Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
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Module - 11
Hardware Case Studies of Advanced Digital Control Techniques and Course Summary
Lecture - 117
Industry-Driven Architectures for Digital Control IC in High-Frequency SMPC

Welcome. In this lecture, we are going to talk about some Industry Driven Architecture for Digital Control IC in High-Frequency Switch Mode Power Converter.

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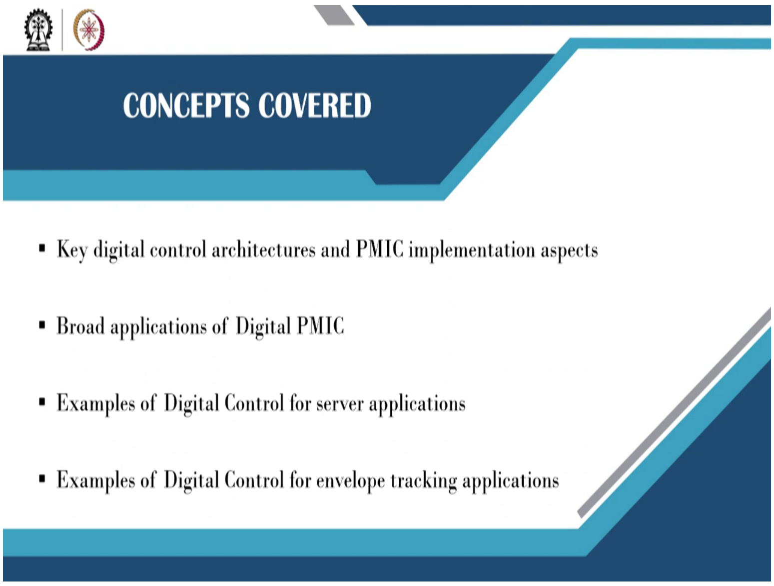

In this lecture, we want to specifically link whatever we learn you know so far to the digital control architecture. If we go for power management IC should it be those architectures or do you need fully digital or do you need mixed signal or do you need analog with digital control assistance like you to know housekeeping arrangement?

So, some aspects we will discuss some. So, we will discuss key digital control architecture and power management integrated circuit implementation aspect, broad application of digital PMIC, then an example of digital control for server application and digital control for envelope tracking application.

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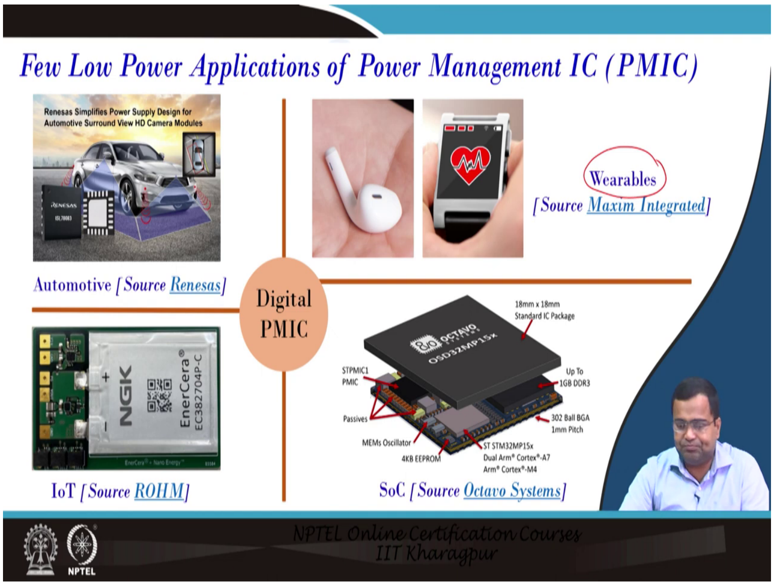

So, if you say consider a few low-power applications for power management IC, one is the wearable device then SoC then IoT automotive, there are many more applications. But, what you want to keep in mind for example, if you take a wearable device, the power level is very very low.

You know for SoC applications the power level is slightly higher but for automotive you can have even higher current applications and server application computing applications. So, the power level drastically varies and you may have n number of digital control architectures you know the level of digitization for different applications.

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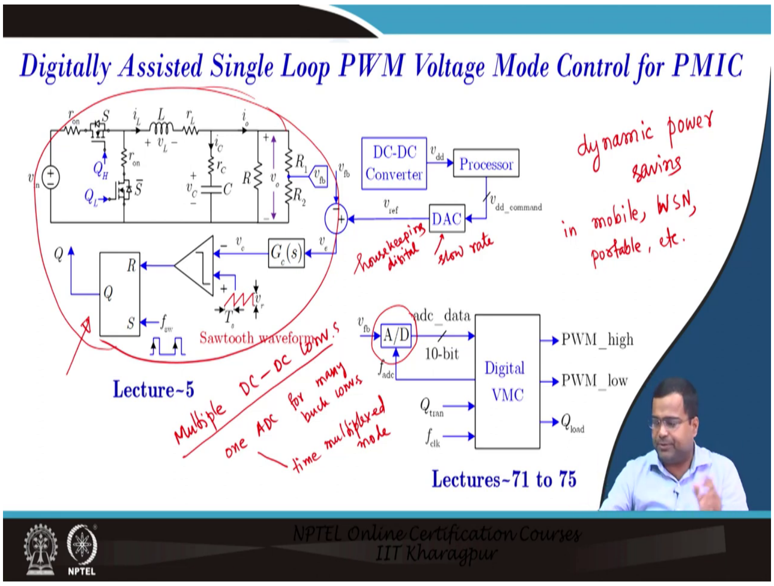

If we start with our digital voltage mode control that we have discussed in lectures 71 to 75, now how can we make a high-frequency digital control voltage mode control power management IC where the power is constant? We cannot afford to have let us say adc; that means, it will be expensive or it can be power hungry the silicon area can increase, but we still need to support it.

For example, if you go for wireless sensor network power management. Where whenever you are sending data then the power supply voltage level should be higher and when it is in idle mode the voltage level has to be reduced. So, that it will save dynamic power. So, this is particularly for dynamic power saving. So, this can be applicable in I would say a mobile phone, then a wireless sensor network a portable application other portable applications etcetera where saving power is very very important.

And for such applications the reference voltage, if we keep the voltage loop purely in analog which is the existing product, has n number of solutions of very high frequency and very power efficient. Now we can add a very slow rate DAC which for primarily for housekeeping arrangement housekeeping digital. That means, here we are generating V ref from DAC, and where the input to the DAC will come from the processor or the sensor network you need to raise the voltage level of the converter, and the control loop will simply respond.

So, in such an application, you may not need a full-fledged ADC, but suppose you are going for an industrial application. So, suppose you have multiple I would say multiple DC-DC converters then you can have one ADC for many buck converters or boost converters and this can be used in time multiplex mode where the core adc time multiplex mode where the time multiplex the core and maybe one, but we can have analog multiplexer.

So, that way we can save power we do not need even the delay because we have discussed in lecture number 1 and 2 that there are challenges in digital control in terms of cost, in terms of power, and all. If you keep the main loop in analog then there is no problem with the delay quantization nothing, but you can add a feature for this digital control by making housekeeping arrangements for reference voltage transient and there could be some other features also. So, these are the exploration that can help with high-frequency PMIC.

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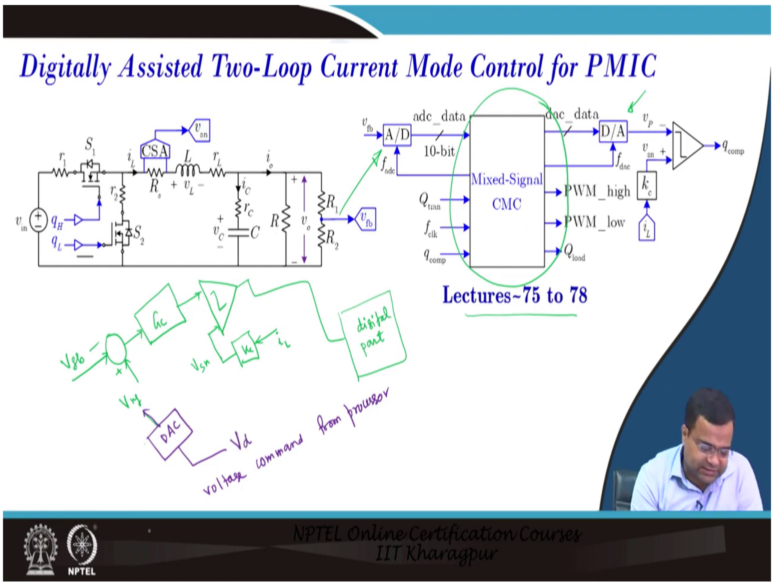

So, that means, the cost of the silicon area of these things matters. Now we are going to two loop control current mode. In lecture number 75 to 78, we discussed the mixed signal current mode control. There we need an A-to-D converter and we need a D-to-A converter. Now, this may not be affordable for many applications because your ADC cost may be high power consumption the delay can be high and that also may be expensive.

So, what we can do? We can take this you know this is the sense current. So, we can consider this feedback voltage negative. If you have a reference voltage then we can have this error amplifier compensator and this can be directly compared with your analog comparator V sense which is a sense inductor current we have discussed the current sensor gain and this can go to your modulator.

From here onward it is a digital part and here I would say the reference voltage can come from this can come from DAC and this can come from a processor command voltage command from the processor. The voltage command comes from the processor.

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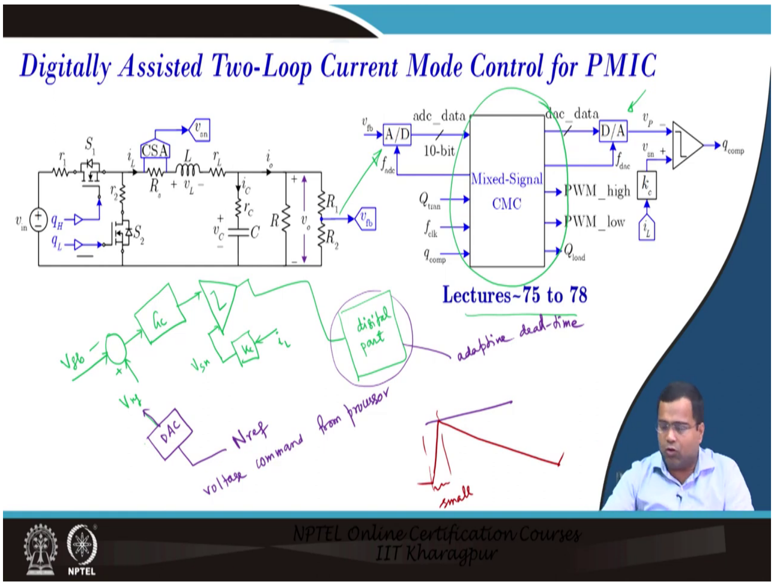

So, this is my voltage command. This is the digital number I would say it is a digital number which will be your N ref right? So, you can make similarly you can do all this timing dead time, you can do adaptive dead time. You can if possible you can use it if there is a ramp compensation also the ramp will be generally generated from a current source charging a capacitor.

So, you can also adjust the current reference, so that you can also adjust the slope of the ramp. So, these possibilities exist for high-frequency current mode control, but this current mode control will have a problem when you go for low duty ratio high-frequency application because we know for low duty ratio operation peak current mode control is stable. But there can be an implementation issue because if you want to compare the inductor current we have discussed that if the duty ratio is very low then this time will be very very small.

I would say it is too small that you cannot use any comparator action. It will be too small in that case you need to go for variable frequency because you cannot go for valley current mode control, it is unstable for low duty ratio and you need to add adjust add too much ramp that is not practically recommended.

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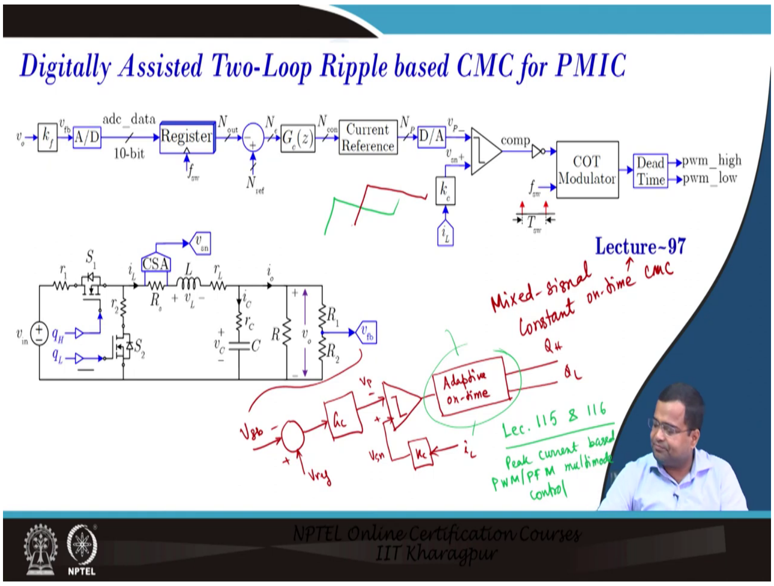

But, if you go to constant on-time control we have discussed the constant on-time control and we have discussed that mixed signal constant on-time current mode control that we have discussed in this lecture number 97.

And we have also synthesized the Verilog code. Now, this modulator; that means, even if you do not use any analog let us say you use this again you continue your feedback voltage which is coming from here, then you have this V ref, then you have this compensator, then this compensator is this is your current sensor V sense, it can be minus plus whatever you can take. So, this is your peak voltage and now this is coming from a current sensor gain.

Now, you are going to hear I will say adaptive on time, why do I say adaptive on time? Because this control can be used we have discussed this in lecture numbers 97 and 100 also. So, if you remember lecture number 100 where we discussed adaptive on-time for DCM. That means, if you are so this will generate then your Q H and Q L and we have considered the multi-mode case study.

If you remember we have discussed thoroughly that lecture numbers I think 15 115 and 116. So, here it is like a peak current base PWM PFM multi-mode control. So, we can keep everything in the analog group and we can use this dead time where in PWM we can optimize the dead time based on energy optimization, we can adjust the on time so that the switching frequency can be regulated ok.

All these features can be enabled here and under light load conditions we can set the current limit according to you know current acceptable range; that means, the ripple voltage and then the switching frequency will linearly vary with the load current. So, you can retain all the constant on-time features. So, light load efficiency will be very very high. By adopting the timing we can achieve the switch fixed switching frequency under a steady state.

So, this can be a very potential candidate and many commercial products are also coming. If you go to most of the multi-phase converters the constant current constant on-time current mode controls are interchangeably we are using for the multi-mode converter. There we also need to balance several phases; that means, for each phase you know they have a constant on-time control and you need to also generate this adaptive phase thing. So, there will be ripple cancellation and ripple minimization and all these features can be enabled.

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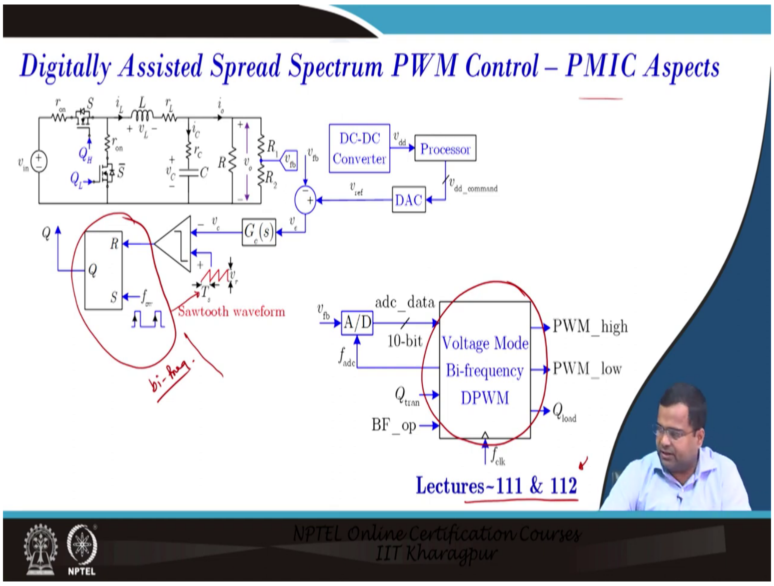

Then if we go for space spread spectrum modulation we discussed with bi frequency DPWM in lectures 111 and 112. Even if you keep everything in the analog loop you can only adjust this person and link with your sawtooth. So, that you can have a bi-frequency operation, you do not touch the loop compensator anything because we show in lecture number 112 and 11 112 experimental results that the performance has no effect.

If in bi-frequency if we do not give too much periodic perturbation for a lower perturbation the spectral will be spread and it will have an insignificant impact on the transient response compared to the unmodulated case. So, we can achieve all these space spectrums even without fully digital we can have a pure analog control with timing control for high-frequency PMIC, but again if we have multiple DC-DC converters.

If you can afford to have adc because most of the products let us say for mobile phone communication devices. So, any particular manufacturer when they make power management IC, then they make IC for various applications and it is like a combo product. So, where you have to drive multiple converters so you can afford to have a few and then you can optimize the cost and you can achieve many of these features here.

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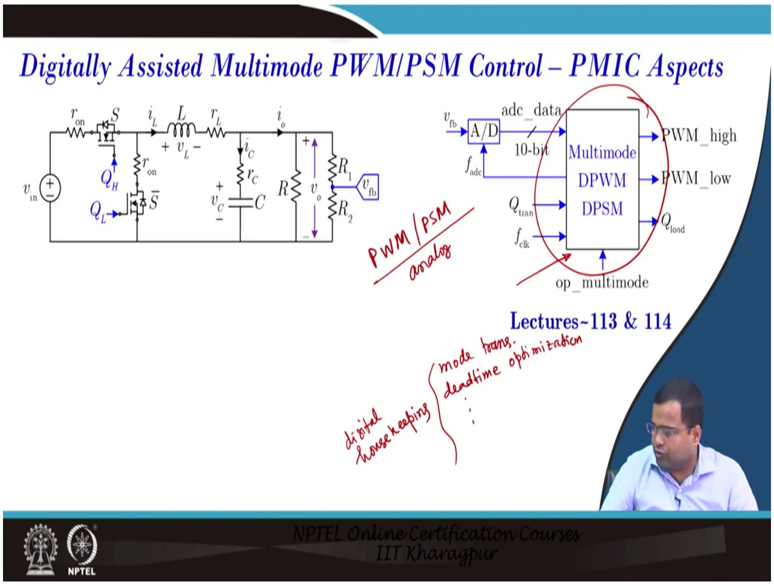

Then digitally assisted multi-mode, so we have discussed multi-mode where we are switching between PWM and PSM. So, this can be easily implemented in analog because there is a commercial product available where it does not require any digital. So, it can be implemented in analog control very effectively, but we have discussed the mode transition effect and then dead time optimization. So, mode transition then dead time optimization during dead time optimization.

So, this thing we can and light load efficiency. You can use digital timing block digital housekeeping very easily and so you do not have to touch the pure analog control voltage control ok. So, this can achieve high efficiency in all this optimization so; that means, this is only a small level of digitization if we remember that we have discussed in week 1 like you know lecture number 5 lecture 8 9 that level of digitization.

So, it is not necessary for us to need fully digitize the loop. We can keep the loop analog for high-frequency low power low-cost solution, but we can play with the timing circuit which is already digital. So, those things are called digitally assisted multi-mode control.

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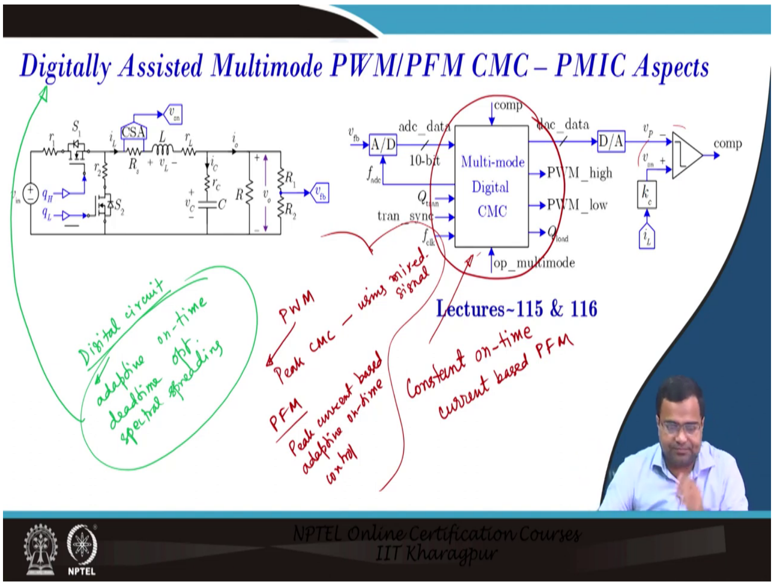

Then digitally assisted multi-mode we discussed lecture number 115 and 116 which is I would say constantly on-time constant on-time current-mode current base would say current base PFM.

So, in this lecture, we have talked about two things under PWM we have discussed we have discussed peak current mode control using the mixed signal. Under PFM we have used peak current mode peak current base adaptive on time while we did all this in mixed signal one can keep analog voltage loop current loop everything analog, but you can combine these multi-mode features with timing adaptation dead time optimization everything in digital.

So; that means, a whole lot of digital circuits consisting of your timing adaptation timing your just timer adaptation adaptive on time, then dead time optimization you know currently I mean you can say spectral spreading this can be digital.

So, that is why it is called digitally assisted where you may not need to touch the current and voltage loop which are already in analog. But again if you want to get a better feature if you can afford a day and if you have multiple such converters this is also a very effective solution.

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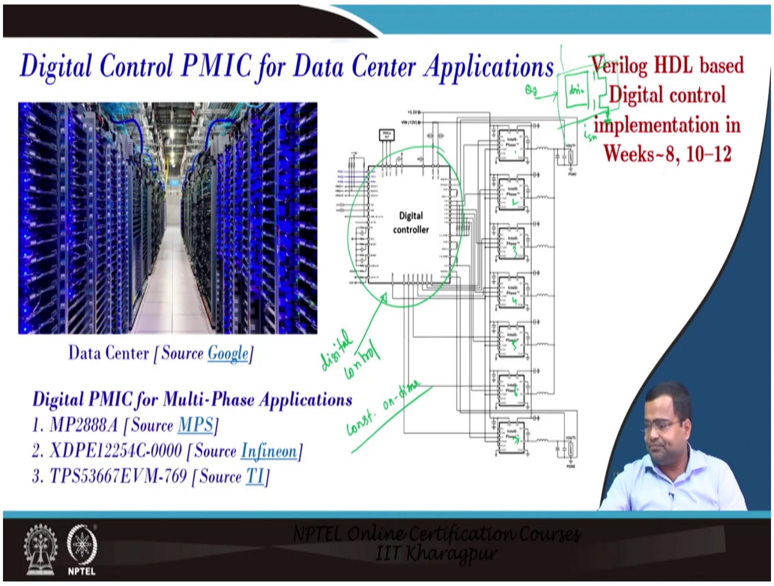

Now, I am going data center application here you can perfectly match that in the data center let us say there are 1234567 phases. So, all these phases have let me each phase has their you know the switch and they also have a driver and they also have a low side current sensing, low side current sense. So, each phase is consisting of this low side.

So, you need to just give the input to the gate signal only once and you can take the sense there is a low current and low side current it may not be very fast. Now we need centralized digital control and there are many commercial products where the whole thing is digital; that means, your control logic is purely digital control.

So, what you can do you can do any type of modulation multi-mode control and purely you can go for constant on-time control, and constant on-time, timing optimization all these features are possible and we have discussed various Verilog HDL-based digital control. In weeks 8 and 12 it will be useful to understand and develop this kind of product where the full control loop is in the digital domain.

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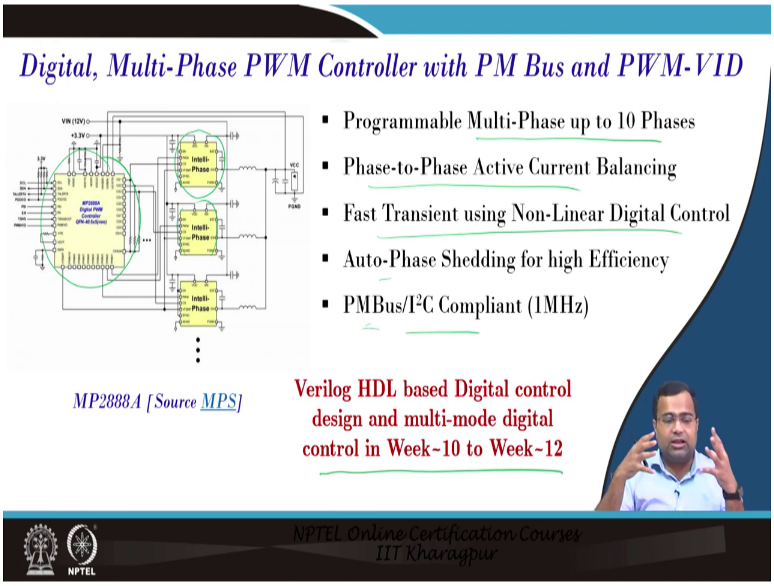

Next, if you go for this ampere solution where we are talking about intelligent phases and the whole loop in the digital controller in digital. So, you can hear it is offering multi-phase for scalable phase up to 10 phase to phase active current balancing then fast transient digital control.

We have discussed the tuning large signal tuning even you can go for trajectory-based digital control or charge control-based charge capacitor charge-based digital control. There is N number of algorithms that can be implemented inside the digital platform auto shedding and then PM bus communication because for DBS application and other applications. So, we have discussed with 10 and 12 lots of Verilog HDL-based digital control which can be useful to come up with a such digital controller for multi-phase converters.

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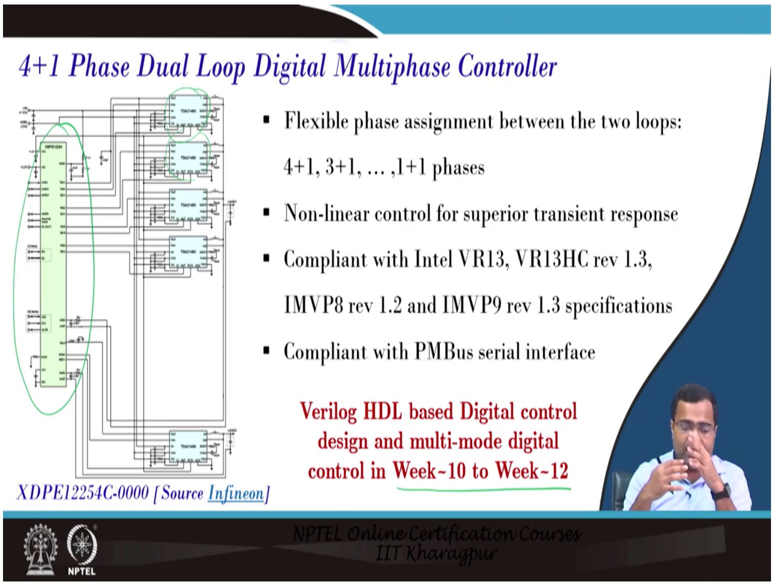

Then this is another Infinium where the flexible phase is also a digital control solution where you know again it is a multi-phase you can have a non-linear controller for very fast transient all this can be possible in the digital domain, but we are not touching the power stage which is in analog.

So, with 10 to 12, we have multiple HDL codes we have developed which may be useful to try to come up with a know solution for a multi-phase digital controller.

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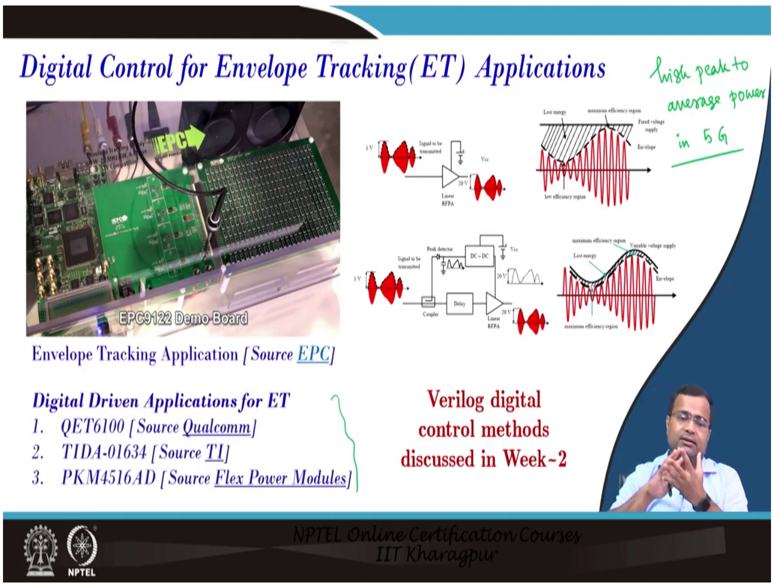

Then there is another application for envelope tracking where if we are talking about 5G communication you know then adders we need a very high-speed power supply for envelope tracking, where the envelopes will change drastically and particularly you can have a very high peak to power high peak to average power in 5G.

And for such an application you need to come up with an alternative topology and people are going by switch capacitor-based architecture, where there are multiple switch caps their gate signal, and the control algorithm the tracking application. So, with the digital control, you may not need to sense all the switch cap voltage. So, you can use some estimated algorithms and different digital control to get very fast super-fast transient for the envelope tracking application and there are many commercial products that we are not sure whether they are using digital.

But, some of them are using digital or some may be using some digitally assisted analog control. So, whatever we learn in week 2 architecture as well as weeks 10 to 12 all the digital HDL code will be useful to develop either a digitally assisted envelope tracking power supply or a fully digital or mixed signal solution.

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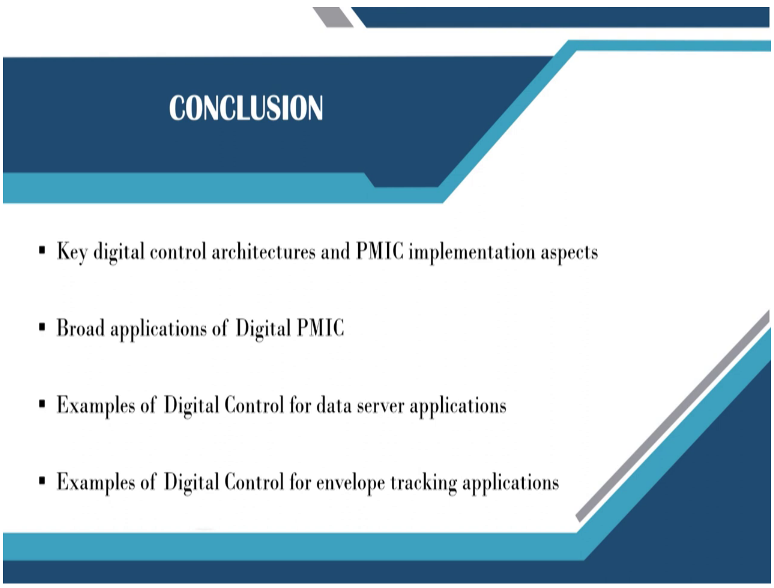

So, in summary, we have discussed key digital control architecture and PMIC implementation aspects. We have talked about the broad application of digital PMIC examples of digital control for data server applications and then examples of digital control for envelope tracking applications. So, this will give a glimpse of you know how this course, what are the concept we learn can be used to come up with high-frequency PMIC either by simple housekeeping digital with a pure analog control loop or can be mixed signal or it can be digital based on the requirement of the number of converter power level switching frequency cost silicon are all these things you know.

So, there can be various tire of products, the premier quality product where you need more sophisticated control digital control. But if you come up with a cost-effective solution market then you may have to go for the digitally assisted things. So, this concept in this course and the HDL code is hoped will be useful to come up with many commercial IC in the future or explore the idea and one can very easily do the FPGA prototyping for the idea validation and rapid development of the digital IC PMIC that is it for today.

Thank you very much.