Power Management Integrated Circuits
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Lecture – 31
Hiccup Mode and Foldback Current Limit

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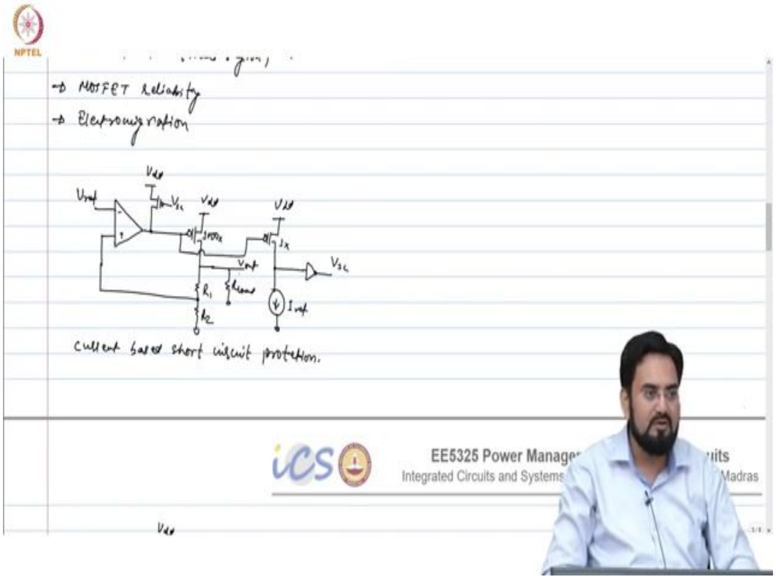

This voltage-based protection may trigger your MOSFET earlier compared to the current-based. The reason is, the current will only change when your feedback responds, ok. So, when you start drawing the load current, what will happen? So, if this is a load, so when you start drawing more current, what will happen? This will, the PMOS can only supply the more current when the gate voltage changes and gate voltage will change through this feedback.

And we know it has a limited bandwidth, but output can, I mean by the time your loop responds; it is quite possible your output may start going low, ok. So, if all of a sudden you make your let us say current from 1 milliamp to 10 milliamp or 20 milliamp whatever, if you connect to the ground, literally you connect to the ground, then you know output is in any case going low. So, this comparator will trigger immediately, irrespective of whether your current changes or not.

But let us say you are slowly increasing the load current and you are going beyond limits. So, let us say you have designed your regulator for 1 milliamp and it has started increasing 1, 2, 3, 4 and going let us say 10 milliamp. So, when it reaches up to 10 milliamp we know, so 1 to 10 milliamp, let us say you give a certain change, then your loop will take some time to respond and your output will keep dropping until that time and it is quite possible that it may go below your threshold and this will trigger and turn off your MOSFET ok. When you turned off the MOSFET, then how do you come back actually? Now this circuit is dead. So, let us say you have applied a short-circuit and most of the time it happens while testing or doing anything in the lab.

So, let us say, in cell phone you have a regulator, this output supplies, this regulator is supplying to some module here, to some other chip and you are testing your phone and accidently you shorted it. Usually these short-circuit protection are for accidental short-circuit because nobody will literally try to connect to the ground output, it does not make any sense.

So, usually for accidental short circuits you try to, or let us say your cell phone you have dropped it in water or somewhere, that may also create your short-circuit between the supplies and your ground. So, once it is shorted, you have turned off PMOS and now you want to boot your phone again or let us say your phone is not restarted, but phone is still on; but this supply is off; that is also possible.

Either you restart your phone, but if you are not restarting your phone, can usually you want to, you want your phone to come out of this situation on its own, automatically. So, how can we do that? You have turned it off. So, your supply is dead now you want to again activate this supply.

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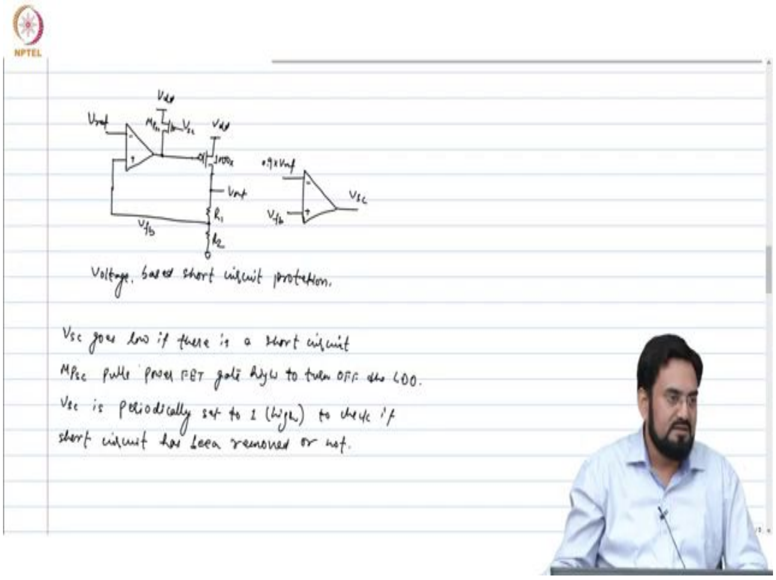

So, what you do actually? You reset this. So, basically you make this V sc again high and activate this regulator again and then again the same process will start. If short-circuit has been removed; so, let us say it was an accidental short-circuit. I mean, let us say you are doing something, let us say you had a screw driver and the screw driver basically caused the short-circuit between output and ground. But when you removed the screw driver, the short-circuit went away. So, then what will happen? You turn on again, this regulator by turning off this or pulling this gate to.

So, you do it periodically, there is some state machine required for that. So, what you do? You take the output, pass it through some state machine which will periodically keep doing what will happen, when it, whenever it goes low, it will immediately pull it to low and after some time you count let us say few cycles. So, let us say every one second or so, or half a second, usually if it's a man-made short-circuit, then you know, we cannot respond in 1 or 2 milliseconds, it may take at least 100 milliseconds also. So, let us say every 100 millisecond you again reset this output, make it high and your regulator will start automatically.

So, if there is a short-circuit your output will not go to, will not increase, it will stuck to 0, then again short-circuit will trigger and it will again turn off. So, it will keep doing that until that is removed. So, let us say short-circuit is removed then when the regulator is started, it will settle to its desired output. So, automatically it will come out of that short-circuit. So, this is periodically done in the state machine and that is called something, the name for that is hiccup mode actually. Because you periodically keep doing; you remove that basically this FET, because this is turning off this by pulling it high.

So, what you do is you turn off this periodically and check whether the short-circuit has been removed or not, if it has been removed. Otherwise if you do not do this, then you will have to hard-start or hard-reboot your cell phone or any other device, whether it is a laptop or … . So, V sc goes low if there is a … . So, let's say I call it MPs, ok. V sc is periodically set to one or logic high to check if short ... removed or not, clear ?

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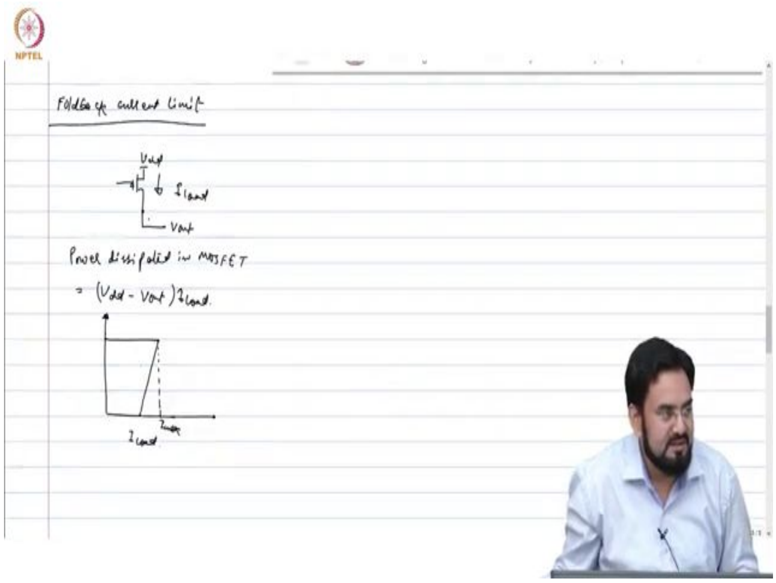

So, and there is something called foldback current limit. So, what happens? This is your MOSFET, this is your load current, V dd and this is your V out. So, what is the power dissipation in this device?

Power dissipated, V dd minus V out into I load ok. So, let us say you have short-circuited, V out is 0 and you have set the current limit whatever the maximum. So, let us say 1 milliamp was the normal drive, you set at 2 milliamp, you are not turning off the device. So, there are two ways I told you, one in, you can turn off, other is you can just limit that current ok. So, limiting the current means, you somehow pull this gate. So, when you are increasing the current, this amplifier will try to pull it low. So, you provide an alternate path which will try to pull it high.

So, it will not allow to pull it too low, certain limit. So, let us say you keep the same MOSFET and just make it strong enough to make sure when this is fully on. So, this voltage is set to some mid level. If you make it too strong then I mean this, this has some current capability, it can sink. So, let us say it can sink maximum 10 microamp of the current.

And if this device can also supply 10 microamp of the current, so, your voltage will be somewhere in the mid ok. But if you make it to have a 100 microamp current, then this will completely pull it to V dd. But so, and if this strength of this device is less than 10 microamp then this can pull it to, towards the ground ok.

So, let us say this is 10 times weaker than your 10 microamp. So, that is how, you make it strong enough that it should not completely turn it off, but make this weaker, so, you can limit the current. So, that is another way of doing current limit. So, in that case you do not turn off the device, but just make your MOSFET gate high enough, so that it cannot supply more than that current.

So, let us say I have said that and maximum it can supply 2 milliamp current. After 2 milliamp, I activate this and it will try to basically reduce the V gs of this, so that it cannot derive, basically it cannot supply higher current. So, but let us say you have a short-circuit. So, with a short-circuit what you are trying? You are trying to limit the MOSFET current to 2 milliamp or so, but what happens to the V ds? V ds is increased here.

So, what will happen to the power dissipation? So, let us say in the normal condition your V ds was 100 milliamp, 1 milliamp. So, what is your power dissipation in that case? 100 milliamp and 1 milliamp is the current. So, 100 milliamp multiplied by 1 milliamp, sorry 100 millivolt multiplied by; so, 0.1 milliwatt and that is how you will size it.

So, you size this transistor to basically deliver that much power, but now all of a sudden you have grounded it and the power dissipation has increased to 10 times, correct or even more than 10 times, if this V dd is 1.8 volt. So, 1.8 volt and this is ground, your current is now 2x. So, 1.8 multiplied by 2. So, almost like 3.6 milliwatt or so, correct?

I mean, it is a milliwatt, don't think that milliwatt is too low, because these devices are sized to carry for, I mean the way you have sized the devices, the milliwatt is much higher watt for them, ok. So, it depends on how you have sized it. So, you do not want this MOSFET to dissipate more power. So, one reason is obviously, that any dissipated power will convert to heat and that heat, high temperature may melt your traces or it may damage the device so, that is a one reason.

Other reason is let us say even if the device is not damaged you are drawing lot of power from the battery, unnecessary. So, your battery will drain that case, quicker. So, you do not want that situation to happen. So, what you do? If I want to maintain this power dissipation, then what I can do? I do not have any control on the dropout because this is shorted to ground. So, only control I have to the current.

So, instead of limiting the current at 2 milliamp, now I will start reducing the current actually so, that I can maintain the power dissipated and that is what we call foldback actually. So, if this is your I load and that is what happens. So, if this is your I max, what you do? You just back off the current. When you back off the current what will happen? Your dropout remains fixed and your current is reduced. So, the product of current and voltage will not increase that much. So, how do we do that? So, you sense the load current and as load current is increasing what you do?

Increase the gate voltage, ok. So, same method is used actually. All you need to do is just instead of comparator, you use some continuous way of, so one way is you can just drop that sensed current to a voltage through a resistor and convert that current into a voltage and then do a control this ok. Any questions? Ok, but most of the time we use this, instead of limiting the current you just turn off the regulator, if short-circuit happens because in the short-circuit, you really, output is gone out of regulation and any system which is, requires a V dd of range plus minus 10 percent, that will you know, that will automatically shut down.

So, there is no point of keeping that regulator on, we just turn off that and but there might be some requirement where you may want to keep the regulator on due to some reason, let us say your regulator is taking lot of time to turn on when you turn it off and in order to avoid that current, that time basically, they just whenever the, again basically system is turned on they can have a supply available instead of waiting for a longer time. But in switching regulators we used both actually. We used current limit as well as the short-circuit protection. So, there might be lot of topologies available. So, the intention is to give you the basic idea of LDO.

If you want to know about new topologies, what are different, you can just go and read the papers, latest papers you can read some of our papers also on LDOs and see what we have done. We have tried some different compensation techniques, we have tried, built the LDO using voltage-controlled oscillators, that is time-based, recently. So, those are all new techniques which we tried.

So, there are some ultra-low current LDOs which are designed using some nanoamps of the current for energy harvesting purpose. So, lot of research is going on there, this is not a only thing but once you know the basics, you can think more about what you can do to improve these or how you can build uh, something which will have a lesser area and lesser power.