

Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.

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Lecture 21: Farfield models of wire antenna& current models

Welcome to the 21st lecture of the course on E MIMC and Signal Integrity Principles, Techniques and Applications. In this lecture, we will discuss the far field models of wire antenna and also we will have some discussion about current models. So, in the previous class, we have found the far field of a dipole antenna. Now, a very common antenna dipole antenna is half wave dipole antenna, half wave means so, half wave dipole. Half wave means your L is taken to be lambda by 2 at that frequency. So, you see what will become of our f theta in that case, f theta will become if you put cos of beta naught sorry cos of 2 pi by lambda naught into L by 2 that is lambda naught by 4 into cos theta minus cos of beta naught L by 2 that is 2 pi by 4 so, and into the sin theta. So, it will become cos of pi by 2 cos theta into sin theta. So, you can see that at theta is equal to pi by 2, f theta becomes 1. So, for broadside f theta is 1 is equal to 1 for theta is equal to 90 degree also you can easily found that that is the maximum for f theta and that by differentiation you can easily see that there is a maximum at theta is equal to 90. So, we can say that what is the upper bound of E max, E far field maximum that is then 60 I m by R. So, what is the P radiated that is P radiated we have seen that 60. So, we have found the power expression before what is our P rad that we can again find from here that E max is this. So, if we do the RMS so, then we can say that the R radiation R rad will be 73 ohm. So, the radiation resistance of a dipole antenna half wave dipole antenna is 73 ohm which is much much greater than the current element.

LECTURE 21: FARFIELD MODELS OF WIRE ANTENNA
CURRENT MODELS

Half wave dipole $\rightarrow l = \frac{\lambda_0}{2}$

$$F(\theta) = \left[\cos\left(\frac{2\pi}{\lambda_0} \times \frac{\lambda_0}{4} \cos\theta\right) - \cos\left(\frac{2\pi}{4}\right) \right] \sin\theta$$
$$= \cos\left(\frac{\pi}{2} \cos\theta\right) \sin\theta$$
$$F(\theta) = 1 \text{ for } \theta = 90^\circ$$
$$|\tilde{E}_{\max}| = \frac{60 \tilde{I}_m}{r}$$
$$R_{\text{rad}} = 73 \Omega$$

So, based on above far field results we can now see that far field of any wire antenna can be written as E_{θ} as it is proportional to $I e^{-j\beta_0 R} / R$ there will be some constant m and f of θ . So, where I is the phasor current at the centre of the antenna f_{θ} is the θ variation of the antenna pattern and it is maximum is 1 and m . So, f_{θ} is the θ variation of the far field pattern it is maximum value is 1 and m is a function of antenna type. So, for current element for current element what is m ? m is to look at the expression of the far field $j\eta \beta_0 I dl$ or now I can write it as I because that is a general expression I is the thing of antenna and if you put this value $j\eta \beta_0 I dl$ if you put it is j into $2\pi \times 10^{-7} I dl$ because from $\beta_0 \lambda$ will come λ will give rise to it and for it f_{θ} is $\sin \theta$ for current element this is for current element and for half wave dipole for half wave dipole m is $j60$ and f_{θ} we have seen that it is $\cos(\pi/2 \cos \theta)$ into $\sin \theta$. So, this is the model we will use that if we have a current element these if you have a half wave dipole these if we have any other dipole a monopole etcetera you can have this type of model. So, in our radiated emission model we will put it here we are leaving this antenna model now because when we will be developing the radiated emission model we will be using them heavily. Now we enter into the current model discussion actually in current there is a model required for EMC thing which is not developed in your undergraduate classes. So, that we will try to develop now you see the unintended radiators we have already discussed that they are where speciable and metallic structures such as cabinets enclosures etcetera. The models help us to understand the factors affecting emissions and how to make the unintended radiators less efficient as radiators.

Handwritten notes on a whiteboard showing the far-field electric field expression for a current element and a half-wave dipole.

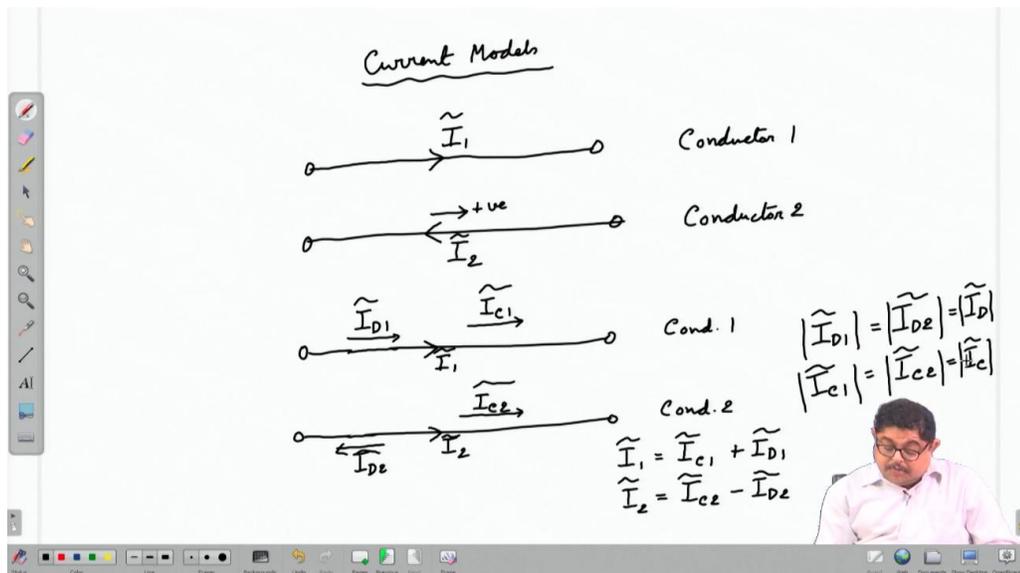
$$\tilde{E}_{\theta} = \tilde{M} \tilde{I} \frac{e^{-j\beta_0 r}}{r} F(\theta)$$

$\tilde{I} \rightarrow$
 $F(\theta)$
 $\tilde{M} \rightarrow$ for current element $\tilde{M} = j \frac{\eta_0 \beta_0}{4\pi} l$
 $= j 2\pi \times 10^{-7} l f$

half wave dipole
 $\tilde{M} = j60$
 $F(\theta) = \cos\left(\frac{\pi}{2} \cos \theta\right) \sin \theta$

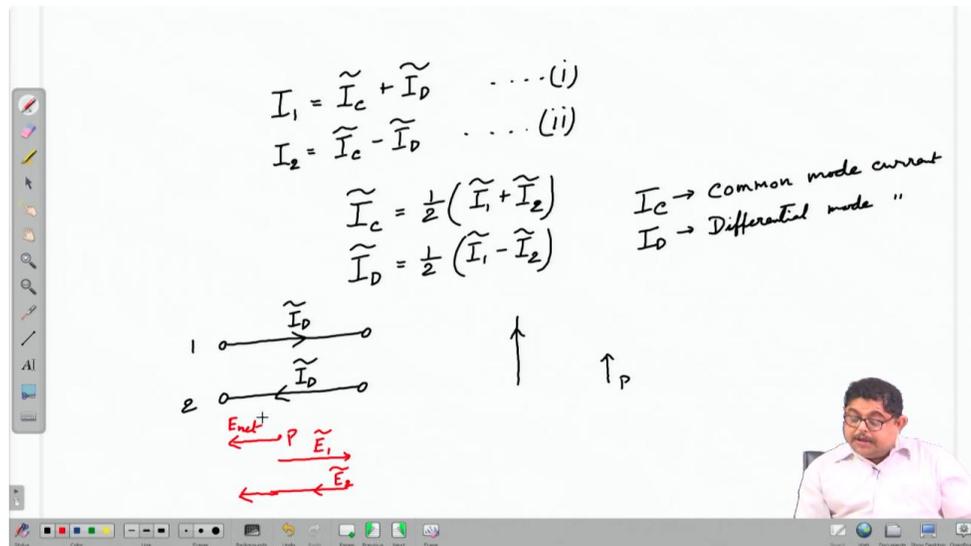
$F(\theta) = \sin \theta$

Now here I introduce next a discussion on the currents. So, consider so, give me the current models consider a parallel two conductor transmission line. So, let us call this conductor 1 let us call this conductor 2. Now functionally we know that if I have a current here I_1 now that should return to the source that means it should come here and the magnitude of I_1 and I_2 are equal, but they are opposite in direction, but so to show that actually I am saying that current I_2 that is actually flowing here with a negative direction. So, because both of them our positive direction is right side so I can say this is basically the positive direction. So, I_1 will be positive I_2 will be negative in our reference frame. Now they are the desired functional current because the circuit actually EMC is not a function. So, the circuit should do something either it is having a it is supplying some power some energy from one point to another. So, that function is done by $I_1 I_2$, but in practical systems another current is also present which in circuit theory we have not considered yet. They are due to noise interference current in some other loop with which some other circuit with which these are connected etcetera. Suppose from radiation some interference is coming so, that will be picked up because they are also were radiators. So, they will pick up these are all antennas these were so they will pick up something also there may be some noise that they pick up etcetera. So, now both these two they will have the interference. Now since they are very close actually I have shown them sufficiently away, but in practical cases you know that they are very close to each other the one and the return one. So, since the two conductors are close to each other both of them will carry same amount of this new type of current. So, the actual picture I can say that is not this it is now now I will call this I_1 and this I_2 as I_D . So, this one is going like this I call it I_{D1} and so, again this is conductor 1 this is conductor 2 and here it is I_{D2} . Now that interference currents somehow I call it $I_{C1} I_{C1}$ and why I am giving this name till now I am not explaining later I will explain and the same current with same direction will come on conductor 2 because they are close proximity. So, whatever is coming from other things there is no reason why they will be different. So, that I am calling I_{C2} . So, total current sorry here let me put it like this this is I_{D1} similarly this is my I_{D2} . So, on the conductor I am again getting I_1 and on this I am getting I_2 . So, I can see what are I_1 and I_2 I_1 is equal to I_{C1} plus I_{D1} and I_2 is equal to I_{C2} minus I_{D2} . Also I can say that I_{D1} magnitude is equal to same as I_{D2} magnitude and let me call that I_D all these are sorry phasor currents. So, let me say all are phasors. And similarly I_{C1} phasor their magnitudes are all same ok.



So, I can write I_1 is equal to I_C plus I_D let me call this equation number 1 and I_2 is equal to I_C minus I_D let me call this equation number 2. So, I can solve for I_1 I_2 to get the values of I_C and I_D easily you can see that what is I_C it is half of I_1 plus I_2 and I_D is half of I_1 minus I_2 . Now I can explain to you why I have given this C and D subscripts actually you see I_C is nothing, but the common. So, I_C is present everywhere and that is why it is called common mode current. So, I_C is called common mode current and I_D is called differential mode current. You see this is the difference and I_C is addition. So, common mode and differential mode I think these two terms you have heard in undergraduate classes if you recall that in Op-Amp you have found common mode rejection ratio that is nothing, but what is the ratio of I_D by I_C because I_C is interference. So, you should try to have it or that ratio CMRR should be as high as possible because I_C is in the denominator. So, they are one of the figure of merit of Op-Amp is how you are your differential mode current is how it is above common mode current how much it is how much factor it is above. So, that this is the origin of that that common mode current is an interference you should not have it much more whether differential mode current is useful that is the functional current. So, you should have it much more than this sometimes this the common mode current is called antenna mode current and the differential mode current is called transmission line current that you should remember that the differential mode current is useful. So, it is transmission line antenna mode currents are something like this if you see this that the current in a dipole etcetera that can be similar to this common mode current. Now let us see that what is the effect of them ah. So, suppose just for understanding the concept let us say I have only differential mode current. So, this is my conductor 1 this is my conductor 2 I have only differential mode current that means, I have I_D here I have I_D here. Now consider a point P this is my observation point. Now here what will be the effect of or what will be suppose a current just what is the far field of this current at point P that means, far field

of ID 1 on point P you can look at your expressions. So, in the previous lecture you see we have derived that that there will be the current that will be minus g ah minus. So, can I say that from that you can see that current is in theta direction. So, that means, that time if you have current like this. So, current is like this what was your direction of theta. So, theta is equal to 90 degree it was maximum. So, if the observation point is here this was your maximum current is not it. So, taking that clue I can say that now here due to E 1 I will have a far field like this that I am calling E 1 and due to ID it is opposite. So, I will be having E 2 that will be something like this in this direction, but this is nearer to P ID than this that means, it is R that is less. So, this one will be greater. So, this is your E 2. So, what is the net? Net effect is in this case is at P now I can draw that net effect is E net in this direction.



Now, let us see a common mode current this is 1, this is 2, this is your I C, this is also your I C again let us see at observation point P. So, what will be E 1? E 1 is something like this if I take E 2 that will be greater than E 1. So, it is this so that means, what will be at P they are now adding up in differential mode they subtracted. So, they will be E net. So, you see that there are various things to note here one is two differential mode current produce oppositely directed electric field. Since, the wires are not co located their net effect is not cancelled by a reduced electric field and the direction of the net field is opposite to the direction of the current. Whereas for common mode current both the produced electric field are in the same direction. So, the net field is much larger than the differential mode produced current field and it is also in the same direction as the current direction. So, you see that in differential mode current the current is in the opposite

direction of the currents in common mode current it is in the same direction as the direction of current and produces much larger field. Now in radiated emission this common mode current is very problematic. Now common mode currents magnitude is much smaller than differential mode currents that I agree, but due to this effect that its electric field is much higher than the electric field produced by differential mode current. Sometimes the two fields that means, the differential mode produced current field and common mode current fields may be of comparable magnitude. Common mode current is unwanted differential mode current is wanted. So, if they become comparable in field then they have they can produce severe problems. So, in radiation emitted emission model you should always check for the I field due to common mode current even if common mode current is very small and this is the reason why an op-amp or any other electronic device should have low type of CMRR. If you do not have if you do not suppress the or reject the common mode currents much much below level of differential mode current you can get severe problems in the field. So, with that I stop the discussion today from next class with this background we will go into radiated emission models directly. Thank you.

