

Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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 Week :05
 Lecture 24: Common Mode Current Emission Model

Welcome to the 24th lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. We have seen differential mode current emission model in the previous class. Today we will discuss common mode current emission model. So, it will be fairly easy now just since we have done the differential mode current emission model. So, again I take two conductors, this is conductor 1, this is conductor 2, there is I_C here, I_C here as well in the same direction, the length is L as before and from here the observation distance, let us say it is D and we know that the EC max that will be in this direction for different common mode current that you can see that when we discussed the current models that EC max will be there in this direction opposite to the direction of current but in the plane of the two currents and I_1 is I_C , I_2 is also I_C .

LECTURE 24: COMMON MODE CURRENT EMISSION MODEL

$\tilde{I}_1 = \tilde{I}_c$
 $\tilde{I}_2 = \tilde{I}_c$

So again if we our model is herzian dipole, so we can write the EC max is $J 2 \pi J \mu$ naught by 2 2 pi into 10 to the power minus 7 FICL by D e to the power minus J beta naught e to the power minus 3 then e to the power J beta naught S by 2 plus e to the power minus J beta naught S by 2. So, we can take J 4 pi into 10 to the power minus 7 FICL by D e to the power minus J beta naught D cos of beta naught S by 2. Then beta naught S by 2 is pi S by lambda naught and again assuming S is electrically short we can see cos of beta naught S by 2 beta naught S by 2 is quite small. So, it is almost like 1. So, EC max magnitude will be 1.257 into 10 to the power minus 6 IC into 10 to the power minus 6 FICL by D and parallel to. So, this is our model.

$$\begin{aligned} \tilde{E}_{c, \max} &= j 2\pi \times 10^{-7} \frac{I_c \ell}{d} e^{-j\beta_0 d} \left\{ e^{j\beta_0 \frac{S}{2}} + e^{-j\beta_0 \frac{S}{2}} \right\} \\ &= j 4\pi \times 10^{-7} \frac{I_c \ell}{d} e^{-j\beta_0 d} \cos\left(\beta_0 \frac{S}{2}\right) \\ \frac{\beta_0 S}{2} &= \frac{\pi S}{\lambda_0} \\ \cos\left(\frac{\beta_0 S}{2}\right) &\approx 1 \\ \left| \tilde{E}_{c, \max} \right| &= 1.257 \times 10^{-6} |I_c| \frac{\ell}{d} \\ &\rightarrow \text{parallel to the wires}^+ \end{aligned}$$

So, let us take an example to understand. So, consider the same cable that 1 meter length to wear cable constructed of same thing 28 gauge were separated by a distance of 50 mils the cable is carrying a 30 megahertz common mode current find the level of common mode current that will give a radiated emission broadside to the cable that just equals FCC class B limit of 40 dB micro volt per meter at 30 megahertz the same problem. So, we can write that ED max will be 1.257 into 10 to the power minus 6 into IC 30 in this case it is simply F not F square. So, 30 into 10 to the power 6 into L by 3 meter and that should be equal to 100 into 10 to the power minus 6 volts per meter. So, if you solve this it comes that IC is 7.96 microampere. So, you see that the 7.96 microampere I will highlight this microampere gives the same field at the same distance etcetera same frequency same distance and what was the value for ID? ID was 19.94 milli ampere. So, as I said that common mode currents are dangerous. So, you see it is almost 500 times less IC but it is producing the same field as the ID. So, this is the danger that an EMC engineer should be aware of.

1 m length cable
 28 gauge
 50 mils
 30 MHz

$$1.257 \times 10^{-6} |\tilde{I}_c| \frac{(30 \times 10^6) \times 1}{3} = 100 \times 10^{-6} \text{ V/m}$$

$$|\tilde{I}_c| = \underline{\underline{7.96 \mu A}}$$

$$|\tilde{I}_D| = 19.94 \text{ mA}$$

Now, let us see as before the clock driving a two wire line. So, you have a clock VS. You have a terminating load and this is carrying IC, this is carrying IC and as before you are seeing this at a distance and your EC max is this. So, what is the transfer function? So, let me see whether we have that space. So, here derive the transfer function that EC max by IC that is here we can put D as 3 meter. So, that will be 1.257 into 10 to the power minus 6 by 3 f into L. So, putting that L so that I can see a new constant let us say KC into f. So, if I draw its spectrum, the spectrum will be EC. So, this will be f that means it will go with a plus 20 dB per decade slope.

$$\tilde{E}_{c,max} = j 2\pi \times 10^{-7} \frac{f \tilde{I}_c d}{d} e^{-j\beta_0 d} \{ e^{j\beta_0 \frac{d}{2}} + e^{-j\beta_0 \frac{d}{2}} \}$$

$$= j 4\pi \times 10^{-7} \frac{f \tilde{I}_c d}{d} e^{-j\beta_0 d} \cos(\beta_0 \frac{d}{2})$$

$$\frac{\beta_0 d}{2} = \frac{\pi f d}{\lambda_0}$$

$$\cos(\beta_0 \frac{d}{2}) \approx 1$$

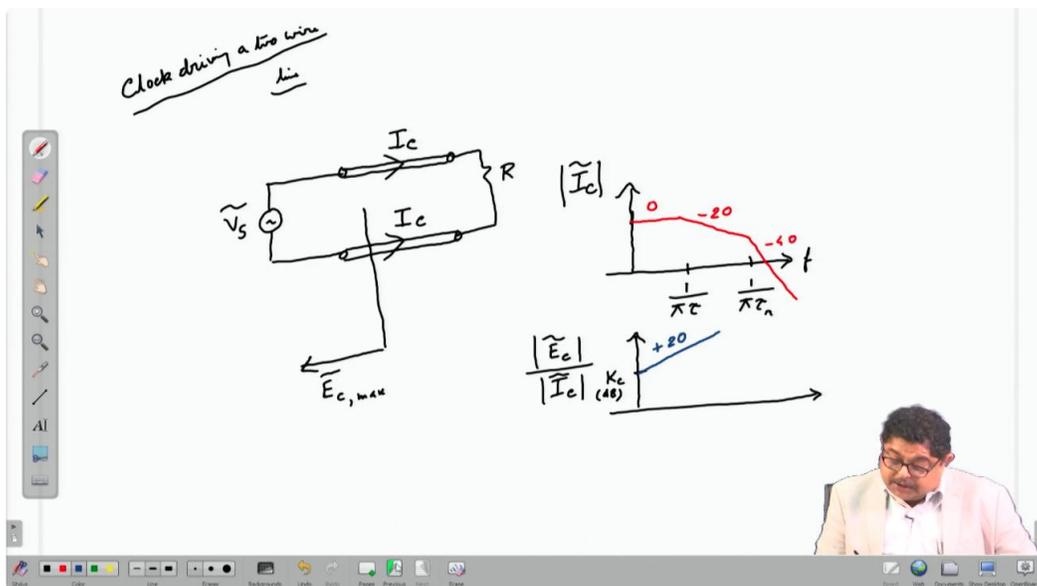
$$|\tilde{E}_{c,max}| = 1.257 \times 10^{-6} |\tilde{I}_c| \frac{f d}{d}$$

→ parallel to the wire

$$\frac{|\tilde{E}_{c,max}|}{|\tilde{I}_c|} = \frac{1.257 \times 10^{-6}}{3} f d$$

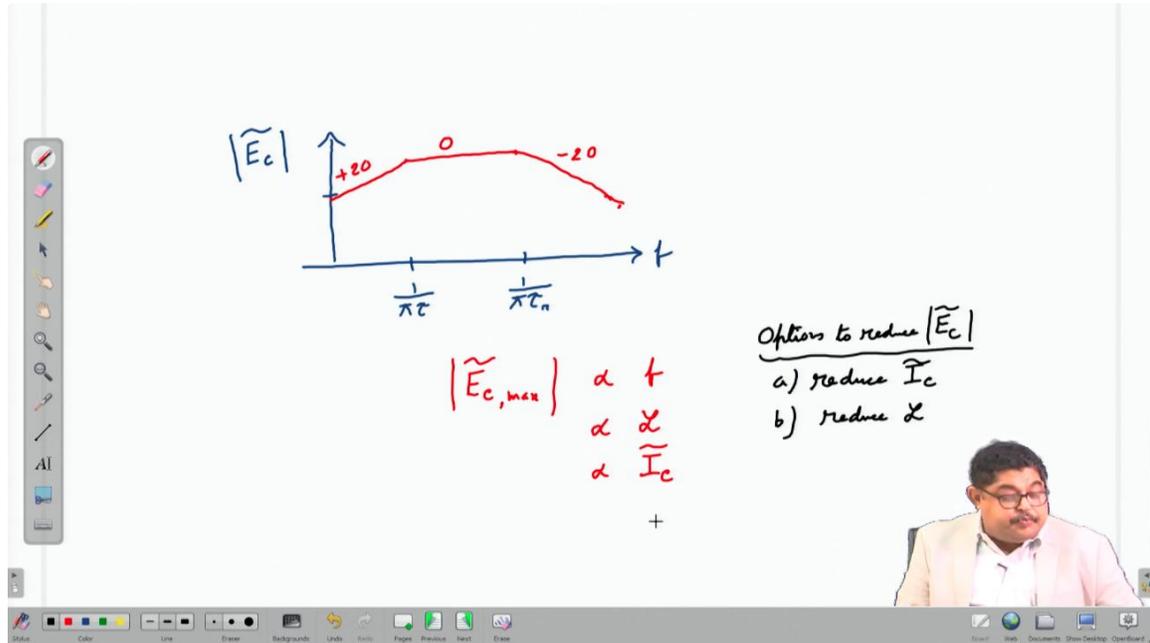
$$K_c = 4.19 \times 10^{-7}$$

So, now let us come here. So, here we know that what is the from the clock thing, what is the same clock. So, then the spectrum is like this that means IC is here there will be 1 by $\pi \tau$, here there will be 1 by $\pi \tau r$. Let us say this is case 0 minus 20 minus 40 and our EC by IC is. What is the value? EC by IC will be KC. So, KC in dB and then it will be going with a plus 20 . So, also let us calculate that KC value. What is the value of KC? KC is 1.257 into 10 to the power minus 6 that will be 4.19 into 10 to the power minus 7 . Let us do not absorb KC everything. So, put it L so that we can say EC by IC KC L into dB is plus 20 .



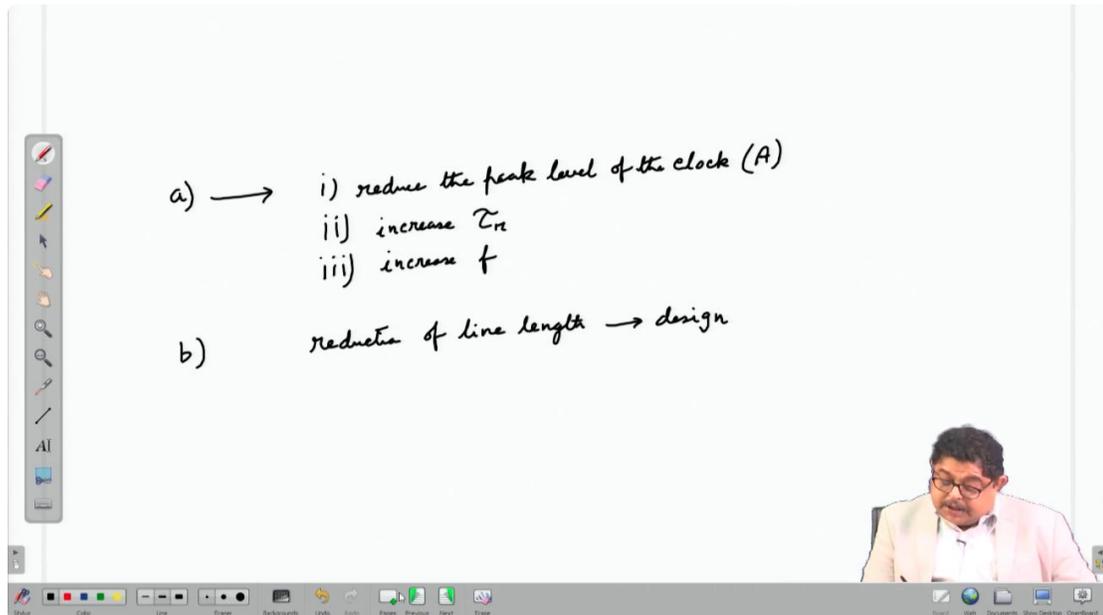
So, finally, we can find that EC spectrum will be 1 by $\pi \tau$ 1 by $\pi \tau r$ and from this value it will go first. So, it is plus 20 , it is 0 , it is minus 20 . So, you can see that at high frequency there is no problem with common mode currents. Common mode current problems are confined to the lower frequency zone. So, they are generally problematic below 200 megahertz. As we said that if you take the same type of clock that is 10 megahertz clock with 50 percent duty cycle and 2.5 nanosecond rise fall time, then break points are same 6.37 megahertz and 127.3 megahertz. So, there you will get roughly that below 200 megahertz you have below 100 megahertz, 200 megahertz you have that problems with it. So, other higher frequency you need not consider while considering the common mode current. Now maximum radiation for common mode currents occur broadside to the wire also it is insensitive to the rotation of the cable because there is no

cancellation. So, it is insensitive. So maximum radiation emission vary with, so EC max varies with frequency, varies with line length L and varies with current level IC. So, to reduce it, what are your options? The first option is, options to reduce EC. The first option is, let us say reduce IC. And another option is reduce L. Now to reduce the current level you see there is no desired thing here. So, you can do whatever you want.

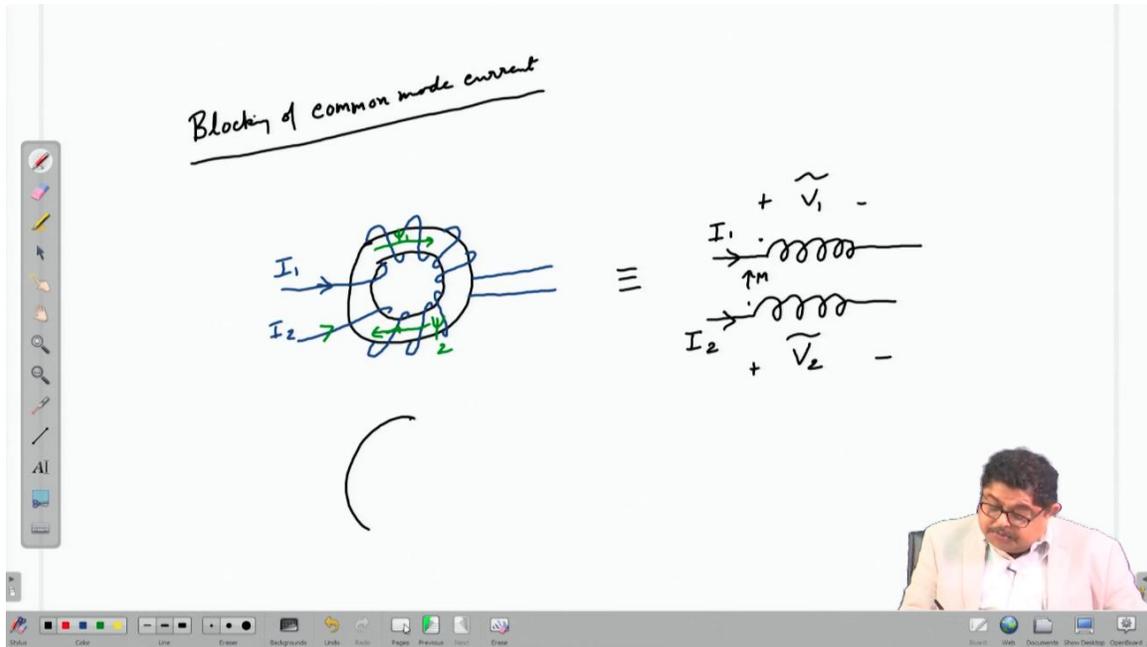


So, either you can, so for option A you can have various options. The first option is reduce the peak level of the clock that means reduce what we call A or you can increase tau r or increase clock frequency f. For option B, reduction of line length. This you require to do at the design stage that do not make very long lines and for PCB place the clock near to the sick module, keep the wire small. So, these are all for reduction of line length.

Now there is a fine method to, suppose all this we have done but you could not reduce much the common mode emission, you can use a, if an use of an extra device is permitted, you can use a toroid to suppress the common mode current, it would not disturb the differential mode current.



So, let us discuss that, how to do it blocking of common mode current. So, I think you have read toroid in your electrical classes. So, you have, so you have a, suppose I_1 is coming and I_2 is coming. So, here we will have to find what is the flux that is linked by this I_1 and by this I_2 . Now for that you apply the right hand rule, what right hand rule says that your thumb along current and fingers point to flux direction for the right hand. So, you place the thumb along current, so thumb along current, so your fingers they will put, so easily you can find that by that rule your flux linked to the toroid core that will be in this direction and for this one what is the, I will have to say the common mode. So, you place your thumb here and see the fingers are pointing here, so your I_2 is in this direction. So, that means now I can also there will be mutual coupling between them. So, the equivalent picture is in circuit that I have, so I_1 is this, I_2 is this and for mutual coupling I am placing that there is m here and so I can say that V_1 will be linked here and V_2 will be linked here. Now let us do, so this was for I_c or this is I_1, I_2 general, so let me draw this thing for I_c and I_d .



Suppose I am getting I_d , suppose I am sorry I will get, suppose I am getting I_d , suppose I_d , let us first see for I_d . So, for I_d what is the flux that is linked, so you see that thumb is pointing for right hand and the flux will be in this direction. Similarly, if I come here the current is like this, the thumb is like this, so the flux is in this direction. So, equivalent picture I can draw that, so I_d and I_d is equivalent is L minus m and this is L minus m , they are opposing each other, so L minus m . If we consider that we assume all L_1 , L_2 same and we are assuming that all the flux linkages of one current are also linked to the second current. So, that means L is equal to m , so in this case it will become 0, so that means no voltage get in used. But what is the picture in case of common mode current? So, I see here, I see here, apply the left hand rule, I right hand rule and you will see that flux is here, you will see that in this case the flux is here, you see I am putting my fingers here, so if the current is like this, current is coming like this, so the flux is here. So, this equivalent picture is, so we will get I_c , you will get I_c , in this case L plus m , L plus m and also at high frequency there is some high frequency resistance comes that will dissipate. So, we can see the impedance of the first winding Z_1 that will be V_1 by I_1 is $j\omega L I_1$ plus $j\omega m I_2$ plus $j\omega L I_2$. V_2 by I_1 and for common mode currents, similarly you can see Z_{cm} , I can actually write that is Z_{dm} and this is Z_{cm} is $P L$ plus m . So, for differential mode currents, actually this I_2 is minus, so that goes to minus and this becomes 0, the impedance Z_{dm} is 0 and Z_{cm} is you can see the impedance is if L and m are same, sorry P means actually your $J\omega$, so impedance is for Z_{cm} it is $2L$. So, in the ideal case a toroid has no effect on differential mode current, but places an inductance of $2L$ in series with the two

conductors for common mode current. In addition as I said that there is a frequency dependent resistance comes in series with common mode currents, this resistance becomes dominant at the higher frequency, so common mode currents have their energy dissipated in RF. So, this device if it is permissible you can apply, it would not affect the required current differential mode current, but you can suppress the common mode current that is the beauty of this toroid. So, we have seen common mode emission current model, next day we will see a device how to measure this common mode current and differential mode currents. Thank you.

