Power Management Integrated Circuits

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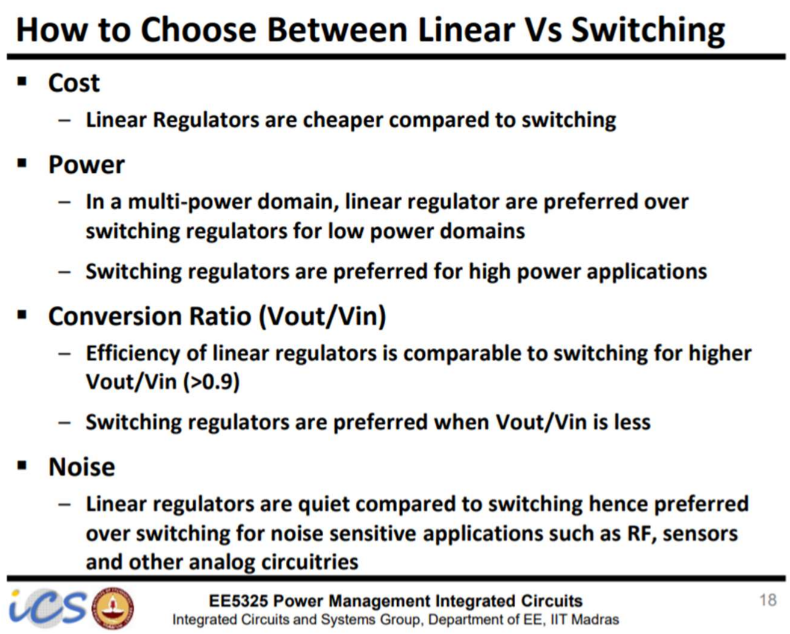
Lecture – 03
Linear versus Switching Regulators

Whether we want to use a linear or switching regulator to deliver power to any system, we need to consider few factors.



Cost: Linear regulators are cheaper compared to switching mainly because it does not require inductor and inductors are costlier compared to capacitors.

Power: In a multi-power domain, linear regulators are preferred over switching regulators for low power domains. Because if let's say 90% of the power is being catered by switching and only 10% power by linear regulators. Even if your linear regulator has lower efficiency overall impact on the system efficiency will be negligible. And switching regulators are preferred for high power applications.

Conversion ratio: Efficiency of linear regulator is comparable to switching regulator for higher V_o/V_{in} because efficiency of linear regulator is nothing but V_o/V_{in}. So, we always prefer linear regulators if dropout voltage is smaller.

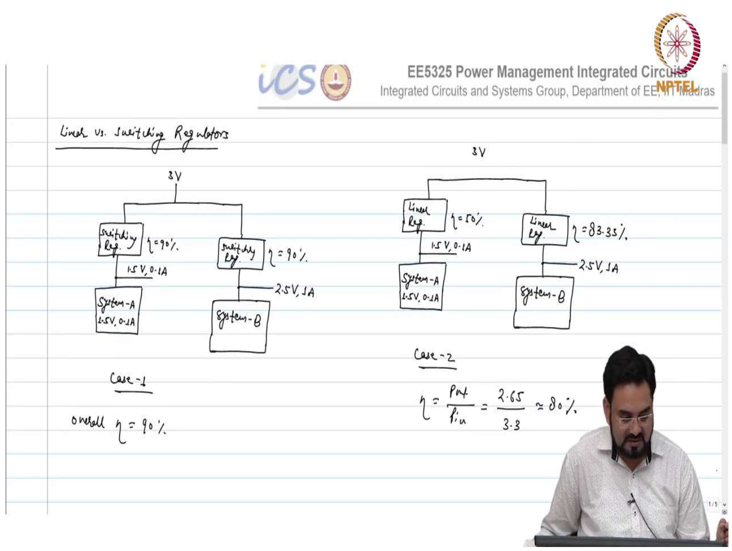
Switching regulators are preferred when the ratio V_o/V_{in} is less. Let us say from 5 V input I want to step down to 1.2 V. Obviously, your dropout voltage is much higher and your efficiency will be very bad if you use a linear regulator. So, in that case we always prefer switching regulators.

Noise: Linear regulators are quiet because they are not switching and since switching regulators are switching, they inject a lot of noise in output as well as in V_{dd} and ground. So, for any noise sensitive applications such as RF, sensors and other analog circuitries we always prefer linear regulators.

Linear vs. switching regulators:

Let us take few examples. Let us say my input is 3 V. I am just taking a number. It may be any voltage or it may not be fixed also if you are considering lithium-ion battery. But for simplicity I am just considering fixed 3 V. So, let us say I have a system-A which requires 1.5 V and 0.1 A which means the input supply for this system is 1.5 V and current requirement is 0.1 A.

Then I have another system and I will call it as system-B which requires let us say 2.5 V and 1 A. Which means I have to convert this 3 V to 1.5 V for system-A and for system-B I have to convert 3 V to 2.5 V as shown in below figure.



Case 1: So, I can use a switching regulator to provide the regulated voltage to system-A and a switching regulator for system-B also. So, we have two switching regulators. And switching regulator efficiency is let's say 90% in both regulators. So, the overall efficiency will remain 90%.

Case 2: Assume both are linear regulators.

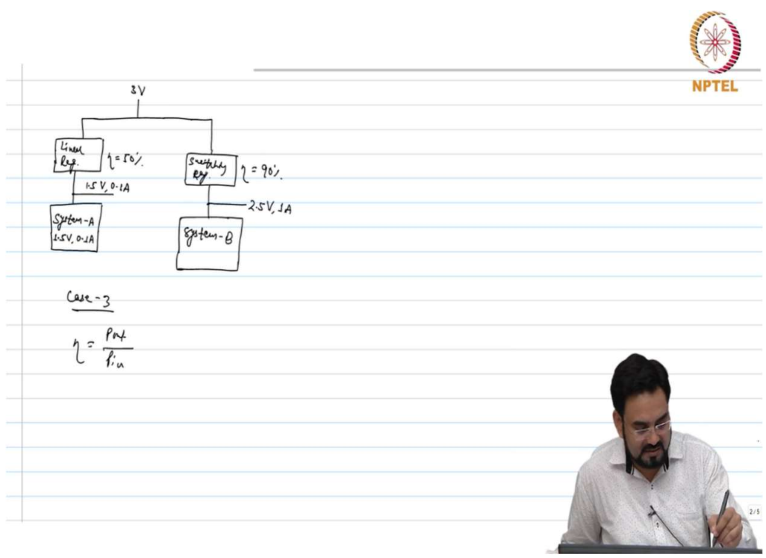
Linear regulator-A efficiency = $\frac{1.5}{3}$ x 100 % = 50%

Linear regulator-B efficiency = $\frac{2.5}{3}$ x 100 % = 83.33%

Total system efficiency $\eta = \frac{P_{out}}{P_{in}} = \frac{(1.5 \times 0.1)+(2.5 \times 1)}{(3 \times 0.1)+(3 \times 1)} = 80.3\%$

We can observe that the linear regulator which is delivering 100 mA current is having 50% efficiency but overall efficiency is dominated by other regulator because we are delivering more power by that regulator. So only 3.3% overall drop in system efficiency.

Case 3: I will use same linear regulator to provide the regulated voltage to system-A and a switching regulator for system-B. Let's say the switching regulator efficiency is 90%.



Linear regulator efficiency = $\frac{1.5}{3}$ x 100 % = 50%

Switching regulator efficiency = 90%

P_{loss} in linear regulator = 1.5 x 0.1 =0.15 W

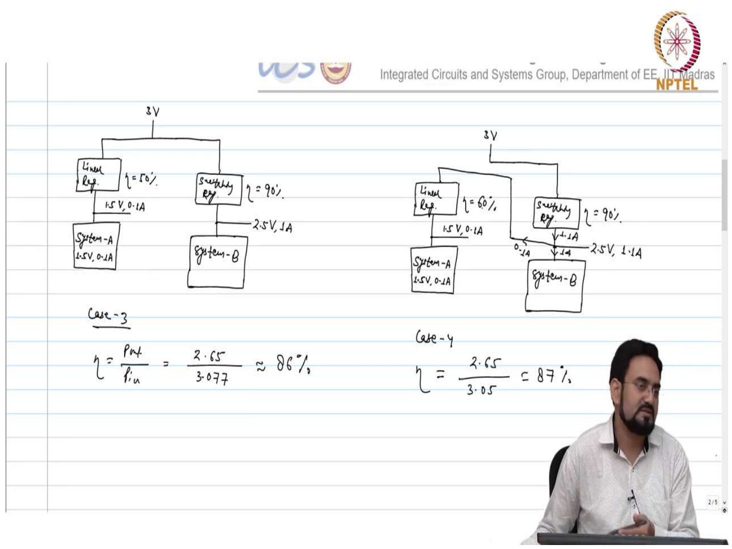
In switching regulator $P_{loss} = \left(\frac{1}{\eta} - 1\right) P_{out} = \left(\frac{1}{0.9} - 1\right)$ x 2.5 x 1 = 0.277 W

Total system efficiency $\eta = \frac{P_{out}}{P_{out} + P_{loss}} = \frac{2.65}{2.65+0.277+\ .15} = \frac{2.65}{3.077} = 86.1\%$

Which means if we replace only the supply of a low power system with a linear regulator then the impact on overall system efficiency will not be that huge. When you use both linear regulators your impact is 10%. When you use a linear regulator to provide 1.5 V, 0.1 A and switching regulator to provide 2.5 V, 1 A then the impact is only 4%.

So, that is how we decide whether to use a linear or switching regulator. If we can afford to have a 4% loss in the efficiency then you can go with this at the gain of cost here. These linear regulators are more cost effective compared to switching regulators because they do not require inductors.

<u>Case 4:</u> We know the efficiency of linear regulators is determined by the dropout voltage and if we reduce the dropout voltage the efficiency will improve. So, instead of supplying 3 V directly to the linear regulator I can give the input from 2.5 V which is generated from the switching regulator as shown in below figure.



Now, dropout voltage is reduced to 1 V. And the switching regulator is supplying 1.1 A current not 1 A. When I say 1.1 A, this is coming from the output of your switching regulator. So, 1 A goes in system-B and 0.1 A goes in the linear regulator which is basically generating the supply for system-A.

Linear regulator efficiency = $\frac{1.5}{2.5}$ x 100 % = 60%

Switching regulator efficiency = 90%

P_{loss} in linear regulator = 1 x 0.1 =0.1 W

In switching regulator $P_{loss} = \left(\frac{1}{\eta} - 1\right) P_{out} = \left(\frac{1}{0.9} - 1\right)$ x 2.5 x 1.1 = 0.305 W

Total system efficiency $\eta = \frac{P_{out}}{P_{out} + P_{loss}} = \frac{2.65}{2.65 + .305 \quad .1} = \frac{2.65}{3.055} = 86.75\%$

We get efficiency pretty close to 87%. So, 1% you can gain by changing the input to the linear regulator. By improving the efficiency of linear regulator by 10%, the overall efficiency is improved by 1% because total power contribution of linear regulator is much less compared to switching. That is why 10% improvement in the efficiency is showing only 1% improvement in the overall system efficiency.

So, case-4 is like the best combination in terms of efficiency as well as cost actually. Because if you go from case-3 to case-4 you hardly see any difference in terms of regulators. Both are using one switching and one linear. In terms of cost there will be hardly any difference, but we are able to achieve 1% more efficiency which is getting us closer to both switching regulators which is giving me 90%.

So, that is how we decide where to use switching and where to use linear regulator. It all depends on the total power and the dropout voltage. Based on these two parameters we are going to decide where to use switching and where to use linear.