Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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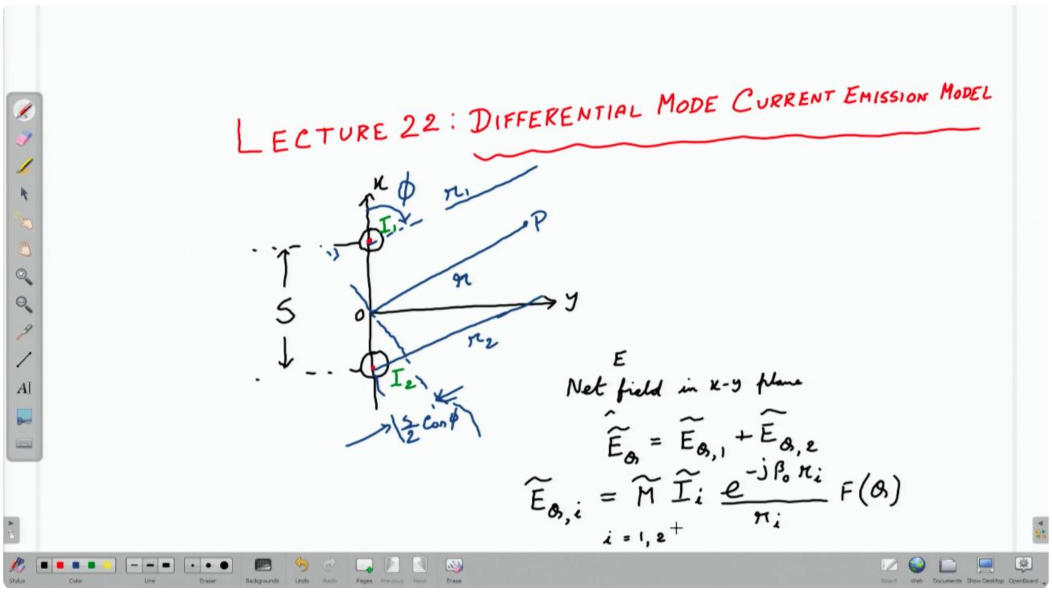
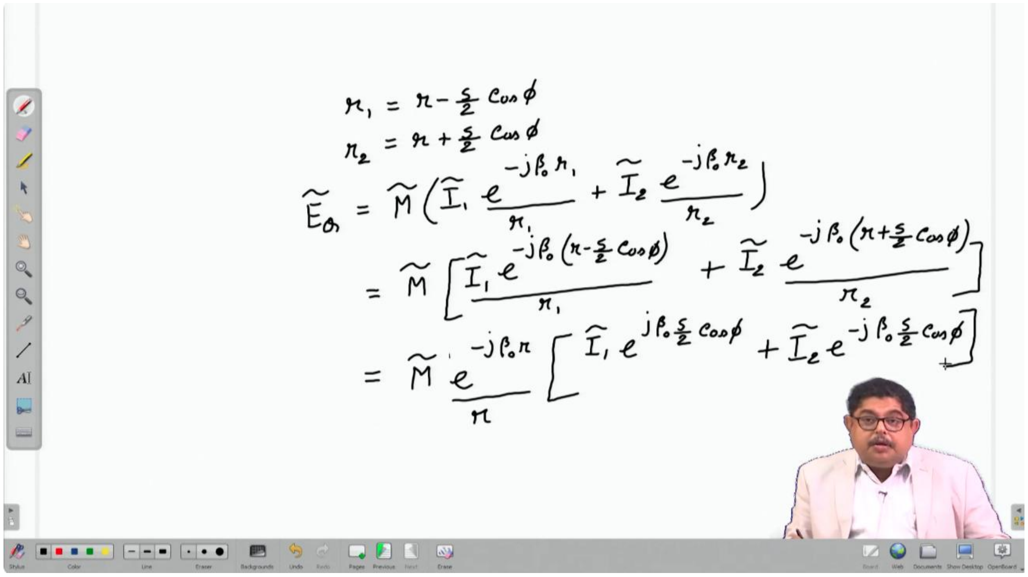
Week :05
Lecture 22: Differential mode current emission model

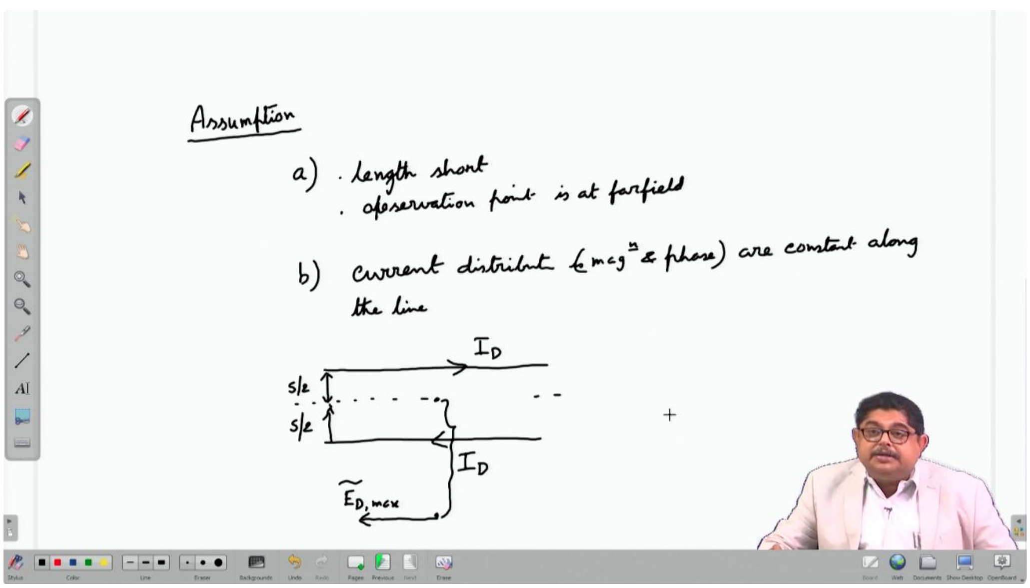
Welcome to the 22nd lecture of the course on EMI, EMC and Signal Integrity Principles, mechanics and applications. We were we have discussed some model of antenna and model of current. So, there we have seen differential mode current and common mode current. Today we will develop the differential mode current model for radiated emission. So differential mode, so there should be two conductors. So, let us place them that two conductors. So, the white board plane is the x y plane and conductors are lying in z direction. So, the axis of the two conductors that means the line joining them is x axis, but the conductors are in z direction. So, according to the notation actually they are coming out of the board to us. And so, the separation between them, let us assume that to be S. So, I can say that the one conductor is placed this is the origin of the coordinate system. So, one conductor is placed at a point z is equal to S by 2, another conductor is placed at a point z is equal to minus S by 2. And the currents that are being carried by let us say this conductor is I 1, this conductor is I 2. And suppose we are observing at far field P. So, I can draw a ray to or this is my R, this is my observation point, this is my R. So, there will be parallel rays from conductor 1, let us call that R 1, there will be parallel rays to P all of them are reaching P, but and let us say that this angle is now we are in the x y plane. So, there is no theta here. So, phi is this angle. So, I can say easily from the previous day's geometry that what is the distance this extra distance, actually if I draw a line perpendicular from here to here, then R 1 is shorter distance, R 2 is larger distance. So, this extra distance that will be you can find easily S by 2 cos alpha. So, the rays from this second conductor they will traverse an extra distance S by 2 cos alpha and the rays from conductor 1 they will traverse a less distance of S by 2 cos alpha. Now, we have already seen that electric field of each of these linear we are assuming linear these are lines, line conductors. So, that means, these will behave as linear antennas and they will be maximum at broadside direction that is theta is equal to 90 degree. So, that broadside will fall in the x y plane, because if I take theta is equal to 90 degree that means from z axis I am having an angle of 90 degree. So, that will be in the x y plane. So, the net field in the x y plane, net field we are trying to measure what is the maximum field that will be generated because we always want to find the upper bound. So, that in any other point any other theta this value will be less than this. So, net field, net electric field in x y plane will be let us call it E theta this theta is 90 degree that will be E theta 1 phasor plus E theta 2 phasor where E theta 1 is contributed by conductor 1, E theta 2 is contributed by conductor 2 and where each these are all at far field. So, for each one I can write I know the form of this that that will be given by M I i e to the power minus j beta naught r i by r i f of theta. This model we have already seen far field model of any linear antenna. So, we can write this that each one. So, I may take values either 1 or 2, i is either 1 or 2 and what is I i? i i is the current phasor at the center of ith antenna.



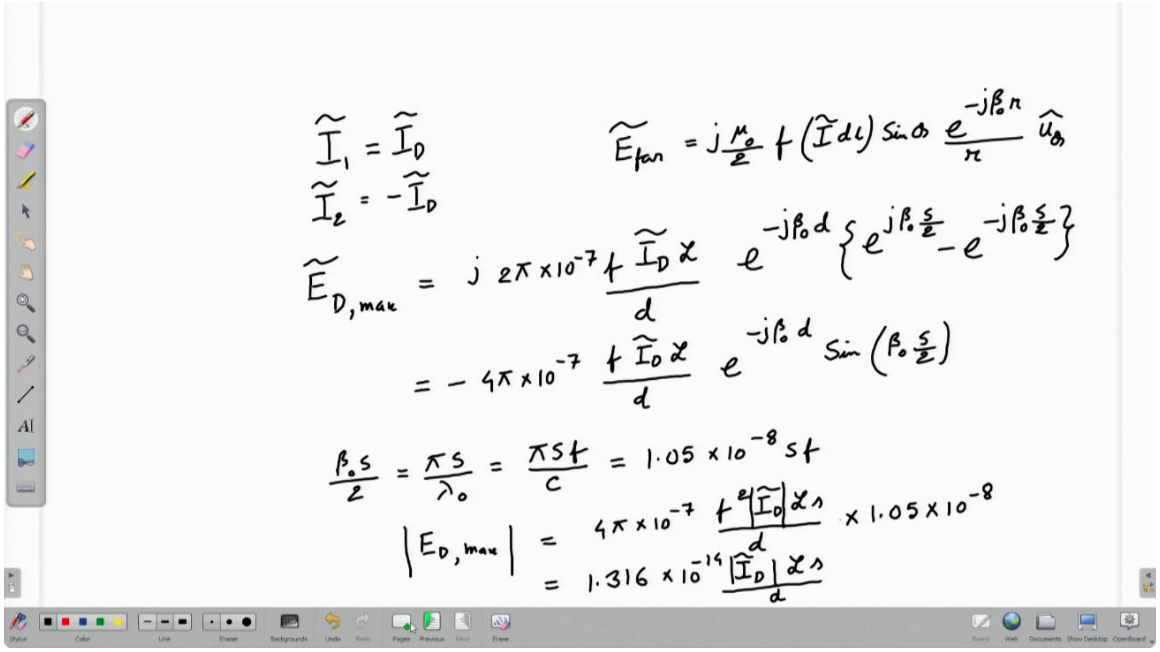
Now, using parallely approximation we can easily see from the diagram that r 1 is r minus s by 2 cos phi and r 2 is r plus s by 2 cos phi. So, substituting these values E theta the net E field in the x y plane will be M we are assuming similar antennas obviously, for a differential mode current the same type of line will be there. So, this is i 1 e to the power minus j beta naught r 1 by r 2 plus i 2 e to the power minus j beta naught r 2 by r 2 is equal to M i 1 e to the power minus j beta naught r minus s by 2 cos phi by r 1 plus i 2 e to the power minus j beta naught r plus s by 2 cos phi by r 2. I can take e to the power minus j beta naught r common. So, that will give me i 1 e to the power j beta naught s by 2 cos phi also I can make that in the phase I am keeping the this distance as we discussed before r 1 and r 2 ah their separation is not much if you see the previous diagram. So, r 1 and r 2 in the magnitude portion of the field for field we can assume that r 1 and r 2 are same. So, I can take r here also that r is equal to r 1 is equal to r 2 in magnitude part. So, this plus i 2 e to the power minus j beta naught s by 2 cos phi ok. Now, let us ah so this is the general expression valid for any two current carrying conductors be it differential mode be it common mode etcetera.



Now, for differential mode model we assume some assumptions every model has some assumptions because without that we cannot proceed. Now, if you want a better model these assumptions you can change make it more realistic. So, here first assumption we are making is that the length of the current carrying wire are sufficiently short. So, lengths obviously with respect to lambda length short and the observation point is observation point is sufficiently distance observation point is at farfield. So, that we could use that parallely type approximation then the current distribution is current distribution is current distribution means both the magnitude and phase of the currents are approximately constant along the line. That means, tacitly we are saying we are using a hard g hand dipole. Now, if not you will have to you can in a better model you can assume that they are any realistic model like dipoles etcetera are constant along the line ok. So, now our with this assumptions we can say that our picture becomes like this we are having 2 antennas for differential mode currents. So, one is carrying a current of I d another is carrying a current of I d in the opposite direction. Now, so this distance is s by 2 this distance is s by 2 and let us say that at a distance d we know the maximum of the field will be parallel to the 2 wires and we have seen that for differential current it is in the direction of the nearer of the 2 conductors. So, can I say that the net E d that will be in this direction because nearer one is in this direction. So, electric field will be in this direction and this will be E d max this we have seen earlier also. So, you can take some examples that which validates this assumption that conductor length should be short. For example, a 2 wire cable of length 1 meter now at 300 megahertz it is of the order of lambda naught. Now, it is up to you whether you will call it short or not if you do not call it short then you will have to go to higher model this model will not be valid or you will have to change the far field accordingly. Now, if you go to 100 megahertz it is lambda naught by 3. So, by that you will have to see in each and every case actually that is the job of an EMC engineer that whether these values you can use or you can develop your own values if you can consider that it is not electrically short then you will have to take some current distribution that means this current distribution that it is constant is not valid actually for any practical antenna which is comparable to lambda naught or as I said lambda naught by 5 if it is more than that you will have to take the actual distribution. A PCB land of let us say 30 centimeter 30 centimeter is a typical value for a PCB land. So, at 100 megahertz you can easily calculate what is this length it will come as lambda naught by 10. So, you can say that 100 megahertz is fairly good even at 200 megahertz also it could have been considered as lambda naught. So, this model could be used because the 200 megahertz it will be lambda naught by 5. So, it is current distribution you can assume that it is approximately constant actually in every case the current distribution is varying along any line but whether practically that makes any difference that as an engineering decision you will have to take ok.



Let us come to our model development. So, we can immediately write that what is our I 1, I 1 is I d and I 2 phasor is minus I d. So, I can immediately write what is E d max that if you take the help of your model of current element. So, you know that it is J into mu by 2. So, mu naught by 2 mu naught is 4 phi into 10 to the power 7. So, I can directly write 2 phi into 10 to the power minus 7 or for your sake I am again writing here that whatever model we developed that if r for a current element was J mu naught by 2 f I dl sin theta e to the power minus J beta mu naught r by r u theta ok. So, from there I am writing. So, that mu naught by 2 I have to give the length then f will come then I can say I d then for dl you see that in this model I will have to give the length let us say the length of the wire is l. So, I dl and for r where is my observation point I am observing at a distance this one let us say observation point from the centre of the 2 lines let me call it d. So, I will write that this is y d sin theta is where we are finding maximum. So, it will be 1 then e to the power minus J beta naught. So, that we write as d into e to the power J beta naught is by 2 minus e to the power minus J beta naught is by 2. I think this part you understood that from here you see e to the power minus J beta naught r in our particular case we are calling r as d and this s the separation that we are retaining. So, it is s by 2 cos phi and this is s by 2 cos phi in this case phi is 0 because it is along the same line. That means, if you are parallel to this wires that means, you are also at z axis. So, your phi is equal to 0 that is why that cos phi part I have taken. So, these if you do this is basically a sin term is coming. So, that will absorb this one. So, it will be minus 4 phi into 10 to the power minus 7 f i d L by d e to the power minus J beta naught d sin of beta naught s by 2. Now, what is beta naught s by 2? It is 2 pi by lambda naught s by 2 that is pi s by lambda naught and there if we again instead of lambda naught if we bring f it will be pi s f by c. So, you can put these values pi value you know c value you know on the s f you do not know. So, if you put that it will be 1.05 into 10 to the power minus 8 s into f. Now, we have already assumed that s is small obviously, s will be s means the separation between the two lines that will be much much shorter because already your L is shorter. So, if that is electrically short if not then it is a problem generally no conductor lines they are separate no two conductor lines their separation is electrically large, but if it is there then we can say that this beta naught s by 2. So, that this value even if suppose f is some megahertz or gigahertz even for gigahertz you see it is 10.5. So, less than that so, that and s will be some millimeter or something or centimeter. So, that can be considered as electrically short. So, sine beta naught s by 2 we can approximate as beta naught s by 2. So, finally, we get that E d max its magnitude that will be if you put the value that beta naught s by 2 that means, here you are getting again 1.05 into 10 to the power minus 8 s by 7. So, it is 4 pi into 10 to the power minus 7 f square I d L into s by d e to the power minus j beta naught will give you in the magnitude portion it will be 1. So, this beta naught s by a by 2. So, by 2 by 2 will come that has gone. So, s into a ah into 1.05 into 10 to the power minus 8. So, if you do that you get this thing 1.316 into 10 to the power minus 14 I d this also will be magnitude then L s by d.



So, in the next page I am writing that this is our final takeaway that E d max its magnitude will be 1.316 into 10 to the power minus 14 I d f square L into s by d. So, this is the worst case formula that means, the maximum electric field that you can get.

So, if you know the structure the current the frequency and the separation between the two and your observation distance then you can estimate without even measuring you can estimate what will be the maximum value. So, accordingly you can decide whether that will pass or fail. Also let me write that this value will come parallel to the wires. So, this is our differential mode current model. I will exemplify this in a problem that we will take up in the next class. Thank you.