Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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Lecture 46: Time Domain Crosstalk (Continued)

Welcome to the lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. We have started our discussion on time domain cross talk or transient cross talk. So, in the last class we have derived the equivalent circuit of the receptor in time domain. So, now we will see that what happens if a arbitrary time variation is there in the clock signal or the source voltage. So, source voltage may be a clock or data signal which is typically we have seen a periodic trapezoidal pulse train. So, our V s t is. This is V s sorry this is V u equal then this is our tau r. This is our tau f etcetera. So, what will happen to V n e t. So, you see that there is a transient. So, there is a derivative here. So, it will be m n e p by tau r and duration will be tau r then it will not be there then it will be. So, here it will be minus m n e p by tau f and duration will be this duration is tau f that is our capital T. This is our on time tao.
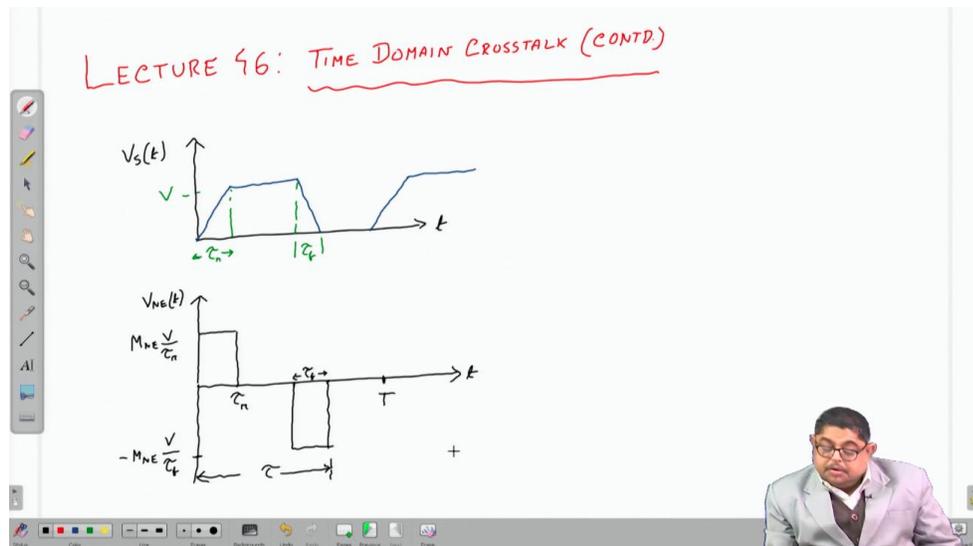
Similarly, we can draw V f e t. So, again. So, this will be m f e V by tau r. This will be tau r this is minus m f e V by tau f this portion is tau f and this is our tau f. So, that means, the crosstalk signal appears as pulses occurring during the transitions of the

source voltage. Now, the crosstalk coefficients we have already seen the for near end m n e is always positive whereas, the crosstalk coefficients for far end m f e is positive if capacity coupling dominates is negative if inductive coupling dominates. So, in that case the this picture may also change. Now, what is the validity of the model? The validity of the model is line is electrically short. So, now, V s spectrum that extends for 0 to infinity, but only those components of the signal that are below the frequency where the line behaves as electrically short will be correctly processed by this model. The frequencies for which line cannot be considered as electrically short will not be correctly processed. So, we will have to determine what is that frequency? Let the frequency up to which the line can be considered as electrically short is 0 f u for a given line length and velocity of propagation these places restrictions on the spectrum spectral component of the signal.
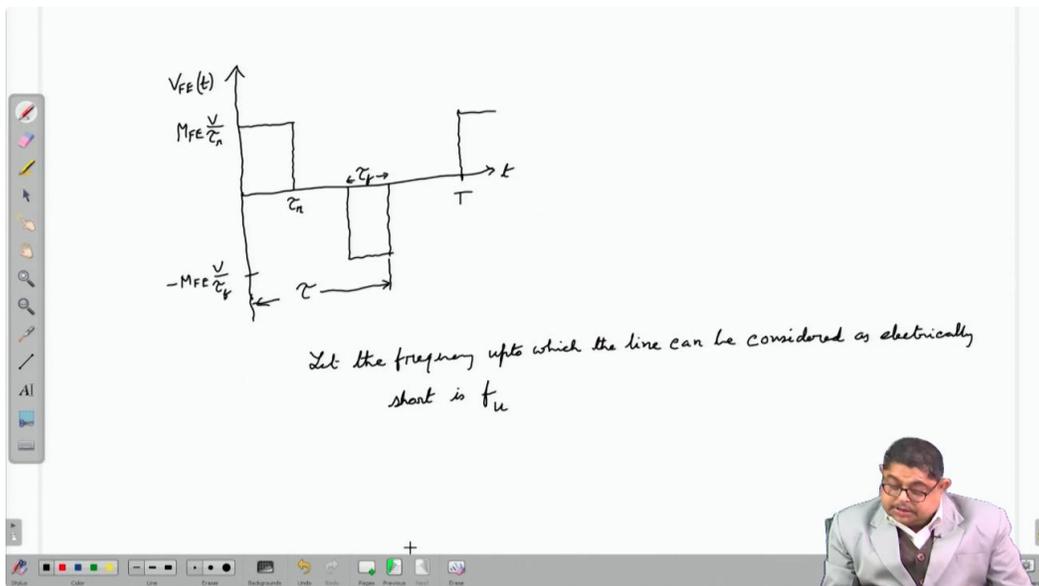

So, how to determine f u? So, let us then find the again go to frequency domain see the bode plot. Or V f e by V s that we are plotting in x axis we know that that graph is plus 20 dB per decade graph. And so, let us say f u is somewhere here up to which this model is valid. So, this is V ne by V s is the transfer function of the three well line. Now, what is the clock spectrum? We have earlier seen the clock spectrum that means, V s f is given by. So, this part is 20 log 10 2 V tau by T these things all we derived that time probably we have taken a now it is V. So, this is a 0 dB per decade thing up to what it which frequency is goes it goes up to 1 by pi tau. And then this is a minus 20 dB per decade this

goes up to 1 by pi tau r the second point. So, here we are assuming again the tau r is equal to tau f. So, that thing and this is minus 40 dB per decade. So, actually this is a discrete spectrum may be the spectrum is something like this that this is the may be fundamental may be. So, arbitrarily I am drawing may be this is 2 f 0 may be this is 3 f 0 where I am doing this you see that gradually the spectral magnitude is decreasing for a thing. So, f u will come somewhere now what is the spectrum of the cross talk pulse. So, that will be this is V s f it is V n e by V s f. So, what is V n e magnitude or V f e magnitude that will be some of these 2 graphs that we learnt earlier.
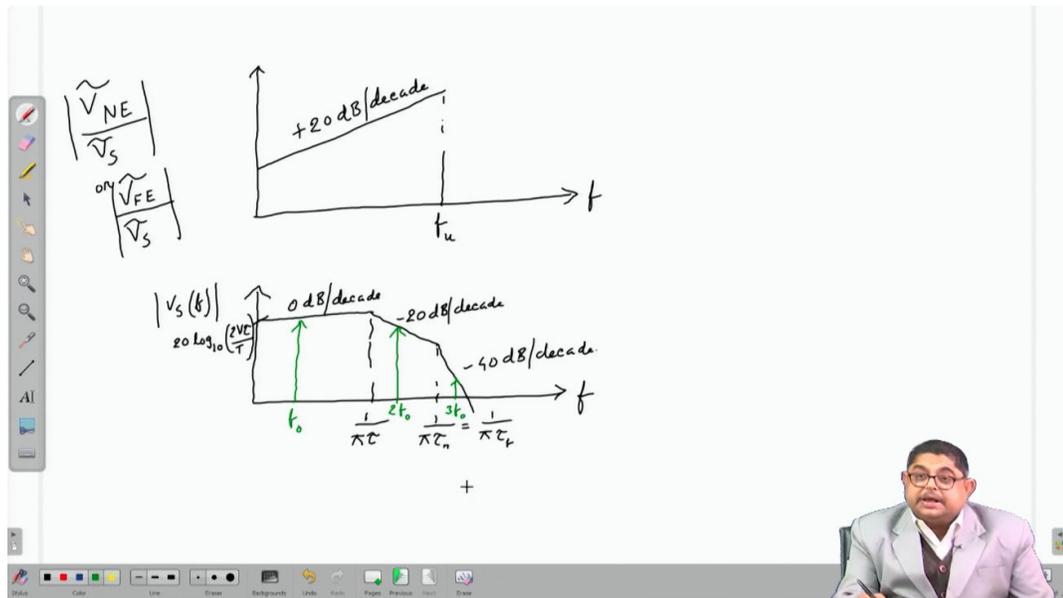
So, that spectrum we can now draw, so we can say cross talk spectrum cross talk pulse spectrum it can be written as a function in dB versus f. So, if we sum this to plus 20 with 0 that will be plus 20 then plus 20 with minus 20 will give you 0. So, there will be a 0 then plus 20 with minus 40 will give you a minus 20. Now, up to where it will go that will be up to a few because that what we will get that is not the correct value. So, what are these break points this is 1 by pi tau this is 1 by pi tau r. So, this I should say log 10 f. So, it is reasonable to assume that those frequency components of the input signal which are sufficiently away from the second break point that is in minus 40 dB per decade or here with this in the minus 20 dB per decade thing does not contribute significantly to the overall pulse amplitude. You see that in the previous one that actually it is going down. So, the spectral component is getting smaller and smaller. So, up to f u will get if you will get correct result then it is that means, we will have to place f u greater than this 1 by pi

tau r. So, that is our job. So, we can choose f u approximately as a constant alpha into 1 by pi tau r where alpha is a constant greater than 1. Now, due to the restriction of short length at this high frequency that means, at this f u the line length should be a fraction of lambda. So, L will be k into lambda at f is equal to f u where k is a constant as well as a fraction much less than 1. But, we know what is lambda, but lambda at f is equal to f u is nothing, but V by f u and here we can put the value of f u from this that is alpha into 1 by pi tau r. So, we can now easily find what is L by k because L by k is lambda.
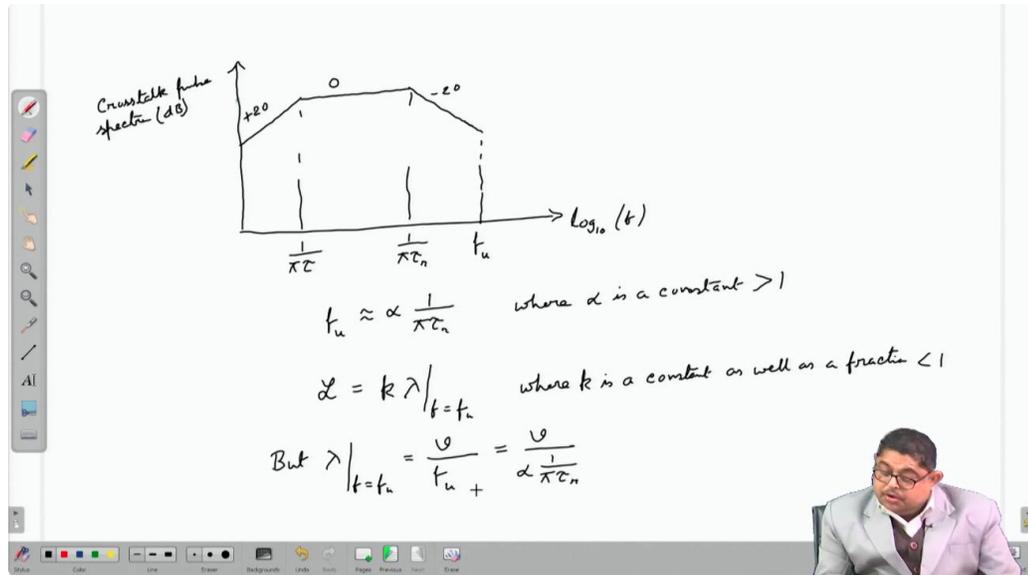
So, we can write our L by k. So, if we take L by k to be less than this that means, L by k is less than equal to V by pi tau r by alpha then our job is done because this is this side is this side is lambda. So, lambda should be less than this where there are 2 constants 1 is k another is alpha they needs to be chosen. So, now, what is L by k not L by k what is. So, from here we can go one step that what is tau r that is now greater than alpha by pi k into L by V and that is equal to alpha by pi k L by V is what L is the line length and V is the propagation velocity of the wave. So, that is we can say t d where t d is the line. Now, we will have to decide on the values of alpha and k. Now, what was alpha where we have defined f u is alpha where alpha is a constant greater than m greater than 1. So, can we choose a reasonable choice for alpha is if we choose it to be pi pi is greater than 1 and k what was k where is k where. So, k is that line is electrically short for that we know that generally we take if this L by lambda is 1 by 10 that is a good choice always we generally do that. So, that will take that alpha is this and k is 1 by 10. So, if we do that immediately tau r or tau f that becomes greater than 10 t d. So, if we maintain this relation that means,

tau r is 10 times greater than t d one way travel time then the whatever model we get the cross talk will be correctly predicted.

$$\text{co} \quad \frac{\alpha}{k} \le \frac{\vartheta \pi \tau_n}{\alpha}$$

$$\text{co} \quad \tau_n > \frac{\alpha}{\pi k} \frac{\mathcal{L}}{\vartheta} = \frac{\alpha}{\pi k} T_D \qquad \text{where } T_D \text{ is the one way transit time of the line}$$

A reasonable choice for α is π
k is $\frac{1}{10}$

$$\tau_n, \tau_f > 10 \, T_D$$

$+$

So, that we will do now through an example.4.737 meter is the line length the separation is 50 mils and this is your generator this is your receptor this is your reference you have a V s t here. Now, between this and this. So, I can say this is plus this is minus this is minus this is minus there is a R n e this one is V n e t because this is also a pulse similarly here you have a R here you have a R radius is 7.5 mils and R is 50 ohm. Actually you see always we are taking this type of values 4.737 meter radius is 7.5 mils separation is 50 mils. So, these are actually R s 232 the serial cable the standard R s 232 they have this specifications serial data stream. So, that cable R s 232 cable that have these values that is why we are always using these. Now, we take that what is V s t specification V s t is 2.5 volt 20 kilo hertz trapezoidal pulse strain.So, how to choose our rise time etcetera or rise time is there we will have to check whether that condition is made. So, that our model of crosstalk in time domain is whether it is well we can use that model or not. So, what is T d one way transit time T d is L by V now L is 4.737 and V is homogeneous air medium. So, that gives you 15.79 nano second. Now, we want from that relation that tau r should be greater than 157.9 nano second oh I have not given these. So, pulse strain 50 percent duty cycle and tau r tau f is 400 nano second this is R s 232 specification. So, we need that tau r should be greater than these already tau r is greater than these it is 400 nano

second. So, the model will give correct prediction. So, what will be near end crosstalk waveform.

M n e n e t V s t d t and if we put the value M n e i n d M n e cap you can easily calculate from all the values that will be 1.2 into 10 actually previously we have done this problem you see the in previous what was our M n e value in the previous lecture we have done that for 50 ohm. So, M n e i n d was 1.13 into 10 to the power minus 8 M n e cap was 6.12 into 10 to the power minus 8. So, 1.14 plus 0.06 that is 1.2 10 to the power minus 8. So, this problem was solved for common impedance coupling cases. So, from there I am directly taking this value that where it has gone. So, then d V s d t d V s d t now during the rise time what is during rise or fall time what is d V s d t this is also called slew rate of a pulse. So, that is it is going to 2.5 volt from 0 volt. So, d V s is 2.5 and time is 400 nano second 400 into 10 to the power minus 9. So, it is 6.25 into 10 to the power 6 volts per second.So, if we put that in V n e t during transition this will be 1.2 into 10 to the power minus 8 into 6.25 into 10 to the power 6 that will be 75 milli volt and V n e t during what I will call transition. So, during on time or during on during flat portion d V s d t will be 0. So, this will also be 0. So, that means, if I draw this in a time domain. So, 7 we got 75 milli volt.

$$V_{NE}(t) = \left(M_{NE}^{IND} + M_{NE}^{CAP}\right)\frac{dv_n(t)}{dt}$$

$$= 1.2 \times 10^{-8}\frac{dv_n(t)}{dt}$$

during rise or fall time $\left|\dfrac{dv_n(t)}{dt}\right| = \dfrac{2.5}{400 \times 10^{-9}} = 6.25 \times 10^{6} \text{ V/s}$

$$V_{NE}(t)\Big|_{\text{during transit}} = 1.2 \times 10^{-8} \times 6.25 \times 10^{6} = 75 \text{ mV}$$

$$V_{NE}(t)\Big|_{\text{during an flat front}} = 0$$

So, here I am drawing V n e t versus t. So, let me change the colour. So, let me mark it then up to 400 nano second it will go again it will go to 24.6 micro second then the next one will be starting at 50 micro second 50 percent duty cycle. So, now, let me change it. So, it is 75 milli volt then it is 0 then here. Minus 75 milli volt 0 I have shown. So, this will be the near end cost of similarly, you can find out the far end cross talk also exactly the similar rule. Now, so, this is time domain cross talk, but we have made those 4 assumptions. So, electrically short we are satisfying, but lossless now we will relax that and include losses. So, common impedance coupling will come that we will see in the next class. Thank you.