Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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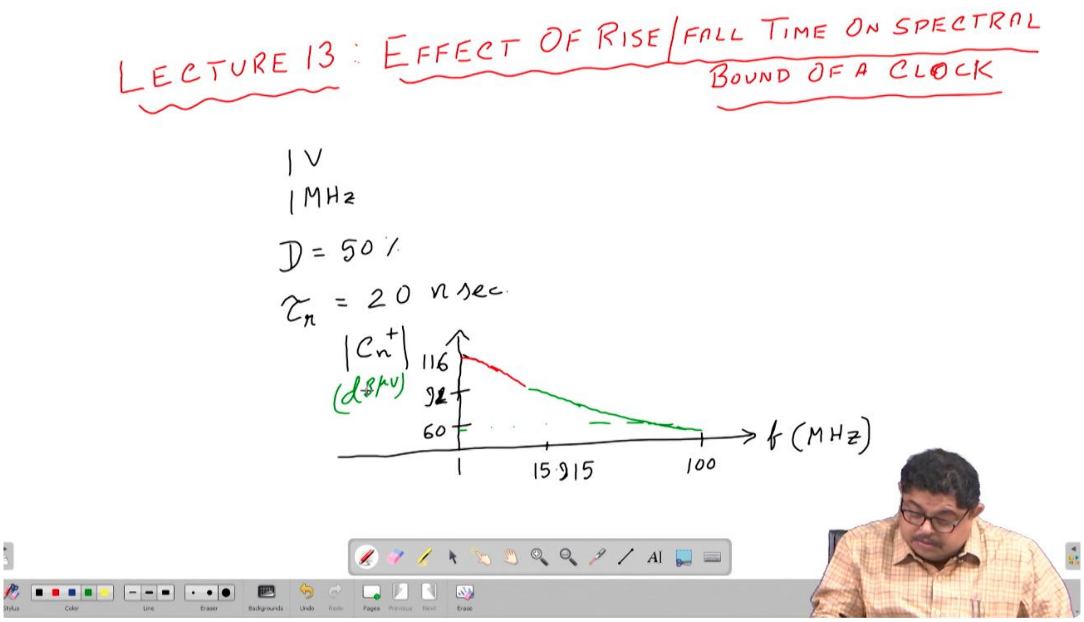
Week :03
Lecture 13: Effect of Rise/Fall Time on Spectral Bound of a Clock

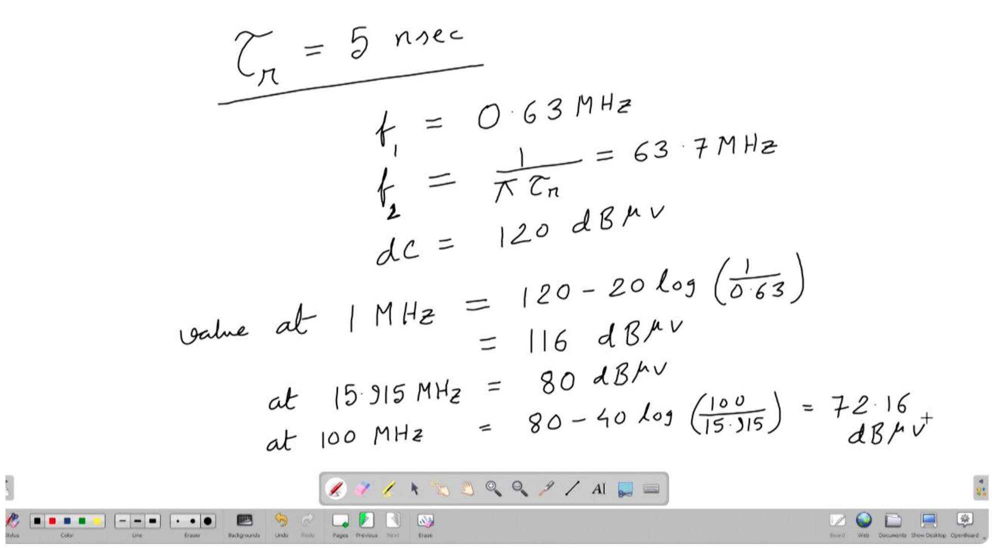
Welcome to the 13th lecture of the NPTEL course on EMIMC and Signal Integrity Principles, Techniques and Applications. Now, in your previous class we have discussed the effect of duty cycle on spectral bound of a clock. Today we will discuss the effect of rise or fall time on spectral bound of a clock. In yesterday's class we have seen that the pulse duty cycle that does not affect much the high frequency bound of the clock. So, and that time we understood that rise fall time has a profound impact on the upper bound of the clock in high frequency. So, let us redo the previous problem, but this time we will be changing the rise time. So, let us say we have a 1 volt amplitude, 1 megahertz everything I am keeping same as previous days thing. So, that our calculations become easier and duty cycle let us take a standard 50 percent and rise fall time. Let us take that first a or already we have seen in the previous one that there was the rise fall time of 20 nanosecond I think yes. So, 20 nanosecond this problem we have already done.

So, let us just recapitulate that at hour is 20 nanosecond. So, first frequency break point will be 0.63 megahertz, second frequency this we have done before. So, I am not writing it just I am recalling that second frequency break point will be 15.915 megahertz, DC level will be 120 dB microvolt, spectral amplitude at 1 megahertz will be 116 dB microvolt, spectral amplitude at first sorry second break point that will be 92 dB microvolt and spectral amplitude at 100 megahertz will be 60 dB microvolt.

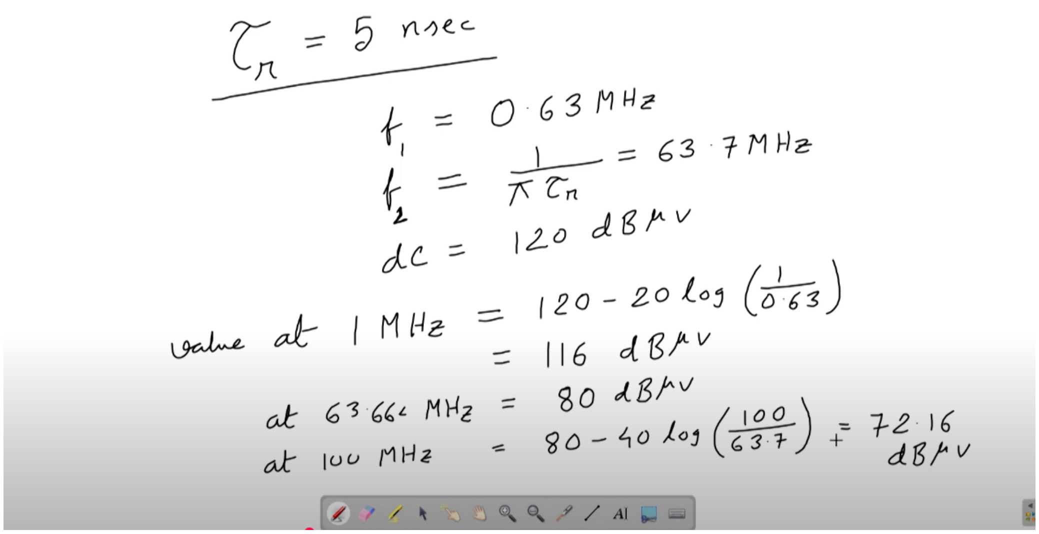
So, we can draw the same graph that our C n plus will be this side is frequency in megahertz in semi log paper and so this one will be 116 this is 1 megahertz we will see 15.915 megahertz this is 100 megahertz. So, 116 then there will be a level 92 and then there will be a 60 per most line and to draw as before that it will. So, the graph was like this and we have seen that means, at 100 megahertz the high frequency content or the spectral content will be 60 dB microvolt this is in dB microvolt.



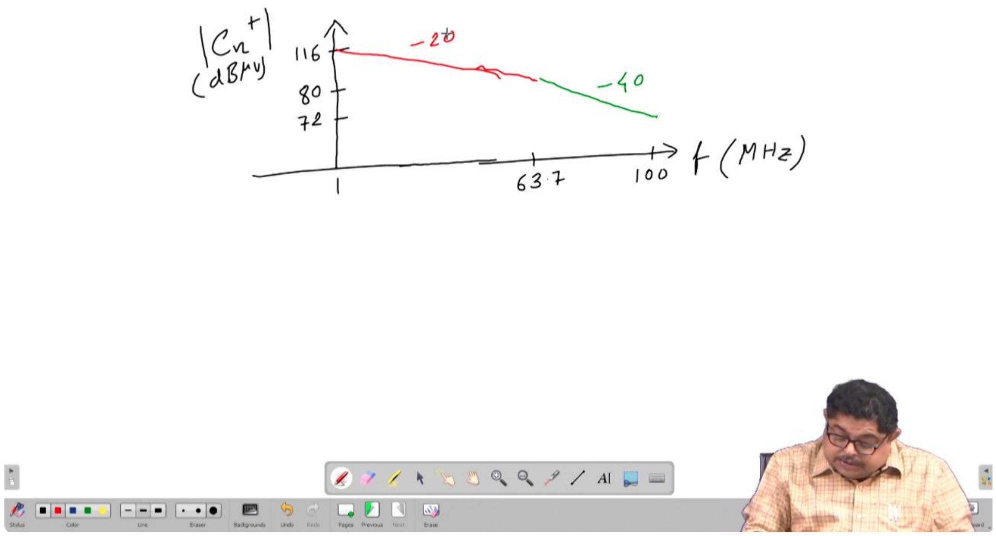
So, now let us make the rise time shorter that let us take the rise time as 5 nanosecond. So, the first frequency break point that is unaffected because the pulse width we are not changing. So, it will be still 0.63 megahertz, but second break point will change. So, second break point will be 1 by pi tau r. So, that is 63.7 megahertz and DC is as before because we have not changed the duty cycle or anything. So, it is same as 120 dB microvolt. So, spectral amplitude at value at 1 megahertz is if you do with the same thing that at up to f 1 it is 120 dB microvolt. So, at 1 megahertz how much it will be that will be 120 minus 20 log 1 by 0.63 and that will give us 116 dB microvolt. And value at 15.915 megahertz now we can do that because that is the with this 20 dB microvolt. So, that 80dB microvolt, at 100 MHz 80 minus 40 log 100 by 15.915 that will give us will give us 72.16 dB microvolt.



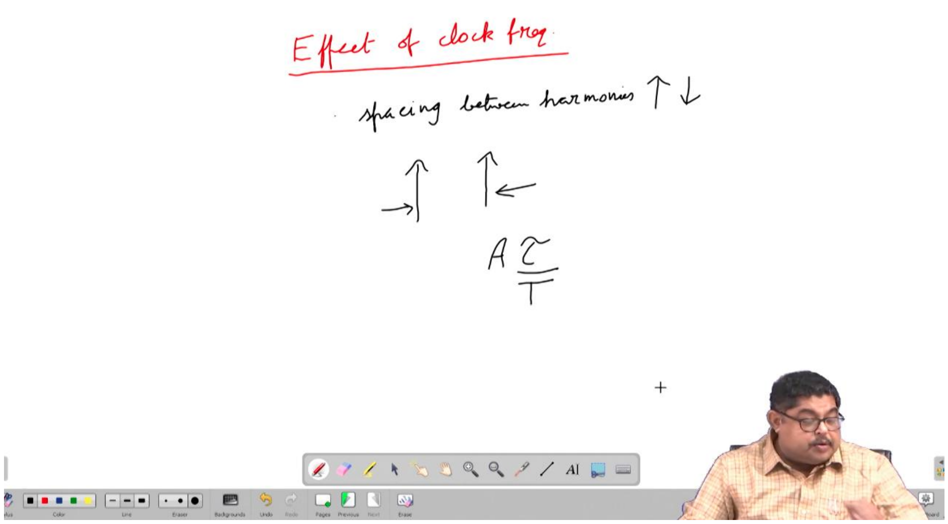
So, you see that now our if we draw the curve it will be something like this f omega hertz E n plus in dB microvolt we will have at 1 megahertz we will have 15 sorry I think the second frequency break point is not this second frequency break point was 63. So, we will have to erase it that it will be at 63.662 it will be 80 dB microvolt. So, here also I will have to erase it at here it is 100 by 63.7. So, that will give me 72.



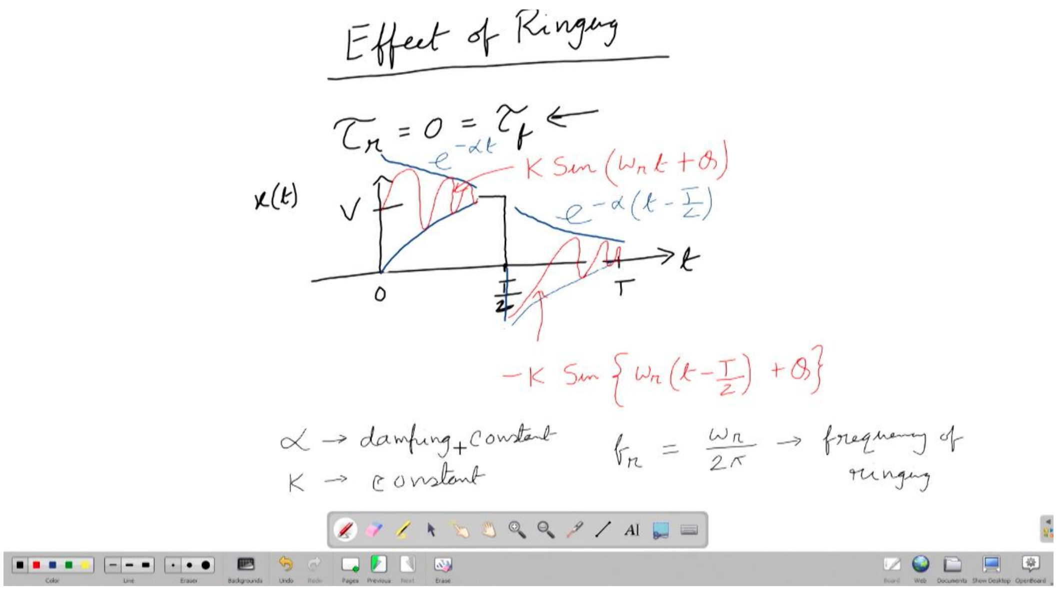
So, 1 then the first second break point is 63.7 then it is 100. So, you see that the second break point has shifted more towards high frequency. So, that is why many most of the components they are attenuated by 20 log whereas, only between this range 63.7 to 100 there will be a 40 dB type thing.So, that means, the here I will have to write the values. So, at 1 megahertz it is 116 at 63.6 it is something like 80 and 80. So, here it is something like 72. So, now, the first one we go roughly up to here. So, this will be the first one the 20 log thing and the. So, this is minus 40, this is minus 20. So, you see that in all the previous cases that means, when we varied the duty cycle it was 60 or here also with 20 nanoseconds it was roughly the spectral amplitude at 100 megahertz was 60 dB micro volt. Now, it has increased to 72 dB micro volt. So, a significant increase 12 dB increase has occurred in spectral amplitude of the high frequency signal. The reason is you know that shift from shift of f 2 from 19 megahertz to 63 megahertz. So, the resolution reduction of minus 40 dB per decade is for very small range of high frequency most of them are reduced by minus 20 dB per decade slope. So, we have seen the effect of rise time variation that from our physical knowledge also we know that if you make a very sharp transition because reducing rise time means I am rising very fast. So, that will lead to generation of high frequencies that is happening here.



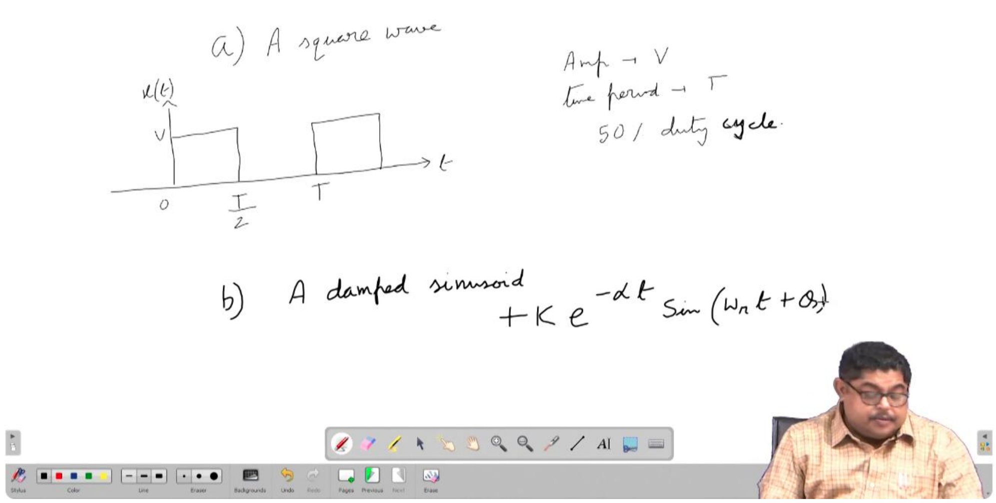
Now, the next we will see what is the effect of variation in effect of clock frequency. So, that means, clocks fundamental frequency if we vary that what will happen that means, if we vary f naught or if we vary 1 by T that means, if I vary T what will happen? So, obviously, the first thing that will happen is the spacing between harmonics they will increase because if I change that increase or decrease that we do not know, but depending on whether we increase the frequency or decrease the frequency. So, based on that the spectral lines. So, this gap they will either increase or decrease also it will affect the DC level because if a tau by T. So, they are suppose if duty cycle is kept fixed, but fundamental frequency is changed then DC level will change ok.



Now, another interesting thing we will now see that another effect that is called effect of ringing. Now, you know that as the signal level transitions from one logic to another logic that means, either going from 0 to 1 volt or 1 volt to 0 volt there is a tendency of oscillation because there are always in the clock circuitry there will be some parasitic inductance parasitic capacitance. So, they there will be an also there will be some resistive things in the lines which we are not assuming. So, in RLC circuit you know that there is a oscillation takes place generally if the with the presence of resistance resistive components that will be a damped sinusoid. So, that you have seen in your fundamental classes that there will be a ringing that is the any with pulse response we try to get that things that. So, to make the whole thing simple because ringing means there will be second order terms. So, to keep the thing simple we are going back to our pulse waveform without any rise or fall time because trapezoidal clock is a more sophisticated model more complicated also. So, we are assuming that tau r is equal to 0 is equal to tau f that is with our clock just we are trying to focus what will happen in ringing. So, let us say that our clock is going from 0 volt to V 0 volt. So, I have 0 volt this is I am just drawing the clock that means, my clock signal x t let us say. So, 0 and t volt or so, this is x t versus t. Now I have a period t I have a half period t by 2 and now without ringing what will happen it will go from 0 to V, but with ringing. So, this is our pulse waveform. So, this is our pulse waveform. So, there will be a ringing, but the ringing is getting damped. So, this red coloured one. So, actually what will happen after going certain distance the ringing will start and the we can say that the envelope of this ringing that is something like e to the power minus alpha t. So, and the ringing one that you learnt that we can describe it by this ringing thing by k sin omega r t plus theta. And this ringing we can describe by minus k because you see that was in the positive part this is in the negative part. So, minus k sin omega r t also this is shifted by T by 2 plus theta and what is this envelope I can say e to the power minus alpha t minus T by 2. So, the blue colour is the envelope the actual ringing pulse is like this. So, whenever there is a transition there is a transition from 0 to V there is a ringing there is a transition from V to 0 there is a ringing, but this is from positive to 0 level that is why the ringing is having minus k. So, here I think you have already guessed that what is our alpha? Our alpha is nothing, but damping constant in any LC circuit there is a damping constant and what is k? k is some constant and finding lot of difficulty in writing and what is the damping frequency? Damping frequency is f r. So, f r is we can say omega r by 2 pi it is the frequency of ringing sorry I said damping it is not damping damping is done by this alpha. So, there is an exponential damping t and this is frequency of ringing. So, now we will have to analyze this it looks complicated, but with the tools that we have developed for finding the spectral bounds we can easily tackle this problem. Let us see that and finally, our aim is how it affects the spectral bounds of our clock. In a clock this is always you will see you would not get any pure transitions in clocks, but clocks are meant for transition. So, there will be ringing always. So, EMC engineer should be able to model that.



Now let us see that there are three components to this ringing clock waveform. The first one is our a square wave normal square wave you can think it like this that it is just like our normal square wave 0 to V x t t with this is T by 2 this is T. So, a square wave its amplitude is V its time period is T and duty cycle 50 percent. Now the next part is a damped sinusoid. That is that plus K e to the power minus alpha t sin omega t plus theta



and the next part is also a damped sinusoid, but shifted in time it is given by minus K e to the power minus alpha t minus T by 2 sin of omega r sin of omega r. So, sin of omega r t minus T by 2 plus theta. So, again I am showing you the thing you see that I have as if a square wave then I have a damped sinusoid this first one which is occurring from t is equal to 0 and another damped sinusoid which is occurring between T by 2 to T. So, using linearity we can find C n of the composite waveform. That means, we can say that C n is equal to C n of square wave plus for the first one I do not know what is the value. So, let us calculate the C n we know how to calculate the first ringing waveform occurs from 0 to T by 2 and its expression is K e to the power minus alpha t sin omega r t plus theta then e to the power for Fourier coefficient I will have to multiply it by J n omega naught t and then this will be dt. And then for the other one 1 by T T by to T minus K e to the power minus alpha t sin omega r t plus theta e to the power minus J n omega naught t dt and can I say that since it is shifted. So, just I will add here that it will be e to the power minus J n omega naught t by 2. So, you see both the waveforms were same. So, I am just writing that they are same only this is shifted by a time shift of t by 2 or time delay of capital T by 2. So, I know how to calculate in Fourier series calculation Fourier coefficient calculation.So, it will be just like this ok. So, now, our next task will be just to evaluate these integrals that we will see in the next class today the time is up. Thank you.