Electromagnetic compatibility, EMC
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Module 4.4
Crosstalk near Field Coupling
Electromagnetic coupling in the far-field

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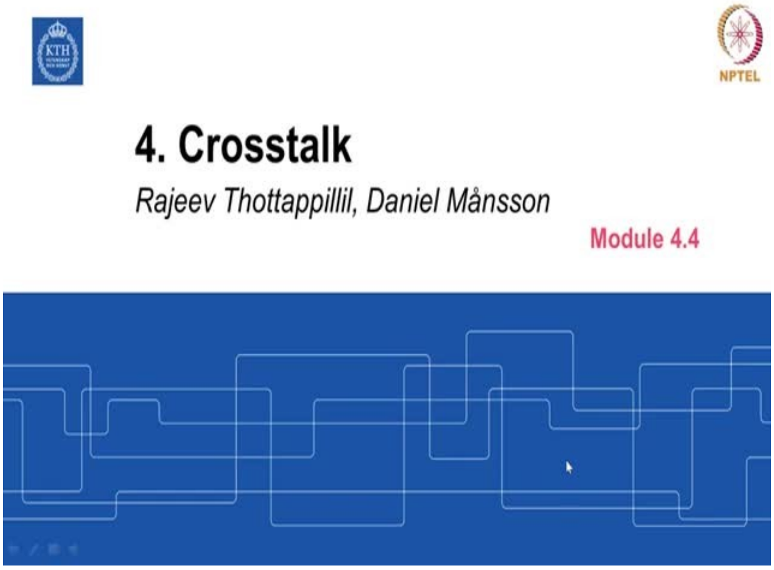

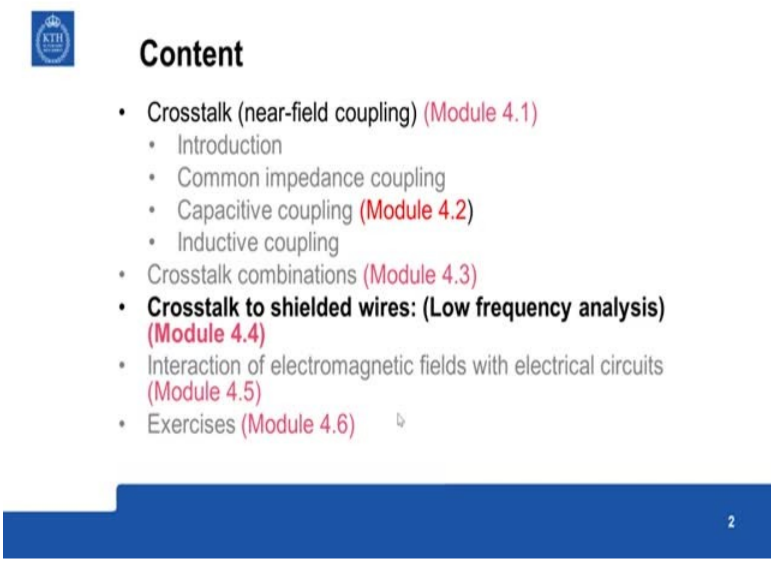

Crosstalk or near field coupling module 4.4, in this module we will investigate crosstalk to shielded wires, will be using low frequency analysis.

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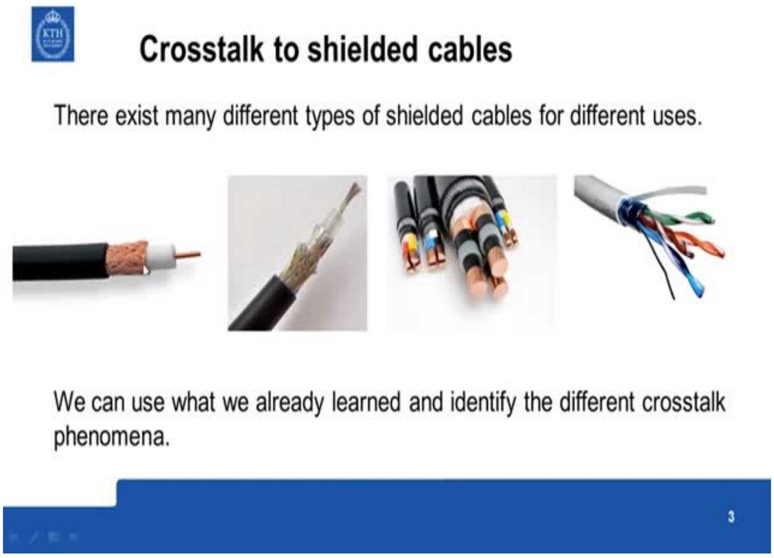

There are many different type of shielded cables that we use very commonly, they can be cigarette cables or power cables, the analyses presented here are applicable for all this cables, but however for simplicity we will be concentrating on single core shielded wire cable as shown here.

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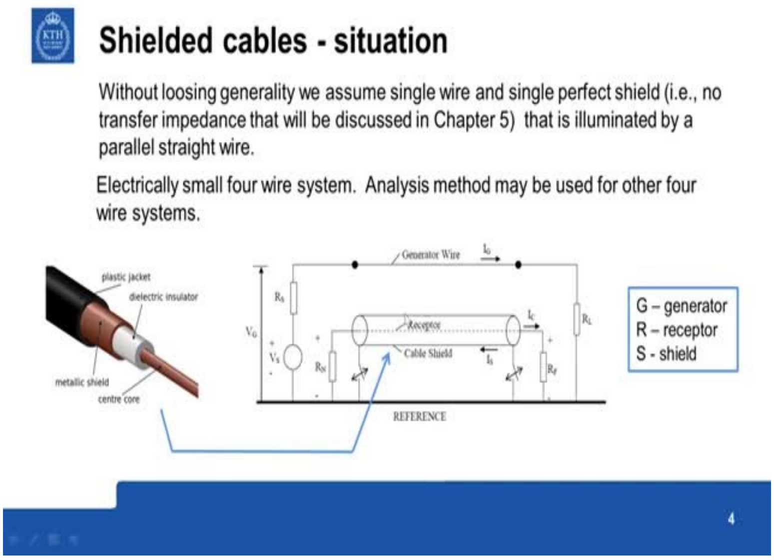

Now this is the generic situation that we will analyse, so this is a shielded cables, single core and that is represented over here, it is for the central core which we call as a Receptor wire and the cable shield and you can have a connection to the ground through a resistor at both ends, so this is the near end, where the source is also coming in generator wire, so generator wire is extended to the shielded cable, may be something parallel to this cable and the far end is away from this generator, resistor RF, say for the shield to work both ends the shield has to be connected, so in that case there can be a current also to the shield, then VG represent the voltage between the ground and the generator wire, so VS is the source voltage, so VG will be equivalent to like V12 that we have seen before, the voltage difference between the generator wire and the receptor wire.

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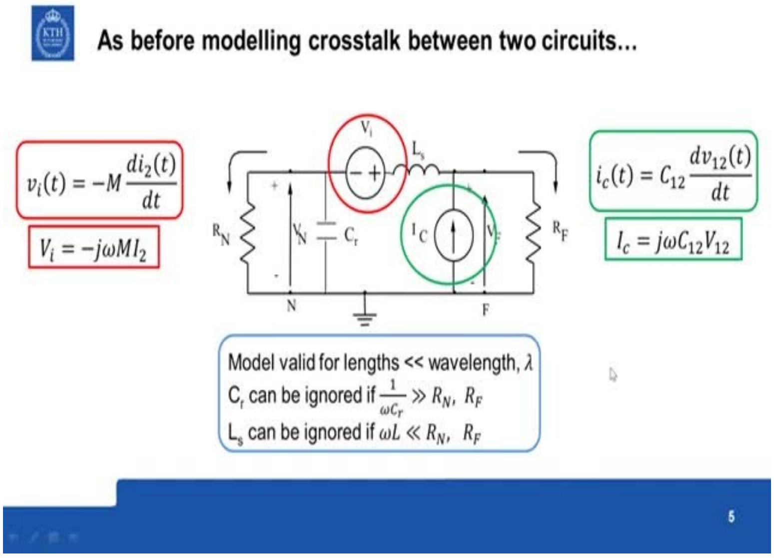

The generic models for inductive coupling and capacitive coupling we have seen before, so these principles will be using in this analysis and as before the inductive coupling is V equals minus M DI2 by DT and capacitive coupling source ICT is C12 DV2 by DT and similarly the parallel capacitors to ground can be neglected if this condition is true and the series inductive impedance can be ignore if this condition is true, all this are valid in this analysis also but there will be some more defecations for that due to the presence of the shield.

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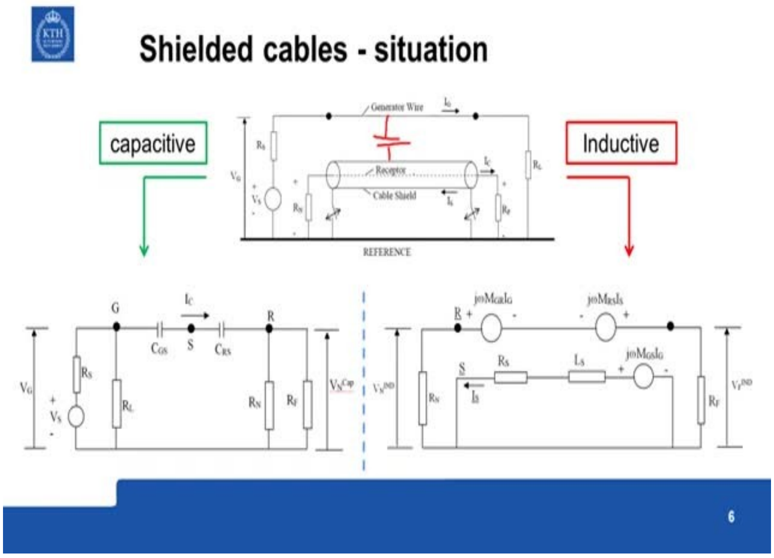

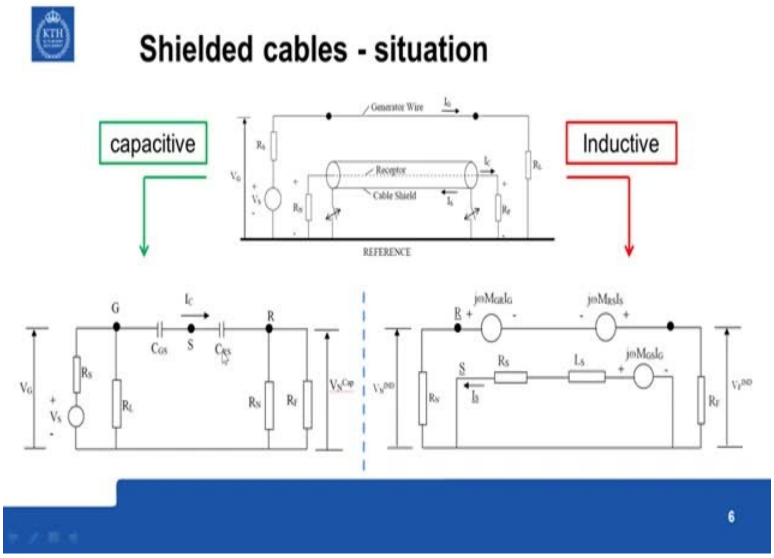

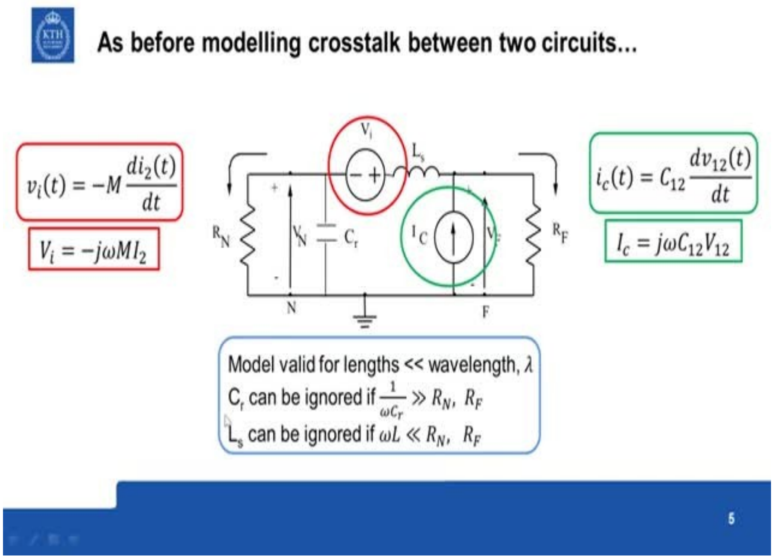

Now let us take this situation and find the equivalence circuit for analysis of capacitive crosstalk and equivalence circuit for the inductive crosstalk, so we have a capacitors between the generator wire and the receptor, so we can draw it like that, well it is not a very good trying but something like this and you have something similar between the receptor wire and the cable shield, so therefore here, so this part is this source circuit and CGS to the shield, so this is the shield point, then CRS between the receptor wire and the shield, so that is this capacitance, then this part is the receptor circuit RN and RF, so while drawing these now we assume that okay the shield is not connected to be more general, so if the shield is connected then of course you have connections directly like this and this is short-circuit and you eliminate the capacitive coupling, so this parallel combination of CGS and CRS is similar to this capacitive coupling, coupling capacitance C12, so there is the only difference in the model

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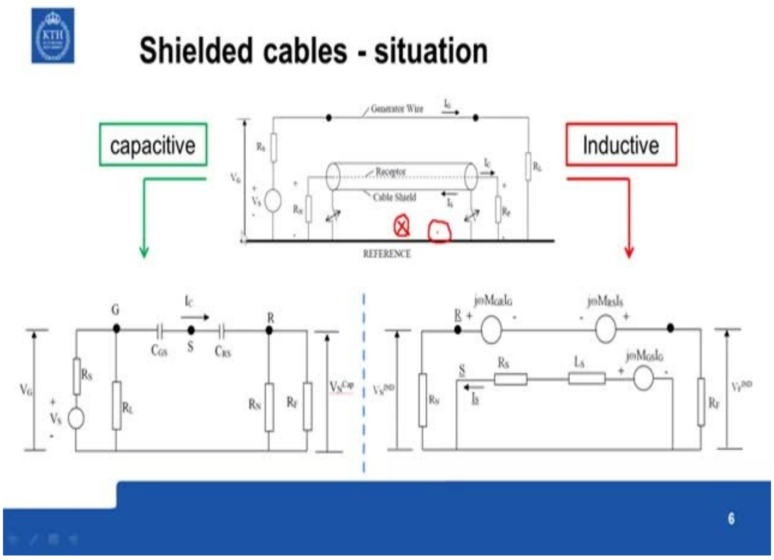

Now let us look at the model for the inductive coupling in the case of a shield, so this is much more complicated than before and instead of one circuit, one voltage source you will find that there are three voltage sources, that is the how it is coming, now take the current in this, so this current will create a flux linkage both with the receptors circuit as well as the cable shield and direction of Bose magnetic field you can represent is going into the paper, so something like this, now since this generator wire is further away and shielded cable, receptor and cable shield or so close to each other, basically it is same flux that is linking with both receptor circuit and shield circuit.

Now we assume that the shield is connected at both ends for the generic case, whereas here it is open for the generic case, now MGR is mutual inductance between the generator wire and the receptor wire, so that is the source J omega MGRIG, so this source is coming in the receptor circuit and it will drive a current in such a way that, it should create a flux opposing this, so that flux is coming out of the paper, so you will have a flux coming out of that paper like that only if the direction of the current is in this way, from here to here, so the polarity is like this, so this will drive current to oppose the original flux, so there is one source.

Now a similar source will be there in the shield circuit also, so you take the mutual inductance between the generator and the shield MGS, so it is this source, now since we do not have any deliberate resistance in the shield, so you cannot neglect the series resistance and the series inductance of the shield, self-inductance of the shield, it cannot be neglected because otherwise it is short-circuit, so that is, that need to be included in the shield circuit, so this will be your shield circuit with the source, now this source will be driving a current, shield current IS and this is fairly substantial current and this current will create, this current will couple, create a magnetic field that be coupled, coupling with the receptor circuit, now that, the polarity of that will be in such a way that, it will opposing this flux shown here.

So that is shown here, so it is J omega mutual inductance between the receptor and the shield, between the receptor in the shield times IS in the shield current, so you have two opposing sources in the receptor circuit and immediately you can see that, this opposing sources will reduce the general circulating current in the receptor circuit and that is how the shield is working introducing the noise voltages VN and VF, so in necessary condition for that is, this has to be connected at both ends and there has to be circulating current, so this gives the complete equivalence circuit for the inductive coupling.

Now we can do for the simplifications in this, say for example if you take the mutual inductance between the generator wire and the shield that will be approximately equal to between the generator wire and the receptor also, so MGR and MGS, so these two sources are almost identical and similarly MRS, mutual inductance between the receptor and the cable shield, since they share the same area that will be equal to the cable self-inductance LS, so MRS can be replace by this LS, so those simplifications we will see next.

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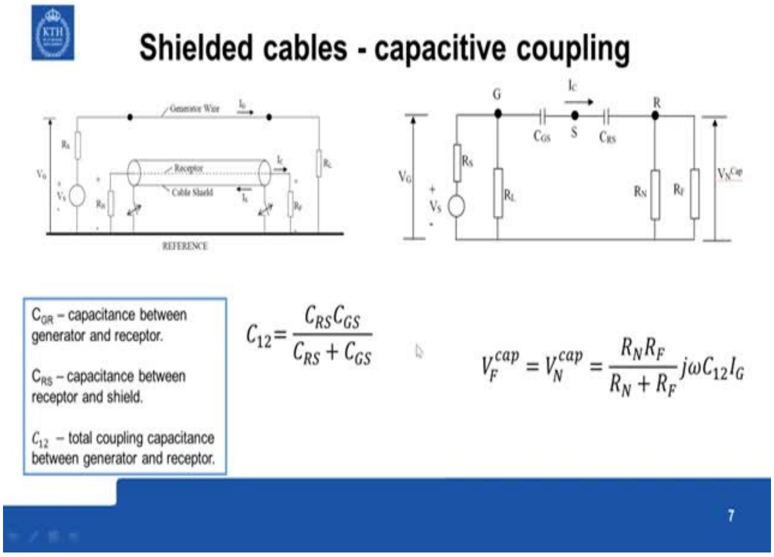

So first before that let us go further into the capacitive coupling, we have seen that a combination of these two is equivalent to C12 the coupling capacitors, in the absence that shield is not connected to the ground, so series capacitance is equivalent to, capacitance is like a parallel combination, then VF equals VN you can write it like this, where C12 is given by this, so total coupling capacitors between generator and receptor, now CRS between the receptor and shield, this is much larger capacitors than this one, so often we are able to neglect this and keep only this one CGS, so basically, then it will be as if there is no shield present, only CGS is present in the case, then they are not connected to the ground.

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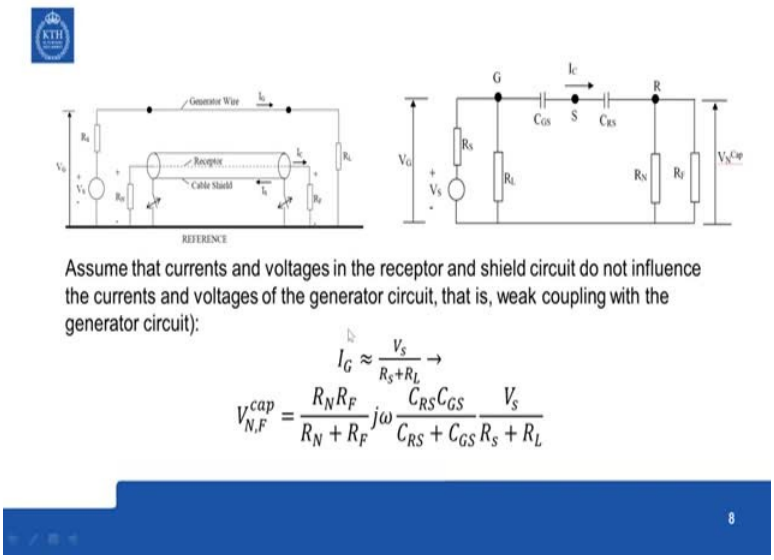

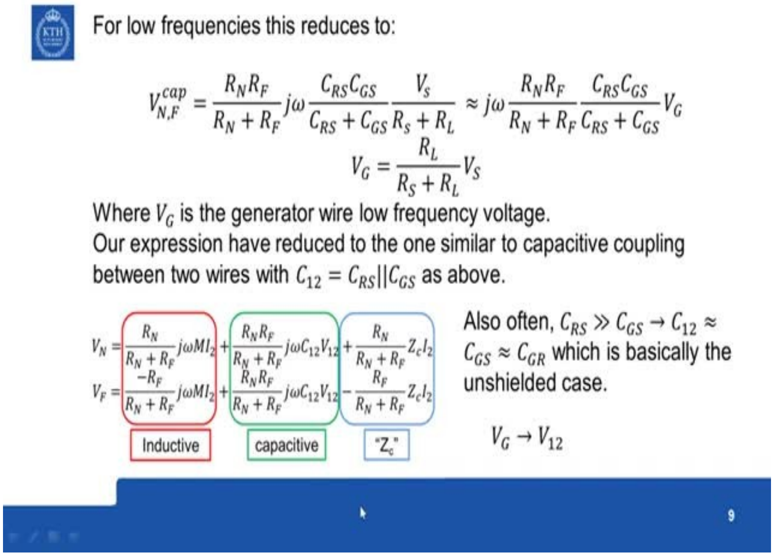

So the current in the generators circuit IG under the assumption of V coupling between them, we can write it as VS by RS plus RL, so substituting that in the previous expression we get this one, then you make simplifications VS, VG in terms of VG you find VG equal to RL by RS plus RL, VS so all VGs generator wire low-frequency voltage, now our expression has reduced to one similar to the capacitive coupling between the two wires, so VG in our case is similar to V12 in the previous case and C12 which is this one is approximately equal to CGS for CGR, so this RS can be neglected within that.

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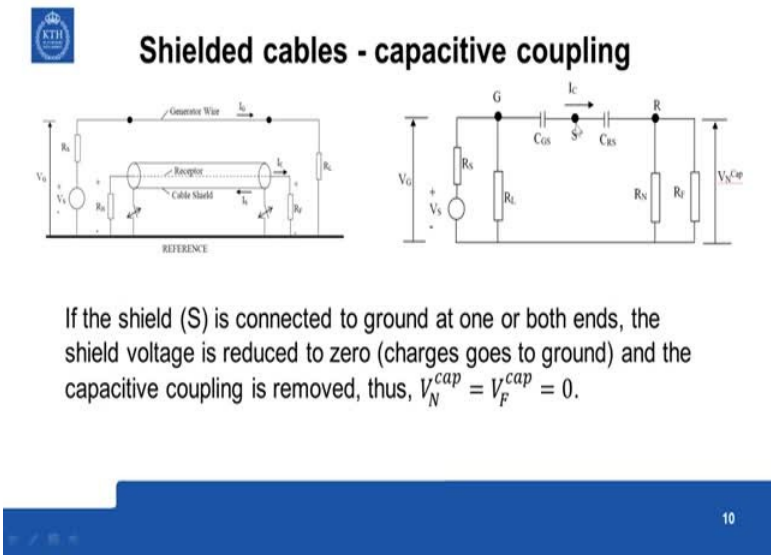
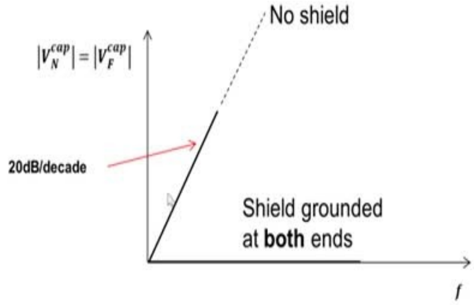
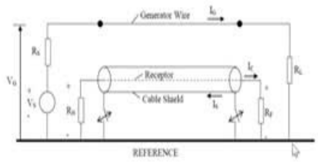
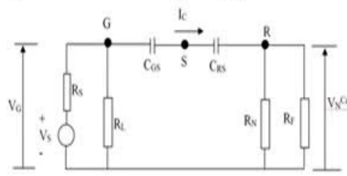


Shielded cable – grounding effect on $\left|V_{N,F}^{cap}\right|$



Shielded cables - capacitive coupling





If the shield (S) is connected to ground at one or both ends, the shield voltage is reduced to zero (charges goes to ground) and the capacitive coupling is removed, thus, $V_N^{cap} = V_F^{cap} = 0$.

For low frequencies this reduces to:

$$V_{N,F}^{cap} = \frac{R_N R_F}{R_N + R_F} j\omega \frac{C_{RS} C_{GS}}{C_{RS} + C_{GS}} \frac{V_s}{R_s + R_L} \approx j\omega \frac{R_N R_F}{R_N + R_F} \frac{C_{RS} C_{GS}}{C_{RS} + C_{GS}} V_G$$

$$V_G = \frac{R_L}{R_S + R_L} V_S$$

Where V_G is the generator wire low frequency voltage.
Our expression have reduced to the one similar to capacitive coupling between two wires with $C_{12} = C_{RS} || C_{GS}$ as above.

$$V_N = \frac{R_N}{R_N + R_F} j\omega M I_2 + \frac{R_N R_F}{R_N + R_F} j\omega C_{12} V_{12} + \frac{R_N}{R_N + R_F} Z_c I_2$$

$$V_F = \frac{-R_F}{R_N + R_F} j\omega M I_2 + \frac{R_N R_F}{R_N + R_F} j\omega C_{12} V_{12} - \frac{R_F}{R_N + R_F} Z_c I_2$$

Inductive | capacitive | "Z_c"

Also often, $C_{RS} \gg C_{GS} \rightarrow C_{12} \approx C_{GS} \approx C_{GR}$ which is basically the unshielded case.

$V_G \rightarrow V_{12}$

If the shield is connected then VN cap or the capacitive crosstalk will be zero as before, so this can be represented in this way so this is a plot of frequency versus the capacitive crosstalk and in the case of capacitive crosstalk VN crosstalk is always equal to the far end crosstalk respective the impedances that near end and far end, so when the shield is not connected to the ground even at one end, then we have this expression, so you can see that it is changing the J omega, so it is 20 DB decade change, so this is shield not connected to the ground or which is equivalent to having no shield at all, so when the shield is, shield grounded at both ends or even at one end, this is applicable even for connection to one end, then suddenly it becomes a zero, for capacitive crosstalk control you need to connect the shield to ground only at one end, both is need to be connected for inductive crosstalk, elimination or selection.

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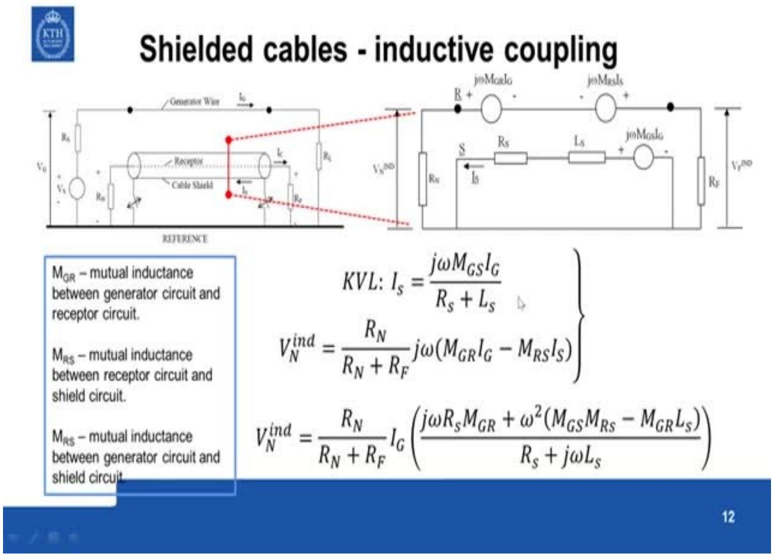

Now coming to inductive coupling, now the equivalence circuit is shown here, we have derived that before, now the shield current can be written as J omega MGS IG by RS plus LS, then this VN induced can be written as from the circuit analysis, from these two sources you can write it like this, where IS is given by this expression, that can be substituted over here, then you get an expression like this is.

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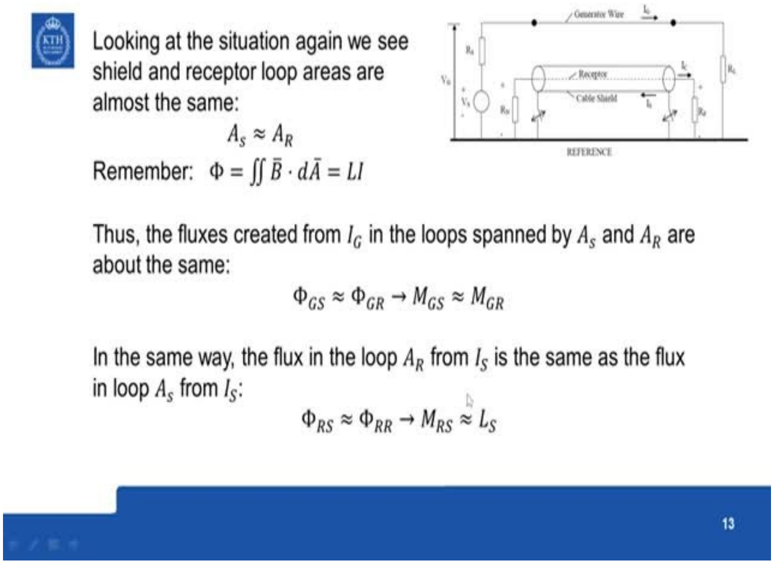

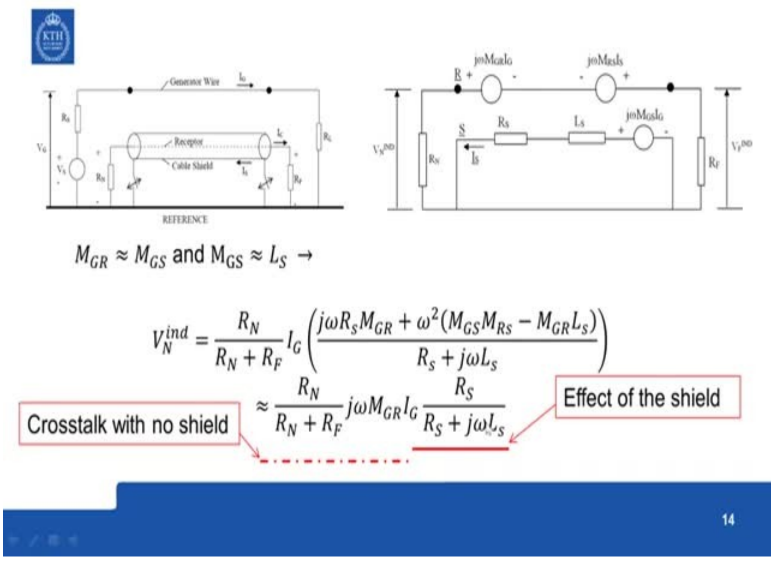

Now as said before you can say that this loop area for the receptor circuit and the shield circuit there are almost similar, so MGS and MGR they are almost equal, similarly mutual inductance between the receptor and cable shield MRS is approximately equal to the cable self-inductance, so with this two simplifications in the previous equation we can write the expression like this, so here there are two terms that are a function of frequency one is this and another one is this one, the two factors, so now if we are increasing the frequency from very low value and rising it up what will happen you can see that, so this part is crosstalk with no shield at all or shield open circuited and this part comes only when there is a shield current or when there is a shield, so this is a modification of the crosstalk due to this, so immediately from this equation you can see that in the direction of crosstalk is a function of the shield properties and the frequency RS is the resistance of the shield unless is the selfinduction of the shield, so the shield properties and frequency decide how much is beneficial effect the shield will have in the inductive crosstalk, so this is the effect of the shield, so at very low frequency you can find that, this would be almost equal to one because this part will be very small compare to this part, so this ratio will become one, so there is no effect on the shield, only after certain frequency you can see from this equation, the shield will have an effect and that you know ten around frequencies given by when RS is equal to omega LS, so this is what we will see next.

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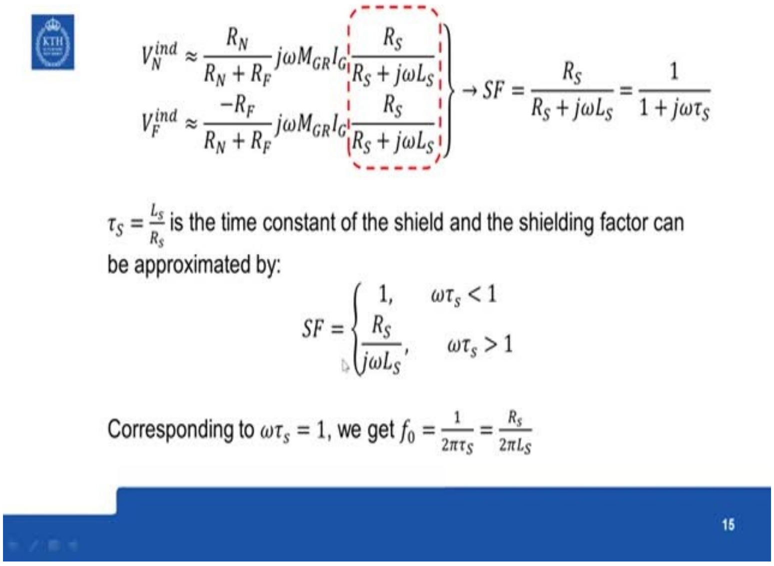

The expression for the near end crosstalk and expression for the far end crosstalk due to the fields, so this part is the shielding factor RS by RS plus J omega LS then by dividing numerator and the dominator by RS we define a new term at time constant LS by RS by shield time constant it is called, which is the property of the shield, so we write it as 1 by 1+ J omega tao S, now the shielding factor will be 1 if omega tao S is less than 1 approximately and this will be equal to RS by J omega LS or 1 by J omega tao S, if omega tao S is greater than 1, so this 1 can be neglected, than it is 1 by J omega tao S which is nothing but RS by J omega LS, so corresponding to omega tao S is equal to 1, we get a frequency which is called the cut-off frequency is 1 by 2 pie tao S is equal to RS by 2 pie LS, so below this frequency there is no effect of the shield and above that frequency you will have a shielding fact,

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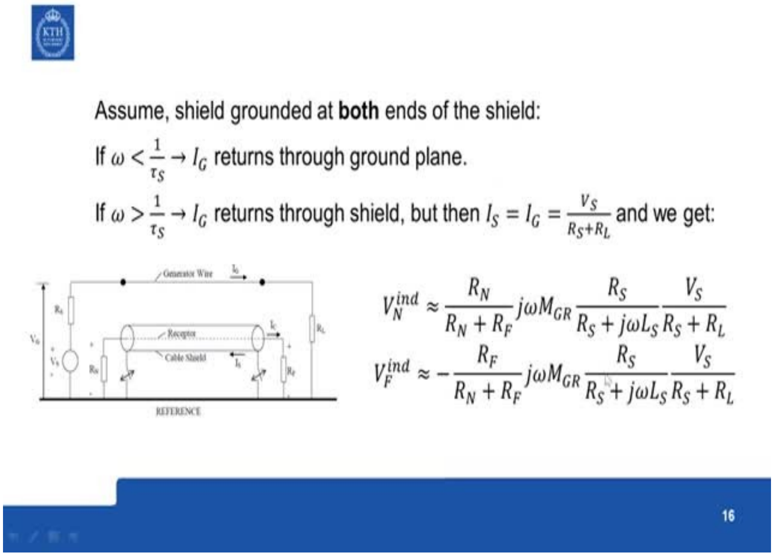

So how do we represent that what is it mean? So we will omega less than 1 by tao S, so the below that frequency this IG returns wire the ground, it is not going wire the shield, whereas about the frequency IG is returning through the shield and IS is equal to IG then substitute those values we get near end crosstalk and far end crosstalk by these expression VS by RS plus RL, so this is only when omega is far greater than 1 by tao S the expression is valid.

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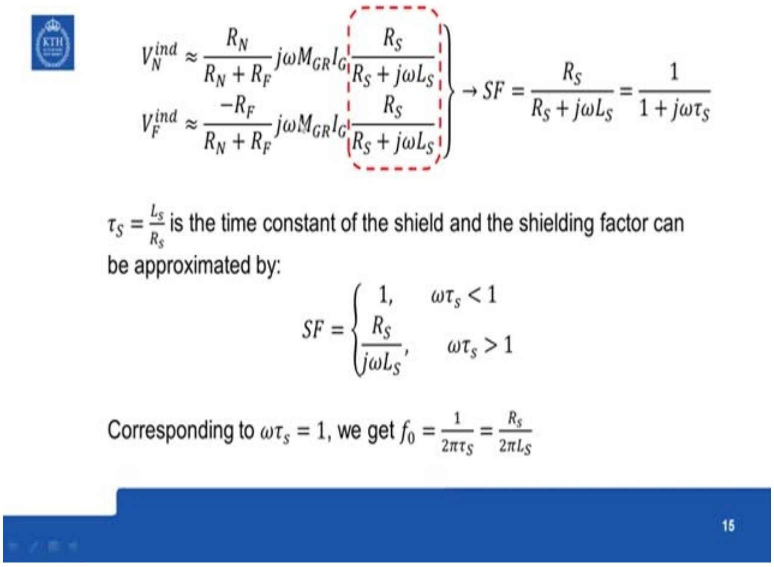

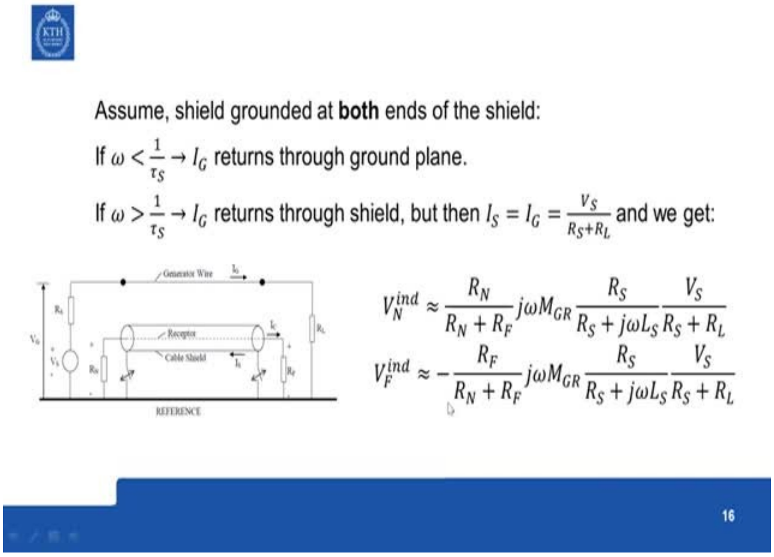

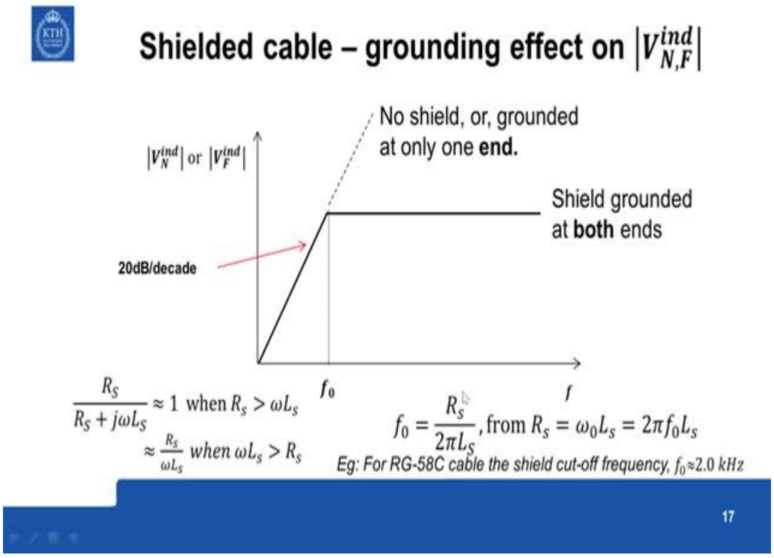

So below that shield cut-off frequency, it is but decade increase, where shielding factor is 1, so it is just J omega MGR IG, J omega MGR IG here, now about the shield cut-off frequency it becomes RS plus J omega LS, so this J omega, J omega cancels, so you get a kind of a such ratio in the this voltage, so it is noted frequency dependent anymore beyond that cut-off, so for RG 58C cable the shield cut-off frequency we can find this about 2 kHz, so what is it mean? It means that below 2 kHz, this particular cable will not be helpful in preventing inductive crosstalk, whereas about 2 kHz we can prevent or it can reduce inductive crosstalk.

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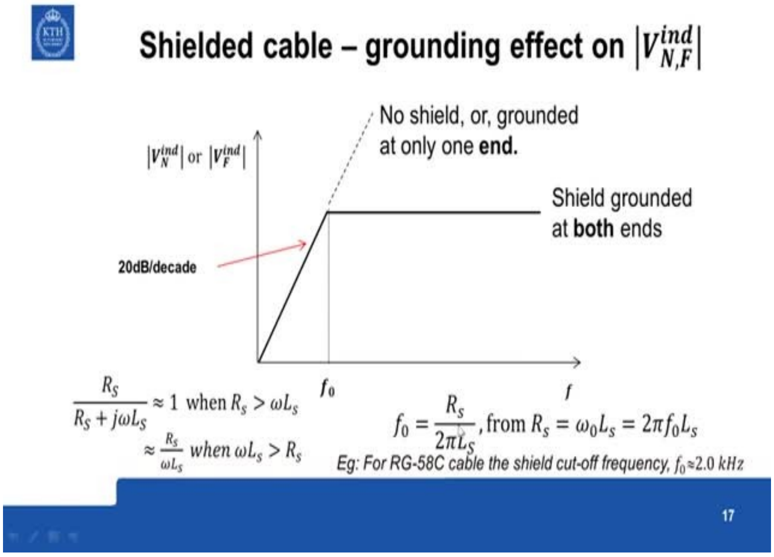

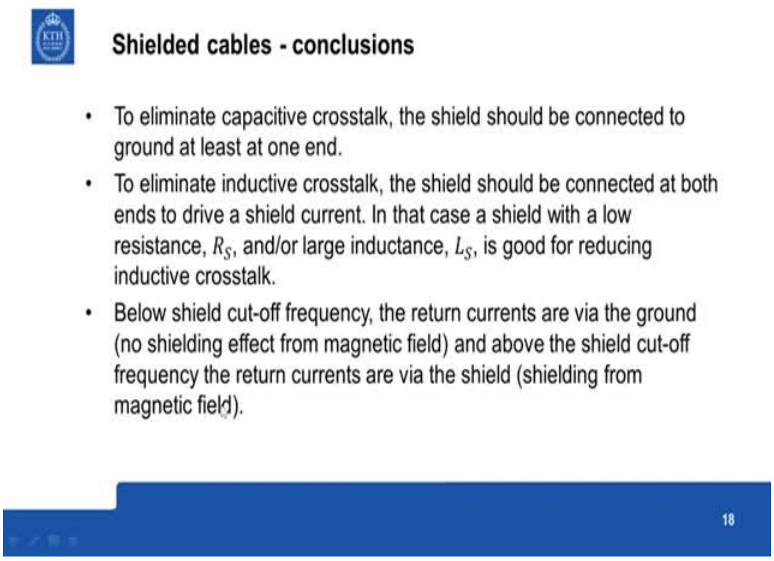

So conclusions, to eliminate capacitive crosstalk, the shield should be connected to ground at least one end and to eliminate inductive crosstalk, the shield should be collected at both ends to driver shield current. In that case a shield with the low resistance RS and a large inductance LS is good for reducing inductive crosstalk, so this comes from say shield cut-off frequency, low resistance and large inductance means F0 becomes smaller, so it means that even from very low frequency, you will have the effect of the shield. Below the shield cut-off frequency, the return currents are via the ground (no shielding effect from magnetic field) and above the shield cut-off frequency the return currents are via the shield (the shielding from magnetic field).

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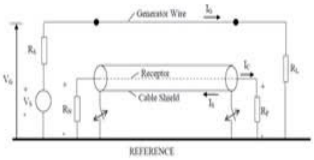
Assume, shield grounded at **both** ends of the shield:

If $\omega < \frac{1}{\tau_S} \rightarrow I_G$ returns through ground plane.

If $\omega > \frac{1}{\tau_S} \rightarrow I_G$ returns through shield, but then $I_S = I_G = \frac{V_S}{R_S+R_L}$ and we get:



$$V_N^{ind} \approx \frac{R_N}{R_N+R_F} j\omega M_{GR} \frac{R_S}{R_S+j\omega L_S} \frac{V_S}{R_S+R_L}$$

$$V_F^{ind} \approx -\frac{R_F}{R_N+R_F} j\omega M_{GR} \frac{R_S}{R_S+j\omega L_S} \frac{V_S}{R_S+R_L}$$

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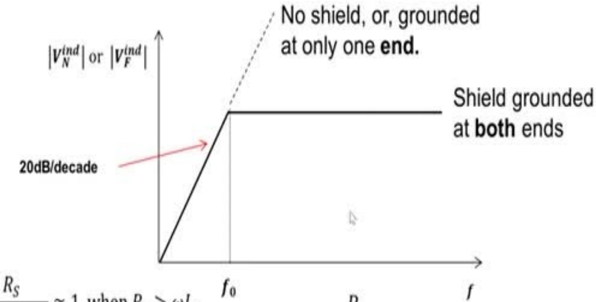
Shielded cable – grounding effect on $|V_{N,F}^{ind}|$



$$\frac{R_S}{R_S+j\omega L_S} \approx 1 \text{ when } R_s > \omega L_s$$
$$\approx \frac{R_s}{\omega L_s} \text{ when } \omega L_s > R_s$$

$$f_0 = \frac{R_s}{2\pi L_s}, \text{from } R_s = \omega_0 L_s = 2\pi f_0 L_s$$

Eg: For RG-58C cable the shield cut-off frequency, $f_0 \approx 2.0$ kHz

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Shielded cables - conclusions

- To eliminate capacitive crosstalk, the shield should be connected to ground at least at one end.
- To eliminate inductive crosstalk, the shield should be connected at both ends to drive a shield current. In that case a shield with a low resistance, R_S, and/or large inductance, L_S, is good for reducing inductive crosstalk.
- Below shield cut-off frequency, the return currents are via the ground (no shielding effect from magnetic field) and above the shield cut-off frequency the return currents are via the shield (shielding from magnetic field).

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So here we have shown a very important principle or sum because often AC currents returns via a path that will minimise the flux, so this is general principle, so it is not, you know it may look like that, the current will be following always through the reference because you have some inductance and resistance but that is not the case with AC currents, so the flux new assertion principle is valid, so this will have a lot of practical consequence, I mean here we have, we are doing this analysis in terms of packing over shield, but you can have another conditions also, say for example in electrified railways you have high frequency components, so for imposed on retraction currents and the rail is supposed to be the written path in that case but often the high-frequency currents may returned not via the rays but via the wagons and it may damage even the bearings because of that currents, so in AC the returned currents, the currents would like to return through path where the flux is, the coupling flux is minimised.

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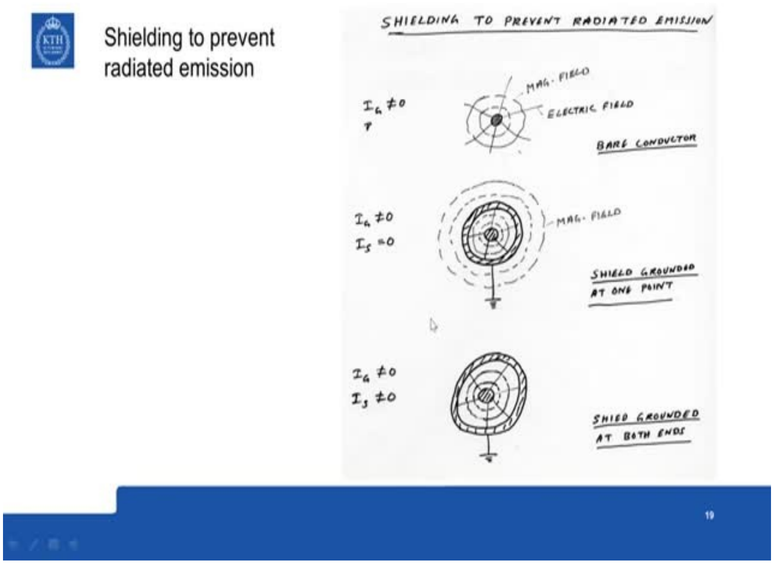

Now shielding can also be used to prevent radiated emission, so here it is illustrated here, so for you have been seeing how shielding can prevent noise pickup from outside, now it is shown how it can be used to prevent emission, so in this case the cross section is shown, the bad conductor no shield, then you have magnetic field and electric field freely transmitted to this space surroundings, now suppose you have a shield and at least one end of the shield is connected to the ground, then all the electric field lines are terminating on the shield, so you do not have any electric field emission but you still have magnetic field emission, so shield current is zero, even though the generated current, here this under this, now this inside conductor, that is not zero, now if the shield is connected at both ends it will drive current through the shield, so the shield current is not zero anymore, which will combine all the magnetic field to the inside the cable, so then shield is grounded at both ends it will prevent radiated emission,

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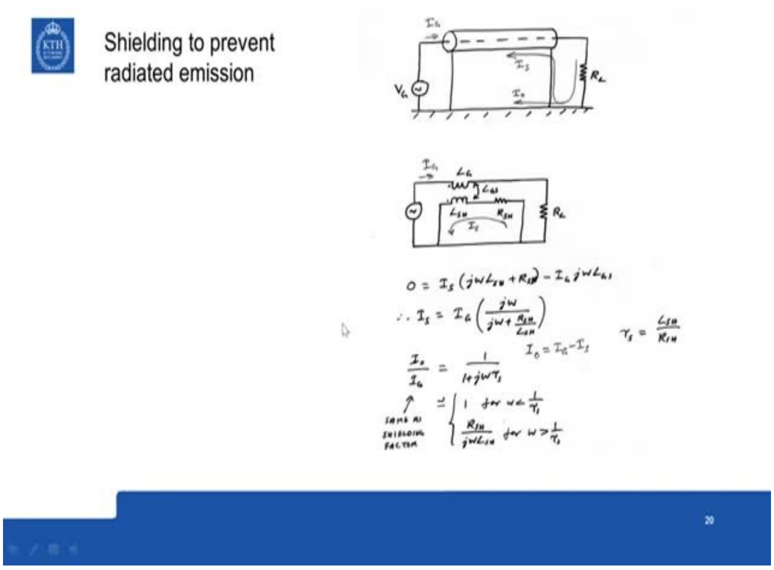

So some more detailed analysis, so you have a source, now the source is connected to the inner conductor, so the load here, so the current has, the shield is connected at the both ends, the current can return either via the ground like this or via the shield current, now this, you can find equivalence circuit for this, it is as if you have a inductive coupling between the inner wire and the shield, so LG and LSH, so you have this mutual coupling also between them, LGS so you write the loop equations, so this is the shield current IS J omega LSH plus RSH minus a source created in this IG J omega LGS, so from that you can find what is the value for IS, then shield constant is LSH by RSH and I 0 in the sum of this IG and IS, so the difference actually is for the going through the ground, now I 0 by IG is same as the shielding factor and that is equal to 1 by 1 plus J omega tao S, this you can find from this expression here then which will be equal to 1 for omega far less than 1 by tao S and RSH by J omega LSH for omega greater than 1 by tao S, so very similar kind of the questions you get when you analyse the shield to prevent radiated emission, so that this end of that particular module, one shielded cables, crosstalk in the presence of shielded cables. Thank you.