

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

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Lecture 29: Radiated Susceptibility Model

Welcome to the 29th lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. In the last class, we have discussed the how to determine the L and C of quack shear line and we due to paucity of time we could not take an example, let us first take that example, then we will proceed to develop the radiated susceptibility model of a two-wire line system. So, consider a you know this quack shell cables they are given by a there is a nomenclature that is RG that stands for quack shell then 58U is a very popular model used. So, consider a RG 58U quack shell cable which consist of an inner conductor whose gauge is 8 gauge and it is a solid wire, it is a conductor inner conductor and the braided shield that is inner the shield radius shield radius is 58 mils. The shield is made of polyethylene, polyethylene a very good dielectric and the manufacturer specified two things about the cable that one is the velocity of wave propagation wave propagation as a percentage of the free space propagation value is 66 percent. And another thing is specified that per unit length C is 30.8 pico farad per meter. Now, we will have to determine our question is we will have to find characteristic impedance of the line. You know that if we want to use this we need to know what is the characteristic impedance so that we can design the RF part of the circuit because without characteristic impedance we are nowhere in microwave circuit. So, we will have to find from this specification actually manufacturer specified like this. Now, what he meant by the first specification that actually the velocity of propagation through the shield that means basically the phase velocity inside the shield is two third of C the velocity of light you see velocity of wave propagation as a percentage of the free space propagation value is 66 percent. 66 percent or 67 percent means basically two third and this one is obvious so you need to find out basically LE but how to find LE. You see the diameters etcetera given so this diameters are given so we can find out or not. Let us see that what is LE because if we get LE we get Z naught because Z naught is nothing but we know it is equal to root over L by C this is again per unit length impedance. So, if we know L if we know C or I can write LE also LE by C root over that will be characteristic impedance so page.

LECTURE 29: RADIATED SUSCEPTIBILITY MODEL

RG-58U

inner conductor \rightarrow 8 gauge

shield radius \rightarrow 58 mils

\uparrow
Polyethylene

a) Velocity of wave propagate as a percentage of the free space
propagate value \rightarrow 66%.

b) per unit length $c \rightarrow 30.8 \text{ pF/m}$

$$Z_0 = ? = \sqrt{\frac{L}{C}}$$

So, what is L ? We have our L formulas you can see that and just convert those things so it is μ or those let me erase we have given only thing we cannot use the free space value because it is not free space. So, we will have to see our basic values basic equation to solve this so you see that μ it is ferromagnetic the polyethylene dielectric that is non ferromagnetic so no problem in taking μ_0 then R_S by R_W R_S is said that what is R_S ? R_S is it has 58 mils so and the 8 gauge solid wire means its radius is 0.4 millimeter so I can convert everything to millimeter so that means in denominator for R_W I am writing 0.4 and the shield gauge that will be 58 into 0.001 so it came to inch now it came to centimeter now it came to millimeter so that is all and that unit will be Henry per meter if you solve this I have solved that so I know the value but you can easily solve this it will be 0.261 micro Henry per meter. So, the moment I got that I know Z_0 so Z_0 will be you put the values and you will see that it will come to 50.56 ohm also if I ask you what is the polyethylene dielectric constant from the first one you can easily get that you see we know the phase velocity V_p of any wave any electromagnetic wave that is C by ϵ_r so he has said that V_p is 0.66 of C that means ϵ_r is basically or you can say root over ϵ_r is 1 by 0.66 so ϵ_r will come to be 2.3 so this is polyethylene A. So, this is an example on the importance of per unit length inductance and capacitance.

$$L_c = \frac{4\pi \times 10^{-7}}{2\pi} \ln \left(\frac{58 \times 0.001 \times 2.54 \times 10^4}{0.4} \right) \text{ H/m}$$

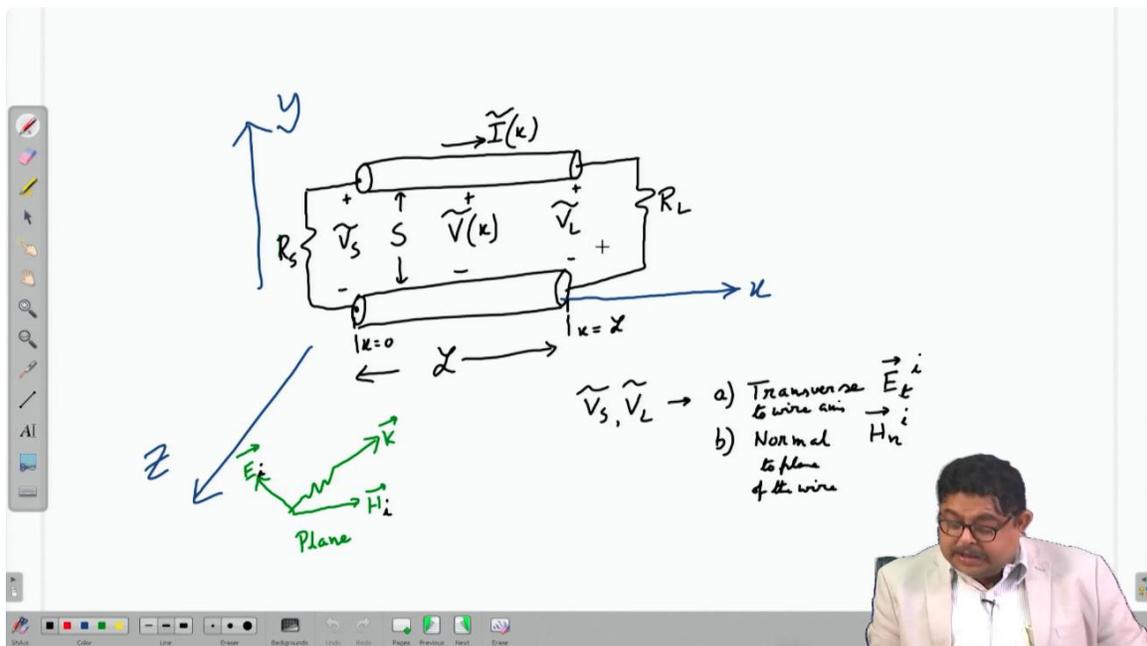
$$= 0.261 \mu\text{H/m}$$

$$Z_0 = 50.56 \Omega$$

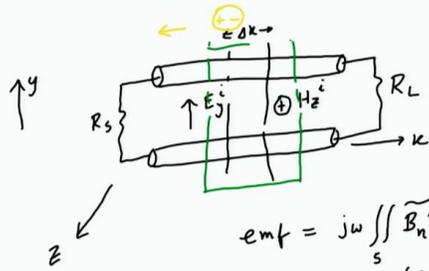
$$V_p = \frac{c}{\sqrt{\epsilon_r}} \quad \sqrt{\epsilon_r} = \frac{1}{0.66}$$
$$\epsilon_r = 2.3$$

Now, let us go to our radiated susceptibility model what you mean by susceptibility means the my two wires they are not energized they are not carrying any current etc. but from somewhere some electromagnetic radiation came and that will generate some voltage and current in my transmission line I will have to measure that. So, first let me draw a two-wire transmission line and it is not connected to any source but obviously this transmission line there should be even if it is open that is also a load so I am writing that there is a load here similarly there is some resistance here because there will be some other circuitry etc. all that I am putting as load there are no sources here till now. Let us take any axis so let me tell in color that this is my x axis this is my y axis so this will be my z axis. Now, let us say that this transmission line each one is of length L and as before the separation between them is S . Now, from somewhere some wave come now that wave that source of that wave may be very near to this where maybe very far to the wire. Now, you see if the source is far away from this thing that means if this were to our system is in the far field of the source then it is a radiated susceptibility problem if it is nearby the source is nearby that means these two are in the near field of the source that is called crosstalk that will tackle separately. So, crosstalk is a near field phenomena and radiated susceptibility is a far field phenomena this is their base in difference. So, now so anything coming from far field we can assume that a plane wave is coming or a number of plane wave is coming but if I know how to tackle a single plane wave I know how to tackle a sum of plane waves because this Maxwell's equations are linear so for many number of plane waves it will be simply superposition. Now, let us say that what color I have taken green so let me show that radiation coming so the radiation let us say is coming like this a plane wave always have this direction of propagation that is actually called k vector and the let us say it is E field E vector and it is H vector they are always mutually perpendicular actually I a three mutually perpendicular thing cannot be shown in a two dimensional whiteboard. So, one of them is out of the board I am not saying which one but all are not in this white board so if E and k vector is in this board H is outside but I am not generalizing that but remember that this is a plane wave so these three vectors three arrows that I have shown for three vectors I can write that this is a k vector this is H vector this is E vector they are mutually perpendicular. So, you can see that the two wires they are lying in the xy plane and let us say which I have not said that this is this is your RS so RS is at let us call this is at x is equal to 0 and RL is at x is equal to capital L . Now, what we wish to find that this will generate some voltage current etcetera we know plane wave this plane waves details that means we know the polarization, polarization means how the E field is oriented. We know that it is a steady state sinusoidal wave its electric field we know and let us call that since it is to show that it is incident I am calling it E_i and H_i I know its k vector that means its direction of propagation also I know so it will generate voltage current here. So, let me say that it will generate some source voltage some at the RS end it will generate some induced V_f

similarly here it will generate some VL. So, radiated susceptibility means determine Vs and VL. So, there was no voltages etcetera when the plane wave was absent now an incident plane wave came so find out what is Vs and VL this is the problem of radiated susceptibility. Now, from your basic knowledge you can say that two components of the incident field contribute to the induced voltage in the transmission line one will be the component of the incident electric field that is transverse to the line axis that is that means which is transverse that only can generate some voltage so that will be so here transverse means if I say that my transmission line axis is x so it will be Ei who can generate if there is some Ex there will be no voltage will be generated. Similarly, who else can generate this voltage what about magnetic field the incident magnetic fields normal component normal to the plane of the wires that can generate. So, I can say that who can generate Vs and VL will be generated transverse in the sense if the this axis of the transmission line or transmission lines lines are in x axis transverse to that that means if you have an Ei or if you have an Ez it will be generated. Similarly, who else can generate the normal component normal this is basic electromagnetic theory says this so Hni watch this I am writing here so better let me change that nomenclature that I let me write here E here this is correct that this is normal and this is I standing for stands for incident N is the normal. So, normal component normal to the plane of the wires plane of the wire means what so normal to plane of the wire so here also let me write transverse to wire axis that clear simply only these two components can it. So, in this case what is plane of the wire plane of the wire is xy so normal to that means it should be z directed. If I have any z directed component of incident magnetic field then only that can generate voltage.



So, let me show that whatever we discussed till now so I have these two conductor line I have RL I have RS so now I have this is my x so I will have to have either a E_i or a H_{zi} plus or minus I do not know but they can only affect me. So, in so let us assume that the our electric component assume positive direction of electric component is in y direction this is our y direction this is our x direction this is our z direction so we are showing it ultimately we can get him if we get a positive value it is in y direction if we will get a negative value we will get a negative direction. Similarly for H_{zi} let us assume that it is going as if it is falling going inside but our z direction is these so let us say that our assumed direction is whatever is going inside so this plus shows that it is going inside that is our assumed direction. Now due to this incident magnetic field why a voltage will be developed because according to Faraday's law an EMF in the loop this is a loop forming a loop two transmission lines and RL and RS that is a loop so EMF in the loop will be induced and we know what is that EMF that EMF in steady state it is simply you see displacement current so that d/dt so in if I write it in frequency domain $J \omega$ I said that in steady state we want to develop that when this came what happened because waves take some time so from the source it has taken some finite time to come here then it took some time to stabilize after that we are looking at steady state so it is a steady state thing so there I can write this EMI is nothing but total flux that is linked so $\oint \mathbf{B} \cdot d\mathbf{s}$ so so this we know is $J \omega$ I can consider that medium is non-ferromagnetic so it is $\mathbf{H} \cdot d\mathbf{s}$ and you know that a transmission line this type of distributed line so this voltage whatever it will be generated let us go previously that this V_s V_L that will give rise to a in different parts there will be different voltages that is the distributed thing so I can see that there will be a distribution of voltage so V is a function of X similarly there will be a current induced that is also a function of X so the effect of this falling off incident wave is V_X I_X will be generated throughout the line so the terminal ones I will have to find out so that I can measure it V_s and V_L so you know that for analysis we will be seeing a part of the this transmission line so let us consider a ΔX portion of the transmission line so that means we can consider a surface over this ΔX portion only so this ds now I can write $\mu_0 \Delta X$ because $\mathbf{H} \cdot d\mathbf{s}$ that is in Z direction or so this dX you see if I take ΔX so the surface is ΔY is remaining so $\mathbf{H} \cdot d\mathbf{s}$ can I say that it is ds because if I have a area in ds it will be Z directed the areas normal that will be Z directed so $\mathbf{H} \cdot d\mathbf{s}$ is we have seen that only the Z directed component will matter so this dot product will then change to simply a scalar multiplication but $\mathbf{H} \cdot d\mathbf{s}$ may have variation in Y direction so that we are keeping that it is under integration Y is equal to 0 to S so this is the voltage that will be generated so that means this will generate a voltage source in this portion so a voltage source on the transmission line will be generated because this emf definitely will generate a voltage source induced voltage source but what will be its polarity what will be the polarity of an induced voltage source recall Faraday's law that you have a changing magnetic field so you have a emf induced and the polarity is such that is given by Lenz's law that the polarity will be such that it will



$$\tilde{H}_n^i = -\tilde{H}_z^i$$

$$\begin{aligned} \text{emf} &= j\omega \iint_S \tilde{B}_n^i \cdot d\vec{s} \\ &= j\omega\mu_0 \iint_S \tilde{H}_n^i \cdot d\vec{s} \\ &= j\omega\mu_0 dx \int_{y=0}^s \tilde{H}_n^i dy \end{aligned}$$

for unit length induced voltage

$$\tilde{V}_S(x) = j\omega\mu_0 \int_{y=0}^s \tilde{H}_n^i dy = -j\omega\mu_0 \int_{y=0}^s \tilde{H}_z^i dy$$

