Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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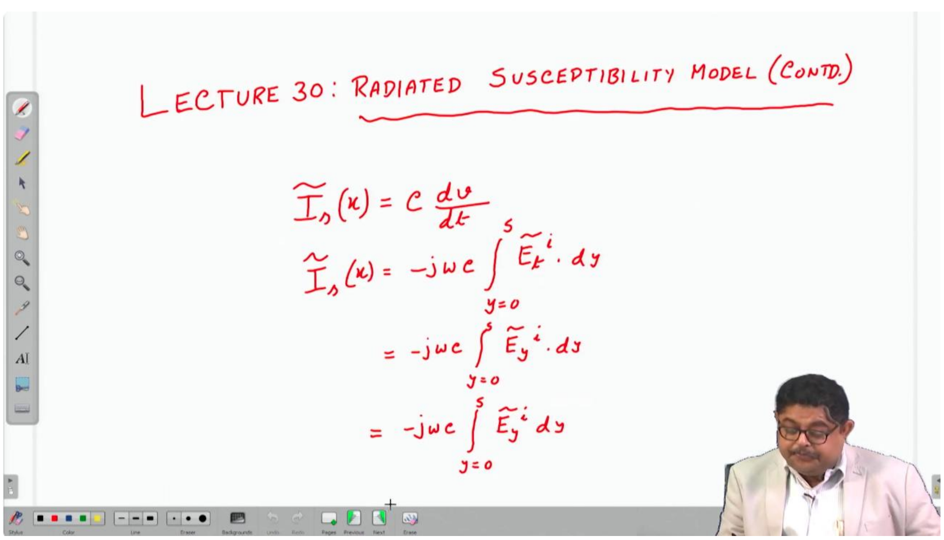
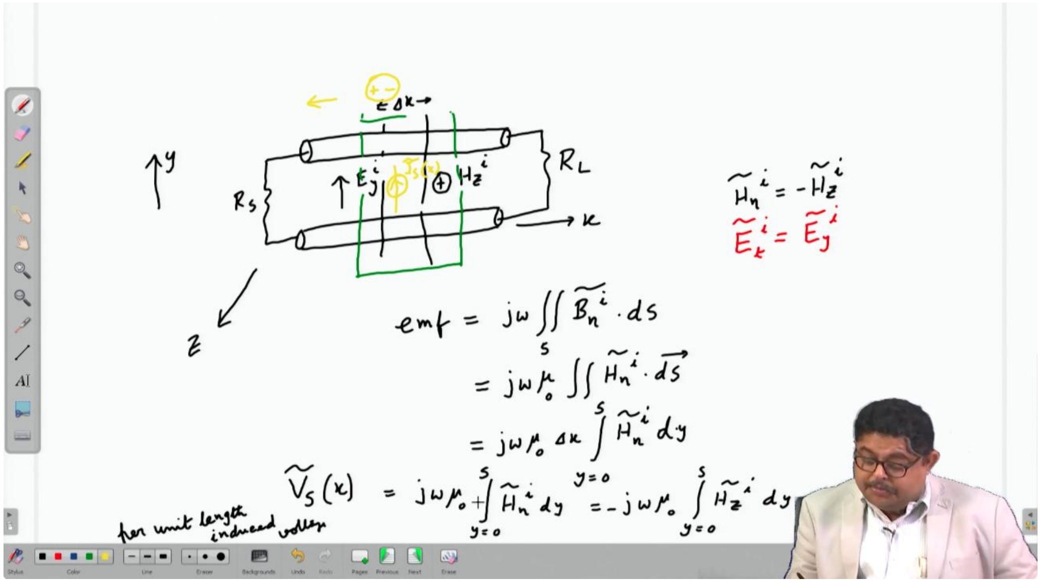
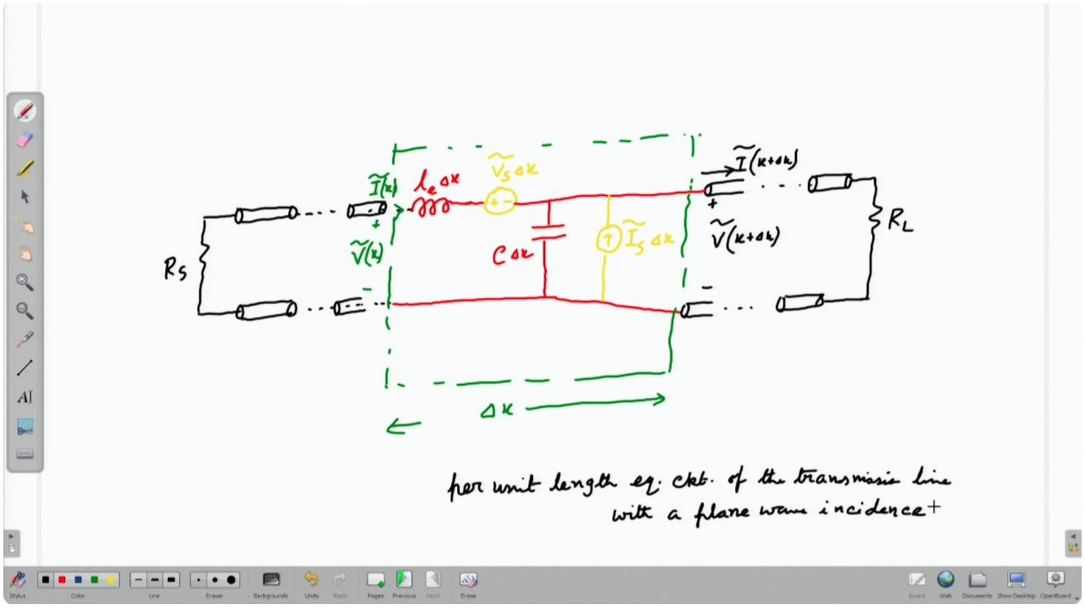
Week :06
Lecture 30: Radiated Susceptibility Model (Continued)

Welcome to the 30th lecture of the course on EMI, EMC and Signal Integrity Principles, techniques and applications. We were discussing trying to develop a radiated susceptibility model, we have already found that there will be a induced voltage source. Now, let us see we will continue that discussion. So, let us see what is the effect we have seen that the normal component of the magnetic field induces a voltage source in series with the line. Now, what about incident electric field? So, you see that between the two lines there is a per unit length capacitance. So, we know that induced source I s x is C v c into dv dt. So, this is in time domain, but we are seeing it in frequency domain. So, in frequency domain we can write that this will give us a minus j omega c y is equal to 0 2 s e t i dot d y. This minus came because this v is minus of e dot dl that is why we got this minus. So, let us see what is our assume direction for assume positive direction for e t that is e y. So, we can write that e t i is equal to our e y i. So, we can write minus j omega c y is equal to 0 2 s e y i dot d y. Now, you can see that e y and d y are in the same direction both are y directed. So, instead of this dot product we can also write minus j omega c y is equal to 0 2 s e y i d y. So, that means there will be an induced current source in the circuit and a current source means here there will be a current source. So, there will be a current source here and that is I s x. So, that our assumed direction is it is going up in the y direction.

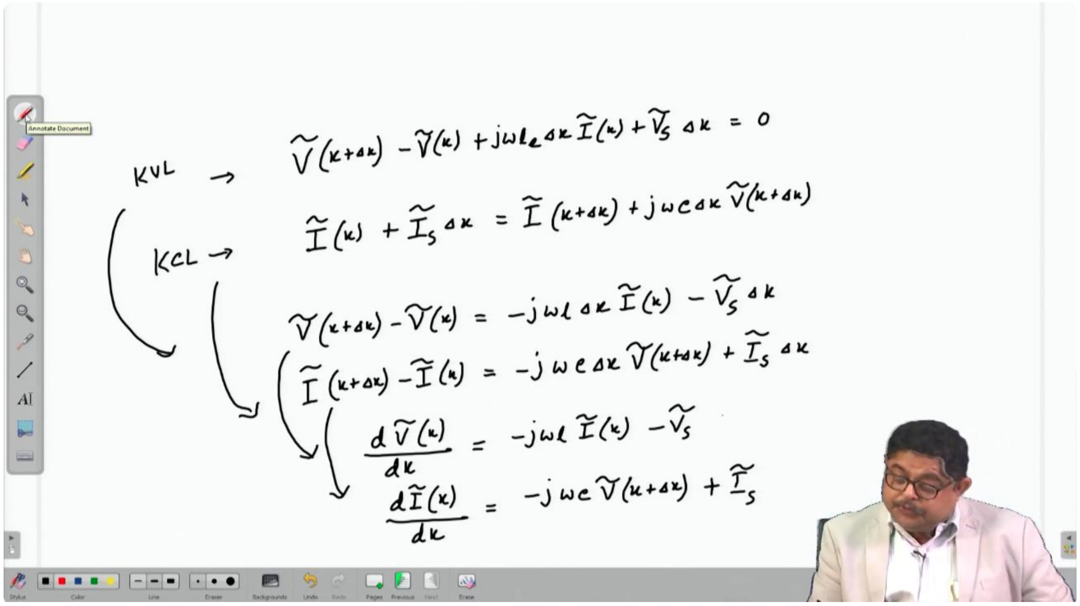




So, let us now see the equivalent model. Basically another thing I want to say that clearly you can see that this is a displacement current because the two conductors are not connected. So, how there will be a current it is not a conduction current, but it is a displacement current which is coming due to the changing electric field time varying electric field. So, let us see the equivalent picture that. So, let me break the transmission line into various parts. So, at the end also there will be part there will be lot such ones, here also there will be lot such ones this side I had a R s. So, finally, from this there will be an R l. So, there are many such small elements, there also I can say there is a.So, now I have. So, let us see. So, let us see. So, let us see. So, let us see. So, let us see. So, I have many sections. I am just amplified a delta x portion where it is already the transmission line was having Le delta x and C delta x inductance and capacitance. Now the added one is the this voltage source in series and in shunt there is a induced current source. So, which I have shown by yellow color. So V x is the voltage at the input port of this delta x section I x is the current entering this delta x section V x plus delta x is the voltage at the output port of this delta x section I x plus delta x is the current going out of this delta x section. So, you can say this is the per unit length equivalent circuit of the transmission line with a plane wave incidence. So, now our job is just to write KVL and KCL equations and solve for them. So, that we will get the transmission line equations. So, write it first let us start with KVL around this delta x portion. So it will be if I start from here that suppose this I am I can write that V x or I can start from here that following so V x plus delta x minus V x plus I x into J omega Le delta x plus V s delta x is equal to 0.



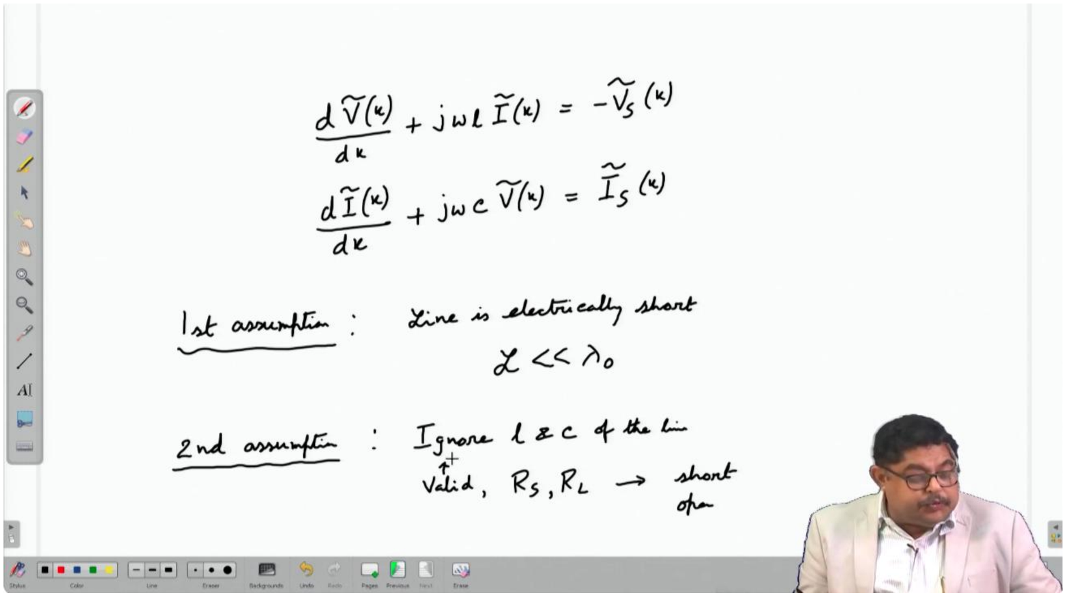
So, let me write that that V x plus delta x minus V x plus J omega Le delta x plus J omega X I x plus V s V s delta x delta x is equal to 0 and this is my KVL equation and KCL you can see that incoming things are I x plus I s delta x is equal to I x plus delta x plus 1 by J omega C delta x V x plus delta x because this is assumed as positive direction that means current this displacement current through this C 1 will be like this, this is already there. So, let me write the KCL that I x plus I s delta x is equal to I x plus delta x plus J omega C delta x into V x plus delta x. So, rewriting we can bring the V x plus delta x minus V x together and others are that side. So, this one will be V x plus delta x minus V x is equal to minus J omega now I am writing L instead of Le delta x I x minus V s delta x and this one will give me I x plus delta x minus I x is equal to minus J omega C delta x V x plus delta x plus I s delta x. Now, divide both sides by delta x and put or take the limit of delta x to be 0. So, that will give us the two equations. So, this equation if I divide by delta x and put it will be D V x d x is equal to minus J omega L I x or minus V s delta x this one will be D I x d x is equal to minus J omega C V x plus delta x plus I s oh sorry I should not have written already it is divided.



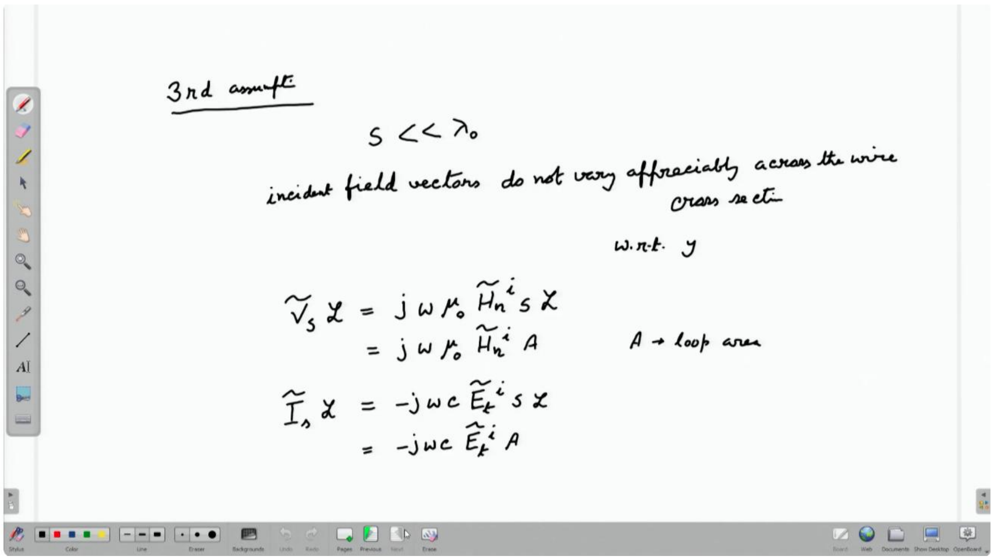
So, this. So, in a better way I can write the final two equations D V x d x plus J omega L I x is equal to minus V s x and D I x d x plus J omega C V x is equal to I s x. These equations can be solved exactly as we do for transmission line equations in normal cases, but EMC engineers are not bothered to solve this equation rather we want to estimate what is the maximum value of those V s and V L not these V s and V L the terminal voltages. So, we will make some simplifying assumption that means, we will make a model. So, first assumption of that model is first assumption is that line is electrically short that means, electrically short at the our frequency of interest that means, we can say that L is much much less than lambda naught if this is there you know that this is a in many practical cases this is true if not true you go back to the this one. So, if this is the case then distributed parameters if line is electrically short then this is no more a distributed line they can be replaced by lump parameters. So, then only one section of the line will serve the purpose that means, whatever we have seen the delta x portion.

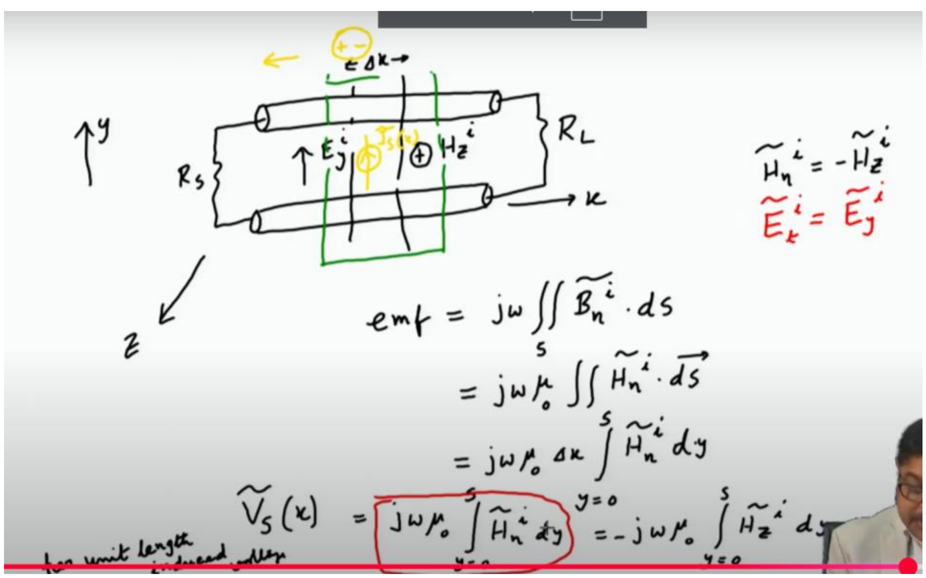
So, that we can take the lumped model and in that case delta x will be simply replaced by L total line length L and from this we can calculate the terminal voltages V L and V s. But we will make another assumption which is very important that is why we spent so much time to determine the L and E. So, you have seen that their values are very small and with this induced voltages their value will be comparatively they will be very small. So, assumption is ignore L and C of the line. Now, this is valid actually this assumption is valid if the RS and RL that means the terminal impedances or terminal resistances they are not extreme values but that means extreme means they are not short or open etcetera.

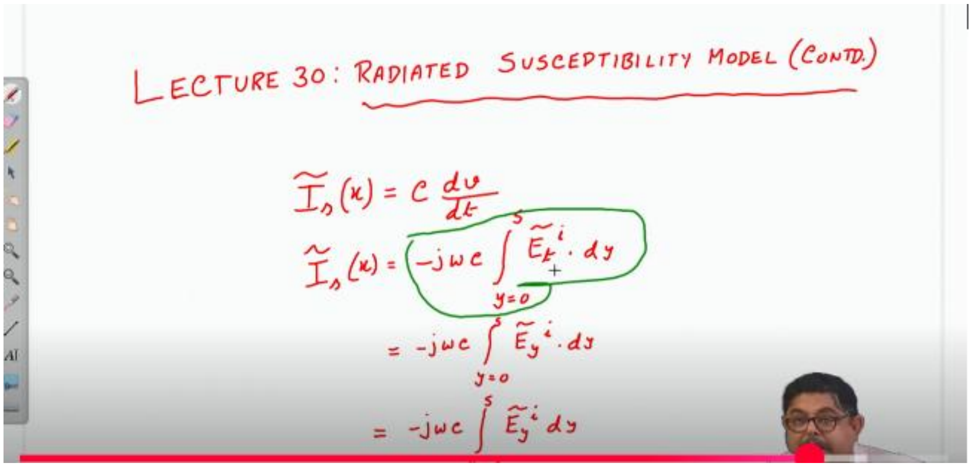
So, if they are not short circuit or open circuit type of cases then this is a valid assumption



and third assumption there will be a will make another assumption that since line is electrically short the separation between the line that is s is also much much less than lambda naught and you know that if lambda naught is not much. So, sorry the any distance is not much then the field does not vary much because field varies over lambda naught if my whole s is a fraction of that then my HNI and ETI they will not vary over the y axis. So, field vectors what we are this third assumption means that field vectors do not vary field that means induced field or incident not induced induced field vectors let me use a incident field vectors do not vary appreciably appreciably across the where cross section that means with respect to y. So, what is the fallout of this the integral in the sources you have seen that our vs and the induced sources. So, vs and vl vs and is they have integration.So, that integration can be replaced with simply multiplication. So, that means we will get that what is vs now instead of delta x we are calling it l. So, vsl you can see what was our vsl or vs delta x that time we called it vs delta x before this that vs delta x is minus j omega mu naught H zi or if you say in these terms j omega mu naught HNI di now I will make due to the third assumption this will be j omega mu naught HNI into s. Similarly, when I come here that this one will be where is ET. So, this one will be minus j omega c ETI into s. So, vsl will be j omega mu naught I am writing in terms of HNI. So, that later reference because that direction etcetera. So, in general I am writing you can write also in terms of z if you write H zi then it will be a minus, but I am writing it like this. So, it will be so vs multiplied with l. So, HN s into l this is the integration. Now what is s into l that is the area of the loop that means the line length into s. So, I can write it also as j omega mu naught HNI into a, a is loop area. Similarly, I can write isl isl is minus j omega c ETI s into l that will be minus j omega c ETI into a. So, with that our previous model of delta x section that means this model now we are neglecting this red colored one. So, only yellow colored ones with those values are there.







So, let us redraw the simplified model. This is engineering that we have made much things simpler we are not interested to find exact things, but we want some worst case estimation that this model will be able to write it as RS and then there will be a induced current source its value is minus j omega c a into ETI. This is RL. So, this is our vs this is our vl this is plus minus assume direction. Now do not confuse previous vs with this vs this is the terminal voltage and this vs was the induced voltage, but now we have made it in terms of the fields. So, now when you come to this there is no problem, but throughout we have used the same terminology because voltage is difficult to replace. So, one is the source side voltage which is a standard nomenclature. So, that is why we did not change, but you should understand the context. Now you see that now with this model we can find what is vs. So, that we will see in the next class because today time is up. So, in the next class we will still continue this model building and we will find some answers. Thank you.