Power Management Integrated Circuits
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Lecture - 32
Introduction to Switching Regulators

So, so far we looked at linear regulators or LDOs, where we know that your control signal is an analog signal V CTRL. The difference between switching regulator and linear regulator is that here the control is the duty cycle which is a basically a pulse-width modulated signal which regulates your output.

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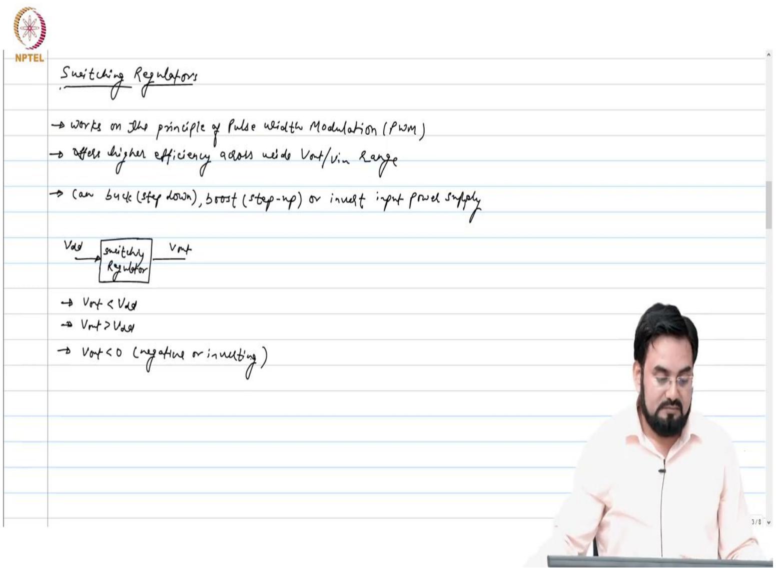

So, it works on the principle of Pulse Width Modulation or PWM. And, this we already looked at, that it offers higher efficiency across wide V out over V in range, ok. Can buck, which is nothing but step-down, boost, step-up or invert input power supply, which means, if we have a switching regulator and if this is your V dd and this is your V out. Means V out could be less than V dd, V out could be greater than V dd or V out could be less than 0, which is negative or inverting.

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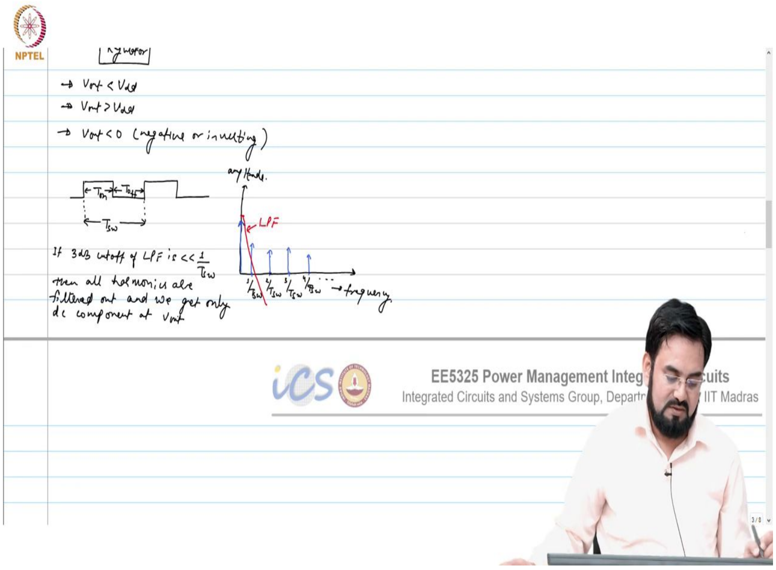

So, how does it work? So, let us say if I have this PWM signal with the period of let us say T sw and I call this T on and this is T off. If you take the Fourier transform of this, how will it look like, spectrum? What all components you will have?

A sine you will have, but how will you plot it on frequency? If this is your frequency and this is your amplitude, what is the first component it will have?

It will have a DC component. So, so, let me draw. So, your 1 over ... then .... and so on. So, which one will be the significant? DC will be the significant component. And, rest of the harmonics will have a smaller component so, it may be like this. In fact, some of them might be more than the, so, odd or even harmonics if you look at, it's not necessary that it will keep decreasing, but it depends on your duty cycle actually. So, the expression is not straightforward here, when you take the Fourier transform of a triangular signal or any other or the Fourier series when you look at it. So, and if it is a perfect square wave then it will have only odd component. But, if it’s duty cycle is not uniform then we will have both odd and even. So, what am I interested in? Output.

What output I would like to have? I want a DC ok. So, which means if I have a filter, very low bandwidth filter, which is a cutoff, which means if this is your low-pass filter. So, if 3 dB cutoff of LPF is much much less than 1 over T sw, then all harmonics are filtered out and we get only DC component at V out ok.

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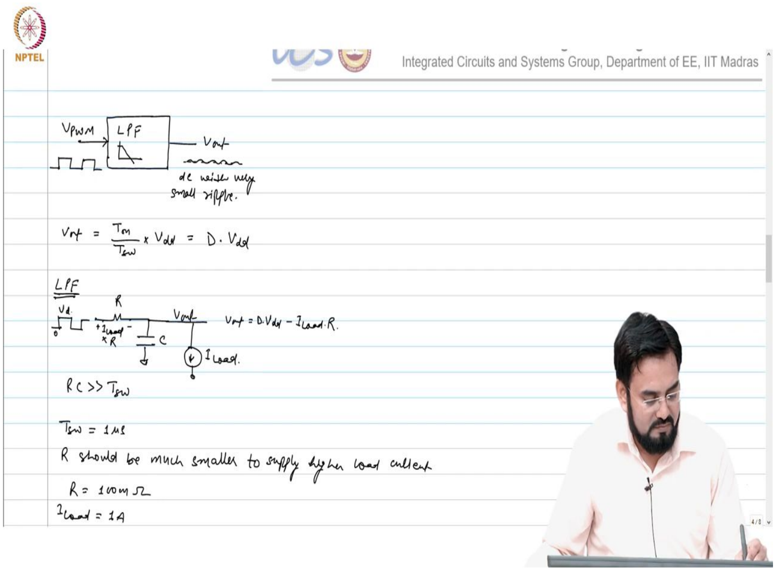

Which means, if this is your LPF which will have something like this, this is your PWM signal and this is V out. So, what do you get here? So, DC with very small ripple, ok. How do we implement this filter? And what, by the way, what is the DC component? V out equal to.

So, that will be the average value of that. So, average of that will be T on over T sw multiplied by V dd, which is nothing but duty cycle times V dd. So, how do you implement this filter? What could be the possible ways of implementing this filter?

RC? Ok, let us see RC. In this, RC time constant is much much larger than T sw. So, this is your V dd, this is your V out. Now, I have a load here, what will be the drop here?

I load; I load into R which means what is V out? V dd minus I load into R and D times basically … correct. So now, let us say, what should be the value of this resistor? What will be the value of this resistor?

Student: T sw by C.

No, but you are putting a load here and that is driving load. How can you make it, so let us say you put a one even 1 ohm you put, 1 amp you draw, 1 volt is directly dropped at resistor output. If we keep increasing that R, you will not get anything at the output, everything will get dropped at our resistor.

So, if now let us take an example. So, let us say your T sw is 1 microsecond; so, which means R should be much smaller to supply higher load current. So, let us say R you make 100 milliohm, I load is 1 amp.

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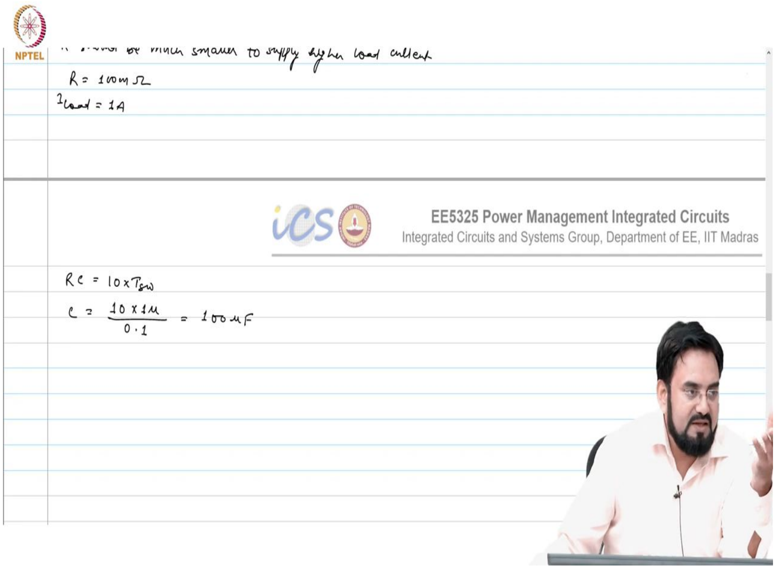

So, you will drop only 100 millivolt which is ok. Now see, let us say you want RC time constant, let us say I want 10 times of T sw; let us calculate the value of C. 10 into 1 micro over 0.1. What is this value?

100 microfarad and even this 10 times I am considering, it is on the lower side actually, usually you would like to have time constant even much larger, so that your ripple can further reduce. So, 100 microfarad is not a small cap, it is a huge cap actually. So, it is not feasible to implement with RC because it will require a very large cap which is not practical actually. So, what else can we do?

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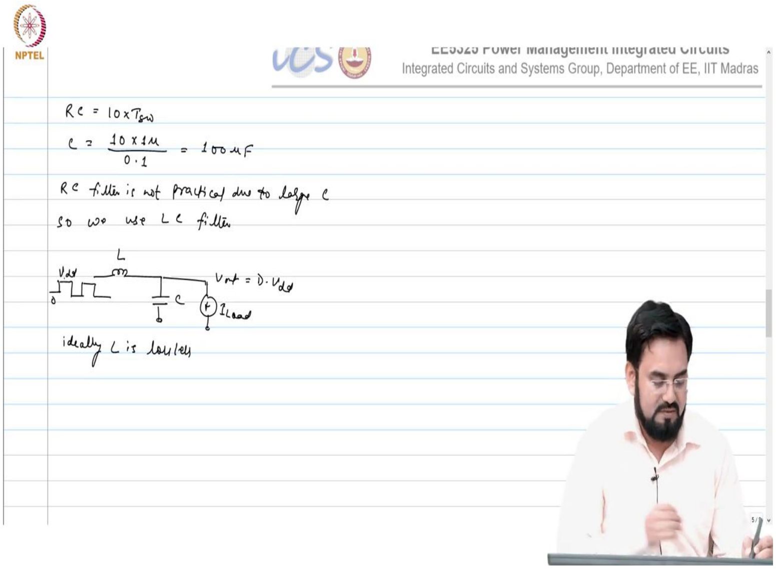

So, RC filter is not practical due to large C ok. So, what do we do? So, we use LC filter. So, ideally L is lossless. So, you will not drop anything, when you draw the load, I load. So, V out equal to D times V dd. So, there are two advantages here; one is to reduce losses and for the same ripple your value of C required will be much smaller because it is a second order filter ok.

So, you get minus 40 dB per decade instead of minus 20 dB per decade like in RC. So, it gives a second order filter and order of microhenry will give you a much better time constant or you can say your cutoff will be much lower. So, now, let us so, let us see if I can derive this V out equal to D times V dd. So, let us go with this principle.

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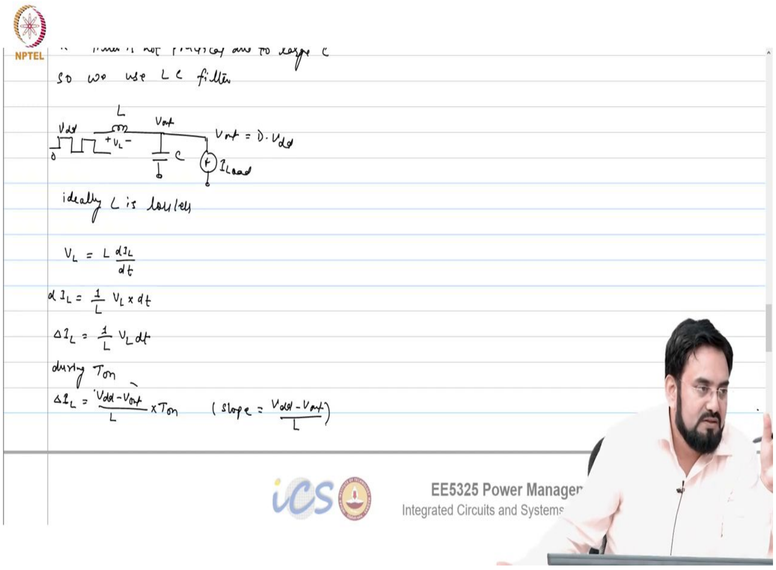

So, V equal to, so if this is plus minus V L this is V out. So, V L equals L d I_L by dt. So, if I want to find the small signal current, what will be that? What will be the small signal current?

So, 1 over L V L times dt ok, correct, I am looking at a small signal. So, if I look at delta component only; so can I write delta I_L equal to 1 over L V L dt. So, during T on your delta I_L will be, what is what is the voltage across your inductor?

V dd minus V out over L multiplied T on. So, this is your current slope. So, this is the slope at which your current will rise and depending upon for how long it is on, that will define your peak. During off time.

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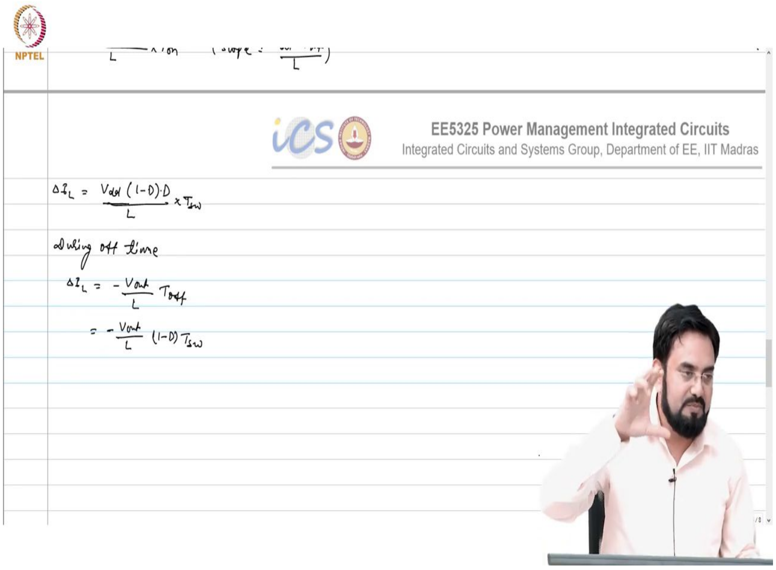

Minus V out over V L into T off correct. And, let, yeah, wait let us fix it. So, this one delta I L can I write like this? V dd 1 minus D, D over L, ok. So, you take V dd common. V out by V dd is nothing but D, duty cycle and T on is.

Duty cycle times T sw, ok, and this one can be written as ... over L into 1 minus D, correct, because T on plus T off over T is nothing but … it is one, so you just break that. So, your D, sorry, the T off will be 1 minus D times T sw, if T on is D times T sw. Now, if you replace this V out by D times V dd, the ripple amount, the peak current will remain the same in both cases ok. So, whether you use this formula, using V_out or using V_in, ultimately your delta I_L or peak-to-peak ripple current would remain the same.

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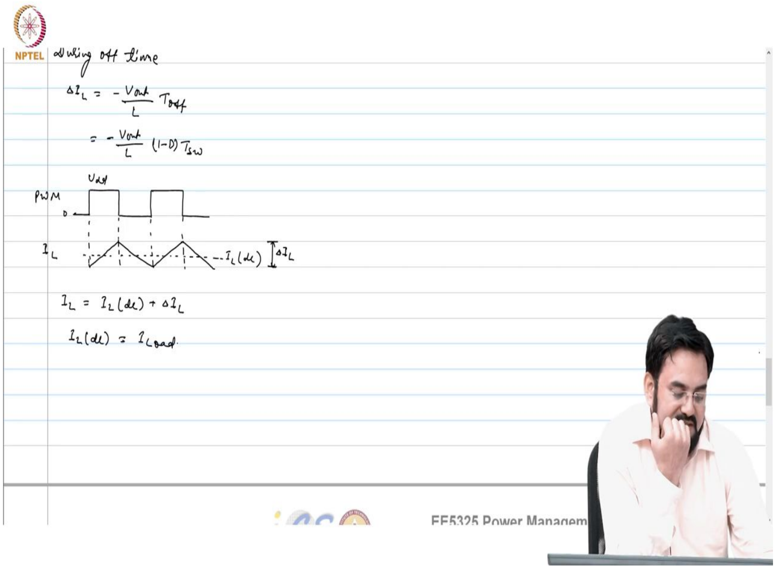

So, if you want to draw the current waveform, if this is going 0 to V dd, if this is your PWM signal, then your I_L or inductor current will look like this and this will be nothing, but I_L DC. So, what you have and this is your delta I_L. So, your inductor current consists of I_L DC plus delta I _ L and I_L DC is nothing, but I_load ok. So, your average current, inductor average current will be same as your load current if your output is constant. So, in the steady-state, your inductor current will settle to I_load and output will settle to D times V dd.