Power Management Integrated Circuits
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Lecture – 79
Frequency and Voltage Regulation Loops in a Fixed-Frequency Hysteretic Converter

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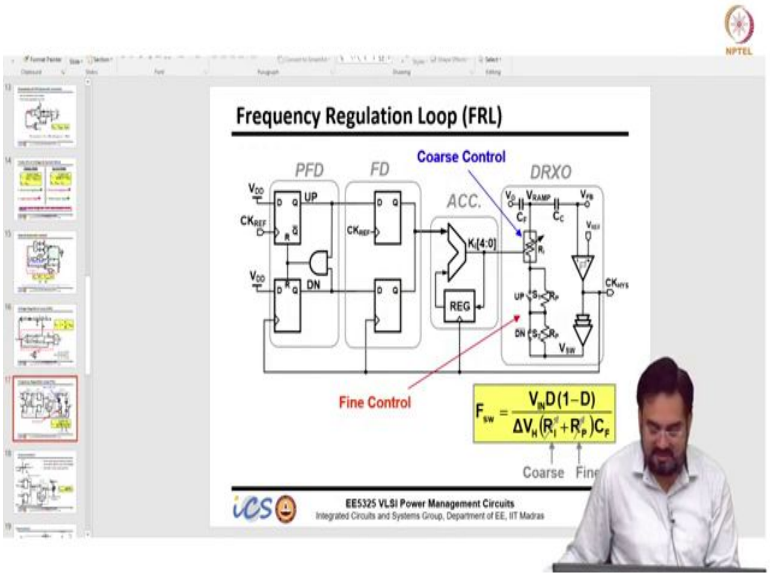

So, this is nothing but simply hysteretic and this is your FRL actually. So you can see this requires 4 flip-flops only to build and this is your digital accumulator and we are controlling here. So, one extra thing we have here. So depending upon how many bits of accumulator you use that will define the resolution of your frequency you can lock too.

So, let us say I am using 5 bit here, 5 bit means roughly 3 percent, accuracy you can get. But if I want to lock it at exact frequency, then you need to have some kind of analog control. With digital it is not possible until unless you have a 10 bit or so then you can say ok, I have a maybe 0.1 percent kind of accuracy ok, if you want a 1 percent then, 7-bit roughly.

So but the problem is that more number of bits will complicate your R DAC. So building a 8-bit or 10-bit kind of DAC is not easy, it will take a lot of area also and guaranteeing that accuracy is also not easy unless you take care of a lot of things in the layout. So what are we doing here? Here we are using both coarse and fine. Coarse means digital, fine is somewhere of analog and I will tell you what analog it is. So we have split this resistor into 2 components.

So, this is controlled by simple digital bits and this is controlled by you can say this up down are nothing but PWM and why is it PWM? So what happens when there is a difference in the frequency between your reference and feedback clock? So, this is your feedback and this is your reference then it based on the phase difference between the 2, it generates up or down ok with that and up and down means one will be 0 other will be high and the pulse width will be defined by the frequency difference.

If it is a positive or negative then you will get either pulse or up or down pulses and the width will be defined by the difference between the phase, and phase difference is nothing but if you have a frequency difference then there will be a phase difference.

So, that is what you get. So what would happen actually? If you look at this, if I ever do you guys remember that we talked about this switched g m? We had a g m with the switch and that PWM will control the g m of that. So the same thing can be applied to the resistor also, correct. So, if I let us say I have a resistor of value R and if I give a if I have a switch and turn on and off that resistor with a duty cycle particular at some frequency then effective resistor will become D times of that R. So the same concept is applied here and so what would happen actually? Now you can think about we have 2 components in the R C time, one is the coarse other is the fine and this R p component is coming from this.

So, if you break your time constant in 2 components, when I say 2 components, it is tau coarse and tau fine correct. So, instead of looking like this perfectly linear.

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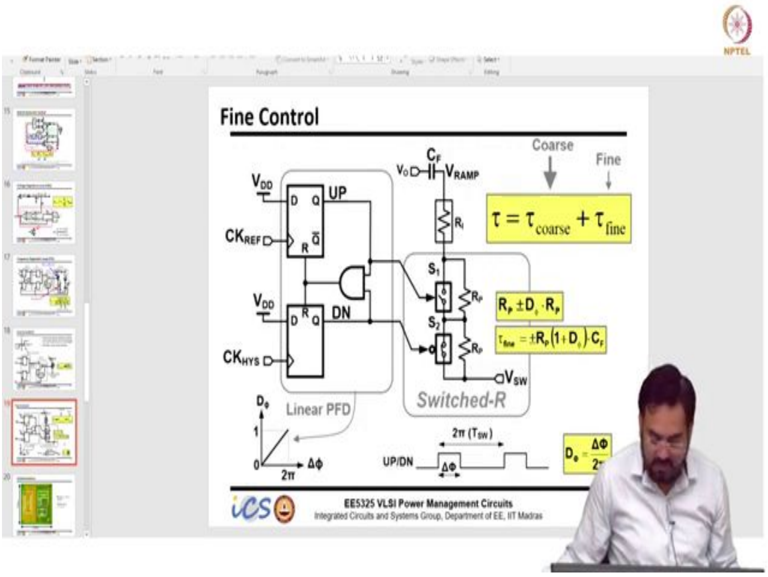

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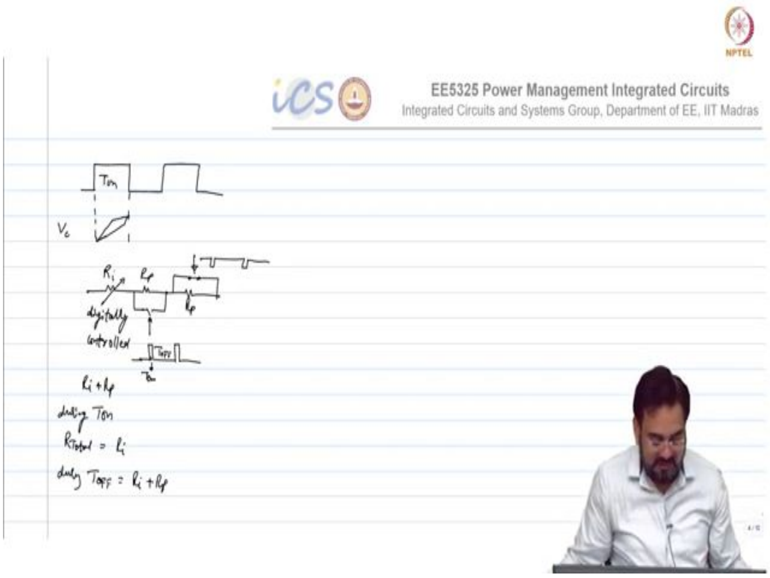

So let us say ok, so if you are looking. So if this is my clock, what am I looking at? This is my V c and see, it will charge like this. But nobody is asking me to and this will be controlled by R c time constant. So, if I change the R then the slope, entire slope will change during on-time and during off-time.

But nobody is saying that you keep the same slope throughout this all time - like if this is T on, I can do this or I can do this also. So which means, the large fraction of that time constant I can control with fixed R and a small portion I can control with some delta width.

So what am I doing here? So I have 2 resistors. So if I call it let us say, R i R p. So this is digitally controlled and if I have a switch let us say, so ok, let us take one, let us take only this one. So this is controlled by a let us say small. So, what would happen if I turn on? So, originally it will be R i plus R p. So if this is let us say I call it T on and this is T OFF. By the way this is this T on T OFF is not same as PWM, this is different. So, what will happen during T on?

What is R total? Ri? And during T OFF? R i plus R p. So, which means your resistor is changed for that small. So if it's reduced means your slope will get faster. So, what if I want to increase? For delta amount I want to increase.

So, you can do the same thing and you can have another resistor let us say, I also I call it R p and so you keep it on for most of the time and you open it for a small fraction then what would happen? It will increase, correct? So during off time you will still get R i plus R p, but if I open this for a very short time like this then during this it will open and add up. So, you will get R i plus 2 R p, during that short period and that is how you control the resistor. So I know and once you lock in the frequency, with some phase difference, this pulse width will remain constant. If there is a frequency difference then this every cycle this pulse will pulse width will keep changing, ok. So your coarse control is already frozen, let us say now I am left with the 3 percent error which is coming due to the finite resolution of that DAC I have. So I want to correct that 3 percent.

So these up down and pulses will be generated based on whether it is a plus 3 percent or minus 3 percent and that will control this. So depending upon up or down coming, you have to control one of these 2 resistors and it will change the resistor value, ok.

Or you can say it will lock with the pulse width for which the 2 frequencies are the same and since this time is constant for this PWM, so they will exactly lock at the same frequency. So, I am not using any analog or anything here, everything is done digitally and this high resolution path or fine control is done using only PWM like control.

So, you do not need any like a very I mean complicated analog to do this actually. So it is as good as analog without using any analog component you can say in this particular control.

So, that is what we did in this and this is what is happening. So, this is permanently on. So when down comes, it will open it and add the resistor when up comes it will close it and reduce the resistor correct. So, this will work like a fine control and once it is locked, this pulse width will keep coming. So, you can say these 2 clocks will lock-in frequency, but not in phase. I mean they will when I say lock-in the phase their edges will not be aligned, they will be slightly shifted, because of this fine control. Because you require that to correct for that extra error which is coming from your DAC or coarse control.

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So, this is what I was talking about. This current sensor is nothing but your R c and you can see this is I mean if you look I mean this is your Power FET and we know Power FET will in any case will be much large, but if you look at this, this is the largest component here in the control. The reason is because those R values, I mean value of R are of the order of megaohms and C is 10s of picofarad.

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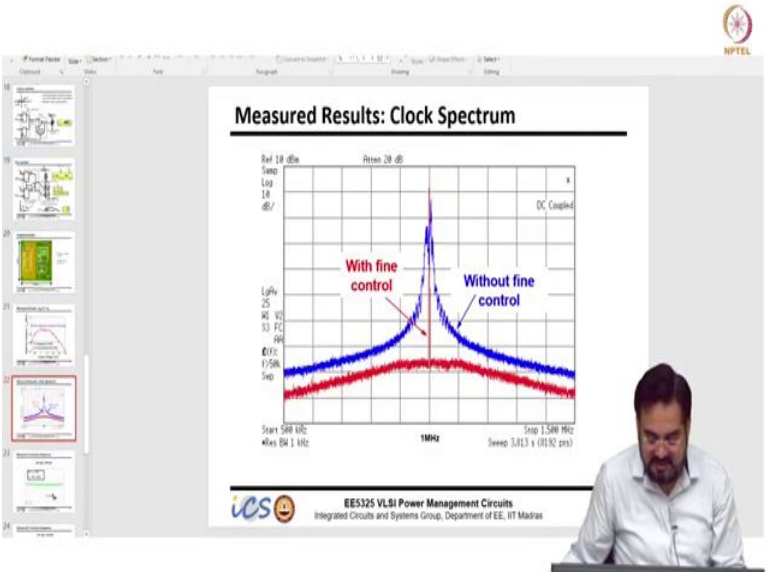

So, this is what. So this is with the without fine control only coarse and you can see your frequency is not locked and there is no single tone as such. It's because I am using only 5-bit. The moment I turn on that fine path, you can see I mean this single tone. So, it locks exactly at the same 1 megahertz frequency and you can see with the output voltage profile.

Remember that duty cycle curve, so when the output voltage is changing, it is as good as changing the duty cycle if its V in fixed and V naught will be parabolic and that is what you are seeing the this variation in the frequency and with that FLL, you get a constant frequency 1 megahertz.

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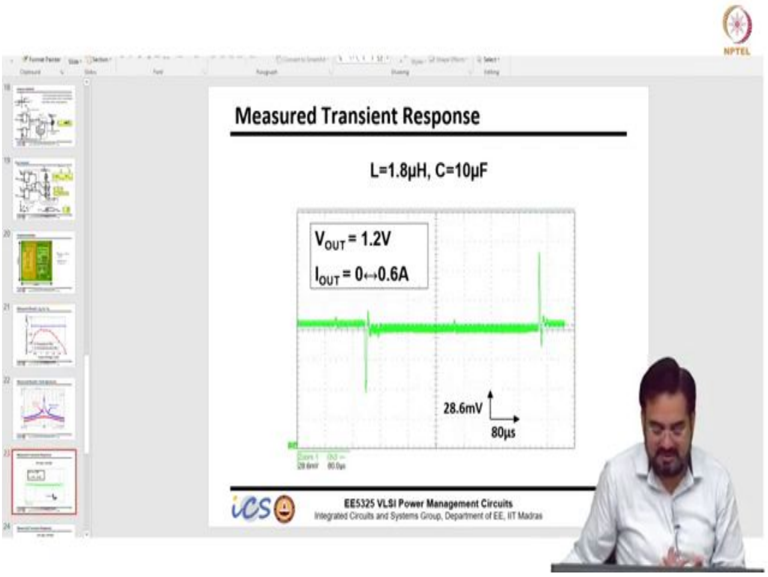

This is your transient response 0 to 600 milliamp, 1.2 volt. So, 28 into roughly 50 56 to 60 millivolt undershoot you see, ok which is 5 percent of this, 1.2 volt and I am using 1.8 micro and 10 microfarad. I mean 1.8 micro is slightly on higher side competing 10 picofarad cap, usually try to keep 10 x kind of a separation between these 2. So, if I use a 20 microfarad obviously, it will improve or I use 1 micro ambient 10 microfarad then you might see better response.

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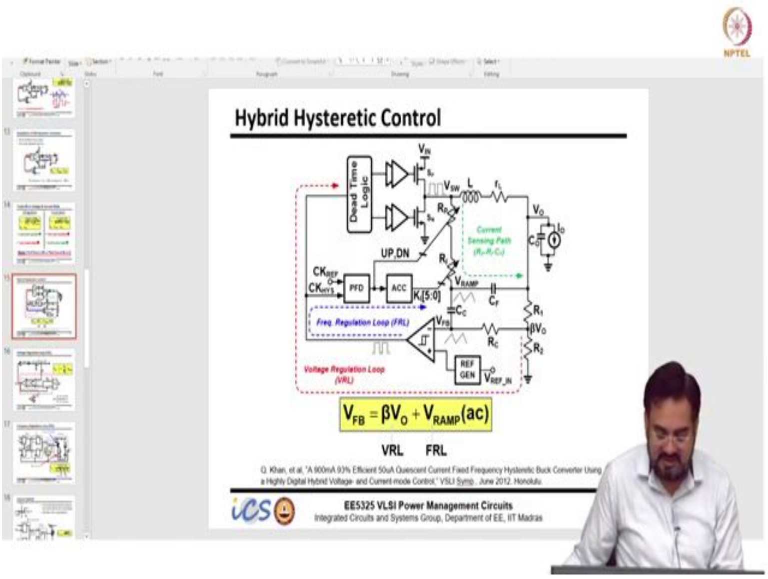

So what happens, but now you have, so if I do try to do this fixed frequency hysteretic converter, what is the drawback of this? Can anybody tell? Do you see any issue by adding this FLL loop?

Student: Switching will also introduce some transient.

Not really actually, it is this is the accumulator. So it will not change very fast. This in the steady state it will not do anything. Once it is locked it is locked. I mean during transient in any case output changes. So during transient only these guys will respond. When you have a, but if it is a slow chain then they will slowly take over and that will not get effect will not be seen in the output.

So one thing you have to remember, this FLL has to be very slow. The reason is, if I make it very fast, if I make it very fast what would happen? You are going towards a normal PWM control and what was the advantage of hysteretic? Fast transient, because your comparator can respond very quickly and the transient improvement is achieved only because it is non-synchronous. So, the comparator can turn on and off all the way, ok which means during transient, frequency is not defined here. It could be anything. It could be turned on all the way for 2 or 3 clock cycles, you do not know. And that, but if I force a particular switching frequency, then you are again going towards that synchronous version of that. I mean the reason we are getting it is non-synchronous.

Now, you are trying to again synchronize by locking to a particular clock frequency. So if this guy becomes dominant, I mean comparator is saying no, I have a transient, I want to on for the entire period or I want to basically reset or set the duty cycle immediately, but this guy will say no, now frequency is changing ok, I will not allow you to do this. Because you have, you are changing the frequency now.

So, you cannot make this path very fast. If I make it fast then, within 1 or 2 cycle it will try to correct which will hamper your transient response. So, better make it very slow. So, during transient, I will allow the comparator to take over and correct the transient and over time, slowly, I will allow this guy to correct the frequency. Only then you get the benefit. Otherwise all the benefits will be gone off what you achieve with the hysteretic. So, this is very important actually. So, the frequency correction loop should not be very fast, otherwise, it will degrade your transient response.

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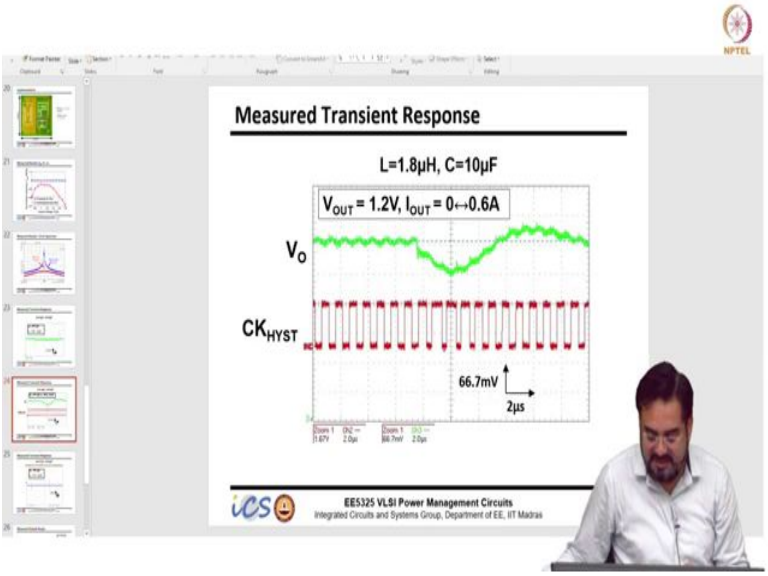

So in this case, if you see here during this transient for maybe 5 to 6 cycles, the frequency is not same as your steady state frequency. So, transient comes and your duty cycle is changed and if you look at a period here, it will be different than this actually, it is not same.

And here, if I made the proportional path which is your up controlled by up and down, the fine path, it will be the stronger, otherwise, you could have seen this guy maybe on for a longer period actually, ok. So, this is taking a still 2 to 3. So, it is not like exactly looking like a hysteretic if you remember, in the hysteretic we had completely on for a very long time until your inductor reaches, but its taking few cycles.

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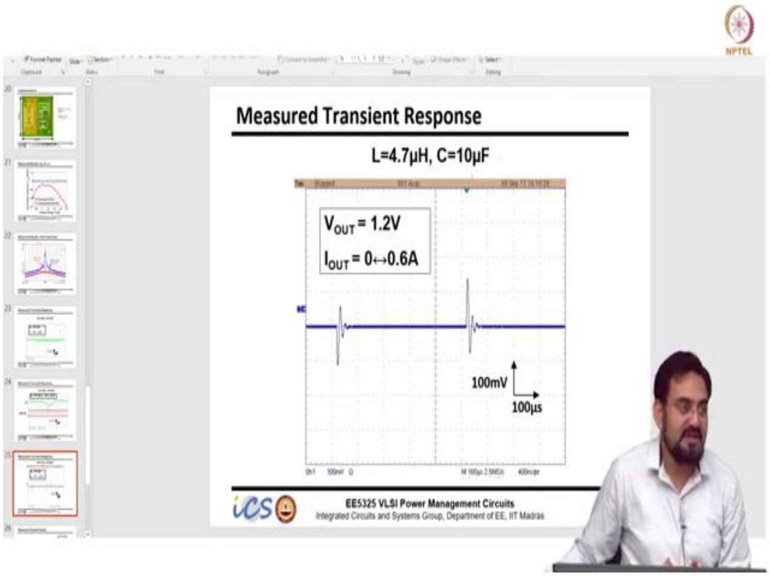

So, another advantage is like its stable for different value. So, I, so this is actual measured result on a silicon. Instead of 1.8, I have put a 4.7 micro which is more than 2 x, it is like 2.5 x of the inductor. If you do this with the voltage mode, I mean you have phase margin for everything defined by one particular LC.

It is possible that it may become unstable. Here is still a stable and you can see the transient response also does not look that bad because look at the capacitor value, I am not changing; 4.7 micro and 10 microfarad. I mean, this is a very bad choice actually I would say. You never want your cap to be too small for such a high inductor value, ok. I would like to keep maybe 10 times of that, 50 microfarad.

So, but it is still it is I mean I am trying to show, I mean even if you choose the I mean you make a bad decision in taking this inductor and capacitor values, it still it is a stable actually it is not that bad ok.

So, there is one more benefit of this hysteretic. You guys remember the PFM mode? How did we do that? We had the same thing, hysteretic comparator and you look at the output, when it discharges below your lower threshold, then again comparator trips and charges the output.

See, you automatically get the PFM here. You do not require 2 different controls here. So, when you go in the light load condition, or you need to just do a 0 cross detect. That is it and turn off the switch or the frequency will be automatically taken care of by the comparator. One thing you have to remember, I do not want frequency to be locked in PFM. So you have to disable this FLL in PFM that is it. Otherwise you will try to pull the same frequency and you will never go in PFM mode, ok.

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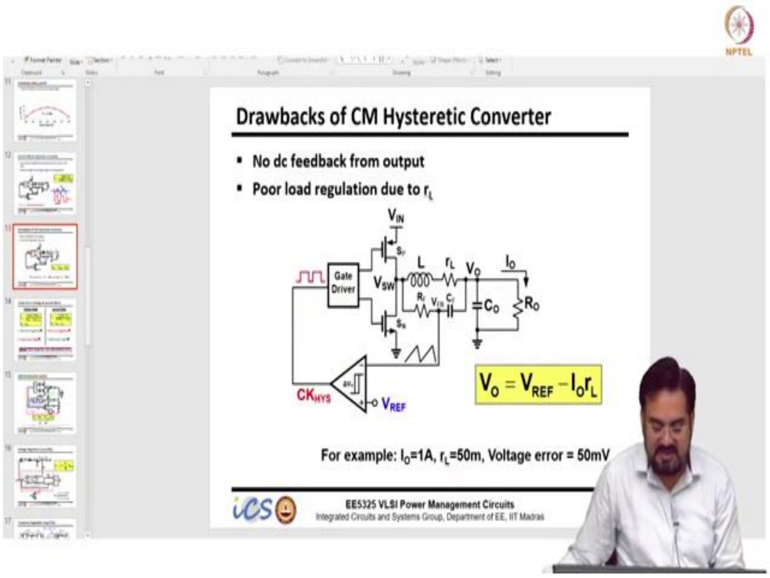

So, the moment you enter PFM mode, you disable this FLL and the PFM loop will take over and the same comparator everything else will remain the same, they can be used as it is. So, the control is just simpler here, no compensation is required, the PFM mode is also simpler because we are using the same comparator in both the cases.

So, the only drawback will be maybe unity check. Accuracy may not be as good as that of a non-linear. There is no integration happening here. So, accuracy but still you get a decent accuracy even if you want an accuracy as good as we already talked about, we can use integrator in the feedback and adjust your V ref.

So, in the steady state you can still achieve the similar accuracy by adding an integrator which is not difficult.