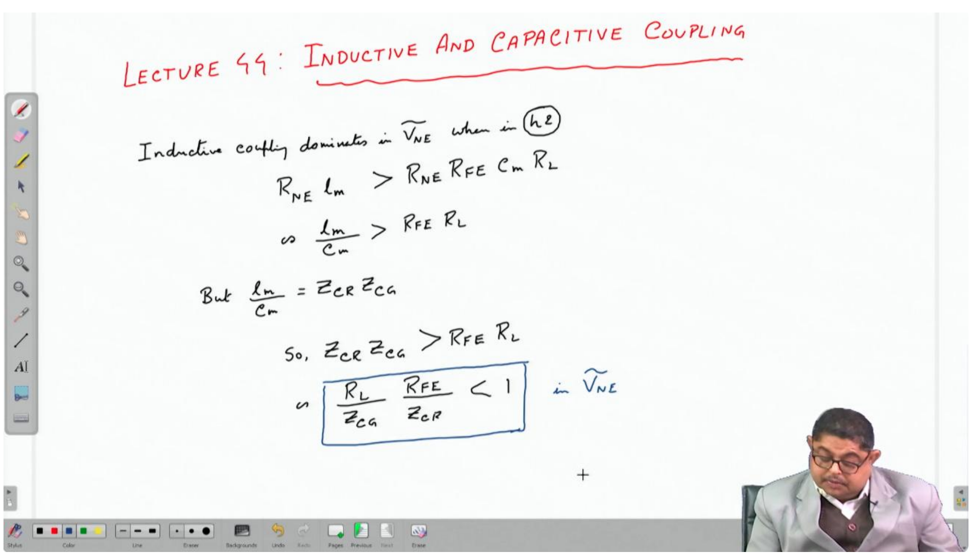
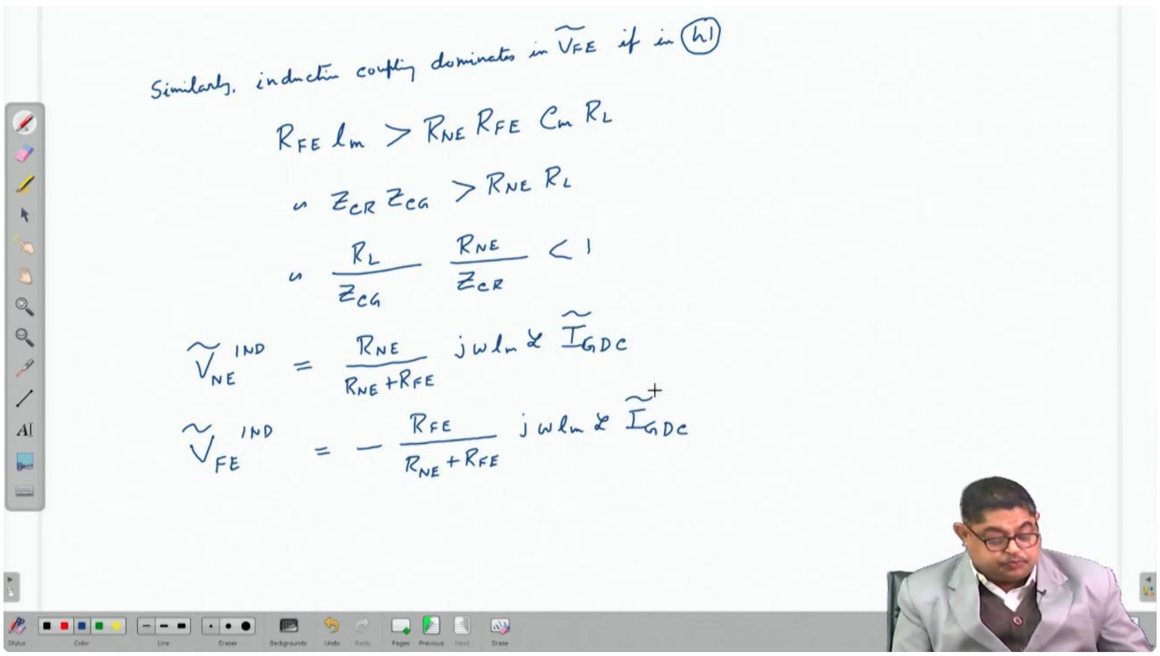
Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
Professor name: Prof. Amitabha Bhattacharya
Department name: Electronics and Electrical Communication Engineering
Institute name: IIT Kharagpur
Week :09
Lecture 44: Inductive and Capacitive coupling

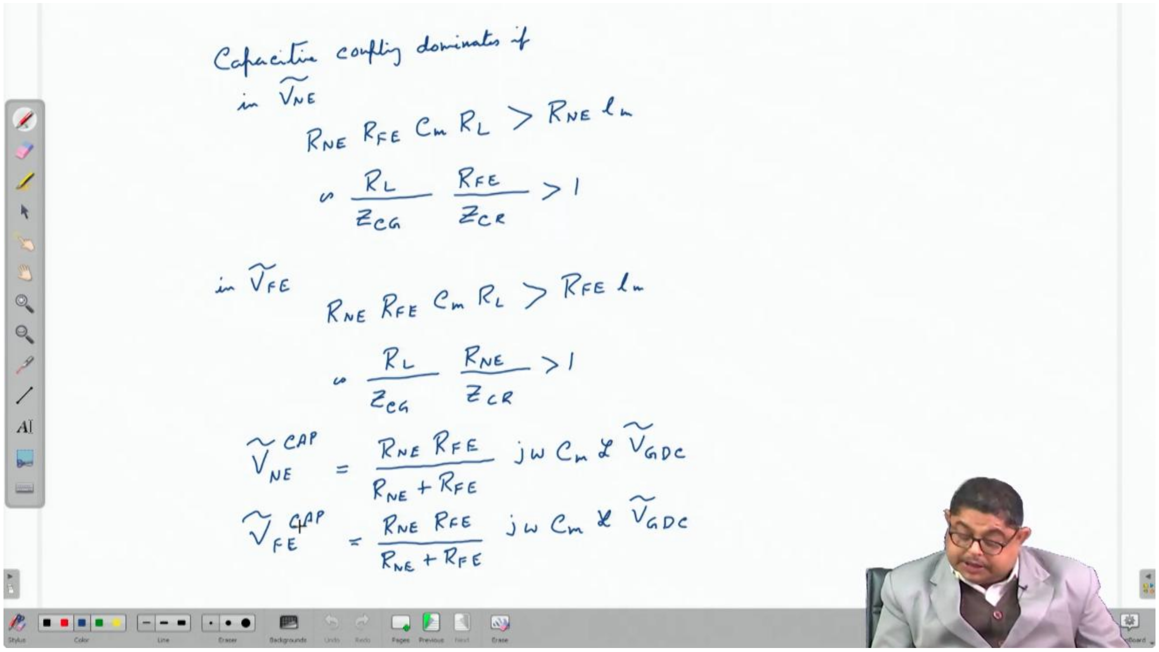
Welcome to the lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. We have in the last class derived finally, the crosstalk expressions in frequency domain. Now, we will see the contribution of inductive coupling and capacitive coupling separately. We have already introduced what is inductive coupling, what is capacitive coupling and saw that the total coupling or total crosstalk is in the receptor circuit is superposition of the two. Now, this inductive coupling dominates capacitive coupling for low impedance load. What do you mean by low impedance load? Low impedance load means high current, but low voltage that is very low impedance.Similarly, capacitive coupling dominates for high impedance load that is low current and high voltage. Now, quantitatively inductive coupling dominates in FVNE when in H 2. So, I can say that inductive coupling dominates in VNE when in H 2. Now, H 2 if you see the expression in H 2 that let us see the VNE expression. So, the last one you should not see because one is IGDC another is VGDC, but this one if you look that the here inductive coupling is RNE LM that should be greater than RNE RFE CM RL. So, that is the condition when RNE LM is greater than RNE RFE CM RL or LM is greater than RNE CM by CM is greater than RFE RL. Now, already we have seen that for any type of coupler or any type of impedance line. So, I can say LNE LM by CM is equal to Z cr into Z cg. So, I can write. So, LNE LM by Z cr into RFE by Z cr should be less than 1. This is the condition for inductive coupling dominance in VNE.



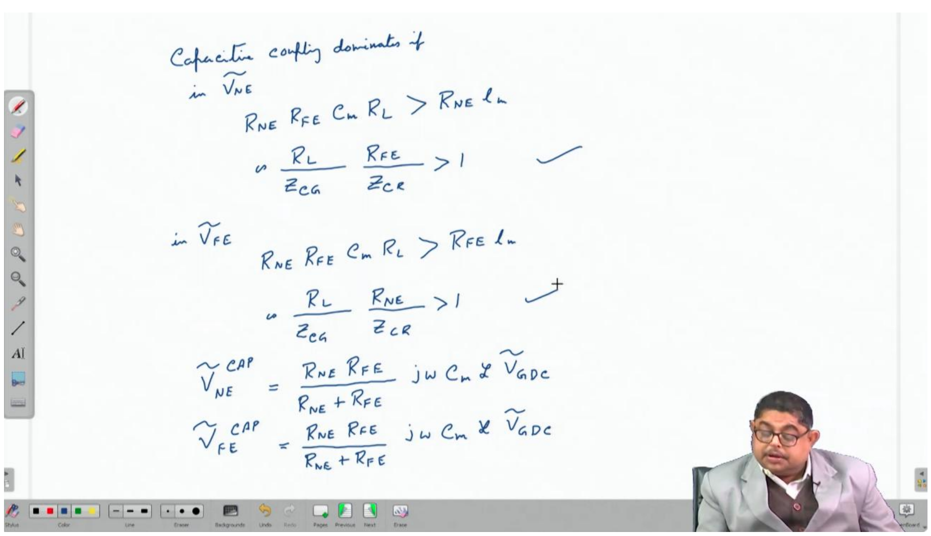
Similarly, inductive coupling dominance in VFE if in H 1 you can see H 1 VFE. Now, this is also VGDC a. So, we will have to see the previous result. So, here we want that RFE LM should be greater than RNE RFE CM RL that will be the condition. So, RFE LM is greater than RNE RFE CM RL or Z cr. Z cg is greater than RNE RL or RL by Z cg into RNE by Z cr is less than 1. So, you see that this Z cg Z cr that is known. So, you choose your RL in such a way that this condition is made. So, we can write that in this case the crosstalk becomes VNE inductive is equal to RNE by RNE plus RFE j omega LML IGDC. And for parent VFE is minus RFE by RNE plus RFE j omega LML IGDC.



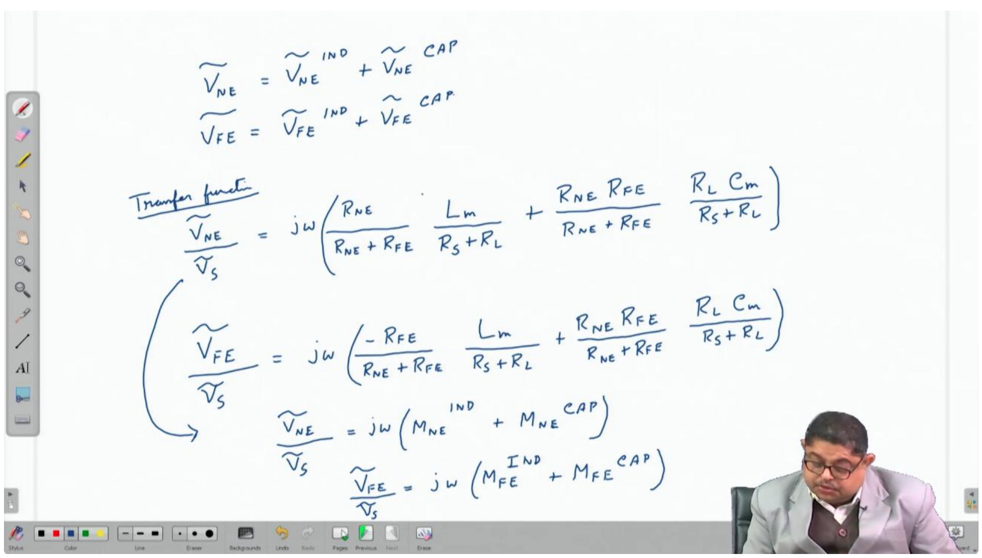
Similarly, we can find capacitive coupling dominance if in VNE RNE plus RFE CM RL is greater than RNE LM or from this you can write RL by Z cg into RFE into RNE by Z cr is greater than 1. In PAP you have the condition RNE RFE CM RL is greater than RFE LM or RL by Z cr is greater than 1. So, in this case you can say that VNE cap capacitive is equal to RNE cap capacitive is equal to RNE RFE by RNE plus RFE j omega sorry LM CM.So, this is equal to RNE cap capacitive is equal to RNE RFE by RNE plus RFE j omega C . So, you see that for capacitive coupling the near end crosstalk and far end crosstalk is same whereas, for inductive coupling they are not same also they are in opposite sign for capacitive coupling they are of same sign.



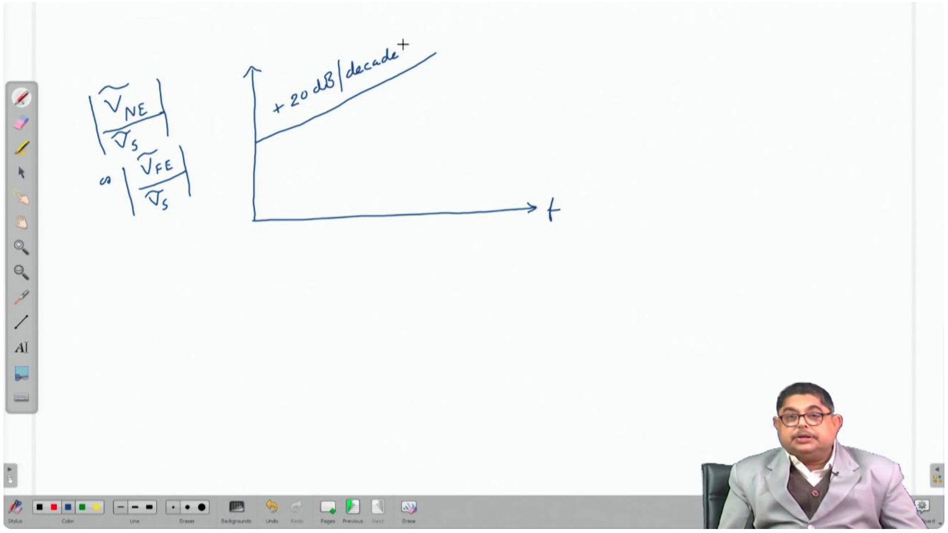
So, the total coupling we can say that we have already seen, but again I am writing VNE is equal to VNE inductive plus VNE capacitive similarly VFE is equal to VFE inductive plus VPE capacitive . Also I think you have noted that capacitive coupling dominates in both the cases you see this expression and this expression. So, if RL is a high impedance load that means, RL high then this is satisfied whereas, inductive coupling dominates if RL is a low impedance load. So, for a given RNE j j j j cr the for low impedance load inductive coupling dominates RL is less than this all these values and RL is if RL is high impedance that means, RL is high than that those ratio then you have capacitive coupling dominates. So, you can choose the termination impedance. So, that inductive and capacitive coupling components can be made into VFE.



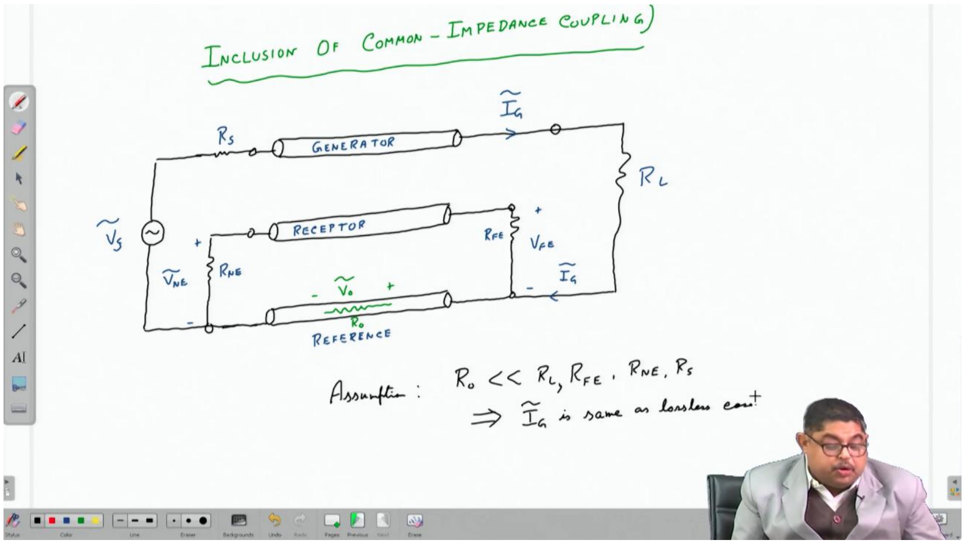
So, in VFE this one and VFE this one now this is the dominance one. So, we know that in VFE this inductive coupling and capacitive coupling they are not equal and they are of opposite sign. So, they can be terminal impedances can be chosen. So, that VFE can be made 0 and this is the basis for designing the directional coupler. So, while deriving this crosstalk we have also seen how to design a directional coupler you choose the impedances. So, that directional coupler is designed we have already seen that what is the mutual coupling ratios L m by C 1 for them. Now, let us see previously also we have modeled sources etcetera. So, this crosstalk also can be viewed as a transfer function between the input V s and output either V ne or V FE. So, I can write transfer function approach. So, you see what is V ne by V s that is j R n e by R n e plus R f e into L m small l m into L small l m into L I am calling it capital L m. So, L m is this one by R s plus R l plus R f e by R n e R l similarly I am writing capital C m which is nothing, but small c m into line length L. So, this is the transfer function V ne by V s similarly I can write V f e by V s that is j omega minus R f e by R m e plus R f e L m e by R s plus R l plus R f e by R m e plus R f e by R m e plus R f e R l c m e by R s. So, you see we can write from these that V ne by V s is j omega plus R f e by R m e plus R f e by R m e inductive plus m n e capacitive and V f e by V s is equal to V f e by V s into j omega m f e inductive plus m f e capacitive. So, you see this is this m n e is a constant m n e i n d m n e cap m f e i n d m f e cap all are constant. So, V ne by V s is just a j omega into some constant.



So, we can easily draw it is bode plot that. So, magnitude bode plot that will be a plus 20 dB, but decade line. So, this is the transfer function or bode plot of the transfer function frequency response of the transfer function.



Now, you see we will further define our model. Till now we have assumed the line is lossless that means, a perfect conductors and lossless medium. Now, this assumption is usually a reasonable assumption below gigahertz range. However, imperfect conductors can produce significant crosstalk even at the lower frequency. This is called common impedance coupling or common impedance crosstalk. Now, this is the first let me. So, let us see. So, let us see. So, let us see. So, let us see. So, let us see. So, let us see. So, let us see.So, let us see. So, this is the case only you see that we are modeling that all the due to imperfect conductor there is a resistance in the line. So, since reference is common between generator and receptor all the and the line is electrically short. So, we are lumping all the resistances in the reference circuit. So, that f x is common between generator and receptor. Let us call this lumped resistance as R naught and the voltage that comes due to that along that lumped resistance that is called V naught. Now, this R naught for typical loads and frequency below gigahertz the R naught is usually very small compared to. So, I can write that R naught is very very small compared to R L, R Fe or R Ne or R S etcetera. So, we can with this assumption this is an assumption and a very very justified assumption. So, due to this the whole of I g still returns to the reference conductor. So, implication of this is I g is same as lossless. So, this I g will produce a voltage drop that is V naught across the lumped resistance.



Now, so what is the value of R naught? Since we have lumped it so we can say that sorry R naught is equal to some per unit length resistance of the line into L. So, voltage drop across this reference conductor V naught that will be R naught into I g and what is that what is I g? I g is V s by R s plus R L. So, you see the denominator we are not taking R naught because it is negligible compared to either R s or R L.So, this is an expression. Now, these voltage drop V naught that affects the V Ne and V Fe in the receptor circuit. This appears in series with the voltage drop due to inductive coupling. So, this is quite significant even at very small frequency and small frequency for resistance it does not matter, but the value of this crosstalk due to this that will be quite significant to inductive coupling at it. So, the crosstalk contribution due to this Vo can be written as a transfer function. So, this is V Ne, V Ne and this is called common impedance V Ne by V s you see from here that will called M Ne Ci and V Fe Ci by V s that will called M Fe Ci where M what is the value of M Ne Ci? M Ne Ci is R Ne by R Ne plus R Fe R naught R s plus R L because this voltage V naught that is now in the receptor circuit also it is going. So, and here we can write M Fe Ci is equal to R Fe R Ne plus R Fe R naught by R s plus R L. So, you see that the moment this voltage came now this part is energized receptor reference 1 and so it is getting a extra term. So, that is given by that M Ne Ci and M Fe Ci. So, since this is a DC condition because this resistance is not this load is not frequency dependent. So, we can easily retain the value of M Ne Ci and M Fe Ci.

I am stopping here we will see what is the effect of this in the next class. Thank you.

$$R_o = r_o \mathcal{L}$$

$$\tilde{V}_o = R_o \tilde{I}_G$$

$$= \frac{R_o \tilde{V}_S}{R_S + R_L}$$

$$\frac{\tilde{V}_{NE}^{CI}}{\tilde{V}_S} = M_{NE}^{CI} \qquad \text{where } M_{NE}^{CI} = \frac{R_{NE}}{R_{NE} + R_{FE}} \frac{R_o}{R_S + R_L}$$

$$\frac{\tilde{V}_{FE}^{CI}}{V_S} = M_{FE}^{CI} \qquad \text{where } M_{FE}^{CI} = \frac{-R_{FE}}{R_{NE} + R_{FE}} \frac{R_o}{R_S + R_L}$$