Power Management Integrated Circuits
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Lecture - 30
Hybrid LDO, Short- Circuit Protection

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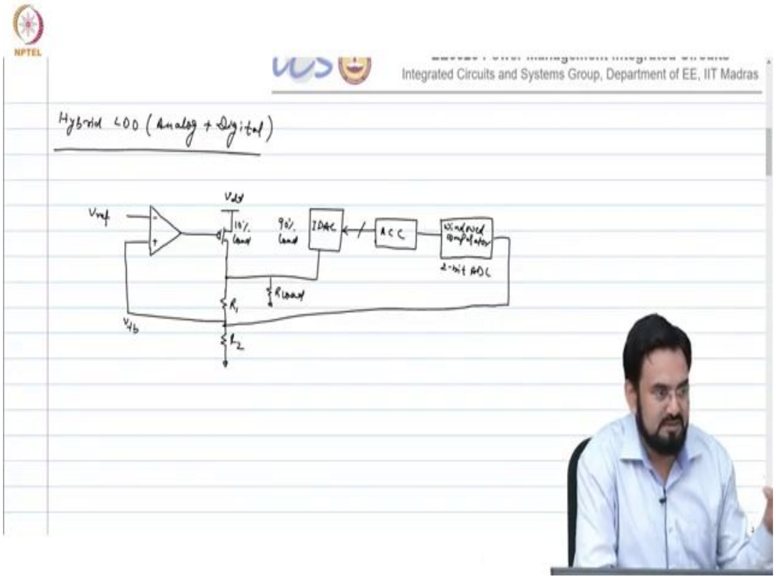

So, we looked at digital LDO and we briefly talked about hybrid LDO. So, I will just show you the circuit diagram for that ... which means analog plus digital. So, the concept here is so, this is my standard analog controlled LDO; V ref. So, you have a I-DAC which is controlled by your accumulator, ok, and then I will just draw a block which says windowed comparator. So, this is windowed comparator, which is nothing but 2-bit ADC, correct. This is your V fb, so the same V fb will go here, ok.

Now, let us say this is your load. So, the way we distribute it, we want analog to only correct the error and most of the current is delivered by the digital, ok. So, 90 percent of load you put here, and here you put 10 percent load only, ok. So, let us say your designing for a 10 milliamp, so you make LDO, analog LDO and size this pass FET to carry only 1 milliamp current and 9 milliamp will be carried by your digital, ok. So, if your load is less than 1 milliamp, then there is no role of digital, analog will take care of that. So, how will you decide when to? Now, you have two loops, they may start fighting with each other. So, how do you decide when to turn on your, basically increase or decrease the code for digital? How will you decide that?

Student: The current form IDAC reaches above a particular limit there.

No, IDAC current is fixed. You have fixed current and you are just turning on and off those current. You have to sense the load current. So, you can sense the, this analog current and you know this analog cannot take more than 1 milliamp, that is what you have designed for. So, whenever current goes above 1 amp, 1 milliamp you just turn on your, activate your DAC, ok. So, you keep increasing that. So, what will happen? Your, this current will start reducing, it will reduce. So, let us say the LSB you have turned on, ok. So, it goes let us say 1.1 milliamp or so, so depending upon the resolution it will turn on that many IDACs which will carry 100 micro amp of that extra current. So, this will remain at 1 milliamp, ok. So, that is the one way. And that threshold you can set it lower also, that does not matter as such, you can set it 500 microamp, so that you do not go for a full 1 milliamp and it, because you do not want to saturate that. That is a one way, other way you can sense this gate voltage also.

So, what would happen? So, let us say you have sized this for 100 millivolt overdrive voltage, ok. So, which means at 1 milliamp your V gs minus V th will be 100 millivolt, ok, and you know V th roughly what is that. So, let us say 500 millivolt, which means your gate voltage will be 600, not 600 but, yeah, plus whatever the, because it's the difference of from V dd.

So, which means uh, your V gs minus V th will be minus 100 millivolt because of the PMOS. So, whenever it increases, the difference between your gate and source, it goes beyond 100 millivolt which means now it is carrying more than 1 milliamp current and you can take the decision to turn on the. So, both ways are ok, whether you sense the current or sense the gate voltage, ok. So, this feedback will not go here, but what you need. See if I want to sense the current how, we already talked about that.

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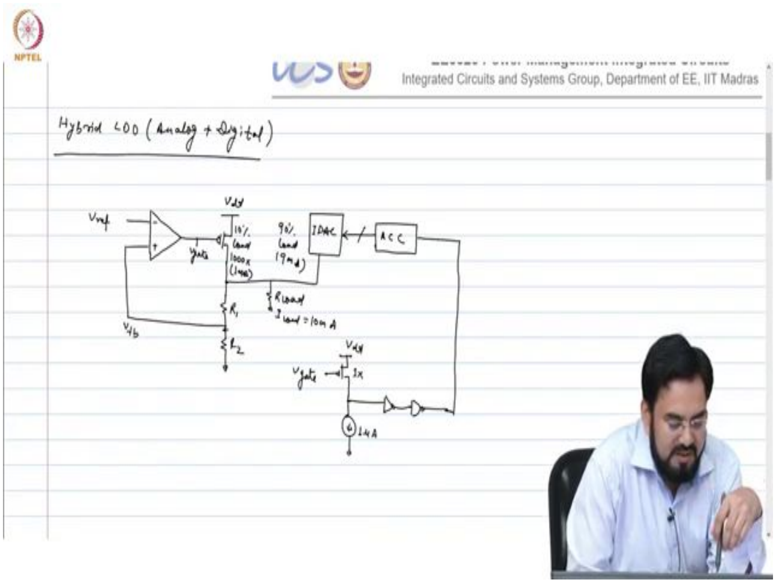

So, if this is your V gate, all you need to do, just take this, ok. So, if this is let us say 1000x you make it, 1x device, so at 1 milliamp it will carry 1 microamp only. So, which means you have to compare with, this with 1 microamp reference current and so let us say this load, I load is 10 milliamp. So, this will carry 9 milliamp and this will carry 1 milliamp. This will go to V gate. So, whenever this current exceeds, this will go. So, this is nothing, but current comparator, ok. Now, this will, so now, you do not need this windowed comparator, this can directly drive your accumulator.

Now, this comparator is replaced by this comparator, voltage comparator is replaced by. So, now, this is a single bit, if you want to make it 2-bit, you can define two current thresholds and make it your windowed comparator again, ok. So, let us say uh, higher side you are turn, increasing the code or when it goes 1 at 100 milliamp, lower side you can set at point, sorry 1 milliamp, you can make a 0.9 milliamp. So, you can keep uh, 100 microamp of uh, hysteresis.

So, the only thing is that this will cause an oscillation in the output because single-bit, we know limit oscillations, so, but this regulator, the analog regulator will try to suppress that because it is in the negative feedback. So, whenever output goes high, it will try to suppress that by supplying the same oscillation, oscillating current, but in the 180 degree out of phase. So, they will try to cancel each other. So, it will suppress. But if you want completely get rid of that, you just make the hysteresis here, basically the two-bit ADC instead of single-bit comparator and you will completely get rid of that, and whatever error is left, that will be corrected by your analog loop.

So, never try to come put the, basically sense the feedback voltage in both analog and digital, otherwise they will try to fight each. So, in one case it may happen that your analog will saturate and it will not increase the code on the digital side or another possibility is that it will draw zero current from analog and all the current will keep supplied by the.

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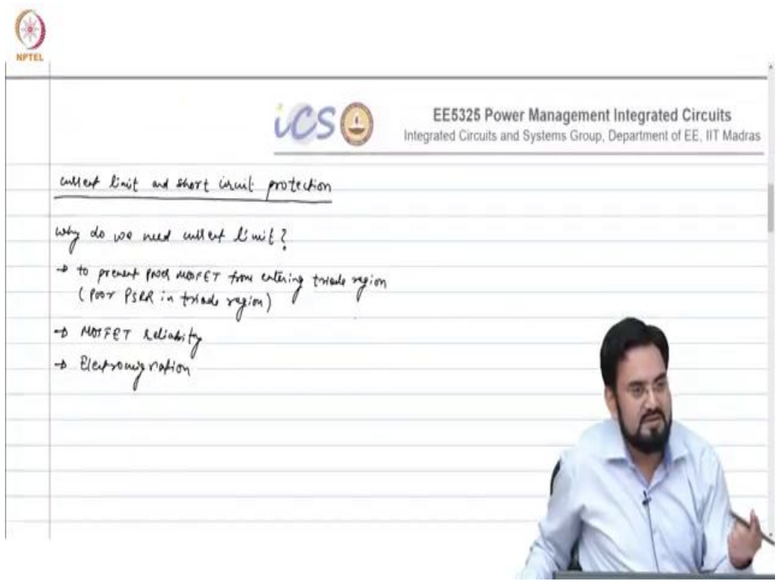

So, let us move to next topic, current limit and, ok. So, there is something called current limit and short-circuit protection, in some cases you may have only current limit or short-circuit protection, in some cases you may have both, ok. So, it all depends what the requirement is. So, why do we need this current limit? Why do we need current limit here? Going to saturation or a linear?

Triode, ok. So, you have sized your power FET for a particular current and you want to operate always in saturation for PSRR reasons, ok. So; obviously, it can drive more current, but your V gs drop will start increasing and ultimately that V gs minus V th will go more than your V d,sat and it will go into linear regions. So, your PSRR will be bad. So, that is the one reason to prevent your transistor, to go into linear.

But there is even a bigger problem, bigger than that if you do not put the current limit. What is that? Yeah, it may damage the device, so reliability is the bigger concern here, ok. It may not hurt you much, if it goes into linear, in the worst case, what would happen? Your PSRR may look bad, but it may be able to drive your, the load current whatever you are putting.

So, let us say you have sized it for 1 milliamp and you have put a 10 milliamp current it may be able to drive, but it will go into linear region, ok. So, triode or linear. But the problem is that you have sized that device for 1 milliamp current and it may not carry 10 milliamp because it may break your metals, it may even damage the source or drain of the device, because usually when you put in the layout, you route and you put the metal width, your basically those traces you connect with the pad, which is, so basically this drain. So, this is a drain which is connected to the load, ok.

So, this drain is routed through a wide metal. So, that metal is usually, the width is defined. So it, I mean usually each process has a current density of those metals. So, per micron square how much current it can carry. So, you have designed it for 1 milliamp and usually size is 2x, to keep some margin because of the temperature variation and all those. So, let us say you have sized it, kept those metal width for, to drive 2 milliamp max, but your load is drawing like 10 milliamp of the current, those metals will melt actually and that is called electromigration, ok. So, when we talk about layout we will talk about that.

So, another thing is, I mean the device itself may not carry that much current, ok. So, metal is the other thing, the device itself, the contacts may get damaged, your source and drains may get damaged, so the device itself may get damaged.

So, number one is to prevent power MOSFET from entering … . So, where do we, why don't we want to have our devices in the triode region? So, poor PSRR, ok. Then MOSFET reliability and electromigration, ok. So, the current limit basically is applicable to both short-circuit as well as high current. So, when you are increasing the load current and crossing that, that is more like a, you can say soft kind of a short-circuit not a hard, when I say short-circuit, literally connecting your output to the ground. So, when I connect this output to the ground, what will happen? This will go to 0 and this gate voltage will go towards ground 0.

So, you are applying the full V gs to the device, so it can draw the maximum possible current it can do, and then it will be defined by your, so this is 0 and this is. So, gate is also 0 and drain is also 0. So, it will look like a diode connected device with the, connected to the ground. So, it is in the saturation, it is not in linear, it is in the saturation. It will go linear if your output is maintained and you keep increasing the current. So, there will be a point where it is possible that your gate V gs will go very high compared to your V ds.

So, it will enter in the triode region. But consider the short-circuit case where you have connected this output to the ground and so we know that you have sized your device for 100 milliamp overdrive and now let us say your V dd is V dd minus V gs, the difference becomes 1 volt. So, 100 millivolt now 10 times increase and you know that it’s a square, so your size is same, mu * C_ox is same, so your current will go 100 times. So, instead of 1 milliamp, it will start drawing 100 milliamp. So, surely it will damage your device and it will melt your pads everything actually because those pads and your metal lines, everything is not sized for, to carry 1 milliamp. Even if you keep 5x, 10x margin is still, 100 milliamp much higher, ok. So, that is why we need current limit and how do we do that, let us see.

So, we already know how to do the, sense the current. All you need to do the, sense the current and from the output take the decision. So, the one simpler way of, so one way would be just turn off the MOSFET, the PMOS, and it will not supply anything. It is just completely cut off. In any case when you are, start drawing a very high current, your MOSFET cannot deliver that high current it will start, output will start going low in that case. So, you, it will go out of regulations, so, you just turn off the MOSFET and your system will be shut down.

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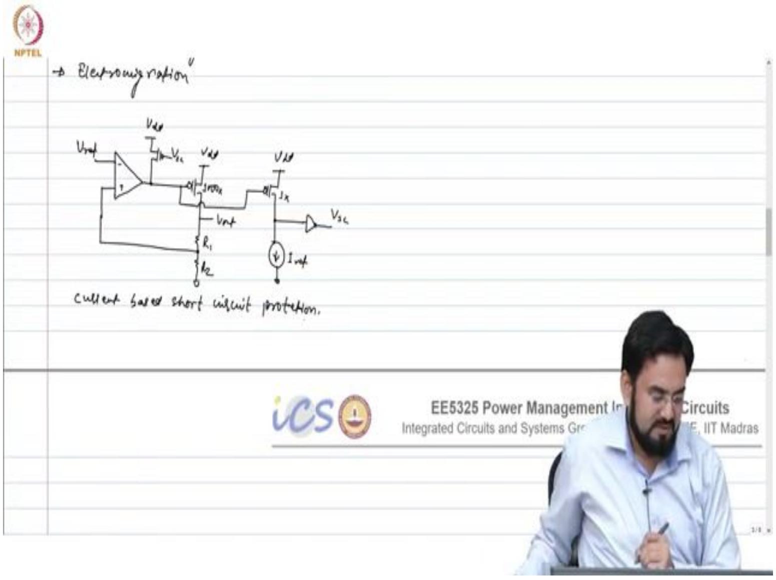

So, let us say I have a PMOS, here, let us say I call it V short-circuit control voltage. I ref, so if this is 10,000x you may get 1 x device. So this, this goes high, this will go low, you make it V sc and it will turn on this device and the gate will be pulled up to V dd and it will turn off this, ok. So, this is the one way and this was your V out. So, this is your current-based short-circuit protection. And another way I can do a voltage-based, so just take the same thing.

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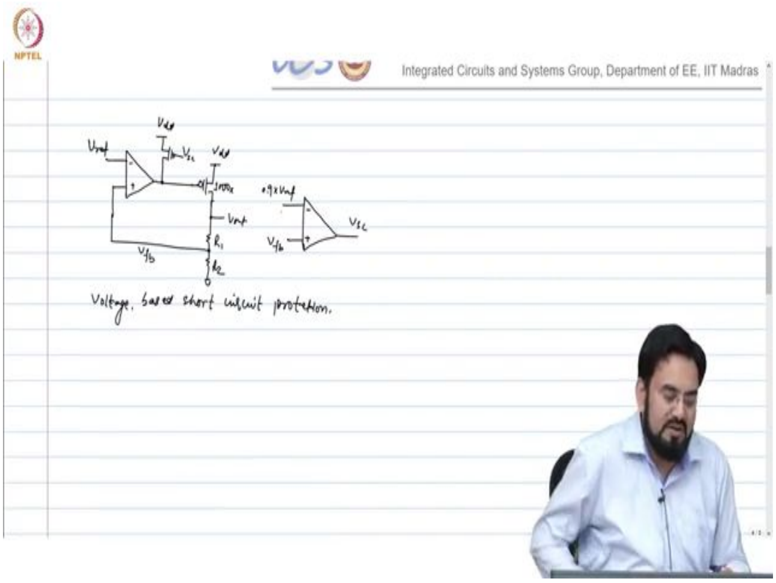

So, we don't need current sensing for this. So, which voltage do I want to sense? If I want to generate the same control voltage to turn off your PMOS power FET, which voltage needs to be sensed?

Output or feedback, because when you start drawing high current this will go out of regulation because your MOSFET cannot carry that much current. So, your output will start going low. I mean ultimately it may enter into linear first. So, IR drop will define your output voltage, and you have not sized for that very low resistance, so it is quite possible your output will go low. So, you can; so, this is your, if this is your minus, so let us say 90 percent of V ref, or 0.9 V ref and this is your V fb.

So, when V fb is higher than 90 percent of V ref, then you know it is in regulation, if you consider plus minus 10 percent, the supply and it will simply turn off when it goes below 90 percent. So, this threshold is depending on you. If you think that when it goes 0.9, still it can carry that much current, you can define it slightly lower 0.8, 0.7 whatever you want. So, so sometimes we use both of them actually, whichever occurs first, you just take the decision on that, ok.