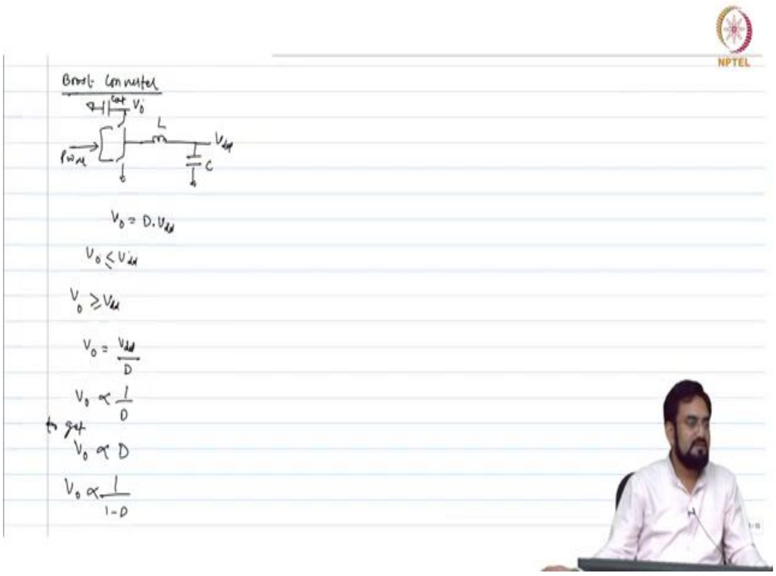
Power Management Integrated Circuits
Dr. Qadeer Ahmad Khan
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture - 81
Introduction to Boost Converter, RHP Zero in a Boost Converter

(Refer Slide Time: 00:16)

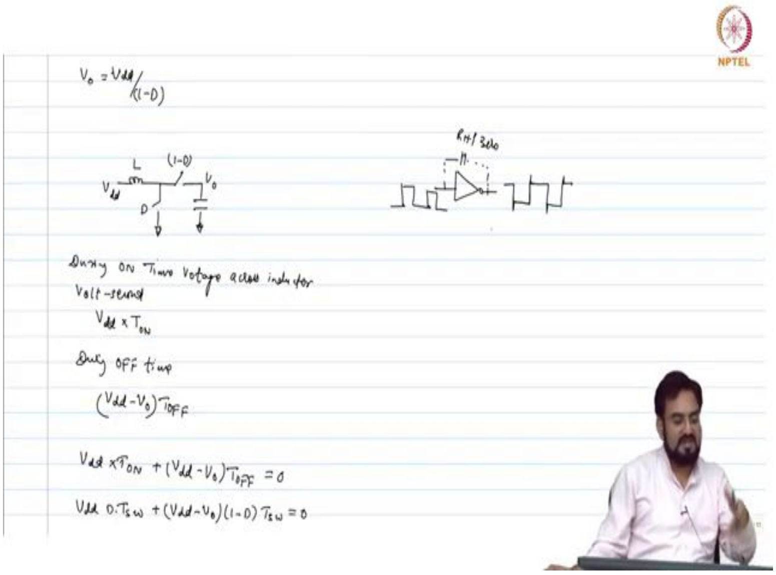


Let us quickly look into Boost Converter. So, this is your PWM, let me draw the switch ok. In a buck converter, V out by V in is always less than 1 or in the best cases V out may be equal to V in. So, what can I achieve, V out greater than V in ok, can I write like this? Same thing huh? Now can I do this? Which means, V in or V dd let me use the same V dd. So, this is your V dd and this becomes my output. So, if this becomes my output, I will need a capacitor also, sorry just put a cap here C out ok. So, what is the ratio now? V out is V dd over D correct? So if I increase D what would happen to V out?

So, V out is inversely proportional to D, but I want output to increase when duty cycle is increasing correct? So, to get this instead of, I will do this; which means I will make the relationship V out equal to 1 minus D times, sorry V dd over 1 minus D. So, D is replaced with 1 minus D which means your high side switch will be? And what is the, I mean high here high side switches basically which is the I mean which switch is charging the inductor think that way the bottom switch or top switch?

Bottom. So, which means your P W M, will duty cycle, will drive the bottom switch not the top switch that is why it becomes 1 minus D. So, now, I will flip the whole converter and draw this way, this will D this will be 1 minus D this is V dd this is your V out. So, this is like an intuitive way of looking into that, but if I want to derive that equation, whether it is true or not how do we do that?

(Refer Slide Time: 03:46)

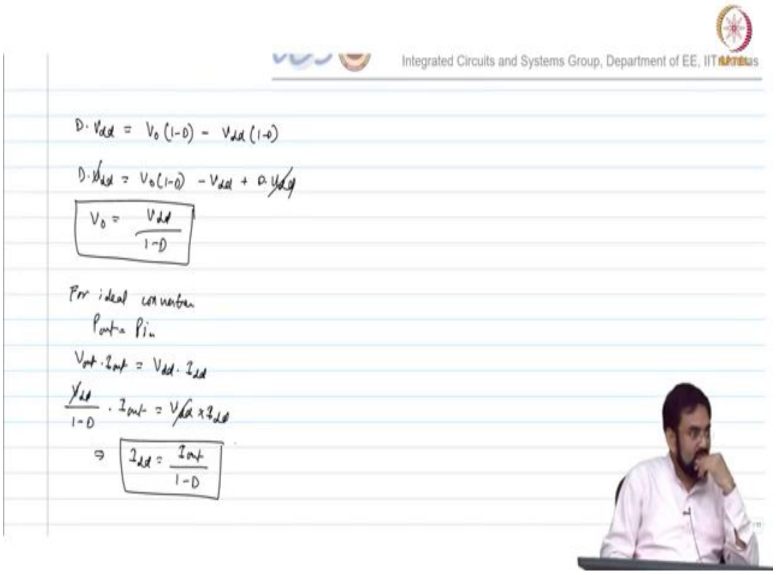


You guys remember volt second balance ok. So, in one cycle average voltage across the inductor should be? 0. So, during on time, what is the voltage? V dd into T on. And during off time? V dd minus V out into T off, so, the average is how much?

Into T off ok, if you want to write in terms of average you have to simply divide by T sw ok, but that becomes 0. So, you do not need to, that is why we call it volt second volt second is not an average voltage actually it is a product of, but ultimately it comes from here only. So, since the right side is 0, so, as good as the same. So, whether you say voltage, average voltage is 0 or volt-second is 0, it is the same thing.

So, now, V dd into T on is you can write T, let us write in terms of duty cycle. So, your V dd D times T s w plus V dd minus V out 1 minus D T s w equal to 0.

(Refer Slide Time: 08:09)



Which means D times V dd is equal to how much? V out 1 minus D minus 1 minus D into V dd correct, D times V dd equal to V out into 1 minus D minus V dd plus D times V dd. So, this is gone. So, V out equal to V dd over 1 minus D ok. So, that was the in duty wave, but if you do not know then you can always derive and this can this is true for any switcher, actually even if you have a let us say I put one more switch pair of switch at input side output side, then you can still derive the same equation.

So, when we talk about the buck-boost then you have four switches there actually. So, in the buck, I mean this is your buck, left side is your buck if this is connected to input right side is your output and if you have a switch at the output side then it becomes a boost.

Now, you have a switch on both the sides and you operate only 2 switches at a time depending upon whether you want to configure in a buck or boost mode and that becomes a buck boost actually 4 switch. So, we will talk about that later.

So, for an ideal converter P out equal to P in; which means V out into I out equal to V dd into I dd and V out we already know what is V out, V dd over 1 minus D into I out equal to V dd into I dd. So, what is I dd here? Which means your current is also boosted the current which is drawn from the supply. So, let us say I am operating at 50 percent duty cycle, my input is 2.5 volt what should be the output?

5 volt 2 x and what should be the, and it is the current is 1 amp then the current drawn from input is 2 amp now. So, if you operate it at very high duty cycle, let us say operating at 90 percent duty cycle and looking at 10 x current drawn from the input. So, and if your current is more in this inductor, what would happen? Which loss will increase? Magnetic, I square R loss 2 x current means 4 x more loss, if it goes from 1 to 2 amp.

If you have, let us say every all the conditions remain the same you are looking at 4 x more losses, that is why boost actually you cannot arbitrarily operate at any high load current. So, whenever we design a boost usually the load may be limited to 1 amp or less than that in boost converters. Especially if you are voltage to input ratio is high, I mean if you are looking 4 x 5 x boost kind of thing, then you cannot just say that I can build a 1 amp current and get a 10 volt output from 2 volt, it is not that simple; you have to look for then very small DCR inductor and very small R ds,on ok.

You can have multiple stages, but again the efficiency problem would be there. You can cascade to boost and the moment you cascade. So, let us see you are getting a 90 percent efficiency from each, you will left with the how much 0.9 into 0.9 80 percent efficiency 10 percent is lost. So, the same you can achieve by single stage and save 1 inductor and 2 switches.

So, ultimately it will not benefit that much when you do any stages, you are limited by duty cycle. So, let us say I limit my duty cycle to 10 percent and I want 20 x. So, that is not possible. So, in that case you do 2 x and 10 x or 5 x into 4 x you get 20 x ok. So, I will not go into detail about the controller and everything. So, um, but I will just briefly tell you there is one problem with this boost, that it has a right half plane zero just like you heard in LDO ok. So, what does right half plane zero do?

Gain is increased and phase is? So, phase response looks like pole and gain remains the same as 0. So, it makes it even worse actually. So, which means your output does not change in a fashion what you want. So, if you guys remember that in the case of LDO, when you had a right half plane zero or wherever you have a right half plane zero, let us say my inverter has a right half plane zero. So, when you give an input clock what do you expect at the output?

It will follow the input for some time and then after that it will change. So, I expect this, but what will happen you will see these glitches. And you can see in the simulation and this is nothing because of this cap, so, the same thing will happen here also. So, I am trying to change the duty cycle, increase the duty cycle. What do I expect my output to increase or decrease?

So forget about undershoot, overshoot - it is a transient thing. I am simply changing the duty cycle to change the output, I am not even looking at the load transient or anything here I want to just change the output. Let us say I am operating at 5 volt, now I want to bring it to 10 volt by simply changing the reference voltage let us say. So, my output should follow the step ok.

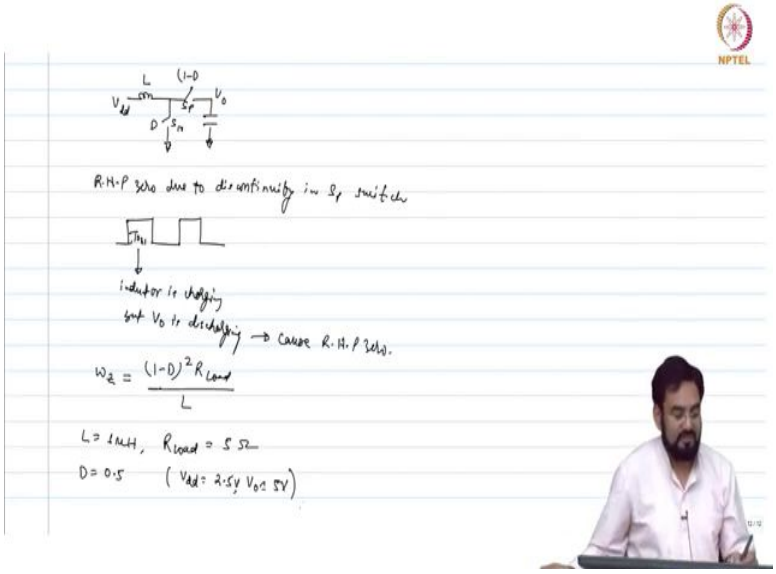
Let us say my reference was 0.6 volt, at 0.6 volt my output was 5 volt. Now I make 1.2 volt reference, I should expect 2x output which is 10 volt. So, I simply give the step. It should follow the step, but it will look like something what you are seeing in the inverter because it has a right half plane zero, but intuitively if you have to explain how will you? So, where is the charging switch - with the ground or with the output?

So, when your switch is connected to ground what happens to the output? What is supplying current to the load? Capacitor is supplying current because it is disconnected. So, there is a discontinuity between these two switches between output and your input. So, if I increase the duty cycle, which switch is connected for a longer time? Ground? Which means you are leaving your output disconnected for even longer time, so output should increase or decrease? It will start decreasing. But at the same time your inductor current is rising. So, next time when you connect the switch conductor will supply all of a sudden huge current and then output will start recovering ok.

It is like a bucket, let us say you have a bucket and you are trying to fill that bucket from a tap and that bucket also has a tap which is leaking the water. So, if you fill the bucket from the tap for a longer your refill basically for a longer time. So, that bucket will keep emptying but then all of a sudden your bucket is full and dumped to that. So, that bucket will be full again. So, it is similar to that actually.

So, inductor basically keeps on charging during on time, but at the same time your output is getting discharged through load. So, if I want to improve this, how can I do? So, this has a right half plane zero, I intuitively explained to you what will improve the.

(Refer Slide Time: 19:43)



So, right half plane zero due to discontinuity in so, let us say I will call it Sn Sp inductor is charging, but V out is discharging causes right half plane so, I will just. So, omega z appears at 1 minus D square R out or R load over l and it is obvious why 1 minus D because? This 0 will become dominant at high duty cycle and which means your omega z is coming at lower frequency I mean we will come at origin at 100 percent duty cycle and you want to push the 0 at very high frequency. So, which means you operate at a very low duty cycle, then it may not be a problem or you operate at very high load, high load means R load is large means light basically in other way a light load current.

So, if I make this R load infinite then it will be push at very high frequency or you may in, what about the L, if I reduce the L? Omega z will go high so, these are the ways to control this and this will limit your bandwidth actually. So, I mean for the D R load and L values you have chosen if omega z lies within your ugb then it is very hard to compensate. So, the only way is to reduce the bandwidth. So, that it is pushed outside your and sometimes this limits your bandwidth of your boost. So, if I want to take an example let us say L equal to 1 microhenry, R load equal to 5 ohm, let us say I am talking about 5 volt and D equal to 0.5 which means V dd equal to 2.5, V out equal to 5 volt ok.

So, let us just do a quick calculation where is this? So, omega z will appear at? 0.5 square 5 by 1 microhenry, so how much is this? 1.25 mega radian per second, so f is 1.25 over 2 pi which is 0.2. So, 200 kilohertz now, I am operating at 1 megahertz I want to keep at 100 kilohertz one tenth. So, 200 kilohertz, this 0 is appearing, it will basically cause a significant drop in the phase margin. Now assume your l is increased or duty cycle is changed. So, that this omega z this f z becomes 100 kilohertz.

So, it will right away make your phase margin how much? Minus 45 degrees huh, that will be whatever if you have a 60 degrees, then it will and it will reshape your frequency curve also. So, your omega ugb ultimately it will push at higher because gain will increase. So, it will make it even worse and I cannot cancel it if I place a pole, that will again drop the phase and make my phase margin even worse.

So, cancelling right half plane zero is very difficult in the other case in the LDO case, we were able to convert it to a left half plane zero by using that nulling resistor, but in this case it is very difficult. So, only way is to just control through your values D, L and your load current, load current is not in my control. So, I can limit it within a certain range and I can define the L you can use and this is the duty cycle range you can operate that to ensure that my right half plane zero. So, there is a trade off between bandwidth and range of load current and your duty cycle you can operate with ok. So, if somebody wants very high load current, then you have to limit the duty cycle. Otherwise this right half plane zero will start making problem.