

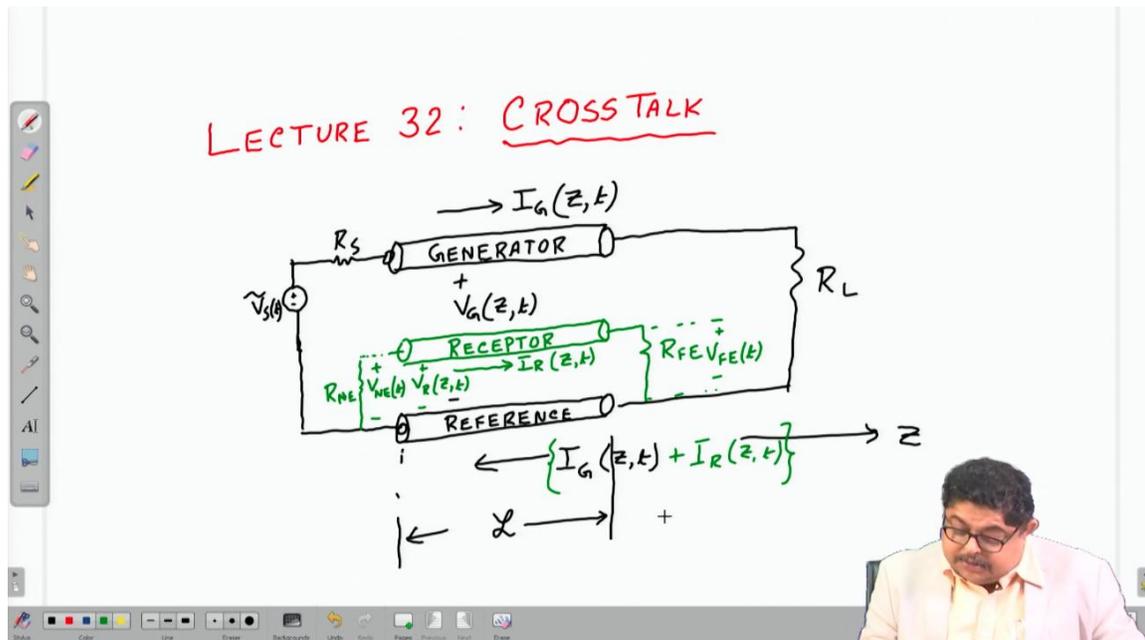
Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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Week :07
Lecture 32: Crosstalk

Welcome to the 32nd lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. Today, we will discuss cross talk which is unintended electromagnetic coupling between wires and PCB lands that are in close proximity. So, as I said in the last class it is a near field coupling problem. So, if you recall to our EMC design it is the third concern of EMC design that product should not interfere with itself. Now, so most of the cases this cross talk is an intra system interference because it happens inside the system. So, between two subsystems it happens. So, we call it intra system interference. Generally, if it comes from another system that becomes a radiated susceptibility, but if one of the conductors is nearby the other a two wire line then this cross talk comes. Now, for a two conductor transmission line there is no cross talk, there can be radiated susceptibility, but there cannot be cross talk. In order to have cross talk you need to have at least three conductors maybe more. So, consider first a two conductor transmission line that suppose the it is being driven by $V_s(t)$ sorry there is a R_s here the source resistance R_s then you have the two conductors. This R_s and R_s I think you are understanding that all the circuitry that is connected at the source end we are calling it R_s as a lumped one this is as an R_s . So, this is the transmission line a distributed line. So, we have a current here $I(z,t)$ this is our Z axis. Now, this is a distributed line that is why the current will be dependent on Z obviously, the source is time varying source. So, it will have a t variation. Now, why I have given subscript Z because generally when we discuss cross talk or three conductor lines this is called a generator generally which is connected to the source driving point. So, it is called a generator and the return path that is called reference conductor return one is called reference. So, there will be also a V_g here plus minus. So, there will be $V_g(z,t)$ and the current I_g that will be returning through this reference conductor these are differential currents.

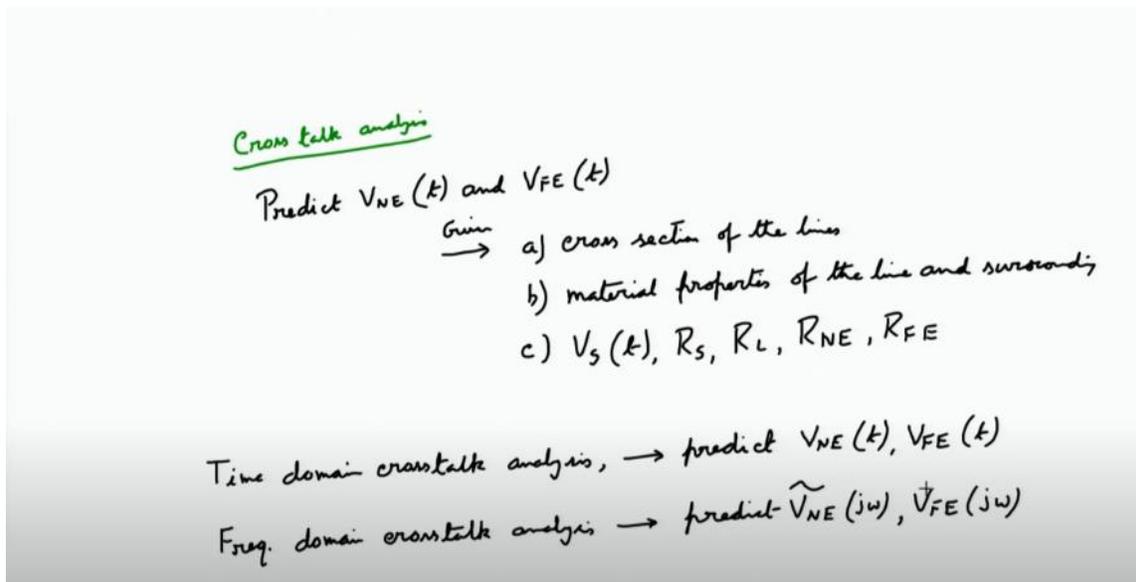
So, same current will come there and let us say that as before this is this line length is L . Now, let us say that we have another conductor nearby. So, another conductor is nearby. So, there will also be some circuitry with this. So, the whole thing we are modeling as a source R_n that we are calling R_{ne} R_{ne} similarly this side there will be again some circuitry I am calling it R_{ap} . Why I am calling like this? This is ne stands for near end,

far end near to whom near to the source. So, this is R n e this side all the circuitry that I am lumping as R f e. There is no direct excitation of this receptor conductor this is called receptor. This is receiving the radiated emission from the two-wire system. So, due to that there will be a this is also a distributed line.

So, there will be a I R Z t and there will be a V R Z t. So, this side there will be a this is the terminal side there will be a voltage everywhere there are voltages. So, this voltage we are calling V f e t and this voltage this terminal voltage we are calling V n e t. And so, this current that is flowing here I R Z t that requires a return path. So, that return path will be provided by reference circuit. So, now that means, this will provide the return path this reference conductor for this one also. So, the current through this will be I R Z t I G Z t plus I R Z t both together is flowing here to the source. So, this is the three-wire line. So, again you can see what are the terminologies here that R n e is the termination of the receptor at near end due to circuitry connected with receptor R f e is the termination of the receptor at far end due to circuitry connected with receptor R n e R f e here we are calling them resistances, but they can be impedances as well. All the conductors are assumed to be of uniform cross section.



The objective of our cross talk analysis is let me go to a new page the objective of cross talk analysis cross talk analysis is predict $V_{ne}(t)$ and $V_{fe}(t)$ from what is given or given is a cross section of the lines then material properties of the line and the line and surrounding. Then you we know V_{st} we know R_s we know R_l we know R_{ne} we know R_{fe} these are known quantities. So, predict $V_{ne}(t)$ and $V_{fe}(t)$ they are time varying quantities. Now, there are two approaches if you go for time domain cross talk analysis you predict as I said $V_{ne}(t)$ and $V_{fe}(t)$. If you go for frequency domain cross talk analysis you predict as $V_{nj}\omega$ vis phasor and $V_{fe}j\omega$ phasor. So, this is our objective first we will go to let us say we will start from time domain that is the actual domain. Now, here you see that the moment I have 3 conductor I do not know how to tackle that because my transmission line equations are developed only for 2 conductor. But the way we have done we have you have done in your undergraduate courses the transmission line analysis a distributed lines analysis. We will have the same approach and we will try to find what is the transmission line model for that 3 conductor or multi conductor line. So, that equations are directly we cannot apply from transmission line because there is a 3 line system.



So, we will have to first derive the transmission line equation transmission line I think you understood the problem that this is not available or when not taught to you transmission line equation for multi conductor line. Actually later we will generalize, but now we will do for 3 conductor from that we will be easily able to generate multi conductor this we will do first. Again our fundamental assumption that the transmission lines are passing only TEM mode that I discussed before that though

transmission line pass other modes also, but this is a mode which TEM mode that generally other systems do not have wave guides optical wave. So, this is that is why for transmission line we always assume that it is having TEM field structure. Other field structures we can easily apply the other concepts and by that we can do.

Now, actually pure TEM mode field cannot exist for imperfect line conductors. Imperfect means that if you have actually we do not have ideal conductors. So, there will be some electric field in the Z direction also because if we have any practical conductor like good conductor they are not ideal conductors. So, there will be a current in Z direction. So, there will be a field E_z in the Z direction or in the line direction.

So, there will be a longitudinal electric field and so you cannot have a pure TEM mode, but people have seen that for up to gigahertz or nowadays up to few gigahertz range you can if you assume a TEM mode for a non ideal conductor also the error is not much that is why we call that it is a quasi TEM approximation quasi TEM. So, let me write that term quasi TEM quasi means similar. So, more or less field structure also remains same the obviously there is an error, but that error is for a most of the applications that does not matter. So, fundamental assumption is TEM mode, but actually it is quasi TEM. Now, what is implicit in this that ideal conductor and another assumption also we are making that homogeneous surrounding medium. Now, generally this assumption also in most of the cases you can have slight inhomogeneous medium etcetera. So, that can be considered under quasi TEM that it is homogeneous medium.

Transmission Line Equation for multiconductor line
(Three conductor)

Fundamental assumption: TEM

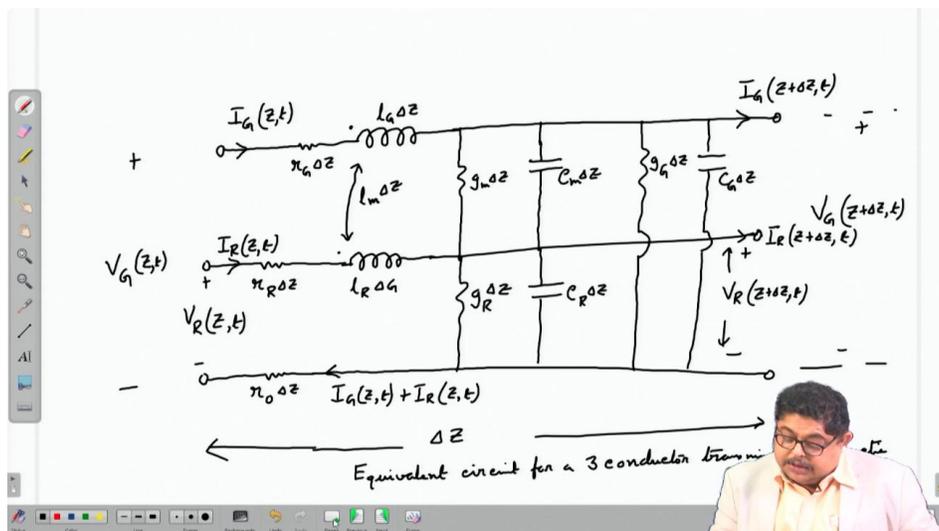
quasi TEM

- a) ideal conductor
- b) homogeneous surrounding medium

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So, now let us find the per unit length parameters for this three conductor line. So, for that I will draw a picture again that I have three lines we know that a two conductor line its parameters are R L G C per unit length parameter R is in series with the line L is in series with the line G is in shunt between the two lines C is in shunt between the two lines. So, I have now three conductors. Let me say that I have a resistance then I will have a thing and now I will have the reference conductor then I will have the receptor conductor. So, there is a current going here I am calling I G Z T as before. Now, this one is the per unit length parameter R G and this is we are saying a delta Z section. So, R G into delta Z this one is L G into delta Z then this one is R R delta Z this one is L R delta Z then you see that between these two there will be a mutual inductance. So, that I am calling L M they are nearby. So, L M delta Z then there will be a mutual conductance also between them. So, that will be G M delta Z similarly between these two wires also there will be a mutual conductance that will be calling G R delta Z then I have a mutual capacitance also you see whenever there are any gaps there will be a capacitance. So, between these two that is why I am calling it C M delta Z between these two I will get C R delta Z then there will be for generator and between the reference there will be the G itself conductance. So, this is G G delta Z then it has its C G delta Z. So, this is R for reference I am calling it O or 0 delta Z and this current we have already seen is I G Z T plus I R Z T this current entering here I am calling I R Z T any other thing now I G I have done.

So, what is V G? This is my V G that V G Z T is the voltage between this end and this end similarly we know that voltage between this end to this end will be V G Z plus delta Z T assume direction these also there will be currents that will be going here that is I G Z plus delta Z T the currents that will be going from here is I R Z plus delta Z T anything else V R. So, there will be voltage here. So, V R Z plus delta Z T between these two and this side also there will be voltage between the receptor and the reference V R Z 2 have I missed any other thing. So, this is my equivalent circuit for a 3 conductor transmission line section the actual transmission line consist many such sections.



So, for later reference let me write what are the parameters I have used here. So, R, G, L, C are the RLGC parameters for generator circuit generator line then R_R, L_R, G_R, C_R are for receptor line and R_{naught} is for reference conductor. All others are between I think similarly I can have I used L, M this is mutual inductance between generator and receptor then G, M mutual conductance between generator and receptor then C, M all are per unit length per unit length parameters parameters. So, C, M is mutual capacitance between generator and receptor. Now, you know why mutual inductance came or any inductance came because of flux linkages due to the flow of current. So, without any direct connection also that can be done that has been done that is why the model has taken that then conductance is loss due to displacement current that is why G, M came and any capacitance is the storage due to the current. Now, C, M came because storage due to displacement current G, M came because it is loss due to displacement current etcetera. So, obviously, it is a lossy transmission line that is why you are seeing R, G etcetera all the parameters. So, now, we will have to derive a thing it is equivalent circuit or a transmission line equation sorry equivalent circuit we have already seen here drawn here. Now, we will have to find a transmission line equation for these a multi conductor transmission line equation a three conductor transmission line equation that we will take up in the next class. We will start from here this drawing will be taken there. Thank you.

for unit length parameters

$R_G, L_G, G_G, C_G \rightarrow$ generator
 $R_R, L_R, G_R, C_R \rightarrow$ receptor
 $R_0 \rightarrow$ reference
 $L_m \rightarrow$ mutual inductance between generator and receptor
 $G_m \rightarrow$ mutual conductance " " " "
 $C_m \rightarrow$ mutual capacitance " " " "