Electromagnetic compatibility, EMC
Professor Rajeev Thottappillil
KTH Royal Institute of Technology
Module 5.5 Solution to EMC Problems
Shielded Cables

Solution to EMC problems in module 5.5 we will look into the problem of shielded cables, previously you have seen shielded cables as a perfect shielded cable, now in this module we will look at the real shielded cables in which there are some leakage of electromagnetic fields and will try to quantify this leakage in terms of models.

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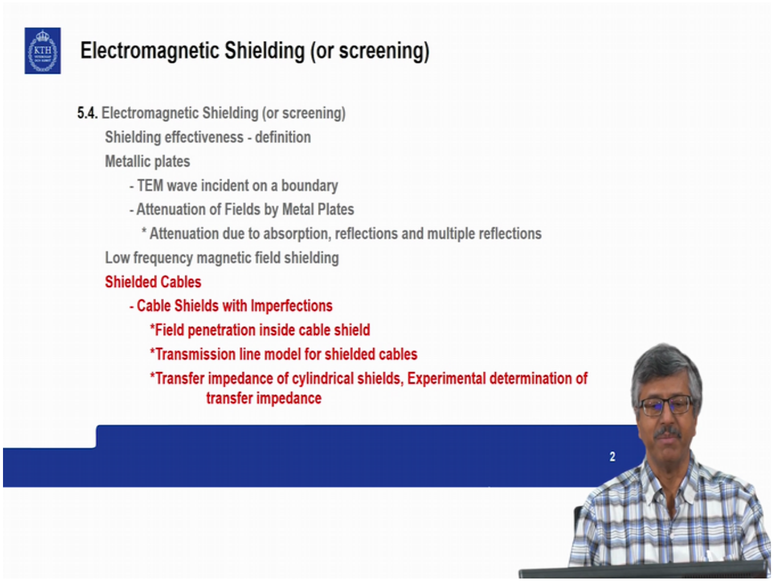

This are the main condense, cable shields within perfections, what are the different kinds of imperfections there and we will develop a transmission line model for shielded cables and introduce the concept of transfer impedance for cylindrical shields and experimental determination of transfer impedance.

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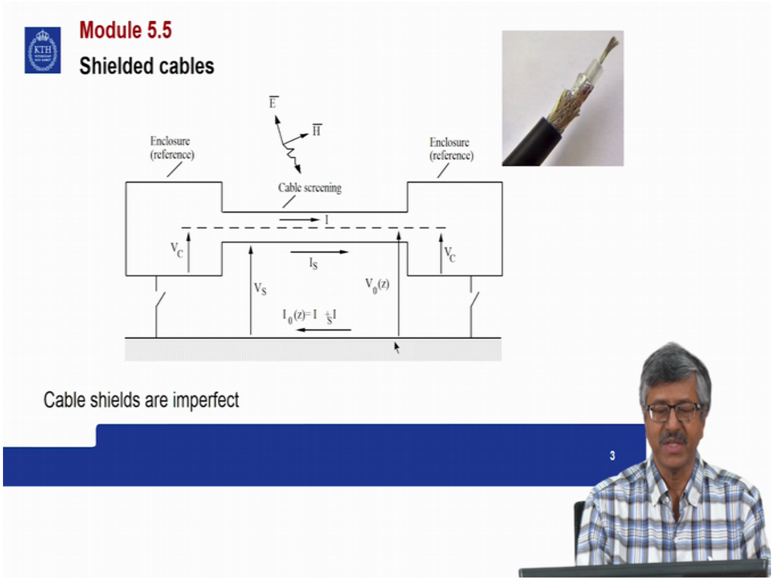

Now consider this picture of the shielded cable, so you can find the shield which is in the form of a braid and you have insulation and also one more shield over here which is more like a solid shield and the inner conductor, so this is one example of shielded cable, then suppose there are two entities that are connected by cable screening, now the inner conductor is stored in the dotted line and if there are no sources connected anywhere ideally you will find this VC at both ends that is between inner conductor and the shield.

The shield is connected to the cabinet over here on both sides, so this voltage has to be zero even when there is an illumination of electromagnetic fields on this cable because there is no leakage but real cables like this will have some leakage and due to this leakage you will find some voltage at both ends and this voltage will try to determine, we will try to model, now if both ends are connected to a ground than it drives certain current along the ground, so the current on the cable shield is here IS.

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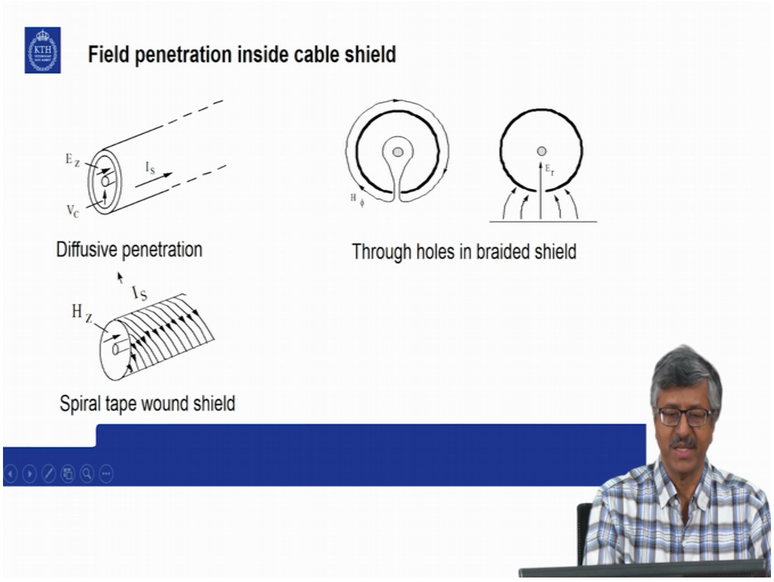

Now let us look at what are the imperfections in the cable shield, first of all from skin effect you have seen that if there is a current on the shield or diffusively it will penetrate to the inside, the skin effect will confine most of the currents to the outside but still there will be some current penetrating to the inside, so this is called the diffusive penetration, we have seen this already in the case of metals, then often the shield is in the form of braid weaved wires for the sake of flexibility and through the holes of the braid you can have filled penetration.

So here is an example of magnetic field penetration to inner conductor from our side is shown and here a case of electric field penetration is shown, so through holes in braided shield and sometimes the shield is in the form of tape that is spiralling around it, so which will the currents on it will be having a spiralling track because of that and this will create unbalanced magnetic field inside and this unbalanced magnetic field can create a current in the inner conductor, so this is the special case for the spiral wound tape on shield, so in all this three shields whether it is solid, braided or spiral wound you will have diffusive penetration.

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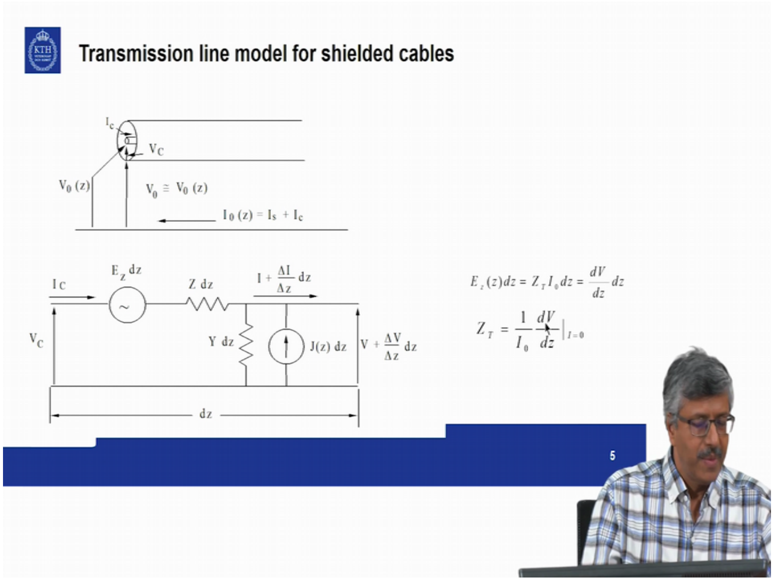

Now how do we develop or transmission line model for shielded cables, so imagine our shielded conductor, so what we are interested in is in response to flow of a current on the cable shield what will be the voltage developed across the inner conductor and the shield, so this is one you wanted to determine, intuitively we know that as we go, as the length of the cable is increasing or as a distance travel is increasing more and more voltage will be appearing here.

So let us try to develop a model for it, so this is the basic transmission line model where you have a series impedance and you have an admittance also, so you have certain currents IC and you have certain voltage imposed here are appearing over here let us say and this voltage is V plus delta V by delta C, now we define our impedance which is called the transfer impedance in such a way that it should be a measure of voltage appearing, the differential mode voltage appearing between the inner conductor and the shield, per ampere of the current along the shield and for distance travelled.

So it means that this transfer impedancity is per metre, ohms per metre unit will be, that you can see it from here, so transfer impendency is defined as DV by I0 DC or this source that that we correct to represent this transfer impedance is ZT I0 DZ, so transfer impedance is multiplied by the shield current, so I0 is the shield current not this inner current, ZT I0 DZ equal to DV by DZ into DZ that is this part.

So this is the voltage drop over here and this is the difference in this, so if we say this is according to the condition that IC equal to 0 only when that condition is that you can write like that, so assume that there is no current through the inner conductor and we have only the action of this VC, so it is open circuited, then you can define this, so I equal to 0, so I have made some inconsistency in the notation here, so please ignore that, so here it is IC and here it is I equal to 0 like that but from the context you may know what it is.

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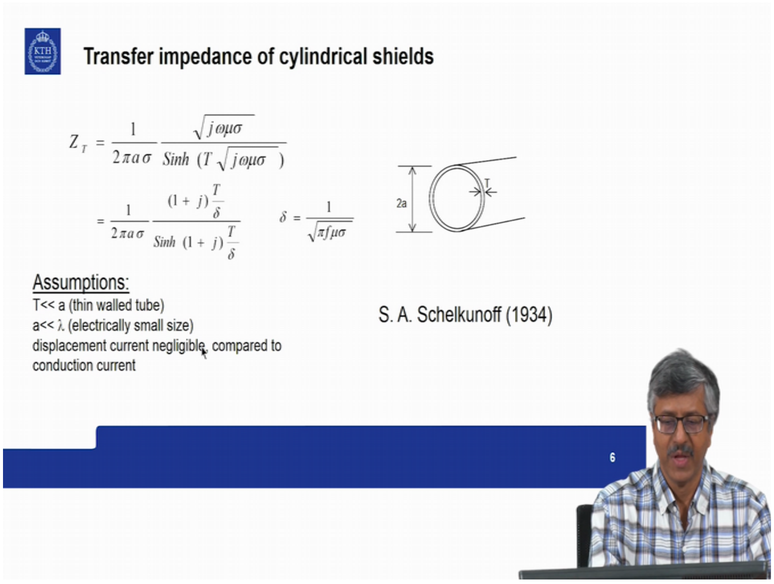

The transfer impedance of cylindrical shields, so there you can from electromagnetics you can derive analytical expression for transfer impedance and this is been done as early as 1934 by the scientist Schelkunoff in his famous book, so he has given this expression for the transfer impedance of cylindrical tube, if the thickness of the tube is very small compare to the diameter of the tube.

So that is given as 1 x 2 pie A, A is the radius of the tube, sigma conductivity and square root of J omega mu sigma hereby sign hyperbolic T thickness and square root, so that can be simplified like this where delta is the skin depth 1 by square root of pie F mu sigma, so let us have this assumption, first is T far less than A and A the size is electrically small, far less than lambda and also we neglect the displacement current compared to the conduction current that assumption also we are making, displacement that is in amperes law you have a displacement current and so that time is neglected, so then it becomes like a diffusive type of questions in heat transfer.

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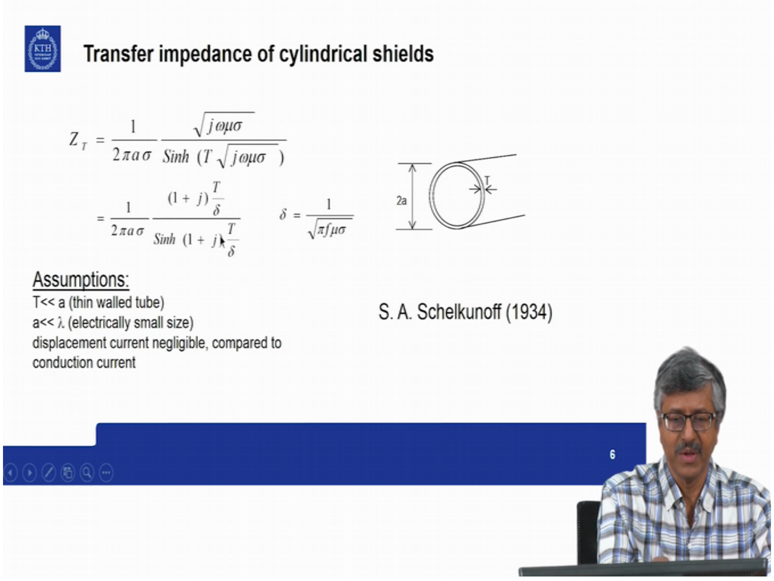

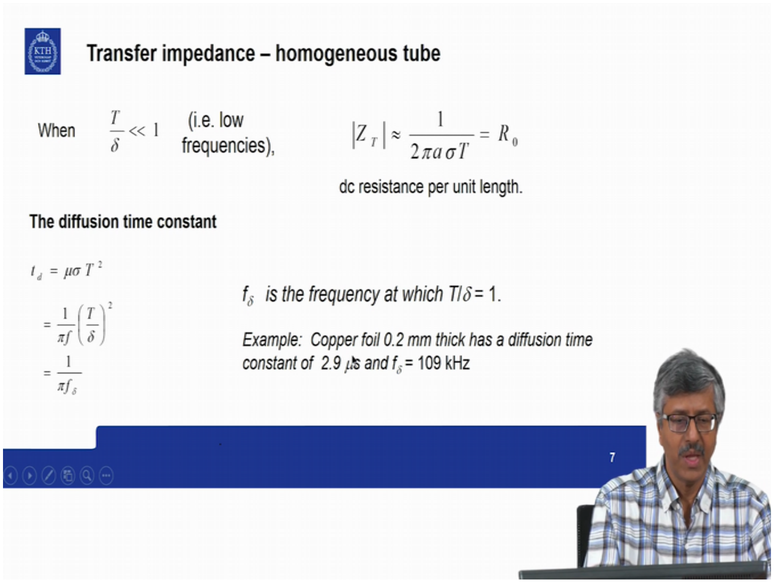

Transfer impedance of a homogeneous tube, when T by delta is far less than 1 that is at low frequencies, that is delta is much higher than T, so you have almost uniform current across the shield, so the current is penetrating across the shield, so that is low frequencies in that case, if you substitute in this one you will see that transfer impedance is nothing but 1 by 2 pie A sigma T, T is the thickness, so which is the DC resistance per unit length, so many ohms per metre you will get, so transfer impedance is nothing but the DC resistance at very low frequencies.

Let us find the diffusion time constant, so that diffusion time constant is mu sigma T-square, T is the thickness, so you can write it as 1 by pie F T by delta by introducing delta and 1 by pie F delta, so you are defining a frequency F delta here and T by delta can be any value in this case, so this is only for applicable over here, so this frequency is when F delta at which T by delta equal to 1.

So when the skin depth is equal to T you can say it is equal to 1, then you can find diffusion time constant for any T, for example copper foil of 0.2 mm thick has a diffusion time constant of 2.9 µs, if you put in 0.2 mm here conductivity of copper and mu over here you will get a the diffusion time constant as 2.9 µs and you can calculate when T by delta will be 1 and that will be 109 kHz.

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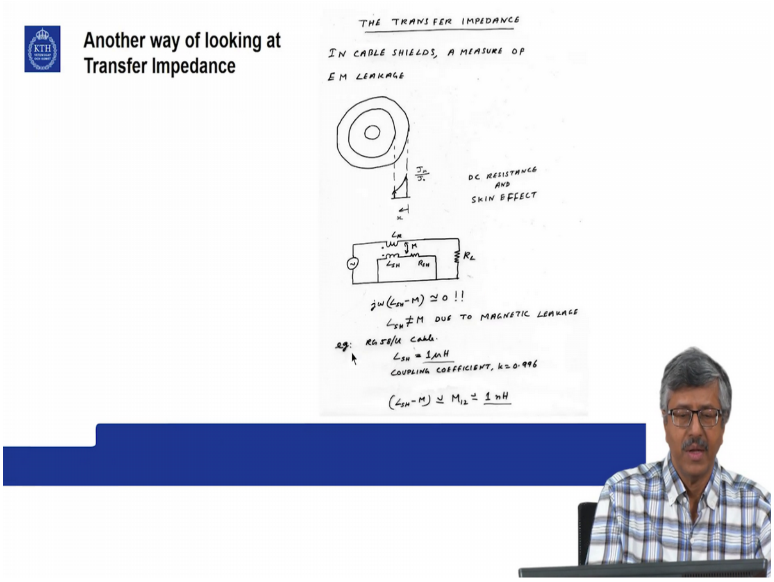

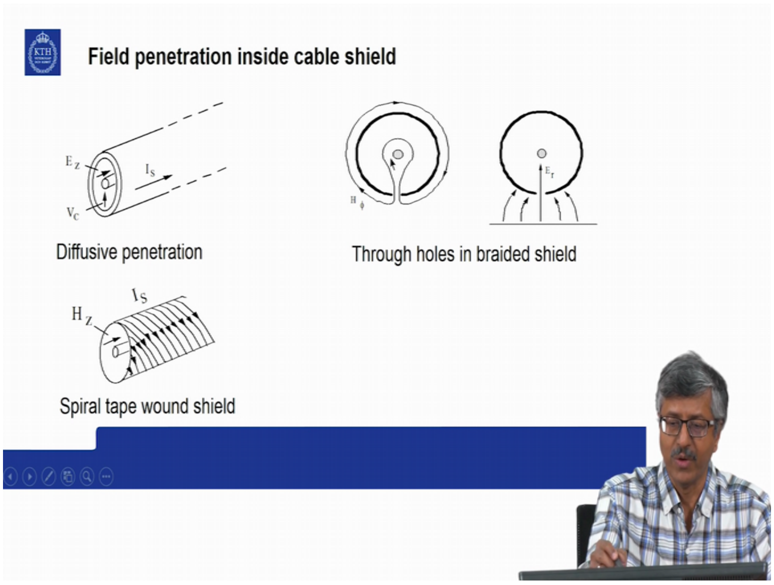

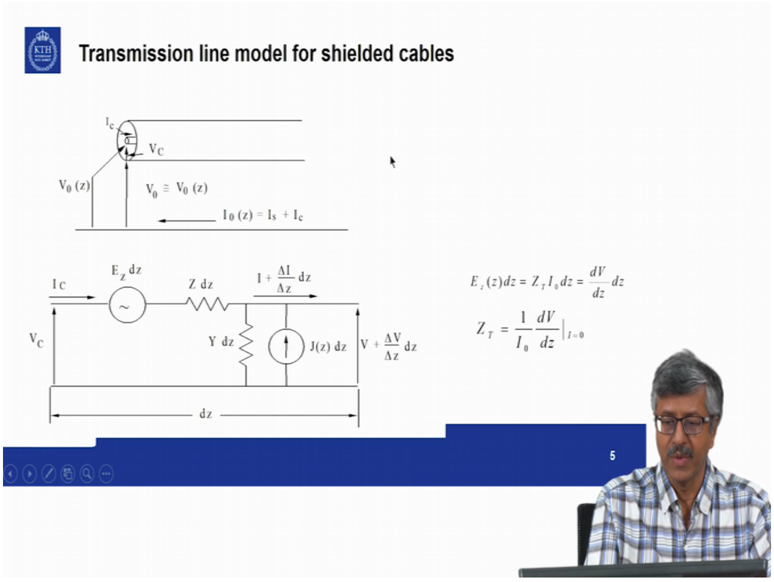

Another way of looking transfer impedance, in cable shields it is a measure of electromagnetic leakage, so as I said before the fields are leaking from the outside to the inside, so this is the current density, so let us have this equivalent circuit for the shield which you have seen before, this is the inner conductor and this is the shield, shield has got shield resistance and shield inductance, we have seen that there is a mutual inductance previously we called it as LRS or so something.

So that is mutual inductance between receptor and the shield and previously we assume that they are almost equal to 0 in reality it will not be zero, there will be a slight mismatch between mutual inductance and self-inductance of the shield and that mismatch is the one causing the leakage, say for example inductively leakage into it, for example the difference between those two inductance may be altogether M12 or 1 nanohenry for a coupling coefficient of 0.996.

So this is very small compared to the self-inductance of 1 microhenry, thousand times smaller but this is enough to have induced M of inside, so this is the mechanism of leakage that is depicted over here, the first one is diffusive penetration just we saw this mechanism how through holes, so it is this hole that is giving this leakage inductance.

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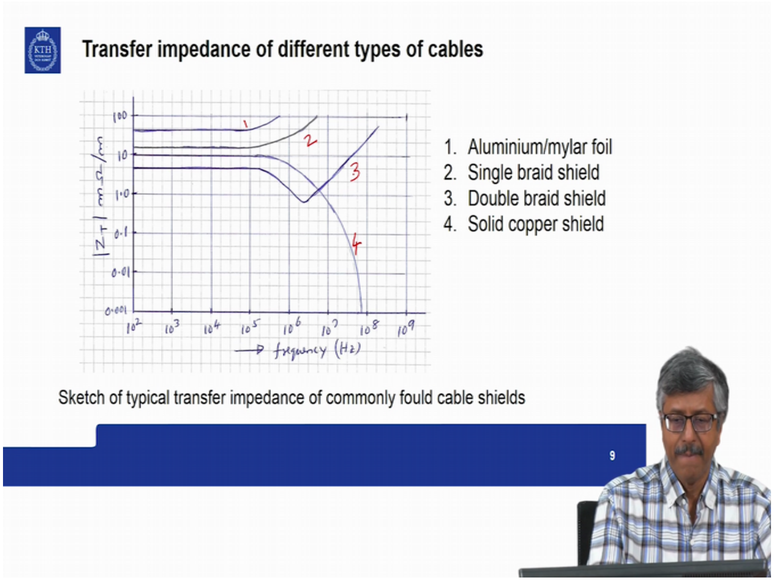

So transfer impedance in different types of cables we can write, we can calculate those transfer impedance so these are some typical calculations using the realistic properties, so this is the kind of sketch of it, for example one is aluminium mylar foil, so let us start with solid copper shield with this one the number is missing over here, I will write it here, so this is number four solid copper shield, so there are no holes, so no penetration of magnetic field.

So at low frequencies it is like DC resistance than as a frequency is increased, you know less and less field penetrate to the inside, so the transfer impedance goes down than double braid shield, so that will be like this number three and single braid shield will be this two and aluminium mylar foil will be one, so here in aluminium mylar foil you have a gap in this because they are not really solid shields, so that gap you will be having leakage, so this is the inductive part of the leakage and this is the low frequency part, this is the high-frequency part.

So the high-frequency part changes with 20 DB per decade and in the double braid shield initially it comes down due to be diffusive part then after that the inductive part takeover and you have it increasing upward.

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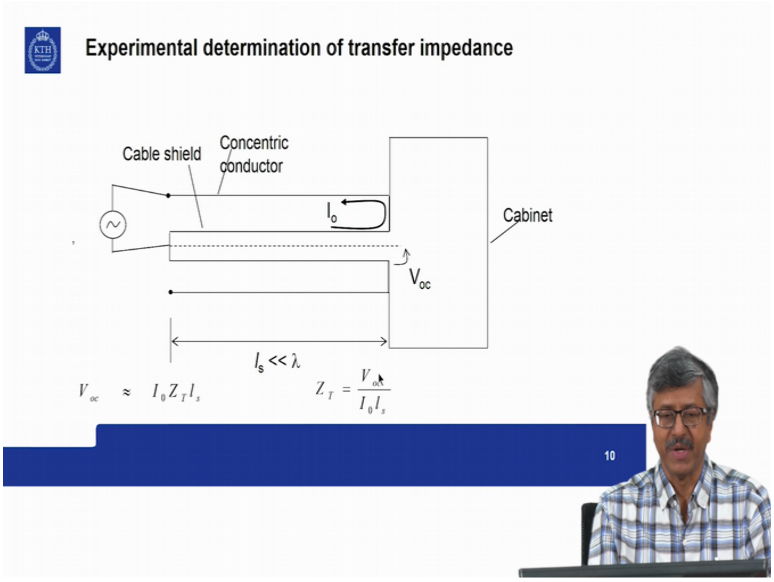

So experimentally the transfer impedance of cables can be determined, this is kind of a setup that could be used, say for example if you have a shield, this is the shield and put that shield into a tube, the concentric tube and those are connected to a cabinet and inside the cabinet you have oscilloscope and you can measure this differentiate mould voltage and one end of the shield and the inner wire are connected together and you are injecting a current to this shorter combination and that is I0.

So basically you are circulating a current along the shield, so this is the cross-section what is been shown, now I assume that the length of the tube is far less than your wavelength, so this is electrically short then since it is short over here the voltage between inner conductor and the shield is 0 but if you measure it over here you will find a voltage and this voltage is only due to the action of the current and the penetration of electric and magnetic fields into the shield, that is the measure of that.

So V0 open circuit this defined as this current times transfer impedance times the length of the tube or transfer impedance is defined as this measure voltage divided by the current times length, so in this way you can find the transfer impedance.

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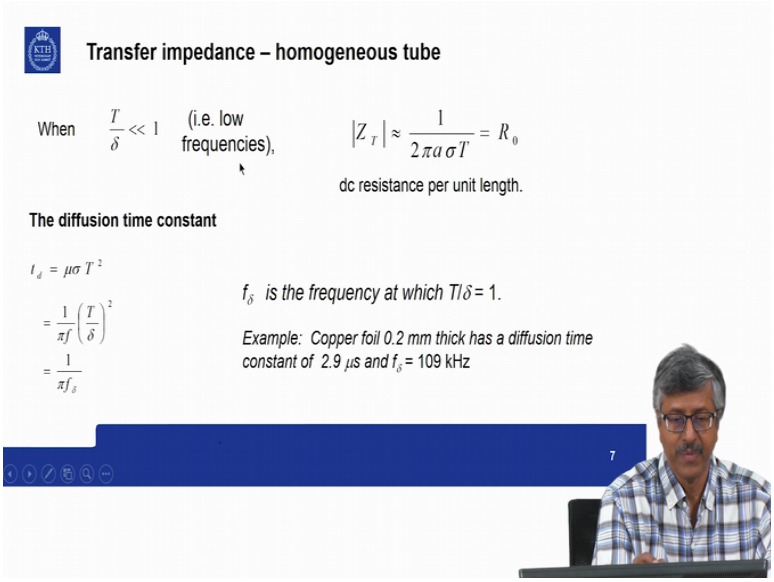

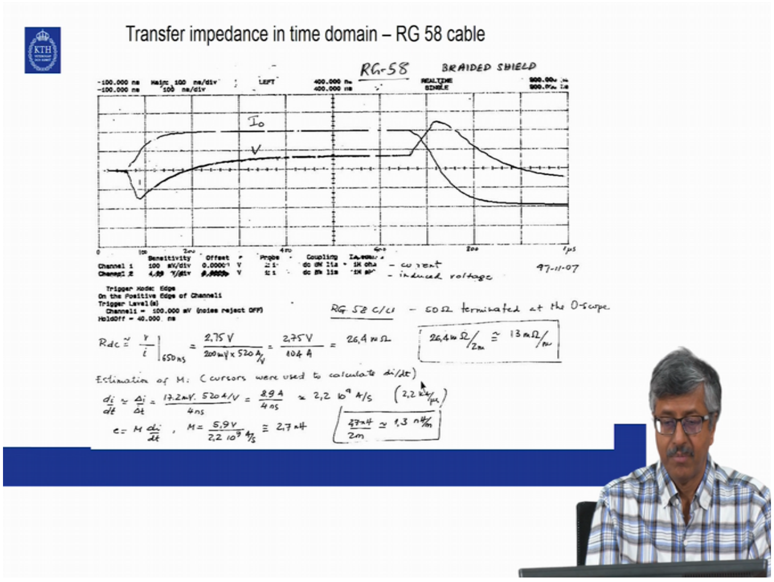

Now what is shown here is an oslogram of transfer impedance in time domain of an RG 58 cable, so down here you can find the time division this is 1 μs, so each one is 100 ns and here it is in terms of voltages or a current this scale, so the current through the shield injected using the setup that you have seen previously is given by I0, so you forget about these half of it because that is because of the reflections and other things, so you do not have to considered that part.

So consider only the first half of the graph, so I0 is rising within a few nanoseconds to a steady value and that value is about 120 ampere per division, so here the rise time is several nanosecond and you can see the voltage, this voltage is what you measure, the opposite circuit voltage in this and that voltage you can see is peaking when the current is having maximum derivatives almost.

So that is very characteristic of inductive kind of a coupling, then it goes down and take a long time and before that voltage reaches a steady value, so this time taken by the voltage to rise all this way kind of representing the diffusive time constant that you have seen over here, diffusive time constant TD, so this current applied is 104 amperes and the corresponding voltage, the peak, the steady voltage that you find is around 2.75 V, so that gives 26.4 m ohms and the tube used in this experiment was 2 m.

So you get the DC resistance of the shielded cable as 13 m ohms per metre, now for this peak DI by DT you can approximately calculate as 2.2 into 10 to the power 9 amperes per second and if we invoked E equal to M DI by DT or M is, this is peak voltage is 5.9 V divided by DI by DT, that will give you 2.7 nanohenry and per metre gives you 1.3 nanohenry per metre, so this is the leakage inductance, so we have found the DC resistance of the cable and leakage inductance of this experiment, so transfer impedance is a combination of both.

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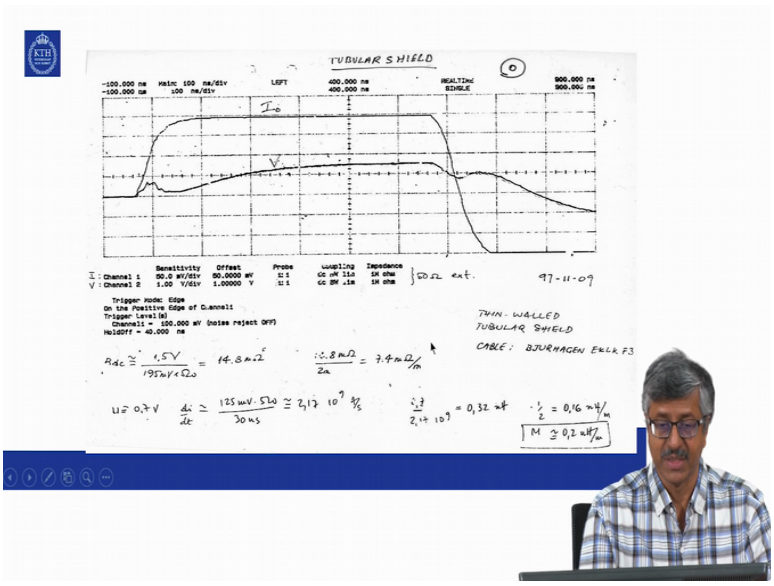

You can also have tubular shields like that, this is the another type of tube, another type of cable having a tubular shield used in insulation in wet areas, power line insulation wet areas, so this cable even though it is not intended as a shielded cable due to the fact that for keeping away moisture, you have aluminium foil, the solid shield it is a very good performance and this DC resistance is only 7.4 m ohms per metre and it does not have any holes, it is only a small gap at the adjust where the foil is folded over.

So the leakage inductance also is very small, it is 0.32 nF, so this shows the illustration of transfer impedance how to find both diffusive part as well as inductive part of the transfer impedance in shielded cables.