Power Management Integrated Circuits
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Lecture – 34
Transformer Model of a Buck Converter, Conduction Efficiency, Efficiency of an LDO versus Efficiency of a Switching Regulator

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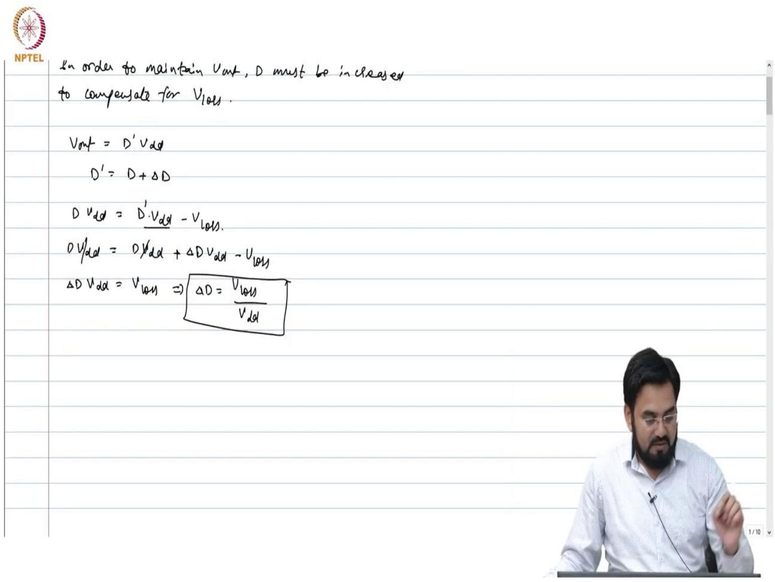

So, we looked at how you calculate the losses, basically the voltage loss and that should be nothing but change in the duty cycle multiplied by your input supply voltage, which is V dd.

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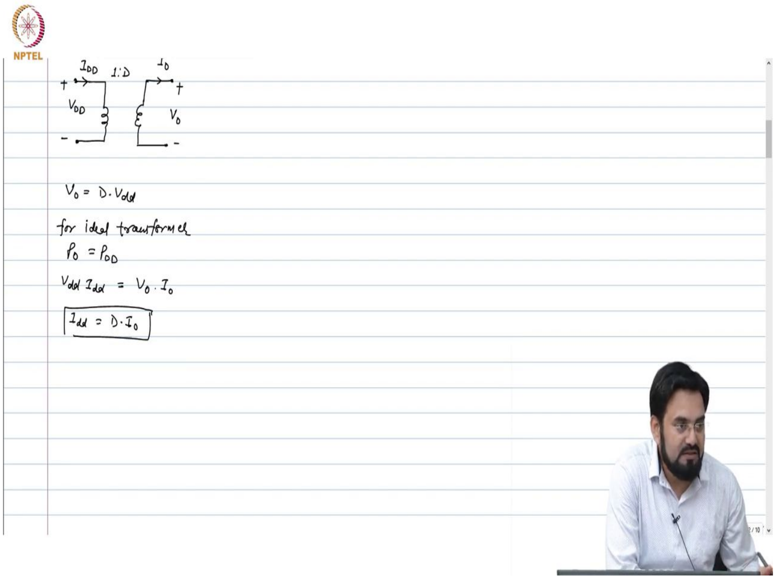

So, buck converter can also be modelled as a transformer. So, if this is I_DD and output current is your I_out, so, for ideal transformer P_out equal to P_DD, correct, which means; V_dd.

So, we know V_out is D times V_dd, so what is I_DD? D times I_out ok. So, your output voltage is multiplied by duty cycle, but when you look at the current then, input current is multiplied by the load current, which is your output, which means and D is you know it is mostly less than one. So, input current will always be less than load current and that is how you get very high efficiency.

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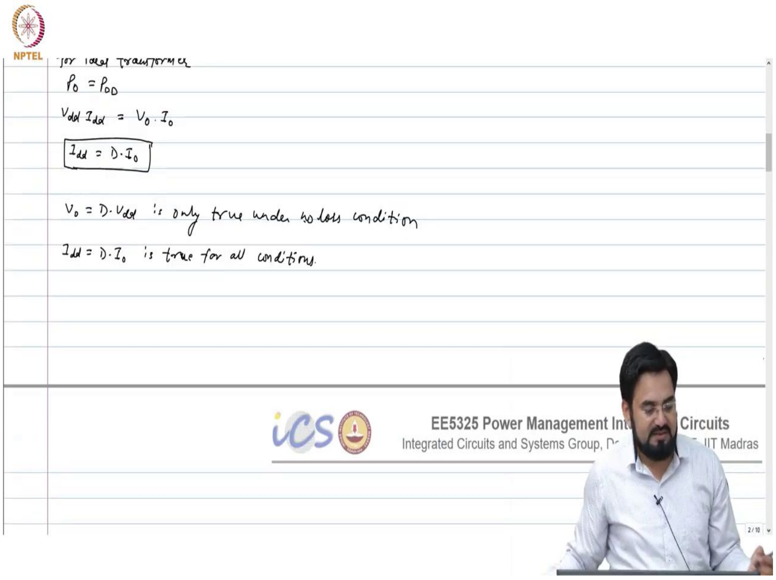

So, this V out equal to D times V dd is only true under no-loss condition which we already looked at ok. Otherwise D times V dd minus V_loss, but this I_dd equal to D times V out is true for, true for all conditions ok. So, it does not matter whatever the actual duty cycle or, so, your current will automatically get scaled, but because it is a current, you are looking at a current; so and but when you look at the voltage, you drop the voltage in the resistance this power stage losses and that is why your voltage is not the actual voltage, but it will get … , but current will always be the same irrespective of whether you are looking at a no loss duty cycle or a duty cycle under the losses.

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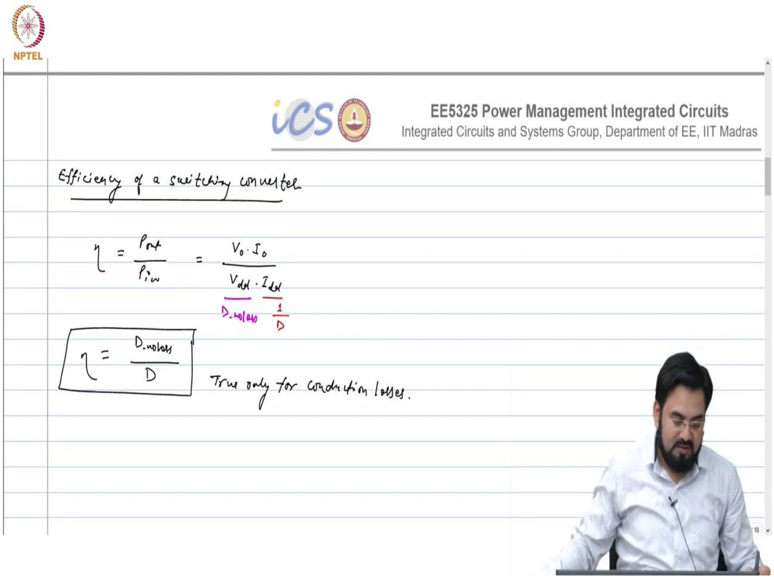

So now how do you define the efficiency? Efficiency of P out over P in and this is one for ideal condition and less than one for, in reality when you have losses in the power stage.

So, this can be written as, V out into I out over V dd into I dd. So, what is this?

D lossless, D no loss and what is this? this portion let me change the color. So, this is your D no loss and what about this? 1 over D, which is the D actual which means I can define efficiency as, D no loss over D actual. How do you find? So, which means you do not really need to measure the power. You just look at the duty cycle you can find the efficiency, but this is only true for conduction efficiency, conduction efficiency means you are only considering the conduction losses which are occurring in the resistance i squared r losses. But if you consider the switching losses, then this formula would not be valid.

So, this is true, only for conduction losses. So, how can I find the lossless D, what is the loss actually here, i square r? So, if you make i 0 loss will be 0. So, under no load condition you get the no loss duty cycle and when you apply the load, you get the lossy duty cycle so, you can easily measure it. So, just by changing the load you can measure both D no loss and D and take the ratio of that you will get and you know, that D no loss will always be less then D because D has to increase in order to compensate for the losses. So, your efficiency will always be less than 1 or less than 100% ok.

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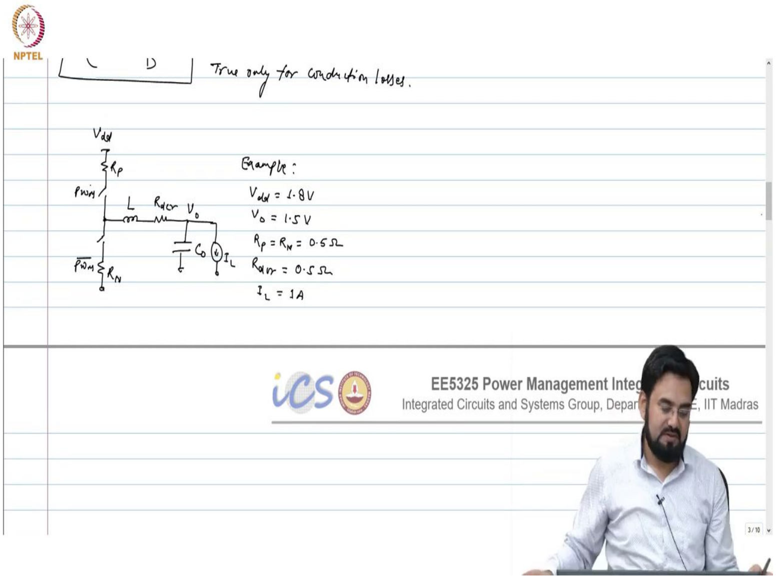

So, now let us go back to your power stage. So, this is so, let us take an example where V dd is 1.8 volt V out is 1.5 volt and R p is let us say. So, for simplicity I am considering both R p and R n same, so the total loss will be your R resistance actually because 1 minus D and plus D so, dd will cancel out. So, leftover will be, but if you have a R p and R n are different then you have to take that 1 minus D expression into account, because in that case your losses will change. Equal to 0.5 ohm and your R dc are equal to 0.5 ohm and I load is this; I l equal to 1 amp ok.

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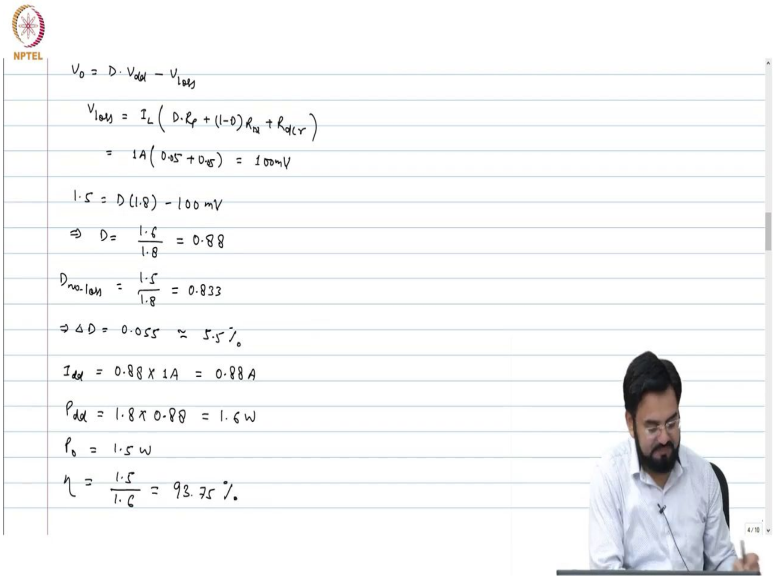

So, what is V out? V out is nothing, but D times V dd minus V loss, and what is V loss? I l multiplied by R p times D, D times Rp plus 1 minus D Rn plus R dcr equal to I l is 1 amp. So, this will become 0.5 correct plus 0.5, so this is nothing but.

1 volt, no sorry 0.05 sorry; no 0.5 is too high. So, 50 milli Ohm correct. So, this is 100 milli volt, V out is already known 1.5 volt 1.8 minus 100 milli volt this implies D equal to.

1.4 over, how much is this? Sorry, yeah, 1.6 over one point, how much is this? 0.833. This implies delta D is 0.033 or 3.3%. So, you get 3% change in the duty cycle in order to compensate for the losses. And what about the efficiency? So, let us calculate both ways and see if you get the same, so one way you just you know the input power output power ok. What does the input current I dd? So, your I dd is. Multiplied by 1 amp which is ok, P dd 1.8 multiplied by 0.88, how much is this?

Student: 1.5 volt.

1.8, 1.6?

P out 1.5 watt efficiency is, 1.5 over 1.6, 93.75%. Ok if I am looking at percentage.

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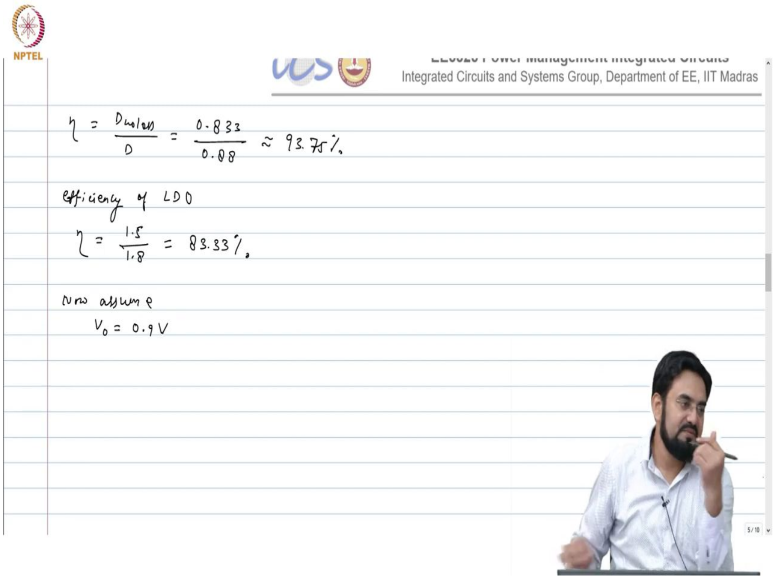

Now, from D no loss over D 0.833 over 0.88, how much is this? 94.6, no actually it should be same. We took an approximation there that is why, 93.75%. So, I am just put a approximation here ok, so, in both the cases you get almost 94% efficiency. So, you can calculate either way if you know the power numbers, then you can just do P out by P in. If you do not know the power number you do not have a way to measure the power then and, but you can measure the duty cycle then you can just look at the duty cycle by removing the load and then applying the load and just take the ratio of that you will get the efficiency, under only conduction losses we are ignoring the switching losses here ok.

So let us see, if the same 1.5 volt was generated from LDO. So, what will be the efficiency 1.5 over 1.8, which is 83.

83% so, almost 10% decreasing the efficiency, which is not that bad. Now assume everything remains the same, but V out is 0.9 volt, which is just half of your supply ok, so, your losses will remain same because resistance is not changing load is not changing. So, from the same formula, only this factor will change 1.5 will become 0.9.

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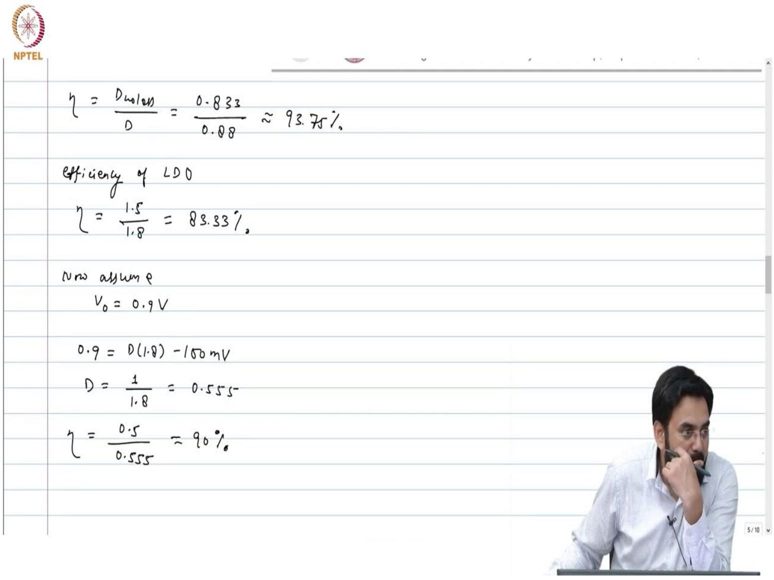

So, 0.9 equal to D times 1.8 minus 100 milli volt. So, D is 1 over 1.8, how much is this? 55.55? So, or 0.555, we know under no loss it will be 50%. So, you are seeing 5% difference, so, efficiency is how much 0.5 over 0.555, 90% correct? What will happen in case of LDO?

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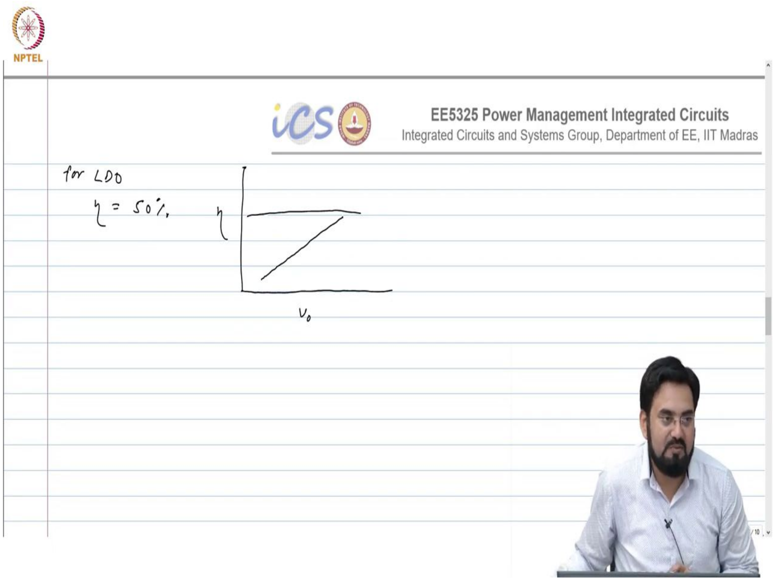

So, and now if you remember the efficiency curve, if this is your V out and this is your efficiency what was happening, when V out was increasing LDO efficiency was increasing, but switching regulator was keeping very high. So, that is why you get almost flat efficiency, I mean you will see some differences because your output power is changing ok, but losses are not changing. So, there will be some differences in the power number, but ok. But in case of LDO what happens? Your dropout voltage is reducing then V out is increasing.

So when your drop out voltage is very low then this efficiency, maybe quite similar to your switching regulator or it may be in some cases even better if your dropout voltage is too low. So, let us say 50 milli volt also you are looking at dropout voltage. So, we know here we are losing 100 milliwatt in switching regulator because of this Dcr and switch resistance. So, which means if your drop out is 100 milli volt that is the V loss? So, the V loss is same in to in the two cases then efficiency would be same. Now if your drop out voltage is less the 100 millivolt your LDO efficiency will be better than your switching convertor efficiency ok. So, that is the reason, we prefer LDO only here for low drop out and switching regulator for smaller V out by V in ratio or larger dropout.

Yeah, it will, but the efficiency of switching regulator will improve, but when you hit a very light load then a switching losses will start dominating and your switching converter efficiency will also a start dropping actually in that case. But in overall if you look at the average efficiency switching regulator will have a better if you look at the wider, wide wider load rang or wider V out by V in ratio in both the cases your switching regulator performance will be better compared to your LDO.