Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
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Module - 02
Fixed and Variable Frequency Digital Control Architectures
Lecture - 17
Constant On/Off- Time Mixed-Signal Current Mode Control Architectures

Welcome to this lecture we are going to talk about Constant On/Off-time Mixed-Signal Current Mode Control Architectures.

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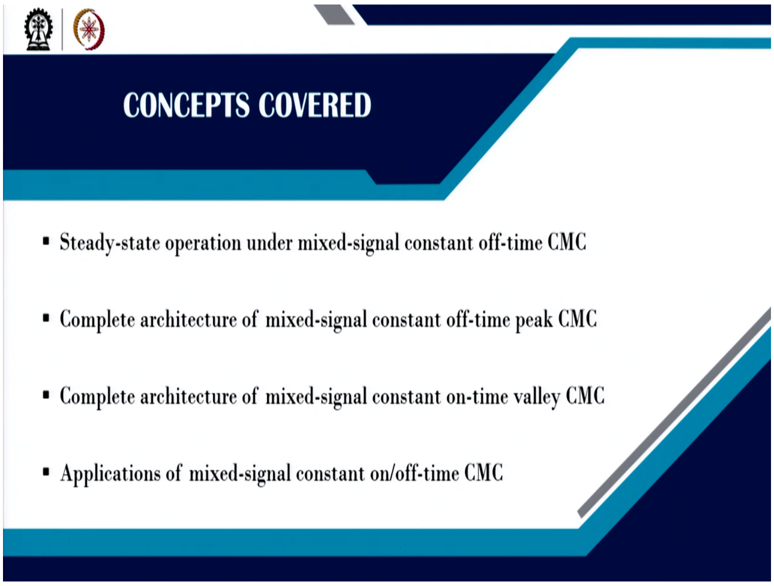

So, first, we will talk about the steady state operation under mixed-signal constant off-time current mode control. Then what is the complete architecture of mixed-signal constant off-time peak current mode control? The constant on-time valley current mode control a mixed-signal architecture and what are the applications as well as you know, what is the difference and you know similarities, what are the benefits and shortcoming in constant off-time mixed-signal architecture that we will also discuss.

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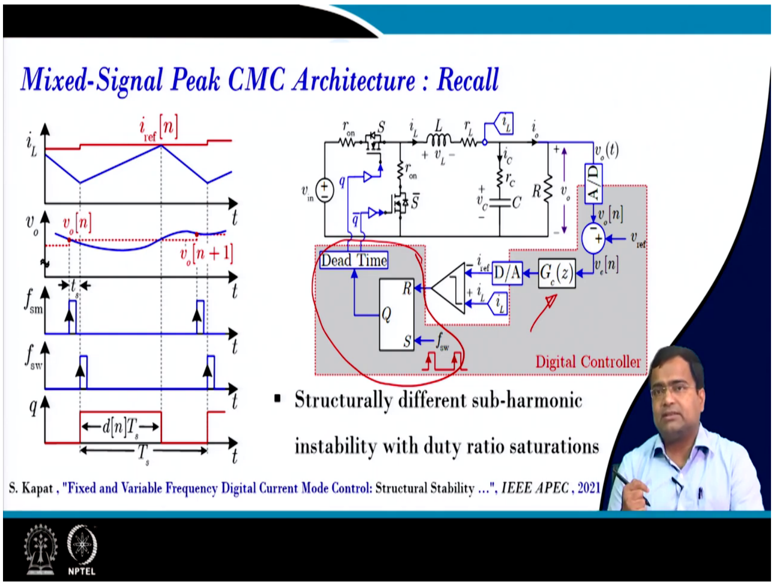

So, in this lecture first, we will talk about mixed-signal peak current mode control architecture. If we talk about if you recall the fixed frequency control then we know here only the difference will be the modulator. So, this modulator will be different otherwise you know you have an analog comparator then you have an A to D converter and D to A converter.

So, this thing we have discussed in you know in this week particularly subsequent lecture previous lecture we have already discussed in detail. And in this paper, it has been reported that if we use a mixed signal like a fixed frequency peak current mode control, then we try to increase the gain of the controller. That means if you want to increase let us say if you want to speed up the response by increasing the controller gain.

Then it will lead to structurally unstable behavior; that means, it will lead to a duty ratio saturation problem and that means, there will be subharmonic instability, but it will also lose the structural stability. But in this paper, it is also discussed such structural stability will not be lost in variable frequency control.

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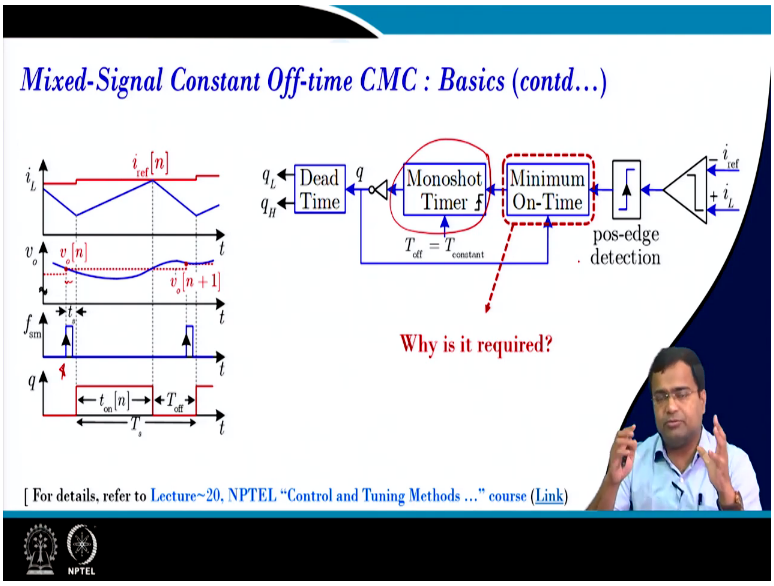

And we have discussed in the previous lecture what is the mixed-signal constant off-time current mode control. And we have discussed that if we trigger that means if we link the sampling with you know monoshot timer event. That means, you know here as if we are sending the sampling command before the monoshot timer finishes counting, then we can provide some delay for conversion and computational time and the current difference will be updated accordingly.

Now, in this timer there is a monoshot timer and this monoshot timer will be loaded with a constant off-time that is the timer. And there will be a minimum on-time and this logic we have discussed in detail in our NPTEL lecture in the previous lecture. Because you know if we want to avoid a potential collapse then most of the commercial products use a minimum on-time and that we know.

And in case of constant on-time control, there is a minimum off-time. So, these two parameters are there which will avoid such modulation and may not lead to a complete collapse of the system.

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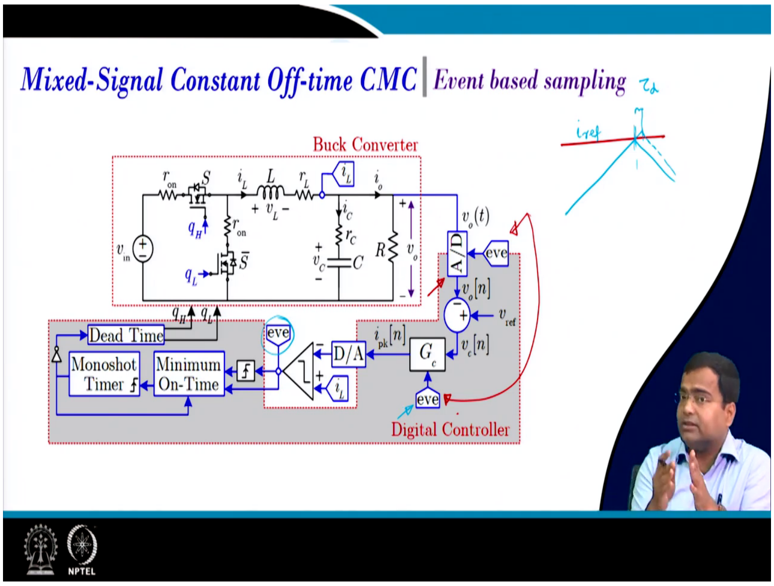

Then if I take the full structure of the constant off-time control, we need to compute this A to D coA-to-Dr. That means, we need to sample the voltage of like A to D converter using the A to D converter that sampling should be with respconcerningt. So, when you say the event this is a clock that will generate the event and that will sample the A to D converter. The same clock should be used to sync with the controller computation ok.

That means, but there can be a time shift because the computation may happen after some time; that means, it may not be exactly at the same time as the sampling. Whenever you send the sampling command the competition should happen a little later, because that will accommodate the conversion time of the A to D converter. And then the event can be detected from the comparator output.

So, whenever this comparator goes high then we will detect the event because suppose you are talking about a constant off-time; that means, this is a peak current reference.

And we are talking about the inductor current; that means, whenever sorry inductor current. So, whenever the inductor current hits this peak current, this is the limit whenever it hit we take the sample. But practically we cannot turn it off immediately because there will be driver delay and all. So, the current will potentially go a little bit later; that means, this will be a delay this delay tau d due to the driver delay may be a dead time delay, so you cannot turn it off.

So that means, whenever you see the comparator hitting the current is hitting reference current then you send the sampling comment and that can be generated. So that means, we can get a clean sample. But this should be delayed phase shifted because the computation cannot happen immediately. After all, only the data should be available.

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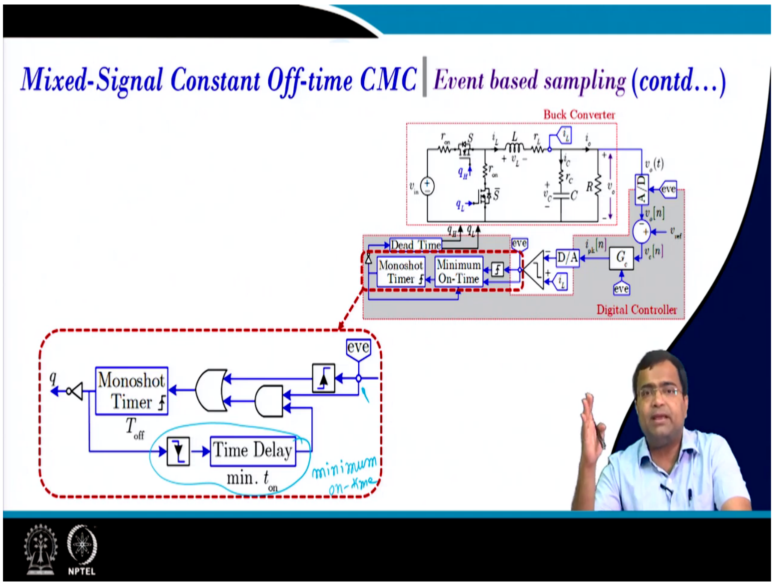

So, this is a full architecture, and the monoshot timer has a detailed description; that means, you know if you go inside the monoshot timer there will be a time delay and this delay is a minimum on-time. So, this is our minimum on-time, if we want to avoid a complete collapse of the system minimum on-time and this is there in all commercial products and if you talk about constant on-time there will be minimum off-time.

So, this is a typical implementation. This implementation aspect, other than this sampling clock we have discussed in our NPTEL previous lecture. The only thing in digital that we need this clock edge to this is the event concerning this event we are going to synchronize the sampling and the computational process.

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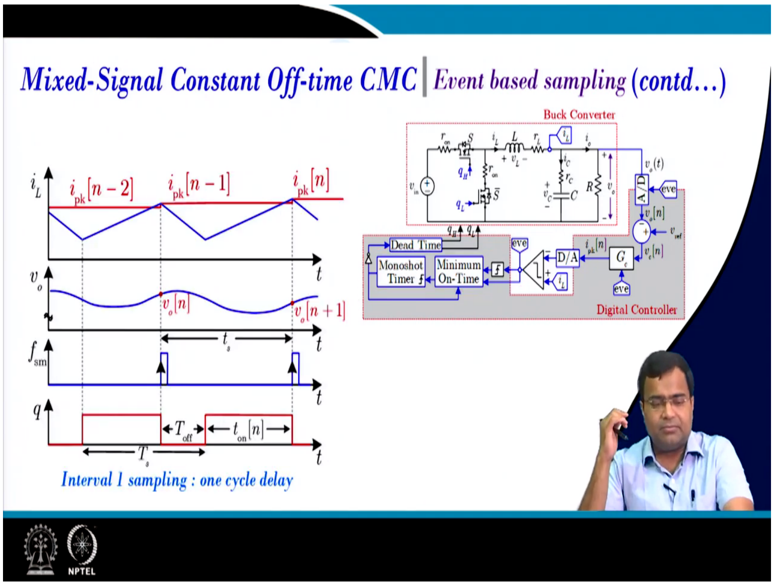

So, in constant on-time off-time this is with one cycle delay; that means, you can provide sufficient delay for the conversion and computation ok.

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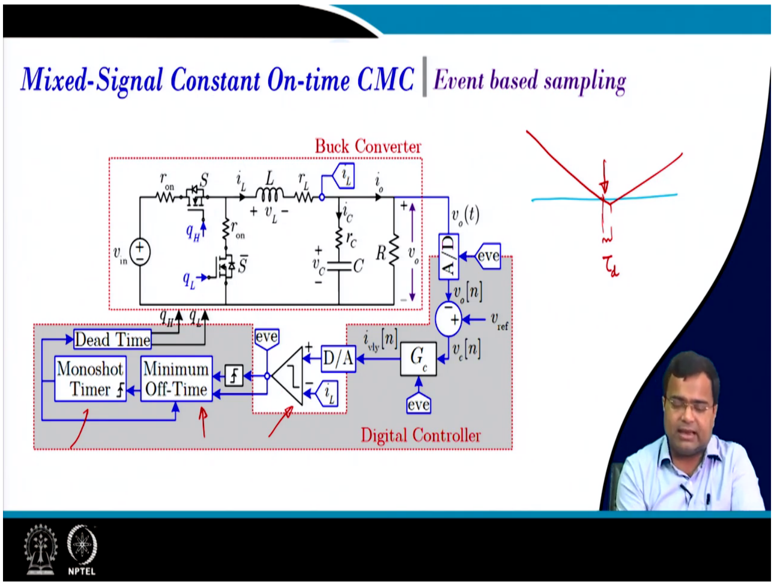

And this will also have a potential problem in terms of stability and performance if you go to constant on-time. So, this architecture also we have discussed here is like a valley current mode control; that means when the inductor hit the lower limit current. That means, whenever the inductor hit the lower limit than you turn off the; that means, you should send the sampling command, but since there is a delay. So, essentially the current will go a little further down.

So, this delay you know that delay is due to driver and you know the delay due to the driver as well as the delay of the dead time, and you can take the sample here, and then the output voltage will have a clean sample because there is no switching event at the time, I am talking about this particular time.

So, this is a minimum off-time you have to provide for constant on-time control and the on-time is loaded in the monoshot timer. So, everything else structurally almost remains the same only some logical blocks will be different under this and you know either you can change the terminal of this inductor current to the reference current or you keep it the same and you can take care of the internal logic here.

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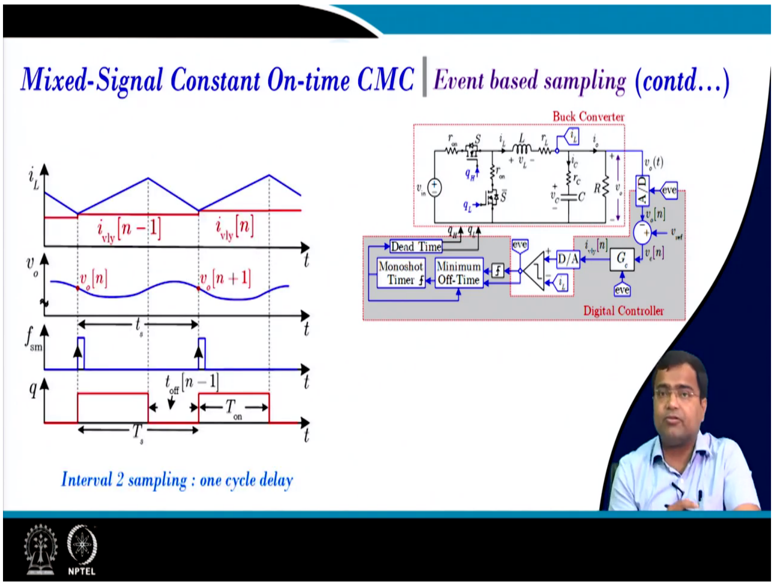

So, this is the constant on-time current waveform here you can see if we take thus it is one cycle delay. That means if you take the sample whenever the monoshot timer is about to turn on; that means, you know this again will be delayed. That means, whenever the monoshot timer the current hit the reference current limit then actually you send them because it is one cycle delay.

So, whenever it hit the current limit then you send the sampling command, but there will be a small delay the current should little bit go down in this case, and then it will go up ok.

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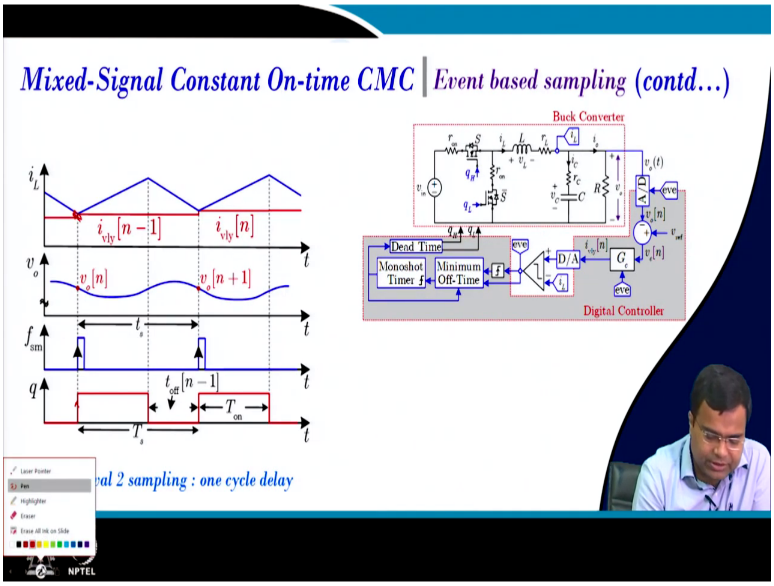

So, if we take them here. So, it should be the current should go a little bit on this side, and then it will have because this is the time the dead time a delay due to the driver as well as the dead time. So, that time you can take the sample and you can use it in the next cycle. So, it's a one-cycle delay. So, otherwise, it is the same only fundamentally how this modulation and the timings parameters are generated that is the difference.

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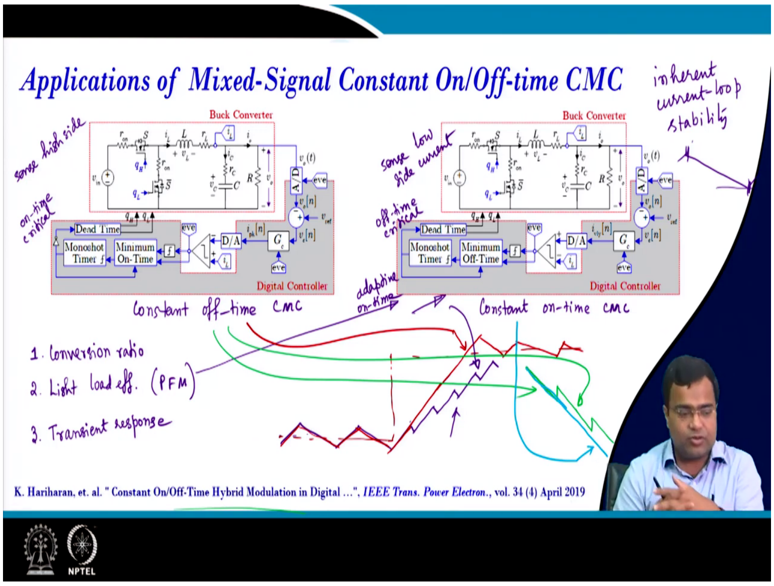

Now, we want to compare and it is reported in this paper that it is well known the constant off-time. So, this is our constant off-time current mode control and this is constant on-time current mode control. So, we want to see what are the applications right first of all both of them can be used for wide utility operations because we have not discussed the inner loop stability. If we discuss the inner loop stability then both of them offer inherent current loop stability; that means, the current loop is stable for both cases.

So, inherent current loop stability is applicable so; which means, you can use for wide utility operation any of this technique. But if you take a buck converter for constant off-time control we are essentially controlling the peak current; that means, what you need to sense high side current sense high side.

If you sense the full current then you can implement any of this control logic, but if you want to specify only that you know want to implement constant off-time you need to sense the high side currently. Here you need to sense the low side current this is for a buck converter it will be the opposite for a boost converter. So, it is easy to sense low-side current for a buck converter because the low-side switch is a ground reference.

So, you can simply put a resistance or you can take the advantage of RDS. So, it is reasonably easy and that is why you go to the commercial multi-phase product. The majority of these products they are used they use constant on-time control because they can sense the low side currently.

Similarly, if you are talking about a low in a smaller on-time or longer off-time then you will get a longer duration to sense the current. That means, it is a valley architecture, so you will get sufficient time for sensing and computation. Similarly, if you are talking about a longer on-time then this technique may be useful, because if the duration is very very short then sensing because you know this always the current sensor will have some spike here high-frequency current sensor.

So, some portion of this current has to blank; that means, you cannot compare otherwise it will false trigger. So, you will have a limit on the duration for which you can get the clean current signal and you have to compare it with the other analog current difference. So; that means, if you get a longer duration then you can wait. So, that the transient part is removed and you can compare.

So, you do not need a very very high-speed comparator, but if the duration is very small then it will put pose a constraint and it may not be able to implement the mixed-signal architecture because of the sensing noise in the analog current.

So, that is why even though both can be used for wide utility operations, the duration of the time for this critical duration is that; the critical duration is that your on-time duration has to be longer, on-time critical. Because if the on-time is not sufficiently large then you cannot do any comparator action, but you can make a very small off-time because it is a constant off-time there is a timer circuit.

Similarly, the off-time current off-time is critical here because you need to take the action during the off-time. So, based on that if you are going for a low-duty ratio buck converter or a high step-down buck converter then this will be more suitable for constant on-time than constant off-time and that is why the major of the commercial products are coming.

And if you go to the multi-phase product low voltage high current application, most of these people go for constant on-time control. And it is a very very you know well known control technique. So that means, depending on the duty ratio you have to select. Another aspect; is that means, the 1st point is your duty ratio, or I will say not duty ratio because it is a variable frequency modulation I will say the conversion ratio; which means, the voltage conversion ratio.

So, a lower conversion ratio and low conversion ratio constant on-time are preferable for buck it is the opposite for boost and a high conversion ratio constant off-time may be preferable. Number 2 is that what is that the conversion ratio is one is the light load efficiency. So, light load efficiency.

So, it is well known we have discussed in our earlier NPTEL lecture that constant on-time control if you operate in discontinuous conduction mode under light load, offers the switching frequency linearly varies with the load current; that is the property it holds. That means if you apply constant on-time under discontinuous conduction mode in light load.

And if the load current decreases then the switching frequency will linearly decrease as a result it will save the switching loss and it can improve the efficiency. And that is why most of the PFM techniques if you go for PFM Pulse Frequency Modulation, by default use this constant on-time modulation or its derived version.

Either direct constant on-time or it can be peak current difference-based constant on-time equivalent to this or it can be adaptive on-time. So, either constant on-time or something called adaptive on-time adaptive on-time control. So, in this paper, we have also discussed these are all well-known.

The 3rd one is the transient response. So, suppose I am just considering an inductor current reference like this and there is a load transient ok. Now when there is a load change, that means this was my initial load current. So, this was my initial load current now here the load current got changed, let us say it go it goes here.

Now the inductor current has to change this value. So, if you go for constant on-time control. So, if the on-time is constant then after the constant on-time, it will undergo a minimum off-time, so it will go like this ok. So, that is the problem under constant on-time because of minimum off-time because if you want to speed up the response you want to slew off this current. That means you want to as fast as possible increase the current and constant on-time because the minimum off-time will slow down.

But if you take the constant off-time control the same waveform only let us say we are talking about constant off-time. So, it will simply slew up and it will hit the peak current (Refer Time: 16:20), and then it will come back. So, it will go like this. So; that means, in terms of the transient response point of view. So, this is like a constant off-time; that means, this is coming from here and this logic is related to constant on-time because of minimum off-time. So that means, for a step up transient constant off-time by default is better than constant on-time.

So, that is why many commercial products want to adjust or they may disable this minimum off-time during the slew-up process to speed up that one possibility. But if we do not alter such constant minimum off-time duration under constant on-time modulation then you will end up with this you will suffer from know slower step-up transient.

But if you take the step-down transient it will be just the opposite step-down transient the constant of time has a minimum on-time, as a result, it cannot slew down; that means if you take the other transient effect. So, suppose in a constant off-time it will sorry it will go like this. So, this is under constant off-time. So, it will penalize the step-down transient, but if we talk about minimum constant on-time, sorry if we talk about the constant on-time control it will simply go on.

So, this is under this technique and this green one is using this technique; that means, this green one is using this technique. So that means, the transient response point of view constant off-time is good for step up transient constant on-time is good for step down transient.

And in this paper, we have shown that if you hybridize this constant on off-time with some minimal changes in the architecture, you can retain the fast transient response for either configuration ok. And then you can further optimize the performance by tuning the controller.

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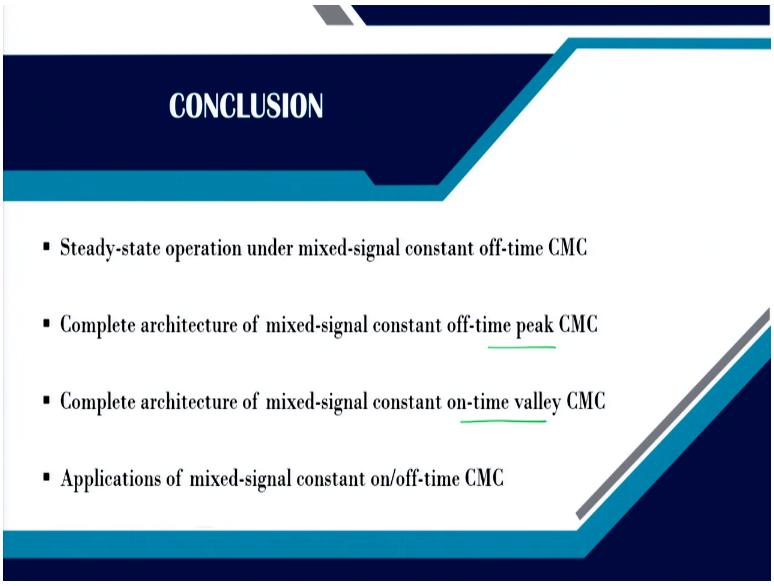

So, in summary, we have discussed steady state operation under mixed-signal current mode control in using both constant off-time as well as constant on-time architecture. So, constant off-time is the peak version of the current mode control constant on-time is a valley version of this.

And we have discussed some aspects of the application of mixed-signal constant on off-time you know current mode control architecture. And we saw that for wide utility operation which is useful in terms of sensing, current in terms of duration of on and off for taking the comparator action in terms of transient performance and also in terms of light load efficiency.

And we want to see some of this aspect when you go to actual hardware implementation or maybe the MATLAB simulation, some case study we can show. And we will show why these techniques are gaining popularity the variable frequency control and also want to see at you know some hardware case studies. So, with this, I want to finish it here.

Thank you very much.