temperature to very high value, because junction temperature determines the life of the transistor and DFD of the instrument again depends very much on power supply, particularly, the life of this transistor decides eventually the life of the equipment.

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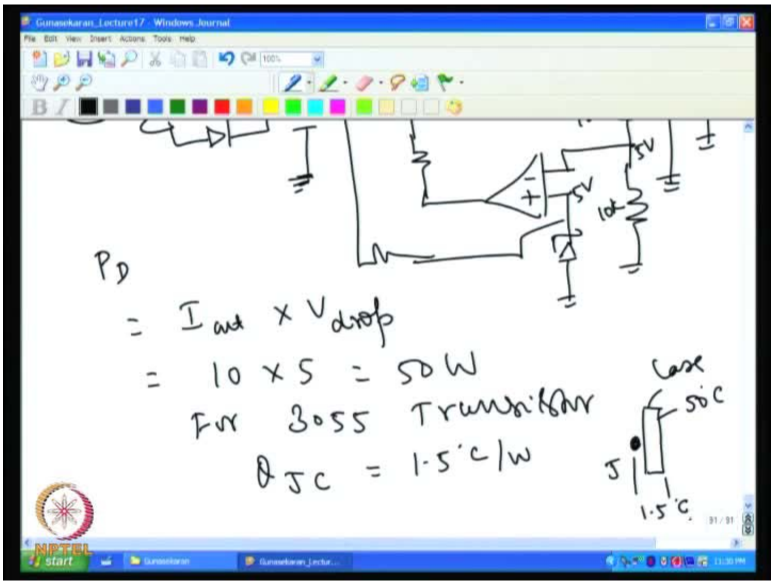

So, one has to make sure that the temperature of the junction - temperature of this - is normally not going more than 80-90 degree to get a long life. In that case, even putting a heat sink will not be enough, because that will demand very high heat sink or even the high heat sink also many times not enough, because - if 50 watts dissipated - for example, if we take 3055 transistor, for a 3055 transistor theta between junction to case, that is, junction to case is 1.5 degree C per watt, that is, 1.5 degree difference temperature required between junction and case to dissipate 1 watt of heat.

That is, from the junction, if the heat comes to the case - this is the case and this is the junction - (Refer Slide Time: 05.38) if 1 watt heat has to come out, then the difference required is 1.5 degree. So, if there is 50 watt dissipation and then we need 75 degree difference in temperature between junction and case. If the case itself, at 50 degree, then junction automatically will go 75 degree above this, that will take it 125 degree - that will make the life of the transistor very short.

So, in many cases, it is not possible - even with heat sink it is not possible - to achieve the required junction temperature. If we see here, we had taken the case of the transistor as 50 degree C. If we keep the case of the transistor at 50 degree C, we - have to - have a bigger heat sink, because normally ampere itself goes many times more than 50 degree. For example, if the - if the - industrial grade equipment, the ampere itself to be considered as 85 degree C. So, it is very much essential to have transistors in parallel in terms of heat dissipation also other rather than current flowing through that. So, how to connect the transistors in series in parallel to reduce the heat dissipation, as well as to share the current?

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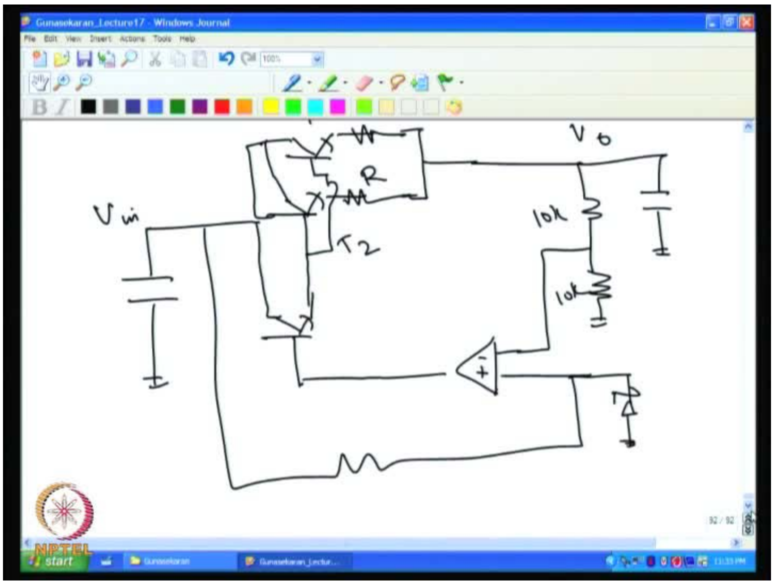

Now, we can do that by connecting (Refer slide Time: 07.30). For example, two transistors connected here, the collector and collector can be joined, then the emitters are joined through a resistance rather than shorting them directly. And then we join the bases together, and then this can be connected through the error amplifier or it can be even driven through a darlington pair; so, that is a V input and then this is actually driven by the output of the amplifier (Refer Slide Time: 08.12) and the rest of the circuit is similar to what we had discussed so far. So, I connect the feedback here and the output here (Refer Slide Time: 08.23). So here, we have connected the two transistors - T 1 and T 2 in parallel and only thing is we have put two resistors in equal values - R and R in the emitter circuit to balance the current. These two resistors are actually to make the currents in T 1 and T 2; so this current must be equal to this current; to make them equal, only these two resistors are added.

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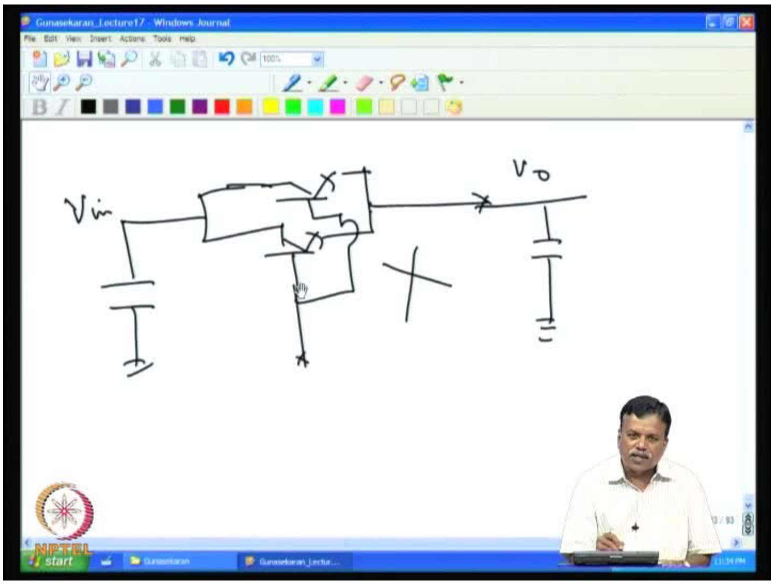

So, this is the essential point - that one not understand in connecting the transistors, without these two resistors, then current sharing will not be assured. This is because, if I connect them, for example, if I connect them directly in parallel without having the emitter resistance; then you have this arrangement. So, we put the V input here and then we get the V output (Refer Slide Time: 09.33).

Now, in this case, this is actually not the acceptable circuit, because the bases are at same potential, the emitters are the same potential, collectors are the same potential. So, both the transmitters will have same base-emitter voltage, this transmitter base-emitter voltage is same as this base-emitter voltage, equal to this base-emitter voltage (Refer Slide Time: 09.59).

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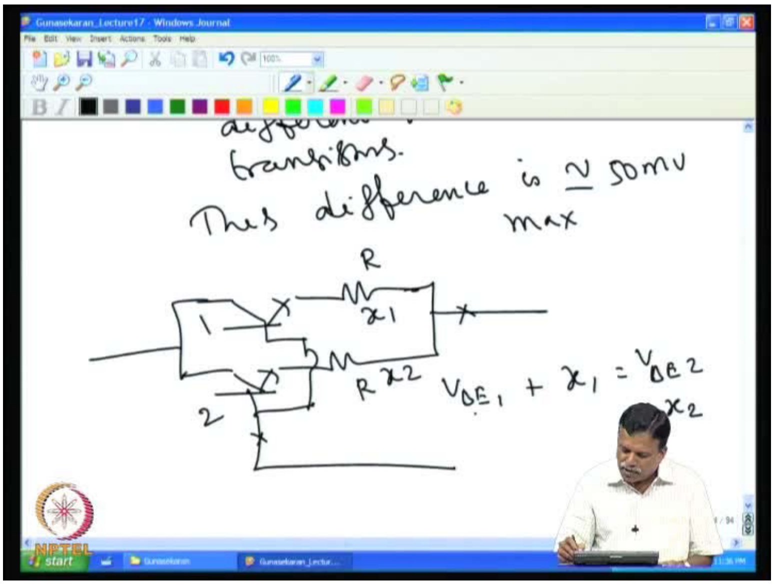

But then, if you look at the characteristics of the transistors, that base-emitter voltage, there will be difference, because for the same - current - collector current - what is the required base-emitter voltage for this and this? There will be a difference; the difference goes up to a maximum 50 millivolt. So, for the same current, for the same I c - collector current, V B E requirement is different for different transistors.

This difference is really 50 millivolt maximum; that means, we have to somehow take care of this 50 millivolt difference to make the current more or less equal. For that purpose only when you are connecting them in parallel, we are adding the two resistors in emitter equal values; so that is what we are doing. So, we take this and connect the two resistances, the emitter and then collectors can be joined, now the bases can be joined (Refer Slide Time: 11.45). Now, we know that the difference of 50 millivolt maximum exist between this base emitter and this base emitter.

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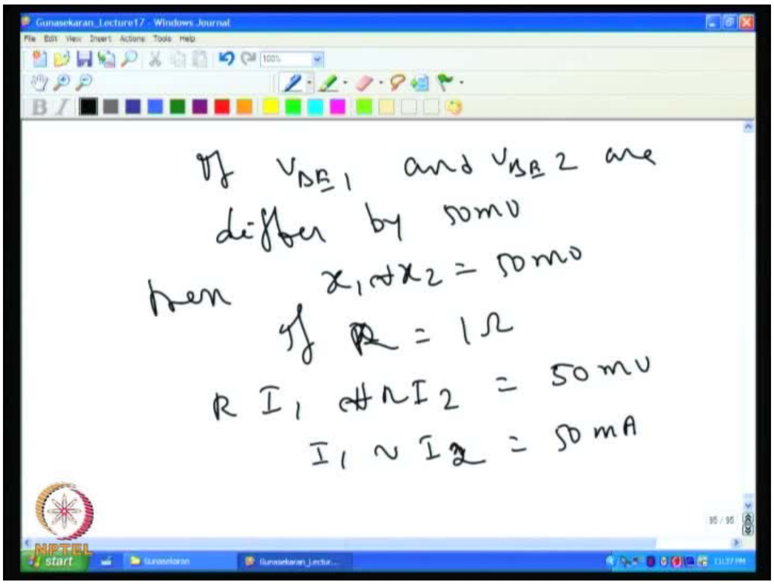

So, if I add these two resistance, now the voltage at this point and at this point are same (Refer Slide Time: 11.58); that means, V B E 1 plus R, I will call this as R, I call this as x 1, this voltage x 2; x 1 must be equal to V B E 2; this is the transistor 2; this is 1; plus x 2. So, if the difference between V B E 1 and V B E 2 are 50 millivolt - if V B E 1 and V B E 2 are differed by 50 millivolt - millivolt then x 1 minus x 2 will be 50 millivolt or rather x 1 minus difference yes millivolt.

So, if the resistance are x R 1 - R is equal to 1 ohm - then delta I current difference between them current difference because current x 1, then then I can write that, R into I 1 plus R into I 2 has to be 50 milli difference between R I 50 millivolt, that will make since R is equal to in this case, 1 then I 1 and I 2 has differ only by 50 millivolt; I 1 minus I 2 difference will be only 50 milliamps. So, the current difference is maintained within 50 milliampere; that is good enough if I increases the resistance of R, increase the resistance of R then even the current difference can be - if I personally put R is equal to 2 ohms - then the difference will become 25 milliamps. So, one can select R, such that the acceptable difference is maintained, but the 50 milliampere difference in 1 ampere current is more than enough for the normal applications. So, any number of transistors can be connected in series by adding the required emitter resistance to each transistor.

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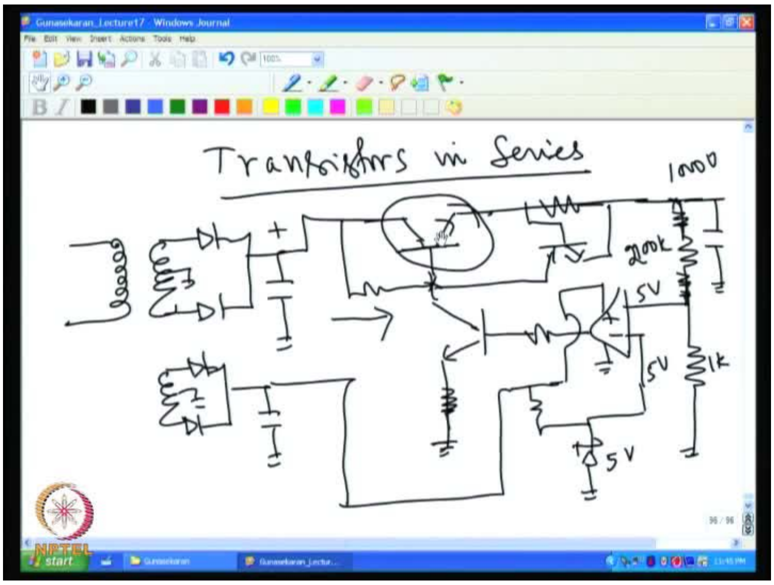

Now, let us see how to connect the transistors in series. So, we had seen so far how to connect them in parallel to share the current. Now, let us see how to connect the transistors in series to boost the voltage; so transistors in series. Now, let us take again the linear power supply; for example, assume that we need to have high voltage power supply, then our regular rectifier circuit is here. Assume I have a 1000 volt supply and I need only very low current, that 1000 volt regulator voltage I need; in that case, how will like I go about designing this circuit? For example, if it is high voltage power supply, I will actually connect the transistor like this; then you have the output and then to get a high voltage supply, then I had to reverse the design; so I have this and you have error amplifier (Refer Slide Time: 15.21), of course, to limit the current I put the. To make sure that the loop is stable, I put one emitter resistance here - I will explain about this little later - that we give the feedback. In this case, it is connected to plus and a minus is given to V reference, I can give this one to V reference, so the supply maybe it can be taken from here or it can be taken from a low voltage supply if it is available, because that we have anyway have to give to this transistor.

So, this can be fed from the low voltage supply rather than from here. So I take this output, then I connect this, may be here low voltage winding that is provided in the transformer can help you to power the zener and operational amplifier. So, this is a 5 volt zener and we want a 100 volt DC here; so, we have a output capacitor connected here to stabilize the loop (Refer Slide Time: 17.01). So, if we take this circuit, this is a voltage regulator, it is a conventional voltage linear regulator only - there is not much difference except that we have put this one in reverse form and we have also put one inverting transistor here to make it as a voltage regulator.

Now, we see analyze the circuit how it is working. See that this point is kept at 5, so obviously this also had to be 5. So, if the output voltage goes higher, then this voltage also will go high. If this goes high, then this output voltage will go high (Refer Slide Time: 17.58). The increase in voltage make this transistor to conduct more, this transistor conduct more, that current actually comes from here, so more current will flow through this. So, if the voltage increases here, more current will flow through this so the more current flowing through this will develop more voltage drop.

So, if we look at voltage at this point, voltage at this point decreases when the current through this increases, because if this is 1000 volt and if it is a 100 volt drop, then you will get 900 hundred volt (Refer Slide Time: 18.32). If more current flows through this, then more voltage drop will be here and you will get only less voltage here. So, eventually if this voltage increase, so this voltage increases that increases the current through this, that increases current through this and that decrease voltage at this point and we also get less voltage. If the voltage at the point comes down, then voltage at this point also will come down and current flowing through this will decrease and make this voltage to go up and the output voltage also will go up. So that is how the regulator works and makes it, if this is at 5 volt, and then this is also will be at 5 volt (Refer Slide Time: 18.32).

So, if I have for example 1 K, and 1 K then if I have 200 k resistance here, then I will have approximately 1000 volt at this point, because 5 volt across this and 5 volt across this; automatically 200 times, that is, 2000 volt across this and then you get 1500 volt (Refer Slide Time:19.48) . Normally, we do not put 1 single resistance per 1000 volt to limit the voltage rating, we put 3 or 4 resistance such that the voltage rating is not exceeded because the resistors have voltage rating as well as power rating. Even if power rating is not exceeded if the voltage rating exceeds, then the resistors can breakdown and then it will act like a short, that will damage the I c and the regulator also not going to work.

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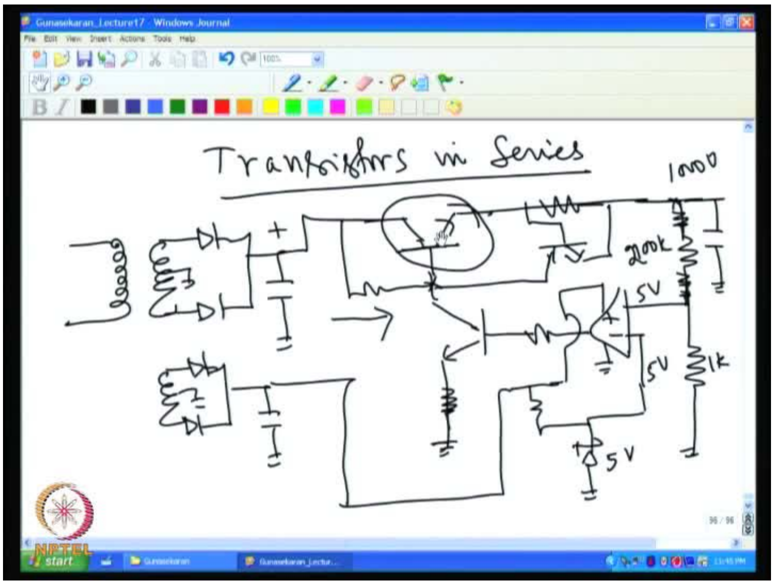

So, we may have to put normally about 250 volt that is what the normal resistor withstands. So, we may have to put per 1000 volt four resistors in series so that the voltage can be shared.

Now, see in this case, this will work all right only if this transistor - whatever we have - is having a voltage rating of more than 1000 volt, because we will soon see that in case if this is short circuited, we want to make sure that this is not going bad. For that, we add the short circuit protection circuit like; for example, we put the resistance here. So, whatever current that is flowing through that will develop a voltage across this. So, so to protect to give a short circuit protection, we add the transistor here and then connect to this (Refer Slide Time: 21.16).

So this transistor now protects the protects this transistor from short circuit protection that from short circuit. What really happens is, when the output in short circuited, then large current flows through this. So, as soon as the voltage across this exceeds more than 0.6, then the base-emitter voltage exceeds more than 0.6 that makes this transistor to connect and the current flows through this. So, whatever current that is coming here that actually goes through this; so the current flows through this the current flowing through that will develop a voltage across that, that will reduce the voltage at this point.

So, voltage at this point will come down automatically - just to make sure that the voltage at this point comes down - so more current goes. So eventually, if further current goes up, then this conducts further and make this voltage come down further. Eventually, if this is 0 volt and this is it at 0.6 and this will come to 1.2 volt, so current through this will go such that this voltage is down to 1.2 volt; that happens automatically, that is how short circuit protection is activated.

So, in that case, if we see when output is shorted, this is 0 volt and if it is a 1000 volt regulator, this definitely will be more than 1000 volt - it may be 1100 volt; that means, this transistor had to withstand 1100 volt - that V C E breakdown voltage should be more than 1100 volt, then only the circuit will work. So, we need to have a transistor which has sufficiently high beta, so that the base current is small and then it is able to withstand 1100 volt. Now, instead of looking for such a transistor which is difficult to get, one can have transistors connected in series to solve this problem.

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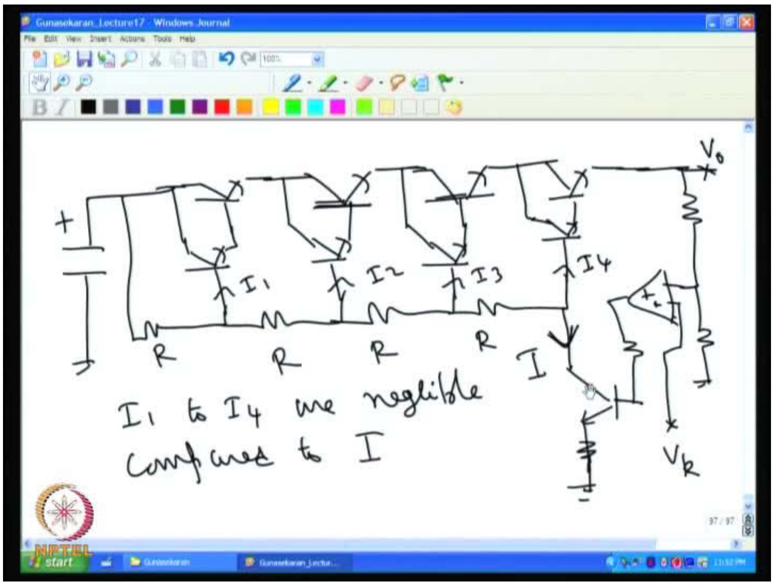

Now, what can be done is, if I want to connect the transistors in series, we can do in the following manner. Like I can take - because we want to make say - 350 volt transistors if I have, I can put four of them in series so that I will get - 1000 each one 350 volt that will make 1150 volt withstand capability (Refer Slide Time: 23.33). So, I can put four transistors in series like this. Now, when I put transistors, I put one darlington also that the base current becomes small. So, this also 300 volt - each one is only 300 volt - so I connect this each one on darlington and gives the output; so, this is our unregulated D C here. So, you have the negligible base current, because if we need, we can put one more darlington also if you want to reduce the base current here. So essentially, we have to have a darlington pair arrangement such that the base current is negligible; it thisis essential for this design to be successful.

So, what I can do this? Now, I add resistance - equal values; then for example, in this case, our regulated transistor can be this (Refer Slide Time: 24.48); if necessary, this also can be made parallel. Right now, I will not look into because this is only low power - 1000 volt low power transistors are available, it is not a problem. So, this can be connected to the error amplifier and the output we can connect to this and then minus voltage is connected to V reference, so that actually becomes V output.

Now, if you see the working of this that we have connected the transistors in series, it makes sure that they share the voltage here. So, we can use low voltage transistors many in series like this (Refer Slide Time: 25.41); any number of transistors can be configured in series in the same format so here. For example, we have to put these resistors equal and so we have all these resistors have equal values.

Now, assuming that these currents are negligible - that you have I 1, I 2, I 3 and I 4 - so if I 1 to I 4 are negligible; this is a very important negligible compared to I is the current that is flowing here, that is the current that is flowing in this and the current that is flowing here we compare (Refer Slide Time: 26.24), then we compare it to I. Compared to this current, these I 1, I 2, I 3, I 4 are negligible; that is a must for this design to be successful.

So, if that is the case, then we know that the current flowing here, current flowing voltage across this and voltage across this, voltage across this and voltage across this will be equal (Refer Slide Time: 26.45) because R equal and same current is flowing because I 1 I 2 I 3 are negligible. So, voltage across this, this, this, all four resistances will be equal and voltage across this is nothing but - the base-emitter voltage of this transistor - that is collector- emitter voltage of this transistor, because base emitter voltage only 0.6; so neglecting that, the voltage across this is nothing but voltage across this transistor (Refer Slide Time: 27.19); that means, the voltage across each transistor is identical. So, the total voltage - 1000 volt - even if it is there, it is shared by the four transistors; the voltage across any transistor will not go beyond 300 volt or 350 volt. So, we can use many transistors in series so that the voltage is shared.

So, in this case, if the output voltage goes high and then this voltage goes high then this voltage goes high this conducts more. When this conducts more, then more current flows through this (Refer Slide Time: 27.51). When more current flows through this, voltage across this increases across each transistor increases, so that output voltage decreases; this way the regulator the transistor can be connected in series. This is very important when you are dealing with high voltage like this; any number of transistor can be connected in series and then one can develop very high voltage power supply.

Of course, even the transistor can be connected in series as well as parallel and even this transistor also can be connected in series in the same manner here if you require, but normally for low power, you get high voltage transistors availabilities. For example, b u 3 2 naught 8 gives you 1000 volt rating, so one can use this. We had seen how to connect the transistor in series and parallel; we connect the transistor in series to boost the voltage.

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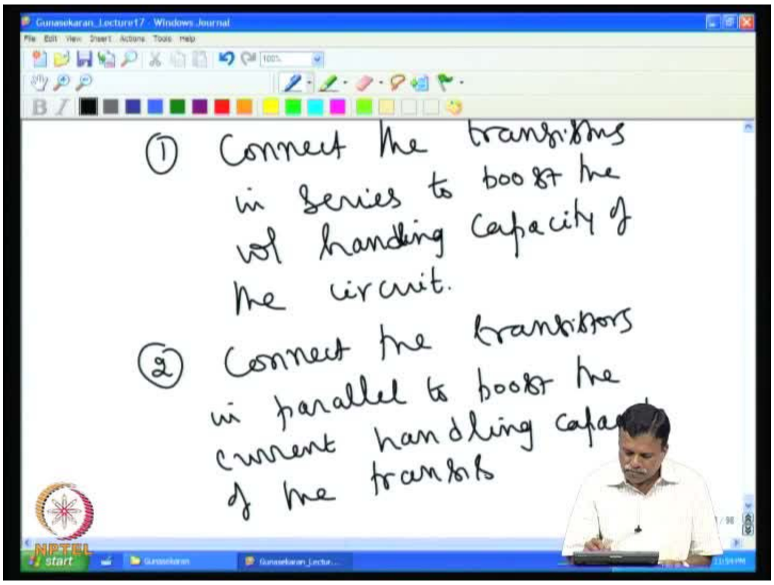

So, connect the transistors in series to boost the voltage and the capacity - voltage handling capacity - of the circuit. The individual transistors are still handling only low voltage, but now we can construct the circuit which can handle much higher voltage. Then, connect the transistors in parallel to boost the current handling capacity of the transistors or it can also be, that is, we can also say connect the transistors in series to reduce the heat dissipation transistors.

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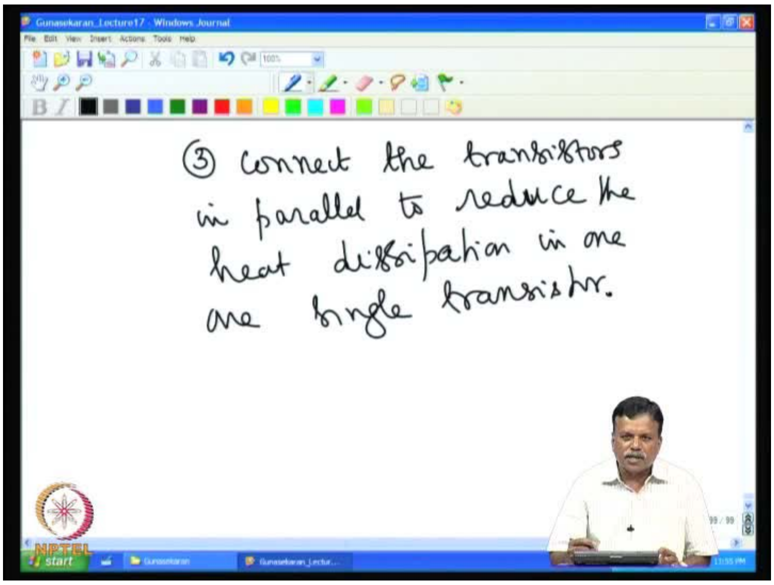

Connect the transistors in parallel to reduce the heat dissipation in one single transistor. This is essential to mainly see that the junction temperature is kept at the junction is kept at low temperature; that is why; we connect the transistors in parallel. So, one can connect the transistors in series or parallel without violating its working principle and then we can derive the advantage of increasing the power or increasing the voltage rating.

Now, let us see next, how to use MOSFET effectively in analog circuits, because we had seen earlier how to use MOSFET for switching applications, because we had seen both how to use transistors as well as MOSFET for switching application.

Let us see, how to use the MOSFET in linear supply, so that it will give an idea of the usage of MOSFET. And the usage of MOSFET is nowadays more and more in linear supply, because the MOSFET has advantage that voltage drop across that can be very small, not like transistors. That for example, if we take 3055, it needs minimum of 3 volt across base and emitter when I current is flowing, whereas MOSFET, even with 10 ampere current, we will have only about 40-50 millivolt drop across that. So, low dropout regulators are being developed using MOSFETS. So, the MOSFETS are nowadays finding its way in linear power supply, particularly low dropout regulators. Let us see how to make a low dropout regulator using a power MOSFETS.

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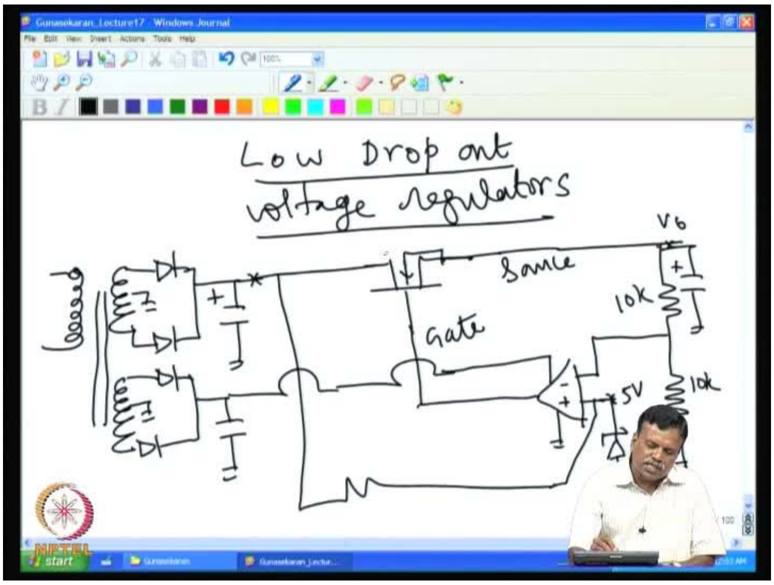

So, in this case, what we do is we will have our conventional circuit. I have a transformer, then we have our rectifier circuit, then put our filter here, so that gives you integrated DC at this point (Refer Slide time: 33.39). So, we got an unregulated DC now that is to be regulated. Only thing that we do is, we now we will not put our transistor; instead of that, I will use a MOSFET and use a P-channel - I will use a MOSFET here - now error amplifier at have a error amplifier here output is there.

The same concept can be used, but you have done it in the linear regulator. This is the output and then we have capacitor here, that part remain same. And then we have an error amplifier plus and minus, so this can be given to the feedback. and I have a so We have used here the zener diode of 5 volt; assume, it is a 5 volt zener and we have biased the zener using this resistor. So, whatever voltage is here, that raise the current through this and we have to keep resistance such that the enough current is flowing through the zener. This we are discussed earlier, so eventually, you will get 5 volt here and you have output at this point (Refer Slide Time: 34.45).

So, part of the output is now compared. Assume that we have here both resistors are 10 K, similar to what we are discussed. So, voltage across this 5 volt and then voltage across this also will be, voltage across this is 5 volt, and then voltage across this also will be 5 volt. So, you will get 10 volt at the output; to get that, we are complete the circuit. So, what we do is, this is an internal MOSFET, I connect this to this. (Refer Slide Time: 35.32) Now, that completes the regulator part.

Now, what is happening is, suppose if the output voltage goes high, and output voltage goes high, then this voltage goes high. If this goes high, then this voltage comes down and that will make this voltage come down (Refer Slide time: 35.53). For then, there is one difference between the transistors and the MOSFET. In the case of transistor, the voltage difference between this and this terminal. In this case, the transistor - this was base and this was emitter. Here, in this MOSFET, this is gate and this is a source. In transistor, we need only 0.6 volt difference for this to conduct, whereas in this MOSFET, we need almost 10 volt difference in power MOSFET for the MOSFET to conduct. In heavy leak, we need about 10 volt difference between gate and source.

So, we have the gate here and then the source. That means, if I want, for example, 10 volt here, then if this is sitting output is sitting at 10 volt, then this has to go to 20 volt; then only you will get 10 volt difference; then only the transistor will get into a deep conduction mode. Otherwise, it will not be conducting heavily and do not able to sustain heavy load current; so need large difference between gate and source. This is one of the drawback of the MOSFET, because if it is a transistor, one can switch on and off with 0.6 volt. There is MOSFET needs extra gate and source voltage which may not be available in low voltage instruments. That is why, the MOSFET is not extensionally used in low voltage power supplies. Now, in this case, all that required is to give supply voltage here much excess or much higher than that of 10 volt - at least 20 volt power supply required.

So, in normal case, what we do is the apply for this normally connect it to this itself Normally we connect this fellow to the input itself and that will not work in the case of MOSFET actually. So, what can be done is that we can have another supply, one of this thing would be another can have winding which may be 20 volt at 25 volt higher voltage, that can be connected to this (Refer Slide Time: 38.24). So, this is a 25 volt available and that can be easily give 20 volt here and then 20 volt here can be easily give 10 volt and this need not be more than (Refer Slide Time: 38.40) - if to get 10 volt all that need it is at this point -even 10.5 volt is enough, because low voltage you get MOSFETS with 5 milli ohm channel resistance. For example, even if it is 10 ampere current, 5 milli ohm and 10 milli ohm resistance, you will need 10 milli ohm into 10, then 100 milli ohm -

100 millivolt. drop So, up to 100 millivolt down, the MOSFET can work; this is the basic principle behind the low drop out regulators.

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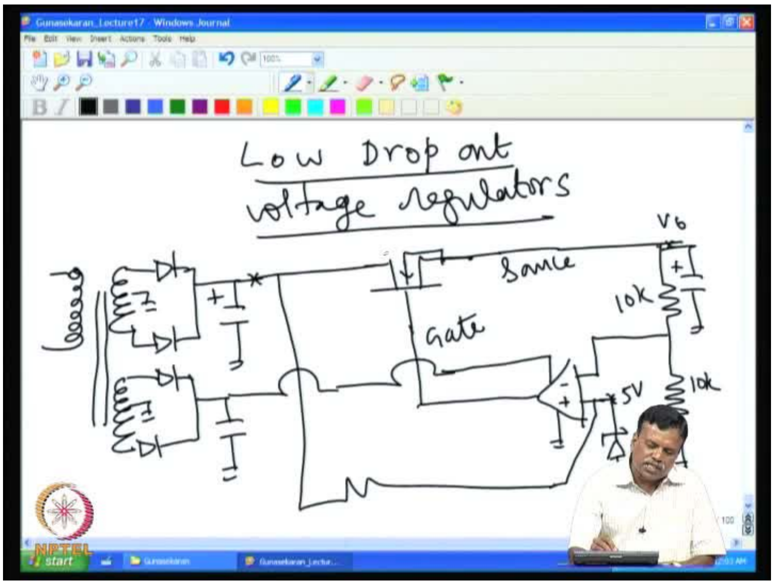

So, only thing is that we need additional supply to boost this thing and even this supply can be achieve in very many different device, of course, if we have a transistor basis supply is more convenient way of obtaining the high voltage supply, that is required for the for this error amplifier; this is actually gives very low drop out. Advantages with the MOSFET is that, extra voltage was lost in the transistors is no more there. One can easily work very close voltages, particularly, this is well suited for regulating the battery voltages, because, here you will have a ripple and then the mains voltage change also will be high and advantage that you gain is not very much.

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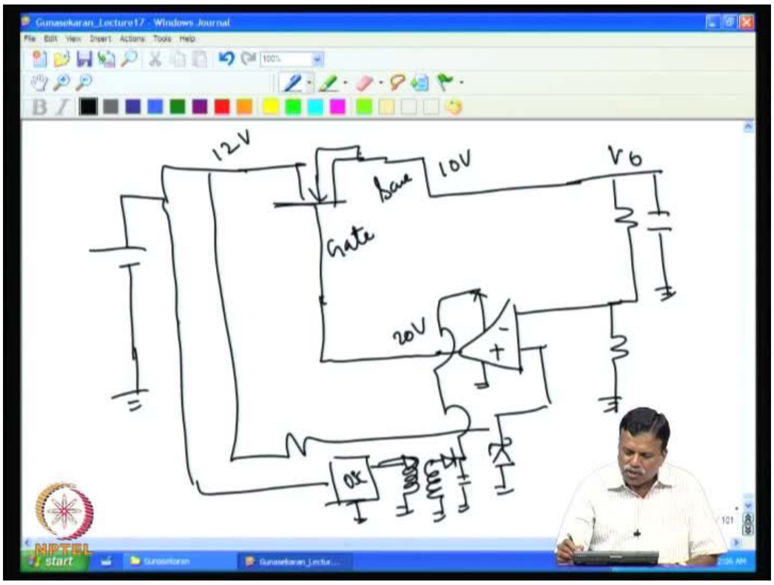

But, if you are operating a battery based equipment or you know already regulated voltage supposed to be regulated further, and then this kind of low drop out regulator is a very use is very much of use. So, for example, if I have battery, if I want to make a battery voltage to be regulate because battery voltage not going to change much, in that case I can go for this low drop out regulator, then this output can be now compared with the reference (Refer Slide Time: 40.40). So, you got V reference voltage and the power for this can be given from here.

Now, only question comes that if what is the power supply voltage I want to give. If I need to give supply voltage much higher than, you know if I connect this chap to this output of error amplifier to the MOSFETS gate, I can connect this one to the gate and source, if I need 10 volt here and if this is 12 volt battery, then if you get 10 volt and I need around 20 volt at this point and this need to go up to 20 volt (Refer Slide Time: 41.38). So, 20 volt cannot be obtained from this; by connecting 12 volt I cannot connect here, I cannot get 20 volt.

So, there is no possibilities of operating, unless I give this one 20 volt. Of course, you can obtain 20 volt from this by using a small DC convertor, because R - this voltage can be boost at and a simpler way; for example, simple boost circuit I can show you, in this case, so remove this for example I can do this in a simpler boost circuit, this is only very low power is required. Now, one possibility, we can also go for on small oscillator circuit and then produce go this needs in very small power only. So, I can have a simple oscillator circuit which has an AC oscillations and that can have a transformer to boost the voltage to 20 volt, because we need only very small power and that 20 can be given to this (Refer Slide Time: 42.38). For example, simple oscillator will do, because we need only a very small power to boost this; so, this kind of low drop out regulators are popular.

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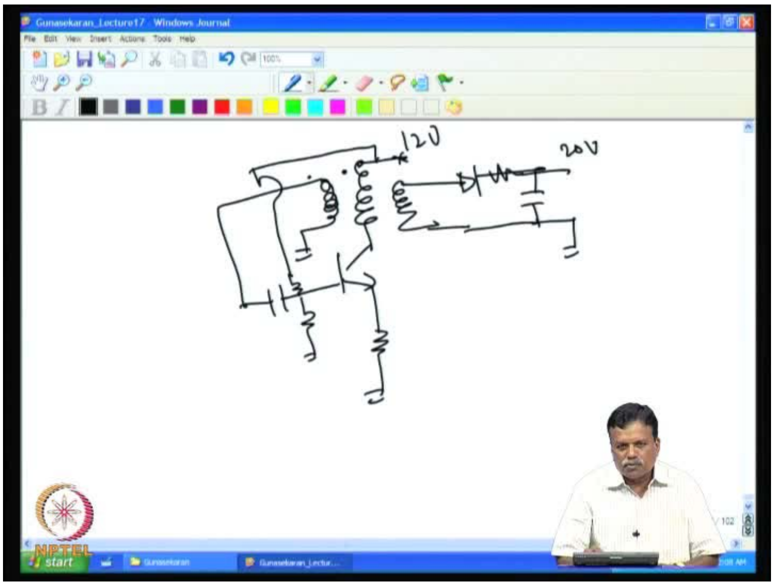

Now, I can show you one of oscillator circuit to go with this. For example, simple artily oscillator circuit will do for this purpose. We already discussed about the artily oscillator circuit. We can have for example 12 volt, because power level what is required is very small. In that case, one can use this kind of oscillator circuit and have this (Refer Slide Time: 43.18); you can have a secondary which is stepped kept up and this can be used to rectify to get D C voltage, having a small resistance helps here and this can go 20 volt; few milliampere current can easily achieve in this circuit. This are basically artily oscillator circuit, which again we are discussed earlier.

So, artily oscillator can be also used to increase the to power the error amplifier, because error amplifier needs much higher voltage than the battery voltage. So the battery voltage fed here and you will get higher voltage at this point (Refer Slide Time: 44.00). So, this way the MOSFET can be used in the place of transistor. MOSFET gives you better performance, because the voltage drop across the MOSFET is smaller compared to the transistor. Then, the gate current is very small, but the disadvantage of having higher gate voltage compared to the source is, disadvantage is there with MOSFET, which was not there in the transistor, of course, that can be handled by using a oscillator circuit like this (Refer Slide Time: 44.36).

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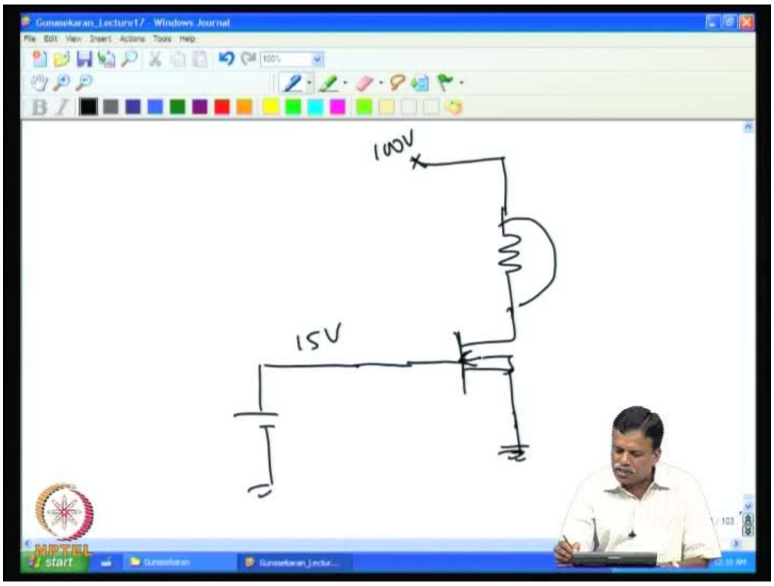

So, now let us see how to provide a short circuit protection for MOSFET, because MOSFET is used many switching applications as well. Like For example, I may be using a MOSFET to switch high loads; for example, if for example I may have a high voltage for example- 100 volt, then I have a load and I want instead of transistor I want to use the MOSFET to switch this - so I use this, here for example I give a voltage with respect to ground - say I have 15 volt (Refer Slide Time: 45.14) - you say 15 volt D C, then the MOSFET is on.

If I give 0 volt to this, for example if I remove this and then connect to 0, then the MOSFET actually goes off. So, I can make it on and off using by applying the gate voltage; that is, if 15 volt is given, then MOSFET goes on and the load conducts. If I give 0 volt, then MOSFET goes off and then no power is delivered into the load. So, one can use the MOSFET to make it MOSFET as a switch, rather than the transistor.

However, in this case, we have to give a protection for MOSFET, because if you take this load, d in case if the load is short circuited and assume that, I had given a voltage to this MOSFET to make it on - I connected this 15 volt, then the MOSFET is on. In case, if it is short circuited, then a huge current flows through that and then the MOSFET goes back. So, it is essential that we give a short circuit protection to the MOSFET; so, how to provide a short circuit protection is one of the important problems.

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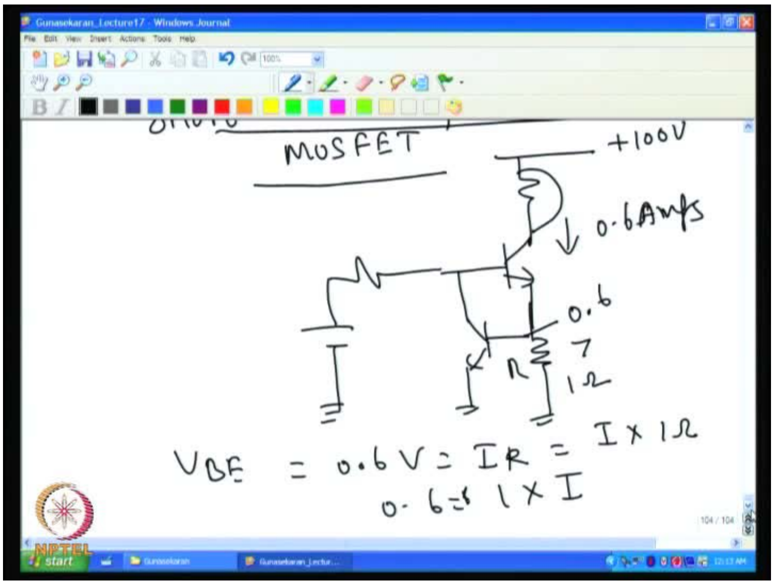

Short circuit protection for MOSFET: in the case of transistor, we had done the short circuit protection very easily. The MOSFET short circuit protection is a little cumbersome and also we had seen how to protect without giving too much of power. Now, the same logic what we had used in the transistor can also be used first in the MOSFET. For example, in case of transistor, what you done was, if this is the load for example 100 volt, then short circuit protection is provided like this that we have done and connected this (Refer Slide Time: 47.48). So, our drive voltage was diverted out; for example, this is what we have done to protect the transistor from short circuit.

In this case, if this load is short circuited, For example if there is a short circuit here (Refer Slide Time: 47.58), then high current goes through that. Then, if voltage at this point goes more than 0.6, then this transistor start conducting. Then, whatever current is flowing, this conduction current actually comes from here, so large current flows through this that makes this voltage to decrease and that makes this voltage to decrease and the conduction here also decrease (Refer Slide Time: 48.35).

So eventually, for example, if I put here 1 ohm resistance, then voltage at this point cannot go more than 0.6; that means, current through this cannot be more than 0.6 amps, because voltage at the base-emitter cannot go more than 0.6. So, V B E is equal to 0.6 volt, that is equal to I into R - that is, this R - if R is 1 ohm that I into 1 ohm, so 0.6 comes as 1 into I

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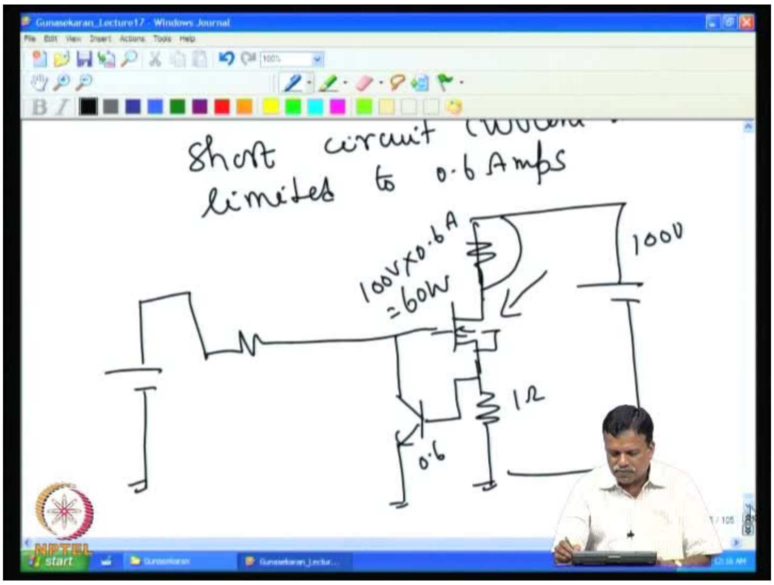

So, the current I comes as 0.6 amps. In this case, even if you are short circuit, current will not go beyond 0.6 ampere; so, short circuit current is limited to 0.6 ampere. Short circuit current is limited to 0.6 amps

Now, the same technique can be used even in the MOSFET; the MOSFET what can be done is that, if I take the MOSFET case, I put the resistance to ground, then assume this is the load and this is the supply voltage and the drive voltage here (Refer Slide Time: 50.25), with the MOSFET assume that I connect it through a resistance to the gate, then the same circuit works. All right

Now, from the earlier discussion, we can quickly understand. Suppose, if I have 1 ohm here, then this and this is the base-emitter voltage, which cannot go more than 0.6. If the current goes more than 0.6 amps, this voltage will go beyond 0.6 volt. Once it goes beyond 0.6, the transistor will be short conducting and this would be short conducting and then this voltage will be decreasing (Refer Slide Time: 50.57). As this voltage decreases, the conduction also will decrease and eventually the current will be limited such that, this is sitting at 0.6 and then this will be sitting at few volts such that the 0.6 ampere current is flowing; the same technique can be used.

But, then in both cases, we have a issue that there that the heat dissipation in this case (Refer Slide Time: 51.32). If it is 100 volt and if it is the short circuit - 0.6 ampere going through that, then heat dissipation will be 100 volt into 0.6 amps, that will be 60 watts of power dissipation will be occurring, This is true in transistor also, but then one can actually avoid this 60 watt power dissipation, if we can shut down the transistor once we know that short circuit had occurred. This is also can be done in the MOSFET.

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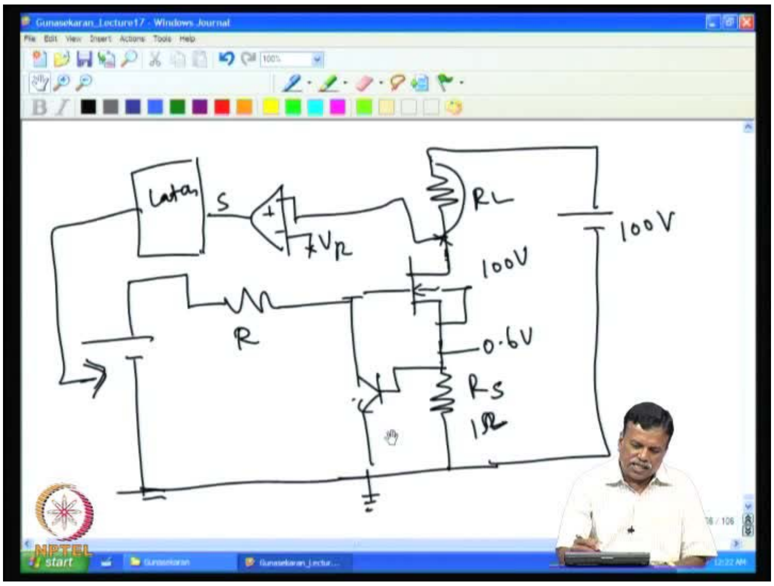

Now, one can think of the following type of circuit, which used invariably in the switch mode power supplies. What can be done is that you can have a load for the MOSFET, I can retain this because this is very quick and acting, I can have a load here, then connect to the source - which say 100 volt, then our regular transistor also can be put here, our short circuit linear power supply stuff that we can connect here and then I can connect the drive part of the voltage, this is connected here and that is connected to the ground, I can put the resistance - this is R this is load this is R sense (Refer Slide Time: 52.54). So, this is the MOSFET which is supposed to be protected against the short circuit.

In this case, if the short occurs, then current will go high in this that will increase the voltage at this point. Then immediately, this transistor will conduct and then more current will flow through this and that will make reduce the voltage at this point reduce and that will reduce the current (Refer Slide Time: 53.25). So eventually, voltage at this point will be limited to 0.6 volt, so 0.6 divided by this resistance will be the current that will be flowing.

Now, we are trying to remove how to avoid the power dissipation in this, because if I put 1 ohm, then as we said the current is 0.6 ampere only can go not more than that. But there, if this is short, the entire 100 volt is here, then 100 volt and 0.6 ampere will give you 60 watt power dissipation which is very high and the MOSFET can go back. To avoid this, one can sense the voltage at this point and then use that information to shut down that transistor. For example, when the MOSFET is fully on - for example even this is transistor not there (Refer Slide Time: 54.30) - if I am switching it on, then voltage across the device will be only a few millivolt. For example, if it is 1 ampere current and if I use a MOSFET of 10 milliohm resistance channeled resistance, then you will have only 10 or 20 millivolt - 10 millivolt drop only there and then you have some voltage drop across this depending on the resistance; so, voltage at this point will be always lower.

So, if it is goes to more than 2 volt, that means this MOSFET can be taken to a linear region; that means, by sensing this voltage one can identify whether MOSFET was taken to linear region by the short circuit protection or not. So, because of high current, this transistor is activated, this voltage is decreasing and the MOSFET is taken to a linear region and then voltage at this point goes up much more than 2 volt (Refer Slide Time: 55.22). So, I can say with the voltage at this point goes more than 2 volt, the MOSFET is taken to higher level.

So, one can sense this voltage and if the voltage is higher than the prescribed amount - say 2 volt, then that I can set as reference. So, when the voltage goes higher than that, then output goes high; then, one can actually remove the source drive itself. Can be removed So, once the drive is removed, then automatically no switching takes place and MOSFET goes off.

Of course, we have to have a latch such that once it goes high that it never comes back again, so that kind of arrangement can be done. This kind of thing is done in switch mode power supply, so that the MOSFET is not getting damaged.

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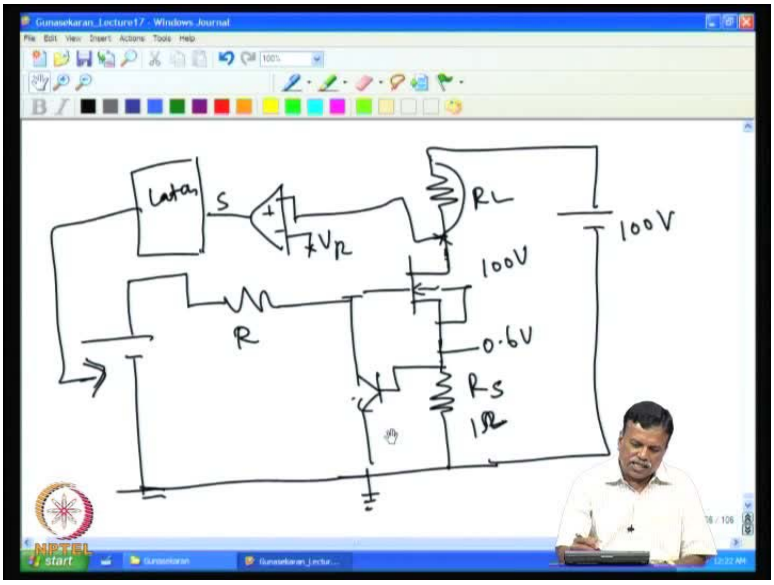

And this In this case, this will act as a quick current limiter, because if I use without this, if I use only this technique, for example: I had to put a latch here, so if I put this one for example I put a latch here and give it to the shutdown terminal of this. Here Now, if without this, for example if I have not used this arrangement and if I short, then this voltage will go high and it will latch and then it will pull down the supply (Refer Slide Time: 57.01). For example, without this, if the short circuit occur, this voltage goes high and then this goes high and latches and then permanently puts down this voltage, but this has its own slew rate, this has its own slew rate and it takes time to shut down. By that time, the current in this MOSFET would have been raised too much higher level and would have destroyed the MOSFET.

So, this arrangement helps you to limit the current during this time interval that is delay time, because when the I mean short circuit occurs the voltage goes high, but then shutdown takes 1 or 2 micro-second. In 1 or 2 microsecond, the current would have been ramped up very high and would have damaged this. So, if I have this plus this arrangement and this arrangement actually limits the current during that 2 microsecond, such that current will not go anyway more than 0.6 (Refer Slide Time: 57.49).

So, the current is limited to 0.6 ampere and then this takes over and switches off the source itself; that way, the MOSFET can be protected without damage. So, this combination of shutdown plus current limiting is a useful technique in MOSFET for protection.

Now, we can see this kind of circuit in detail probably in the next class how to provide a latch and do this I can take one switch mode power supply example and explain how one can protect a MOSFET against short circuit there are many publications available in this topic one can see that one can see these applications many published journals

So, in this class, we had seen how to use the transistors in parallel to boost the power, then how to use the transistor in series to boost the voltage, how to design these two circuits we had seen and I also shown you, how to use the MOSFET as a switch, then how to use the MOSFET in the linear power supply in low dropout regulators and also I had shown you, how to protect a MOSFET from the short circuit protection.

So, we will see more about these in the next class.

Thank you.