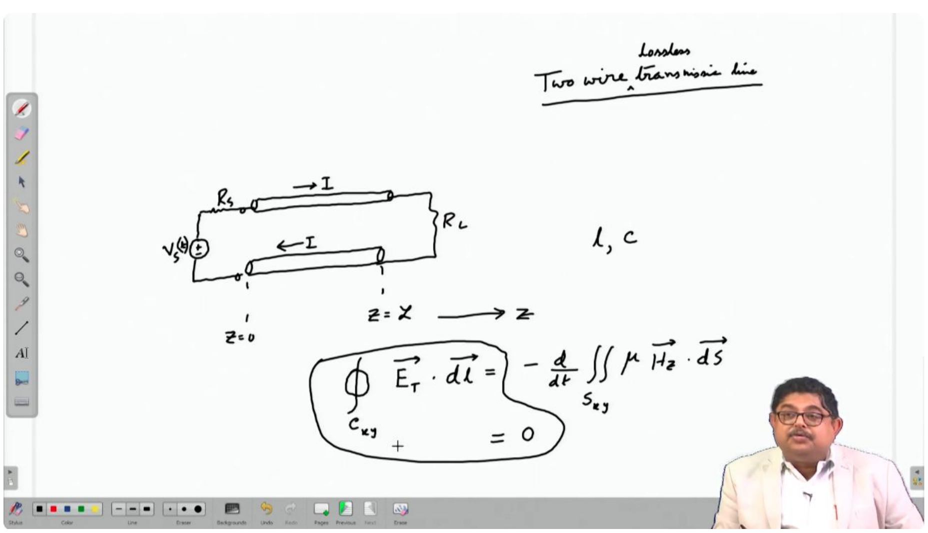
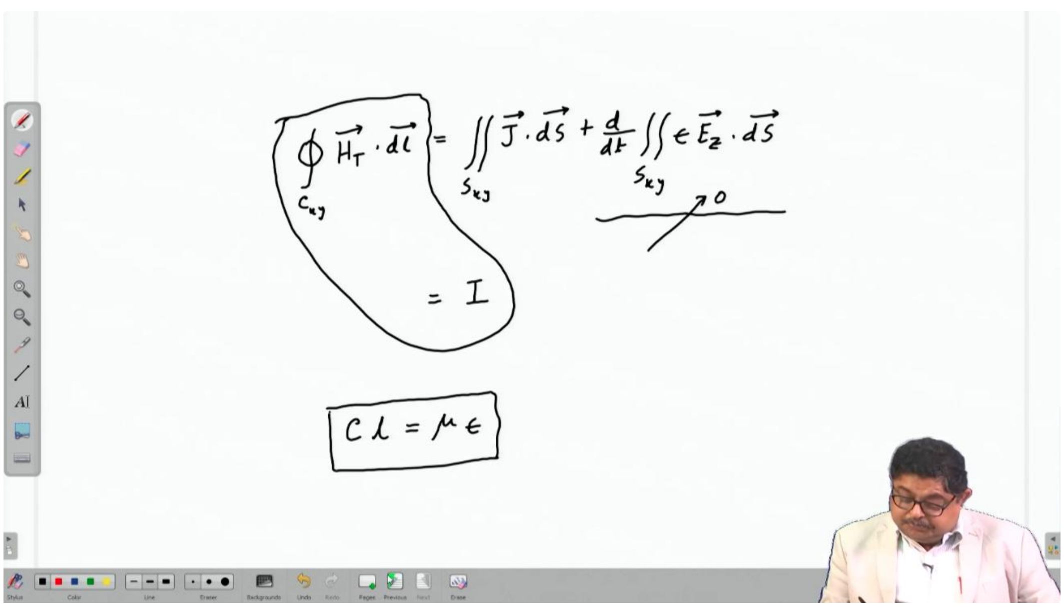
Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
Professor name: Prof. Amitabha Bhattacharya
Department name: Electronics and Electrical Communication Engineering
Institute name: IIT Kharagpur
Week :06
Lecture 26: Radiated Susceptibility Models

Welcome to the 26th lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. In previous lectures, we have seen the Radiated Emission Model, today we will start the Radiated Susceptibility Models. Now, susceptibility is a different ball game from emission, so we need to see some of the basics again, so for that we go to a two-wire transmission line, it is a two-wire transmission line, this probably some of you have studied extensively in your undergraduate, but I since in different universities, different emphasis is given on it, so I am you can say that this lecture is a refreshing one, so some of you may skip it, if you know all these things, but the results of these will be using that is why I am doing it. Now, this actually this should have been covered in electromagnetic theory, but as I said that due to heterogeneity in teaching material, I am again revisiting it because this is very much useful for developing our susceptibility model. Now, let us consider a two-wire transmission line, simply here we are considering the differential mode current and it is driven by a source with a source resistance RS and it is terminated by a load resistance RL and the transmission line axis is in the Z direction, so the X and Y plane is perpendicular to the or transverse to the transmission line. All the structural information about this transmission line such as what type of conductor you are using, what is the wire radius, what is the wire separation, what is the medium intervening medium that all these information actually distinguishes one line from another and they are embodied in the characteristic impedance of the line.

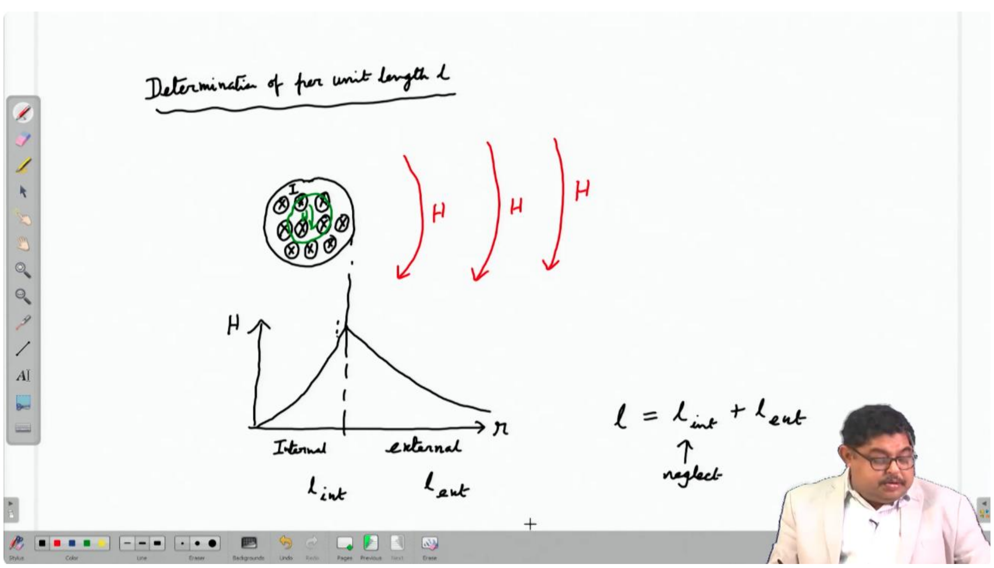
Now, characteristic impedance of a line is made up of various per unit length parameters, actually transmission line is considered to be a distributed line instead of a lumped line, so the in case of lumped elements we know the what is the RLC etcetera of the line, in case of distributed lines we know the per unit length parameters, so actually we should know RLGC the resistance per unit length, the inductance per unit length, the conductance per unit length and the capacitance per unit length, but here we are assuming a two-wire lossless transmission line, so R and G we are not considering now, so that means we want to know L and C but per unit length parameters that means per unit length inductance and per unit length capacitance of the line. So, for solving a particular problem at hand of that means for solving radiated susceptibility problems we need to know the L and C of the line, we need to determine that so from its given structure so that will do now. So, you know that mode of propagation in a transmission line which is not possible in other type of lines or waveguides that is TEM, in transmission line other modes also propagate TEM they can propagate but the basic feature of the transmission line is it passes a TEM line which almost you can say no other structure passes, so that is why transmission line we say that it passes TEM mode and you see we have chosen the Z axis. So, now in the transverse plane that means XY plane we can again use the Faraday's law that means our open surface will be now at XY plane in the transverse plane of the transmission line and there we can write the Maxwell's equation which is known as also Faraday's law, so it is line integral of electric field, so that I can write like this that it is closed contour C XY ET dot DL is equal to minus d dt of this is a open surfaces but it is in a XY plane, so I am calling it mu B I am assuming that the intervening matter is a simple matter, so instead of writing BT D S B transverse D S I am writing mu H and I know that this H will be in Z direction because you see that this ET and mu HZ dot DS. Now, why I have taken HZ because this my surface is in XY plane now the magnetic field should penetrate that surface so only HZ field can penetrate that or come out from that so HZ but for a TM this HZ should be 0 so that means for two wire transmission line I can say that this is nothing but 0. Now, that you see so if you see this part now ET dot DL is equal to 0 that means line integral of electric field is 0 this is like electrostatics in electrostatics we say that but our field is now time harmonic because we have a VST which is changing with time but for two wire transmission line we have this so we can now even though our field is time harmonic or AC field we can attach voltage and current at each plane at each point along the line that means we will have VZ ,V as a function of Z and I as a function of Z. So, we can define uniquely voltage between the two conductors this means that we can compute the per unit length capacitance because there will be a capacitance between the two because if there is any gap between the two conductors that will give rise to capacitance. So, that capacitance per unit length capacitance we can instead of going again to Maxwell's equation we can simply solve by Laplace s equation in two dimension because you see only we have x y dimension now in the transverse plane. So, Laplace s equation which all of you know that will help us to find the capacitance.



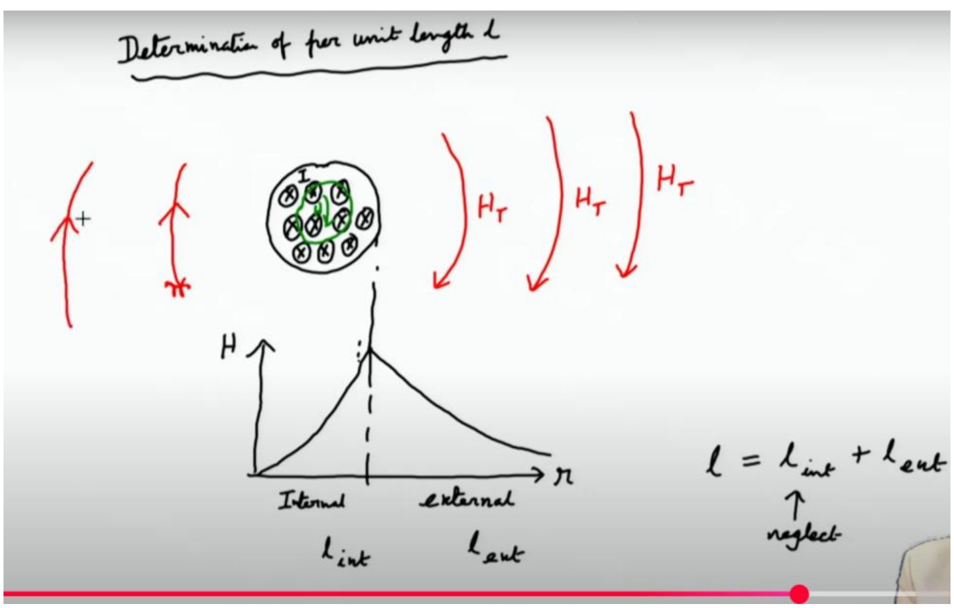
Similarly, if we write the other law the Ampere's law of Maxwell's equation. So, this is equal to s x y s x y epsilon E Z dot ds you see this is the equation now again TM mode means this part this displacement current intensity. So, this surface integral that is going to 0. So, we are left with J and what is J that means which is coming from the x y surface or transverse surface. So, if we integrate that we can get I. So, our equation is now this this is again the static case magneto static case that h t dot dl is equal to I. So, we can now say that uniquely we can define a current flowing in each conductor even though the fields are time harmonic. So, with that with our knowledge of magneto statics we can compute the per unit length inductance L. Now, also it can be shown we are not going there that if the medium surrounding the two conductors are homogeneous means that epsilon and mu are same everywhere then this per unit length C and per unit length L their product is a constant and that is given by mu into epsilon actually you know mu into epsilon if the product is or it is actually reciprocal of the velocity of the electromagnetic wave. So, this is an important relation and it shows that if we know mu and epsilon then determination of both the per unit length parameters are not necessary if I know C I can find L or if I know L I can find C, but you should know how to find out C and L because in some cases finding L becomes easier in some cases finding C becomes easier. So, in our learning in this class we will see both the methods that how to find C of a two conductor line or any basic thing and any basic line similarly how to find L of a basic line in actual case when you develop the expertise you can easily find out which one is easier.

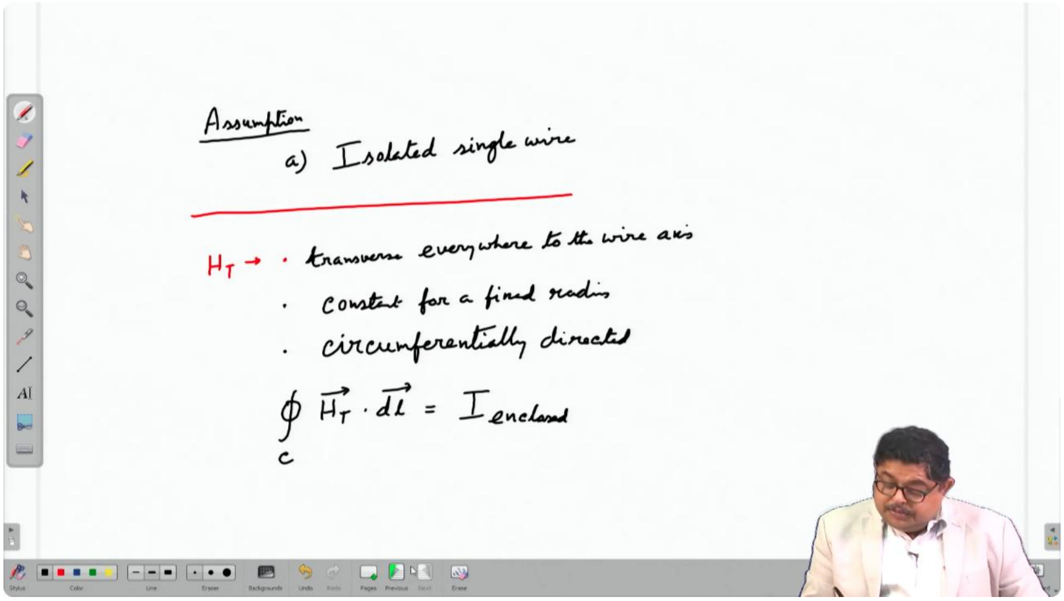


So, determination of one is only necessary with that let us start the determination of per unit length L. So, consider the cross section of a single current carrying wire that means this is the XY plane and conduction current is flowing through it. So, I am saying that there are throughout the surface this current is flowing that is why I am drawing so many crosses and so this is our I it is flowing through the whole conductor cross section. So, you can apply right hand rule and find out what is the magnetic field it will produce you simply point your thumb inside in the direction of the current for your right hand the fingers that will show the direction of H. So, I can say that H will be like this it will go on diminishing as you go away from the current, but its direction I am showing so I am not showing actually I should have shown that there are more number of such lines nearby and as it goes further there are less number of lines that means intensity is falling, but since I am concerned with the distance the direction here I am seeing this. Now also inside the conductor if you see a cross section and suppose you find out a surface like this so some of the currents it is also enclosing so there is some magnetic field also there just at the center there is no enclosed current so there is no magnetic field, but whenever you are moving from the center to any outside inside the conductor you are having the magnetic field and I can show that this will also give rise to some magnetic field here. So, I can say that there is an internal magnetic field there is an external magnetic field. Now if you apply that Faraday's law you can find that this so that it will increase like this then it will fall away as we have seen that in far field the magnetic field also goes away so this is H versus R so this is your this is internal field this is external. So, you know any magnetic field is associated with an inductance so this internal magnetic field will give rise to L internal this external one will give rise to L external the total will be L internal plus L external, but generally this people have found that this L internal is very insignificant compared to L external so that is why the generally we neglect this where this part we generally neglect.

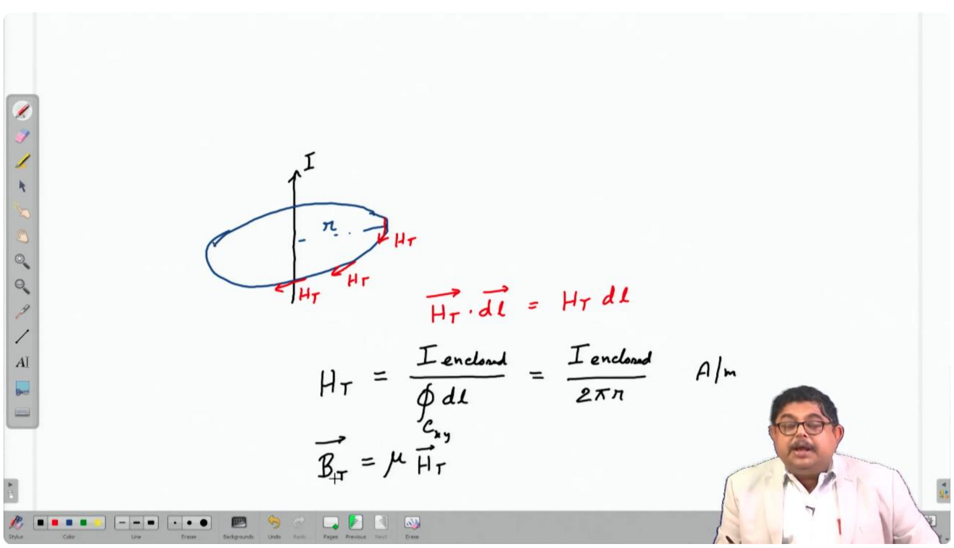


Now, to derive the per unit length L we make some assumptions obviously without assumptions we cannot proceed so we are making assumption. The first assumption is that our single wire is isolated, isolated means in the whole universe there is no other current here no other current carrying wire isolated why we are saying that because this magnetic field will distort if I bring another current carrying wire because you know there are poles not pole and south pole created by these so they will now get changed if I bring another current carrying wire and this field structure as I have shown they will distort so that is called proximity effect actually in two wire line that proximity effect is there but here we are neglecting that so our result is definitely simplified one in actual practice it needs to be some higher order model should come but our model is applicable for many many applications so this model that will develop is valid. Now, let us go that with this assumption we know that since our current distribution is symmetric so our H will also be symmetric and we can see that HT this H is transverse field so we can call it HT because it is in the transverse plane this is there so this is with this assumption we can say HT is transverse everywhere to the wire axis wire axis is Z now this H is transverse everywhere also constant for a fixed radius what does it mean you see at this point it is HT similarly at the same distance here same HT will be there sorry the direction will be in this direction so same HT similarly at this point whatever is there same HT will be there so I can write this thing that constant for a fixed radius then it is circumferentially directed that means it is if you assume this that it is circumferentially directed according to right hand rule circumferentially directed so we can what is the meaning of all this that





so with this property of HT what we will now do we will choose suppose I have a wire here so I will choose a circular contour at a this is a circular contour at a radius R from the wire this is my I axis this is my hypothetical contour a closed contour so here HT will be like this HT HT is everywhere tangent to the wire that we have already seen circumferentially means this and what will be our DL vector that is also along this circumference that means HT dot DL becomes simply HT DL so and also we have proved that HT is same everywhere so can I write now that HT from that relation HT is equal to I enclosed by DL by 2 pi R and what is the unit of HT ampere per meter. And its direction is circumferential HT I have got so this will generate a flux density B so what will be B? B will be also like this so there will be a BT same direction with HT for simple matters and it will be given by mu HT now we know this is flux density vector but we will have to go to flux to get inductance that you know.



so we need to find out the total magnetic flux penetrating a surface S of unit length along the wire direction that means draw this so we have found what is flux density vector everywhere but what is the flux that suppose I have a wire like this and then I have let me take some color that I have a surface cylindrical surface like this and what else color in that suppose from here to here what is the flux that has come transverse to the wire that means this in this portion how much flux is produced by that flux density vector. So let us say that the current is flowing like this so that means here I will show that current is like this this is the top of the top of the surface this cylindrical surface I am showing side actually it has a top it has a bottom because this one this yellow one also if I show it will also have a bottom so bottom surface top surface and this cylindrical portion so that means I can say that from these my actual problem is if I have a radius r1 and if I have a radius r2 then what is the flux that is linked in this green closed green surface open surface whose the surface is one end or the minimum distance is r1 and maximum distance is r2 how much flux get linked with that because that will give me the external inductance thing. So now I have come to my problem that actually I am trying to find out mathematically that this is this is an open surface bt dot ds I am trying to find that now this surface has three parts one is top one is bottom one is the cylindrical part so I can break it into three parts that one is cylindrical side there this bt dot ds plus top bt dot ds plus bottom bt dot ds plus bottom dot ds so what is ds at top ds at top is pointing up and bt is circumferential we have proved that bt is circumferential so they are can I say that they are perpendicular to each other so bt dot ds so two vectors they are perpendicular so I can easily say that this will go to 0. Similarly at the bottom the ds is in the opposite to the current direction and bt is circumferential so they are also orthogonal to each other so that will also go there so we are left with only this part cylindrical portion that we will have to evaluate this discussion will continue in the next class. Thank you.