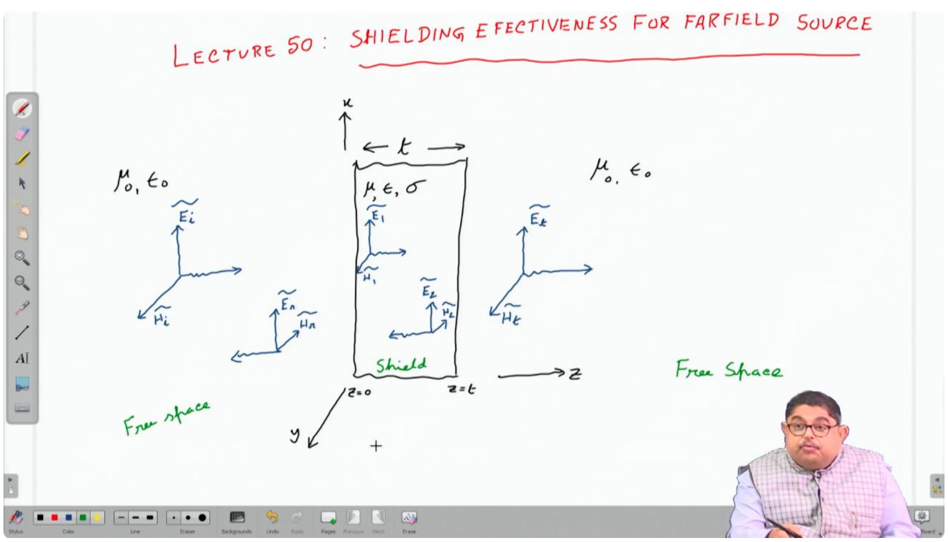
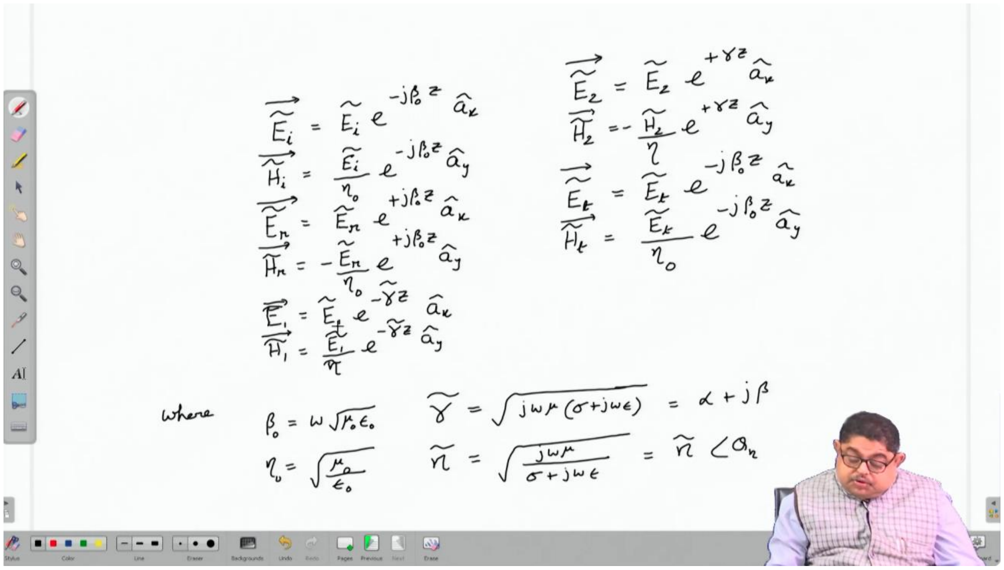
Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
Professor name: Prof. Amitabha Bhattacharya
Department name: Electronics and Electrical Communication Engineering
Institute name: IIT Kharagpur
Week :10
Lecture 50: Shielding Effectiveness for Farfield Source

Welcome to the lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. We were seeing we have seen the definition of shielding effectiveness in the last class. We have seen that there can be two types of sources near field or far field. So, first we have take up the far field case. So, we draw the a far field source picture. This is a shield. So, let me write that this is your, this is the shield with its electrical parameters mu epsilon sigma. This is a free space. This is also a free space this side extending up to infinity that is why no reflected transmitted wave is coming. So, this is the picture. Now, we need to find what is the ratio of E i by E t. Now, to do that E i is known we are assuming that whatever the source has send. So, that electrical field strength is known at the shield. So, we now need to find E t. We have two interfaces of discontinuous materials. One is free space to shield material that is at z is equal to 0. Similarly, we have another discontinuity at z is equal to 2 inter plane that is from shield to free space. So, there we have some knowledge of the boundary condition of the electrical magnetic fields that we will now apply to get that ratio. So, we have already seen discussed that a far field source always at its far field that the wave becomes like plane waves. So, we can assume that all these waves incident wave reflected wave transmitted wave then the wave that is starting from the z is equal to 0 interface inside the shield. Similarly, the wave that is E 2 that is the wave that is starting from the z is equal to t interface inside the shield all of them are plane waves.

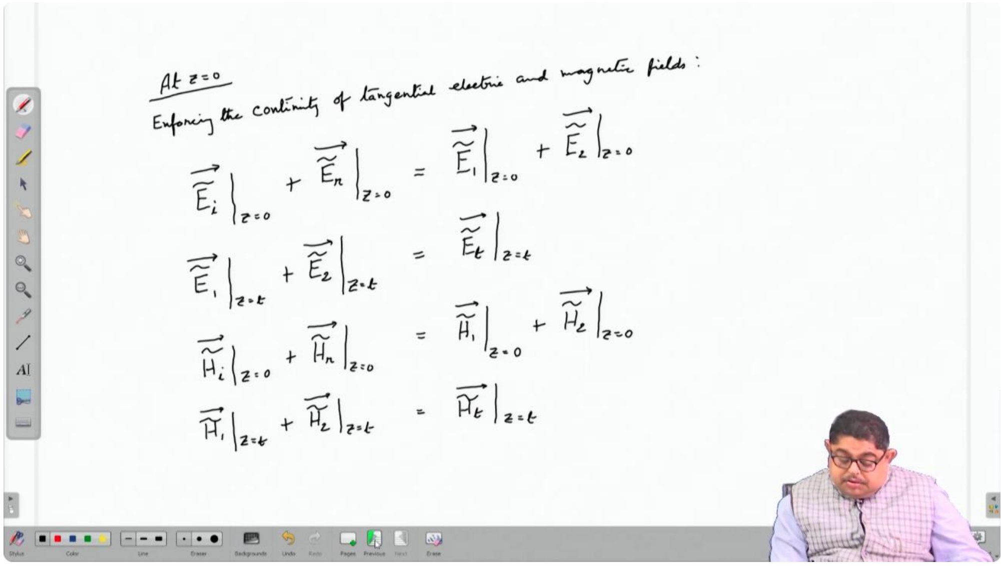


So, we can easily write their expressions that E i is I can say E i e to the power minus j beta naught z in our picture we have assumed it to be x directed. And this beta naught is the phase constant of the free space because this is happening at free space. So, that is omega into mu naught by epsilon naught similarly, H i will be E i by eta naught e to the power minus j beta naught z this is for the plane wave it is y directed and what is eta naught? Eta naught is the free space impedance that is root over mu naught by epsilon naught. So, this is the incident wave for reflected wave I will write the E r and H r. So, E r will be E r e to the power plus j beta naught z because the wave is going in the negative z direction a y sorry a x a x and H r will be minus E r by eta naught e to the power plus j beta naught z a y then we have E 1. So, E 1 will be E 1 e to the power minus j sorry it is a in it is sigma. So, it has the complex part that means, the alpha is also present. So, it is e to the power minus gamma z a x where gamma is the propagation constant of the shield material. So, gamma phasor is root over j omega mu into sigma plus j omega epsilon and this is a complex number. So, that is generally say that alpha plus j beta. So, that is E 1. So, H 1 will be E 1 by eta e to the power minus gamma z a y. So, what is gamma? The impedance is of the shield medium. So, that is j omega mu by sigma plus j omega epsilon and that is generally written as eta into theta eta.

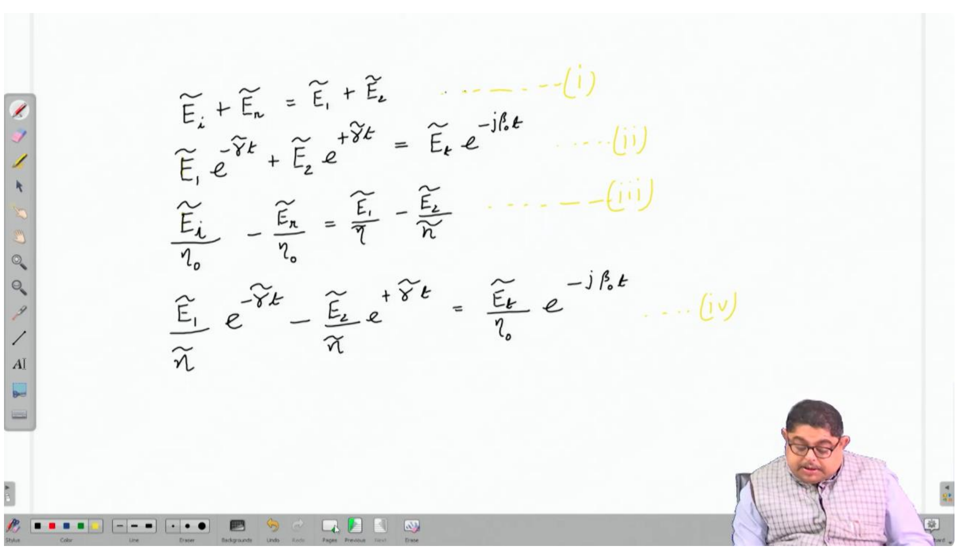
So, E 1 then there will be E 2, E 2 is E 2 vector is E 2 the magnitude part into e to the power plus gamma z a x H 2 minus H 2 by eta e to the power plus gamma z a y because it is going opposite to E 1 or opposite to the incident wave direction then I have E t and H t. So, E t is magnitude e to the power minus g again beta naught has written because this is free space and H t is eta naught by eta naught e to the power minus g beta naught z a y. So, all the waves which we have drawn there we have written their mathematical expression and these are the extra variables that we use throughout. So, that means now you see we have the we will have to determine basically we will have to determine E t, but in the process we have also got the mu another three variables E r, E 1 and E 2. So, we have total unknown four variables E r, E 1, E 2 and E t. So, we need four equations to solve for these four unknowns and that we will get from the boundary conditions at the two interfaces. For electric field there will be one boundary condition for magnetic field there will be another boundary condition. So, there are two interfaces. So, there will be total four equations boundary conditions concerning all these four variables and from that we will be able to solve for our desired one that E t by E 1.



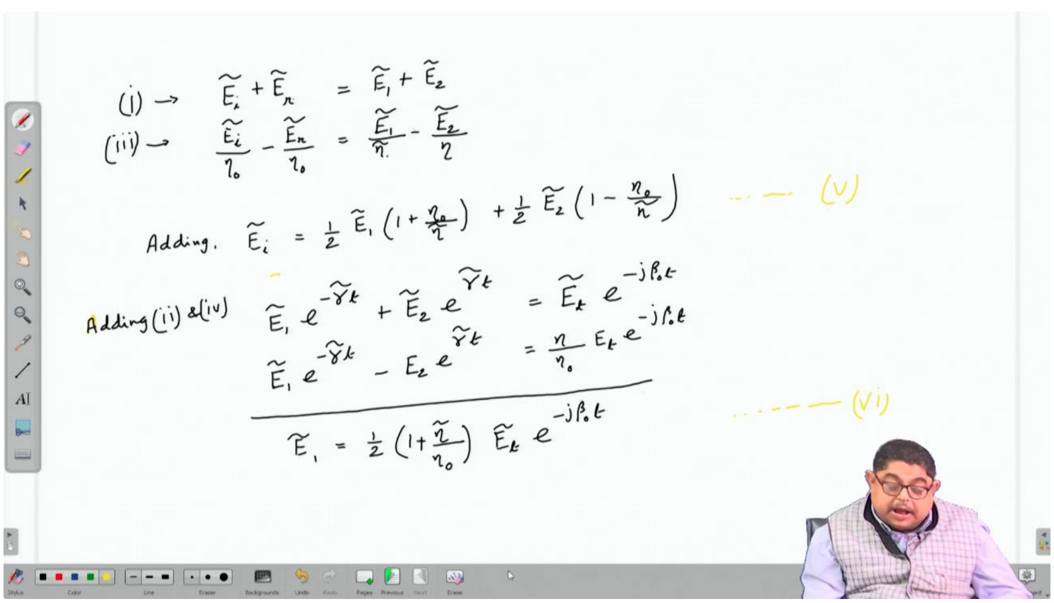
So, we can say that the boundary condition at z is equal to 0 for electric field is that electric field is continuous. So, tangential electric field is continuous. So, I can say that at z is equal to 0 enforcing the continuity of tangential electric field. So, magnetic field is continuous we know that at a conductor boundary and the boundary there are no current on the z is equal to 0 surface. So, magnetic field tangential component will also be continuous. Similarly, at z is equal to t also. So, we will get the electric field tangential electric field continuity and tangential magnetic field continuity again because of the reason that we are not putting any source current source at z is equal to t interface. So, we will have E I at z is equal to 0 plus E r you see your diagram. Let me go there that at z is equal to 0 I can say that E I plus E 0 will be equal to E 1 plus E 2 at z is equal to 0. Similarly, at z is equal to t what will happen to the electric field components E 1 plus E 2 is equal to E t for magnetic fields similarly we will be able to write. So, let us write that is equal to E 1 z is equal to 0 plus E 2 z is equal to 0 E 1 z is equal to t plus E 2 z is equal to t is equal to E 1 z is equal to t is equal to E t z is equal to t H I z is equal to 0 plus H r z is equal to 0 plus H I z is equal to 0 plus H I z is equal to 0 plus H 2 z is equal to 0 and H 3 z is equal to 0 plus H 4 z is equal to 0 and H 1 z is equal to t plus H 2 z is equal to t is equal to 0. Now, we have our mathematical forms of plane wave. So, there we can put this. So, E I is this. So, E I at z is equal to 0 will be E I A x E r at z is equal to 0 will be E r A x similarly E 1 at z is equal to 0 will be E 1 A x H 1 will be E 1 by eta to the power that will go because it is at z is equal to 0. So, like that we will be able to write.



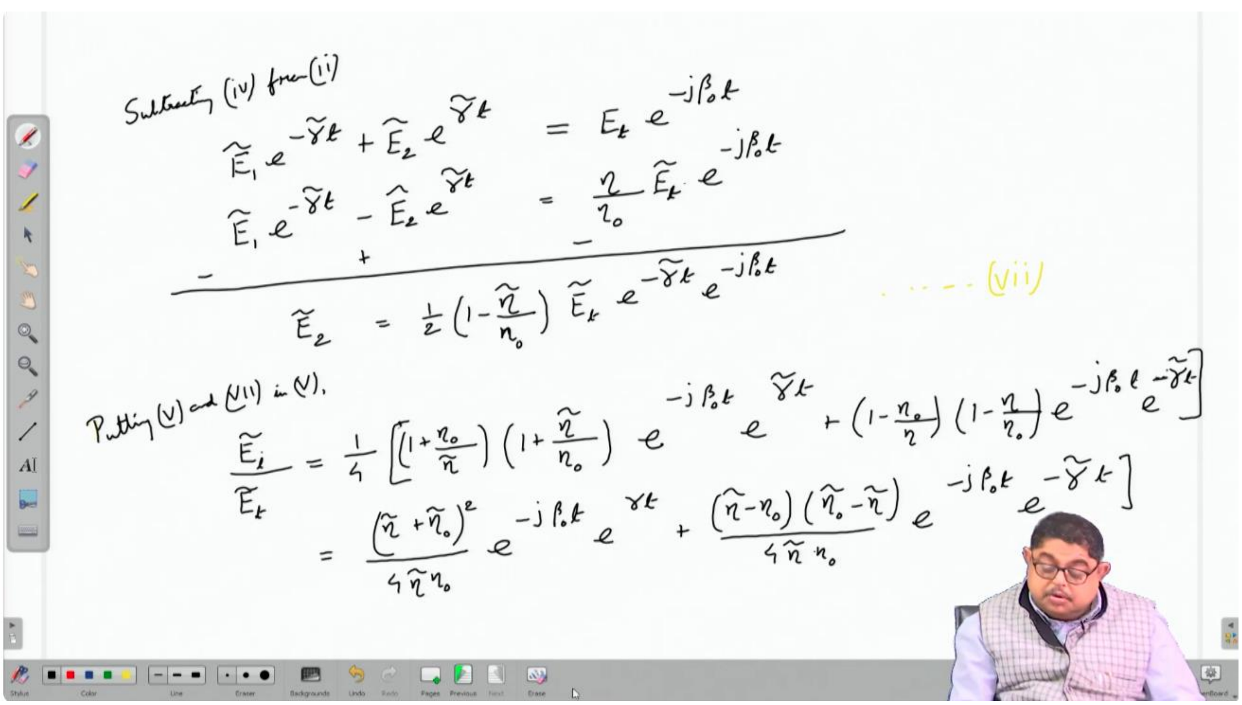
So, let us write that. So, E I plus E r is equal to E 1 plus E 2 let me call this equation equation 2. So, this is equation number 1. Then the next one will be 1 E to the power minus gamma t plus E 2 E 2 E to the power plus gamma t is equal to E t E to the power minus j beta naught t. Let us call this equation number 2. Then the H 1's. So, that we will write as E I by eta naught minus E r by eta naught is equal to E 1 by eta minus E 2 by eta. So, let me call this as equation number 3. And the last one will be E 1 by eta e to the power minus gamma t minus E 2 by eta e to the power plus gamma t is equal to E t by eta naught e to the power minus j beta naught t. So, let me call it equation 4. So, I have got 4 equations. Now, just we will have to do algebraic manipulation.



So, that we will do now. E I plus E r is equal to E 1 plus E 2. E I plus E r is equal to E 1 plus E 2 plus E 2 and 3 gives me that magnetic field 1 that E I by eta naught minus E r by eta naught is equal to E 1 by eta eta plus E 2 by eta minus. That one will be minus because it is in the opposite direction. That is all. So, now we can add these two equations. So, adding what we get is E I is equal to half E 1 1 plus eta naught by eta 1 plus half E 2 1 minus eta naught by eta. There is no eta naught. So, let me call this one as equation 5. So, adding 1 and 3, I have got E I in terms of E 1 and E 2.Similarly, if I add adding 2 and 4. You can easily see. So, I will add this one and this one. So, again you see. So, I will get an expression of E 1. So, let us do that. 2 means E 1 e to the power minus gamma t plus E 2 e to the power gamma t is equal to E 2 e to the power minus j beta naught t and E 1 e to the power minus gamma t minus E 2 e to the power gamma t is equal to E before eta minus eta naught et e to the power minus j beta naught t. So, if I add, I get E 2 is equal to half 1 minus eta by eta naught E t e to the power minus gamma t e to the power minus j beta naught t. I hope I am correct. So, this equation 4, this is not 2 and 4. This was actually subtracting 2 and 4. So, adding 2 and 4, I have not let me do that. So, adding 2 and 4, this is 2. Let me check again. 2 is E 1 plus E 2 is that and from 4, I can write E 1 e to the power minus gamma t minus E 2 e to the power plus gamma t is equal to eta by eta naught e to the power this. So, this is minus. So, I will get E 2, E 1. So, this is wrong. This is not E 1. I will get because if I add E 1, E 1 is half 1 plus e to the power this term also will come. So, I will get e to the power minus j beta naught t. So, that will be my equation number 6.



And now, I will subtract. Subtracting, I have already got E 1. I will have to get E 2 in terms of E t. Subtracting 4 from 2, what we get was what I have done that E 1 e to the power minus gamma t plus E 2 e to the power gamma t is equal to E t e to the power minus gamma t eta naught t.And here, I will get E 1 e to the power minus gamma t minus e to the power gamma t is equal to eta by eta naught e t e to the power minus gamma t. So, beta naught t I will now subtract. So, E 1 will go out. I will get E t E 2 is equal to half 1 minus eta 0 E t e to the power minus gamma t e to the power minus j beta naught t. So, this one I will call equation number 7 fine. And then, I will put this. So, 6 give me an expression of E 1 in terms of E t. The 7 give me an expression of E 2 in terms of E t. So, if I put this into 5, I get everything in terms of E i and E t. So, look at your 5. What was 5? So, E i is equal to half here if you put E 1 in. So, E t will come here if you put E 2 from equation 7, E t will come. So, you are getting E i is equal to something into E t. So, you will get shielding effectiveness. So, we get E i by E t is equal to eta naught plus. 1 by 4 into 1 plus eta naught by eta 1 plus eta naught by eta. So, that gives you eta plus eta naught square by 4 eta eta naught e to the power minus j beta naught t e to the power gamma t plus eta minus eta naught into eta naught minus eta by 4 eta eta naught e to the power minus j beta naught t e to the power minus j beta naught. Now, note that only there because already I have taken it common. So, there will be 2 equations. Now, this one I can finally, write as eta naught eta naught plus eta square by 4 eta eta naught into 1 minus eta naught minus eta whole square by eta naught plus eta whole square e to the power minus 2 alpha t e to the power minus j 2 beta naught t into e to the power alpha t e to the power j beta t e to the power minus j beta naught t. Just writing like this because I will interpret this result in this way. So, that we will see in the next class. Thank you.



$$\frac{\tilde{E}_i}{\tilde{E}_t} = \frac{(\tilde{\eta}+\eta_0)^2}{4\tilde{\eta}\eta_0} e^{-j\beta_0 t} e^{\gamma t} - \frac{(\tilde{\eta}-\eta_0)^2}{4\tilde{\eta}\eta_0} e^{-j\beta_0 t} e^{-\tilde{\gamma} t}$$

$$= \frac{(\tilde{\eta}+\eta_0)^2}{4\tilde{\eta}\eta_0} e^{-j\beta_0 t} e^{\gamma t} \left[1 - \frac{(\tilde{\eta}-\eta_0)^2}{4\tilde{\eta}\eta_0} e^{-2\gamma t}\right]$$

$$= \frac{(\eta_0+\tilde{\eta})^2}{4\tilde{\eta}\eta_0} \left[1 - \frac{(\eta_0-\tilde{\eta})^2}{(\eta_0+\tilde{\eta})^2} e^{-2\alpha t} e^{-j2\beta_0 t}\right] e^{\alpha t} e^{j\beta t} e^{-j\beta_0 t}$$