Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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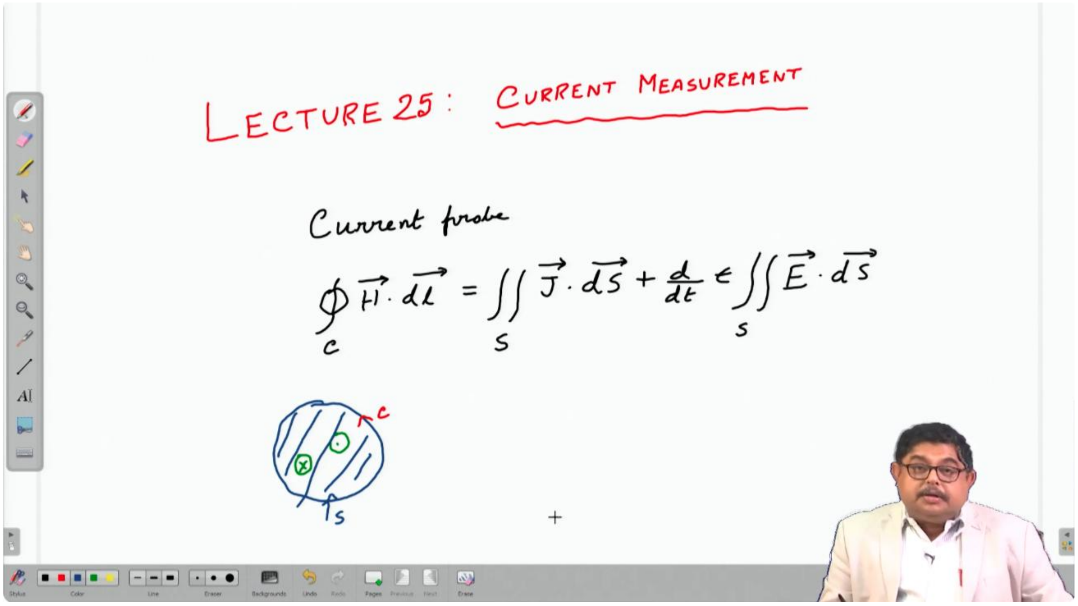
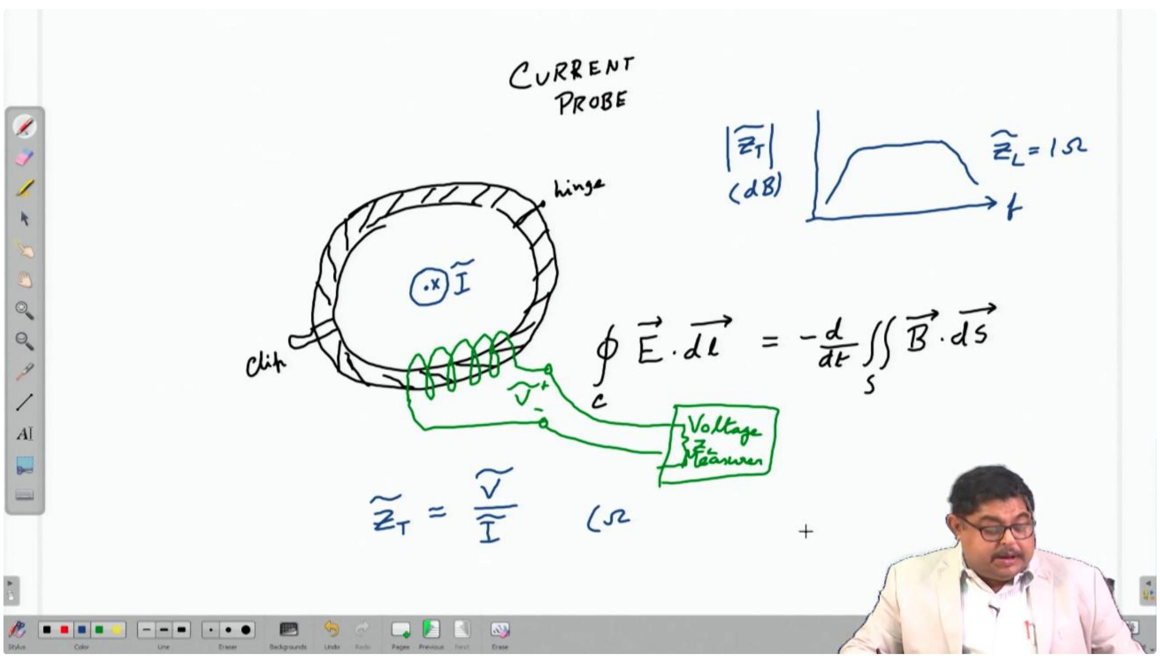
Week :05
Lecture 25: Current Measurement

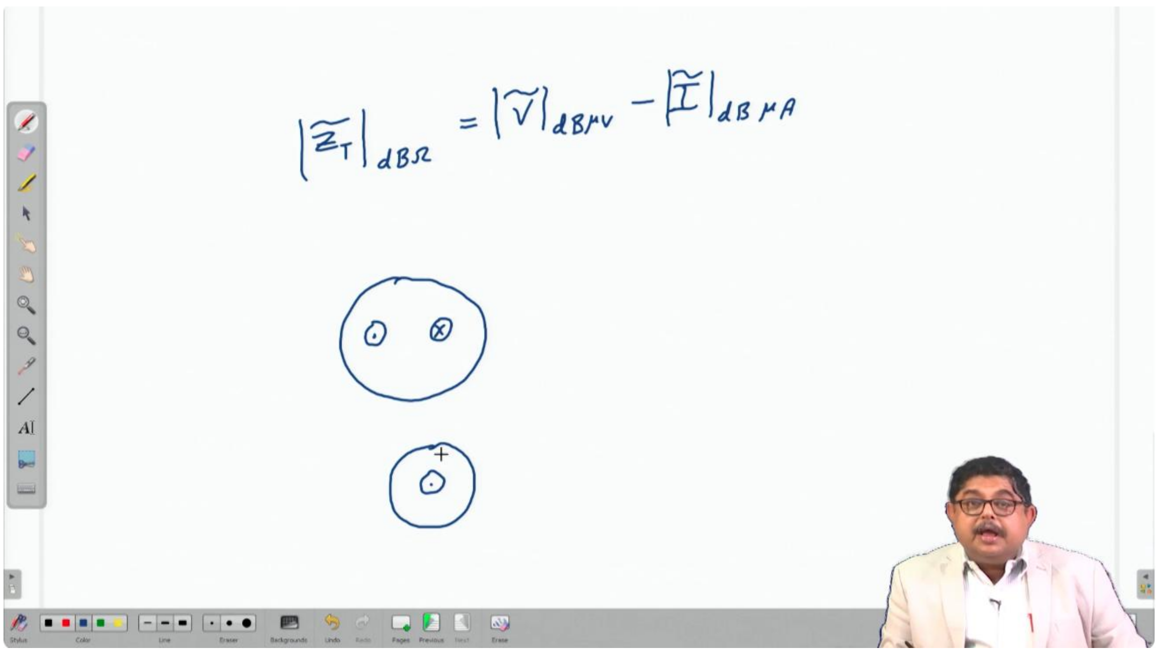
Welcome to the 25th lecture of the course on EMI, EMC and Signal Integrity Principles, Techniques and Applications. We have discussed the differential mode current emission model and common mode current emission model in previous classes. Today we will discuss something about how to measure currents non-destructively. You see we never in our lower classes in your labs you never measure current directly, you measured it by measuring voltage across a known impedance and from that you try to find out what was the current. But you see that for differential mode currents that may be possible because we know the models of differential mode currents, they may be transmission line models or at low frequency they may be lumped circuit models, may be distributed, may be non-distributed. So there we know that if the voltage is such and such by measurement then what is the current. But common mode currents they arise from various non-ideal factors such as proximity to some ground planes, then proximity to some metallic objects or asymmetry in the circuit etcetera which are not known. So modeling of them may be difficult. So we have done emission models, but how to measure that common mode current that is the topic today. So by field theory actually this can be measured the device that is used for that is called current probe.Before going to that let us just recall two of Maxwell's equation. You know that one of the Maxwell's equation is the line integral of the magnetic field that is given by one part is conduction current density and another part is displacement current density. So in terms of our interest we can say that this is the expression. So where this C is a contour of an open surface, contour of a bounding an open surface S. So if I have a conductor like this let that through it suppose two conductors are there perpendicular to this plane. So one is coming out another is going in and this surface total surface we are considering and the contour let us say the contour is this C. So there we know the and the surface is this surface this open surface is S. So this law clearly tells us that a magnetic field can be induced around a contour by either conduction current or displacement current that penetrates in or out of this open surface. So in this case the if conduction current is penetrating the surface then there will be a magnetic field induced in the contour. So every if I draw various such surfaces in every contour I will get an magnetic field. If displacement current is not present then the induced magnetic field is directly related to the conduction current density that is penetrating the surface.



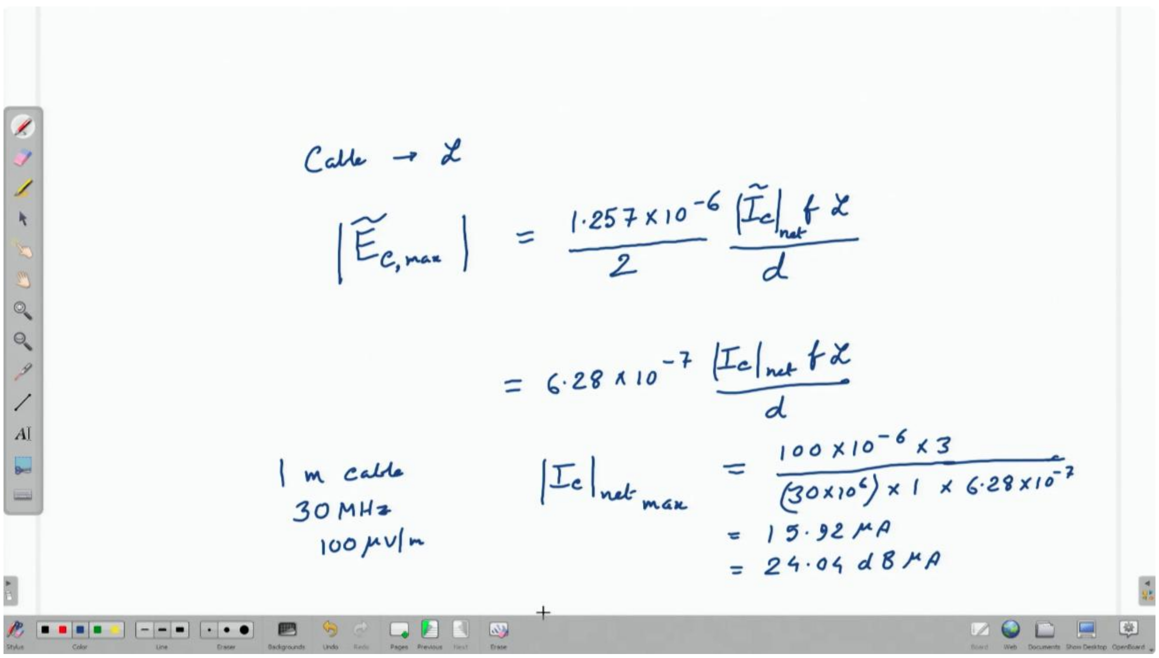
Now current probes they use this principle to measure the current let us see their construction. So it is simply a circular type of core made of ferromagnetic materials you know in magnetic circuits these are used this core to concentrate the current and here there is a clip sort of thing and here there is a hinge sort of thing. So this is a hinge there is a clip. So actually this whole thing can be divided into two halves so semicircular halves. So this is the hinge part and from this clip if you open the clip you can take away those two parts if you close the clip they gets combined together. So that means current probe so let me say that this is the structure of a current probe so is constructed from a core of ferrite material that is separable into two halves which are joined by a hinge and closed with a clip. Now to measure the current the clip is opened the core is this whole core now placed around the wires whose current is to be measured so inside the current is placed current carrying conductor is placed and the clip is closed. So we know a time varying magnetic field is produced in the core that as we have seen the ferrite core is used to concentrate the magnetic flux I have already said that. Now how to measure that magnetic field for that we take the help of another Maxwell's equation which is generally also known by Faraday's law that the line integral of electric field is we know so that means this magnetic field that produces time varying magnetic field will produce a EMF or voltage in the circuit so it produces an electric field that electric field around the contour if we take the line integral of that that is our voltage. To collect this EMF what is done that this there are some coil wound on part of the current probe and that is taken to a voltage measuring instrument that may be a volt meter or may be a spectrum analyzer etc. So we can say that basically this means there is a ZL here that means some impedance is there to measure this. So I can say that it is this voltage that is measured in these two ports. So this voltage can be measured and it is proportional to the conduction current because we have seen that magnetic field is proportional to the conduction current now through this law this measured voltage the EMF that is also proportional to this magnetic field so that means the this EMF is proportional to the conductant current. So from that the current can be measured conduction current but what are the this probe this coils this etc. So it needs a calibration simply if we calibrate that for a given amount of current what is the voltage we can then extrapolate that because all the things are proportional so what we do? So that means there is a current here either this or this whatever the direction so we pass a known current for calibration we pass a known conduction current through the current carrying wire and we see the voltage so we can find the transfer impedance J t of the probe as V by let me call this I so V by I we are calling it transfer impedance because it is transferring our input is I and output in input port we have I in output port we have V so this is called transfer impedance it unit will be open. Now manufacturers of the current probe they give you this calibration chart generally they give it over frequency so they give it J t versus A usually it takes the form of these now generally there is a band of frequency where that transfer impedance is constant also generally it is given in dB scale and usually they give this calibration chart with a ZL is equal to 1 ohm so you can now extrapolate that if you have any other ohm generally if you use spectrum analyzer it will be 50 ohm so you can easily extrapolate that.



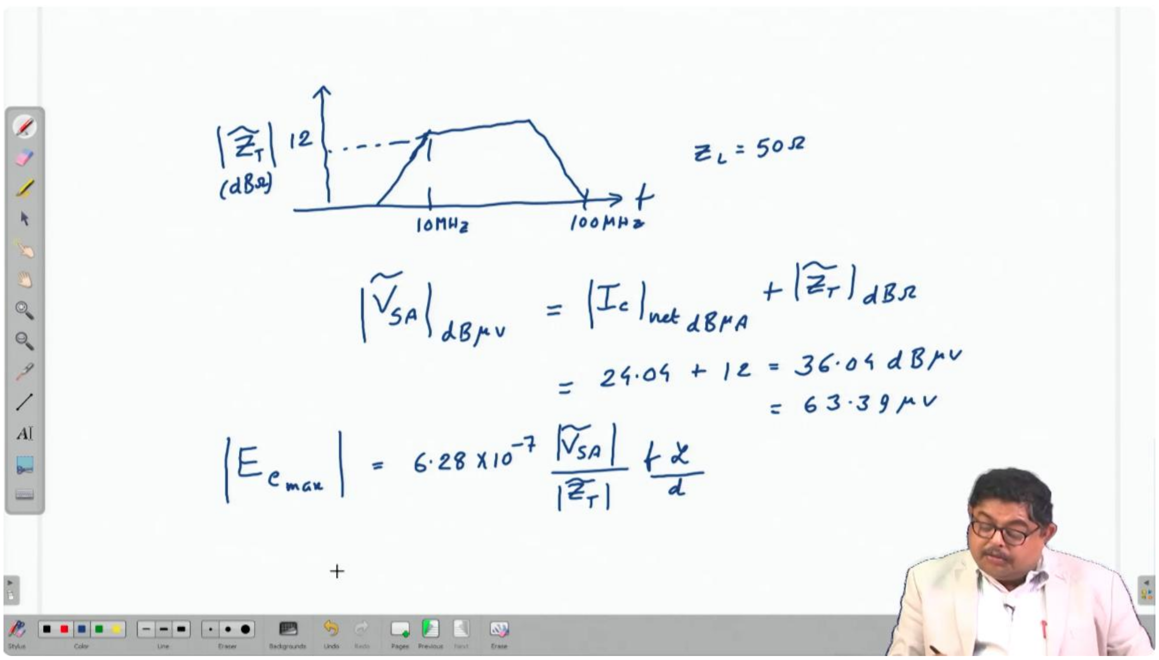
Now so in dB scale we can write that G t dB ohm will be V dB micro volt minus I dB ohm will be V micro ampere the current probe measures only the total common mode current because a two wire system that means suppose you have a two wire system so the differential mode current they will produce the magnetic field in opposite direction so their emf will also cancel but common mode current for them the magnetic field is in the same direction so current probe will measure only the common mode current so you see you can measure the common mode current by this current probe that is the beauty. If you want to measure the differential mode current then do not use that put the only one conductor inside either this or that and then it will measure the differential mode current you require.



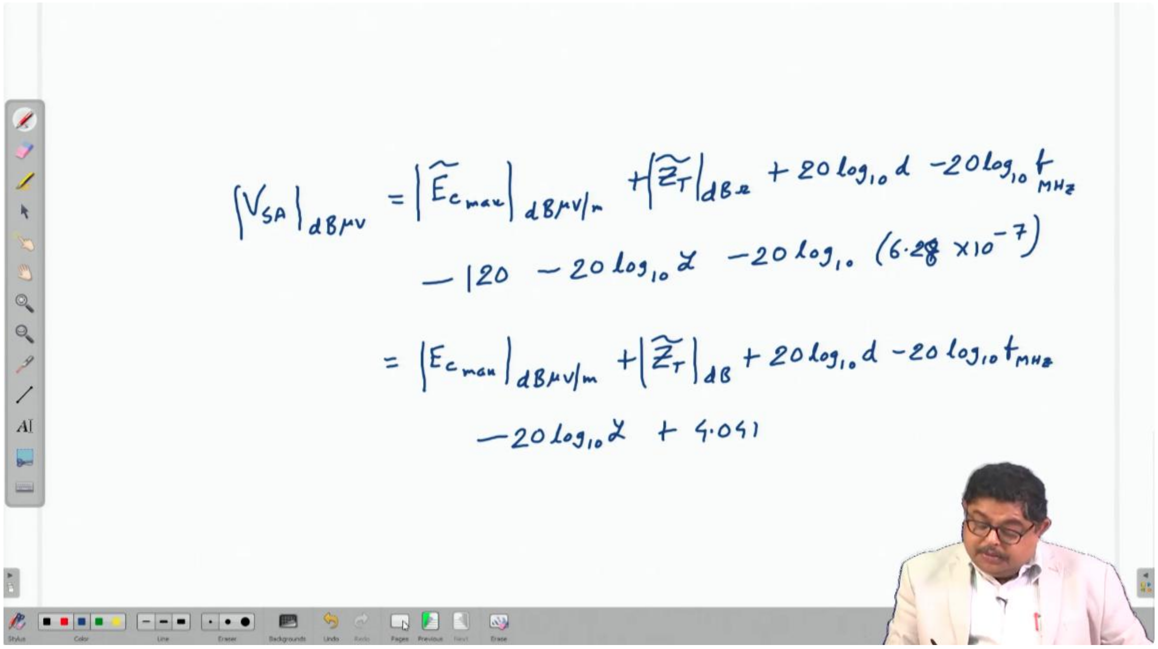
Now let us see some related to with our already emission model that we developed so suppose the current probe is clamped around a cable of a product we want to measure what is the cable sending what is the I c it is sending or what is the I d it is sending so around a single cable we want to say and generally we want to see the common mode current because differential mode current is more or less known so let us say the current cable its length is L now so what will be our E c max for this this is a single cable but our E c max expression was 1.257 into 10 to the power minus 6 I c phasor magnitude f L by D this was we derived but that was for a two-wire system so what we do if we have a single wire we just divide it by 2 because emission will be half of the two so this so that means now we can call this is my I c net of one cable so this is 6.28 into 10 to the power minus 7 I c net f L by D this equation can be solved to give the maximum permissible current for a regulatory limit. For example suppose we use the previous problem the probe is clamped around a 1 meter cable and the probe voltage is made measured at 30 megahertz and we know the in previous problems we have taken the FCC class B limit for emission so class B limit at 30 megahertz was 40 dB microvolt that was 100 microvolt per meter so we can now solve for the permissible common mode current that means what is the common mode current that is permissible so that will be I c net you can say maximum that will be 100 into 10 to the power minus 6 into 3 by f is 30 into 10 to the power 6 the length is 1 and then you will have to bring that 6.28 into 10 to the power minus 7 so if you do this it will be 15.92 micro ampere or if you convert it to dB it will be 24.05 dB micro ampere.



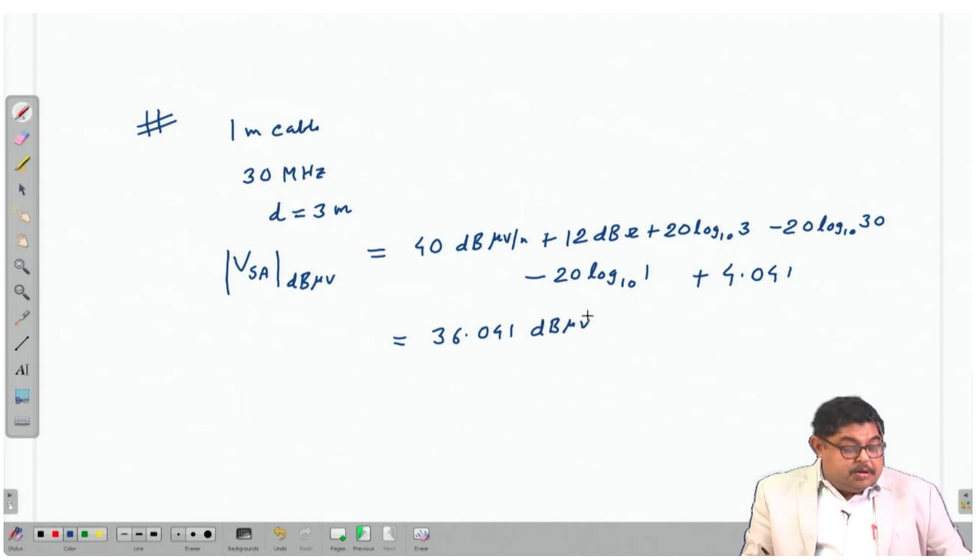
So now we can directly include the transfer impedance of the probe so suppose the one manufacturer has given like this that the calibration chart for the current probe is in dB ohm it will be given so let us say that so let us say 10 megahertz this is what you see this is 100 megahertz and this value let us say it is 12 dB ohm so we can say that V of spectrum analyzer and let us say that already this graph assumes ZL is equal to 50 ohm. So VSA that means spectrum analyzer voltage micro volt is nothing but I c net in dB micro ampere plus J t dB ohm so I c net we have got 24.04 dB micro ampere plus 12 that is 36.04 dB micro volt or if you convert to absolute value it is 63.39 micro volt that means if we measure by the current probe and find that the spectrum analyzer voltage is more than 36.04 dB micro volt then we know that I c has crossed the limit so it would not pass the FCC test. In fact the current probe is an useful EMC tool for diagnostics throughout the design phase of a product simply one can measure the net common mode current on each subsystem or each peripheral cables of a product or a prototype of the product in the lab using the current probe and suppose that has not passed the test you can suppose you have then in the design stage applied some fix maybe you have put a toroid or some other things and then you want to measure again instead of going to an echelon chamber and for measurement etcetera you just with the help of the current probe can measure it. So it is a very useful way for measuring current and we can incorporate this VSA in our EC max equation so with that we can write that because directly then we can relate to the this measurement voltage instead of current we can measure keep this VSA in our equation. So we know that EC max is given by 6.28 into 10 to the power minus 7 now instead of IC net I can say VSA by Z t f into L by d .



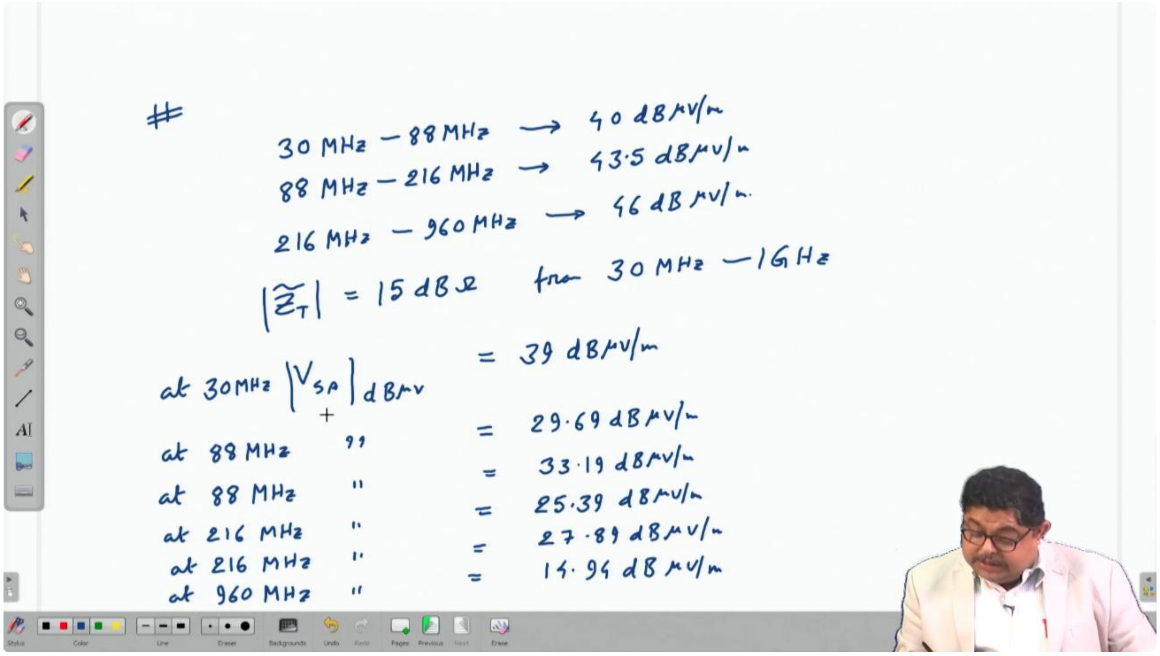
now if I convert this to dB I get VSA dB minus micro volt is equal to EC max dB micro volt per meter plus Z t dB ohm plus 20 log 10 d minus 20 log 10 f now it is useful instead of putting f in hertz in the equation actually it is in hertz let us make it in megahertz so that I need to subtract for that a minus 120 that will do the job then for L it will be 20 log 10 of L and then finally, that multiplier constant 20 log 10 6.28 into 10 to the power minus 7 so this will be the result so finally, if I absorb all these numerals so it will be EC max in dB micro volt per meter this EC max is the regulatory log 10 d minus 20 log 10 f megahertz minus 20 log 10 L and then if you do all those things that minus 120 minus 20 log of this you will get a plus 4.041 so with this you can easily find out the thing.



So suppose consider a 1 meter cable again the same previous problem 1 meter cable and a calibration chart as we already shown that means from 10 megahertz to 100 megahertz it has got a 12 dB ohm transfer impedance and in 30 megahertz we need to comply with that 40 dB micro volt per meter at 30 megahertz and measurement distance for all class B limits are 3 meter so if you put all those in the equation VSA dB micro volt that will be 40 dB micro volt per meter dB micro volt per meter plus 12 dB ohm plus 20 log 10 3 minus 20 log 10 simply 30 now because it is in megahertz minus 2 ,1 meter cable so log 10 1 plus 4.041 that will give me 36.041 dB micro volt. So by comparing the spectrum analyzer reading with the regulatory limit one can conclude whether the product complies or not.



Now think of let us take a more realistic problem that meeting class B limit of so you know that class B limits are between different frequency zones so 30 megahertz to 88 megahertz the class B limit is 40 dB micro volt per meter I could have shown you the chart but I am writing it once again from 80 megahertz to 216 megahertz it is 43.5 dB micro volt per meter and from 216 megahertz to 960 megahertz it is 46 dB micro volt per meter and let this time the probe transfer function is ZT is 15 dB ohm a new probe 15 dB ohm constant from 30 megahertz to 1 gigahertz. So that will do all the measurements possible so we can say that you see that every frequency is coming twice with a new EC max because in one range this is this in another range this is this so we can say that at 30 megahertz VSA if you calculate VSA dB micro volt it will be 39 dB micro volt per meter in previous problem you have calculated it to be 36 now the transfer impedance has increased by 3 dB that is why 39 dB micro volt at 88 megahertz it will be the same VSA will be 29.69 dB micro volt per meter again at 88 megahertz for the lower frequency of the upper limit this will be 33.19 dB micro volt per meter at 216 megahertz this will be 25.39 dB micro volt per meter at again 206 is a border line so at 216 megahertz it will be 27.89 dB micro volt per meter and at 960 megahertz it will be 14.94 dB micro volt per meter. So you can easily draw and you know the EC max frequency dependence or VSS frequency dependent is with f that means with minus f you can see the where is that minus 20 log 10 that your let me go to one more previous yes where is log yes minus 20 dB per decade.



so that means the graph will be looking something like this if I put VSA as dB micro volt then it will be 39 then there will be a 33 then there will be a 30 then there will be 25 then there is a 15 and in frequency it will be 30 f in megahertz so 30 is going to 88 is going to 216 is going to 960 so the graph will be from 39 it is coming to almost 30. it will be a minus 20 dB slope then you see at 88 there is it is again coming up 33 you can say so it will go up to 33 and then again we will start at 216 it is going to 25 so that means so it will come up to here then again it will go up go up where at 216 go to almost 28 so something like these and then at 960 it is coming to 15 so this is the curve you can prepare and you measure at whatever frequency you want to measure if it passes if it is below this level then the product passes otherwise the product fails so that subsystem fails and suppose your current probe as before is usable only up to 100 megahertz then what you will do you will simply give these values that same values 100 megahertz so somewhere here then you indicate that current probe not usable this is your 100 megahertz that current probe is not usable so for that you will have to purchase another current probe and you will have to consider the measurement so we have seen non-destructive way of current measurement that will be very useful for you in your whole professional life. thank you.