

E 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

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Lecture 4: EMC Units and Signal Spectrum

Welcome to this 4th lecture on EMIEMC and Signal Integrity Principles, Techniques and Applications. In the 3rd lecture we have discussed various EMC standards particularly FCC and CISPR. Now today we will start with EMC units. So today this lecture we will discuss EMC units and we will also discuss signal spectra. So, in the EMC you see that electromagnetic interference has very small values whereas the source of intended radiation intended operation that may have quite high value. So there is a long gap or long range between the emitted signal and received signal. So you know that whenever the this long range of values are there it is better to use dB scale that is why the EMC engineers always use the various quantities their units in dB scale. So as we have seen that there are apart from voltage current for wireless applications there will be fields electric field magnetic field etcetera also there will be power quantities energy quantities etcetera. So let us see the conversion please remember that for primary quantities like voltage, current electric field, magnetic field etcetera the dB scale is if you want to convert from absolute scale to dB scale you take  $20 \log$  to the base 10 of the absolute value that will give you dB. So suppose I have 10 volts so in dB how do I convert it is a voltage so  $20 \log_{10}(1)$  is 1 so it is 20 dB but I have taken from volt so it is 20 dB volt similarly if I have 100 amperes so it will be  $20 \log_{10}(100)$  is equal to 40 dB ampere.

Lecture 4: EMC units and Signal Spectra

Voltage, current  
Electric field, Magnetic field.

$$20 \log_{10}(\text{abs}) = \text{dB}$$
$$10 \text{ V} \quad 20 \log_{10} 10 = 20 \text{ dBV}$$
$$100 \text{ A} \quad 20 \log_{10} 100 = 40 \text{ dBA}$$

If I have electric field suppose I have 10 volts / meter in dB scale it will be  $20 \log_{10} (10) = 20$  dB volts / meter. So if I convert it to dB it will be  $20 \log_{10} (10) = 20$  dB ampere / meter. Now in case of secondary quantities that means which are products of two primary quantities: power suppose I have 100 watts of power so in dB scale remember this is important that I will have to write 10 the multiplier is 10 not 20  $10 \log_{10} (100) = 20$  dB watt. Now this is the source side now in actual like my receiver may get very small values so suppose I have 1 watt of power so how much power I have in milli watt that is 1000 milli watt if I now convert this 1000 milli watt to dB scale it will be this is power so  $10 \log_{10} (1000) = 30$  dB m , dBm is an unit for power but the reference is milli watt. Similarly if I have 100 micro volt what is in dB scale  $20 \log_{10} (100)$  so it is 40 dB micro volt that is why if you have noticed that if I have 100 micro volt / meter of electric field then in dB scale it will be  $20 \log_{10} (100) = 40$  dB micro volt /meter.

Handwritten notes showing conversions to dB scale:

$$10 \text{ V/m} \xrightarrow{\text{dB}} 20 \log_{10} 10 = 20 \text{ dB V/m}$$

$$10 \text{ A/m} \xrightarrow{\text{dB}} 20 \log_{10} 10 = 20 \text{ dB A/m}$$

$$100 \text{ W} \xrightarrow{\text{dB}} = 10 \log_{10} 100 = 20 \text{ dBW}$$

$$1 \text{ W} \rightarrow 1000 \text{ mW} \rightarrow 10 \log_{10} 1000 = 30 \text{ dBm}$$

$$100 \mu\text{V} \xrightarrow{\text{dB}} 20 \log_{10} 100 = 40 \text{ dB } \mu\text{V}$$

$$100 \mu\text{V/m} \xrightarrow{\text{dB}} 20 \log_{10} 100 = 40 \text{ dB } \mu\text{V/m}$$

So now this is true for any quantities actually any primary quantity suppose I have 100 rupees I can say that I have 40 dB rupees of money. So if we are to ask that find 20 milli volt in dB micro volt what will be the answer so it is a voltage so I will have  $20 \log_{10} 20$  milli volt means actually I have 20000 micro volt since it is asked that convert it to dB micro volt so how much it will be for  $10^4$  ,I will have 4 so 80 and then for log 2 it is how much 1.4 so if you do it will be 86 dB micro volt. Similarly 50 micro volt in dB milli volt you used your calculator so it is milli volt so I have  $20 \log_{10} 10$  then convert 50 micro volt to milli volt that means 0.05 so if you convert log of 0.05 that will be - 26 dB milli volt . 100 milli ampere in dB micro ampere this we have already seen this is 100 dB micro ampere .30 watt in dB watt so it is  $10 \log_{10} 30$  is equal to so here you required to calculate log 3 also so it will be 14.77 dB watt and if someone ask that convert it to dBm

so I will have to add 30 so 44.77 dBm .300 microwatt in dBm so it will be  $10 \log_{10} 300$  microwatt means it is 0.3 milli watt so this will give me -5.23 dBm.

$20 \text{ mV in dB } \mu\text{V} = 20 \log_{10} 20,000 = 86 \text{ dB } \mu\text{V}$   
 $50 \mu\text{V in dB mV} = 20 \log_{10} 0.05 = -26 \text{ dB mV}$   
 $100 \text{ mA in dB mA} = 100 \text{ dB mA}$   
 $30 \text{ W in dBW} = 10 \log_{10} 30 = 14.77 \text{ dBW}$   
 $\phantom{30 \text{ W in dBW}} = 44.77 \text{ dBm}$   
 $300 \mu\text{W in dBm} = 10 \log_{10} 0.3 = -5.23 \text{ dBm}$

The reverse also is sometimes necessary that you have let us say 60 dB micro volt per meter that means this is an electric field so that means how I will have to do so I will have to take what  $10^{60}/20 = 1000$  micro volt / meter so that is 1 milli volt / meter so this is the absolute value so 60 dB micro volt /meter means 1 milli volt / meter suppose I have 120 dB micro volt per meter so it is how much again it is electric field so  $10^{120}/20$  all 10s are because of base 10 this is how much it is  $10^6$  micro volt per meter that is nothing but 1 volts /meter . suppose I have 30 dB milli volt so it will be  $10^{30}/20 = 10^{1.5}$  that is 31.6 milli volt . I have 66 dBm it is in absolute value it is  $10^{66}/10 = 3981$  watt you see such a huge amount of power it is 66 dBm so that is about the units also there will be cable loss we will have to calculate the losses etc.

$60 \text{ dB } \mu\text{V/m} \rightarrow 10^{\left(\frac{60}{20}\right)} = 1000 \mu\text{V/m}$   
 $\phantom{60 \text{ dB } \mu\text{V/m}} = 1 \text{ mV/m}$   
 $120 \text{ dB } \mu\text{V/m} \rightarrow 10^{\left(\frac{120}{20}\right)} = 10^6 \mu\text{V/m} = 1 \text{ V/m}$   
 $30 \text{ dB mV} \rightarrow 10^{\left(\frac{30}{20}\right)} = 31.6 \text{ mV}$   
 $66 \text{ dBm} \rightarrow 10^{\frac{66}{10}} = 3981 \text{ W}$

So I think you can recall from your electromagnetic theory class that power loss how it is given power loss means  $p_{avg}$ . let us say that the cable is like this this is z direction this end is  $z = 0$  this is your  $z = L$  so power loss is  $P_{avg}(Z=0)/P_{avg}(Z=L)$ . you see it is loss that is why this side power is more power is flowing like this so  $P_{avg}(Z=0)/P_{avg}(Z=L)$ . otherwise it is actually attenuation but when I am writing power loss it is this power by this power now that means I can say it is  $p_{in}/p_{out}$  and we know that if the waves attenuation constant is  $\alpha$  then this is given by  $2\alpha L$ , so power loss is  $e^{2\alpha L}$  where  $L$  is the distance traversed by the wave and is the attenuation constant of the wave so in dB scale power loss is given by  $2\alpha L$  plus in dB will be power is a secondary quantity so  $10 \log_{10} e^{2\alpha L}$  so that is  $20 \alpha L \log e = 20 \alpha L \times 8.686$ ,  $\log e$  is 8 point 686 so this is the expression for power loss in dB. In industry voltage currents of test and measuring systems are specified in terms of their RMS value and generally if nothing is said actually industry also makes the measuring instruments impedances like source a power source impedance a spectrum analyzers impedance etcetera are generally made 50 ohm if it is not it will be specified. So these are about the units.

$$\text{Power loss} = \frac{P_{avg}(z=0)}{P_{avg}(z=L)} = \frac{P_{in}}{P_{out}} = e^{2\alpha L}$$

$$\text{Power loss (dB)} = 10 \log_{10} e^{2\alpha L} = 20 \alpha L \log_{10} e = 20 \alpha L \times 8.686$$

Diagram: A horizontal line representing a cable with an arrow pointing from  $z=0$  to  $z=L$ . Below it, a separate arrow points to the right and is labeled  $z$ .

now let us go to the question of signal analysis which will lead us to the signal integrity problem. So first I will just refresh your memory about the signal spectra because EMC engineers have some innovative ways of finding the signal spectra so before that I just recollect what we learnt about Fourier analysis in your signals and system classes so some of that I will take and show you that it is quite difficult to find those spectra if the things become complicated like industrial signal sources for them finding the spectra is quite difficult but there is an innovative way that we will find to find the spectra. then we will start developing the source model. So let us first consider a periodic signal. periodic signal with a signal that is period  $T$  you know that we are mainly concerned with clock

signal and clock is not a sinusoidal signal it is a discontinuous signal so the I first start with a very simple clock with period T. Let us say the amplitude in the on time is A amplitude in the off time is 0 so we know that this signal is a rectangular clock signal and its spectrum will be come from Fourier series. it is a discrete spectrum Fourier series will give us that so we know the Fourier coefficients.

Signal Analysis

Periodic signal with period T

$$C_0 = \frac{1}{T} \int_{t_1}^{t_1+T} x(t) dt$$

$$= \frac{1}{T} \int_0^{\tau} A dt = \frac{A\tau}{T}$$

$$C_n = \frac{1}{T} \int_{t_1}^{t_1+T} x(t) e^{-jn\omega_0 t} dt$$

$$= \frac{1}{T} \int_0^{\tau} A e^{-jn\omega_0 t} dt$$

$$= \frac{A}{T} \frac{1}{-jn\omega_0} \int_0^{\tau} e^{-jn\omega_0 t} dt$$

$$= \frac{-A}{jn\omega_0 T} (e^{-jn\omega_0 \tau} - 1)$$

$$= \frac{-A}{jn\omega_0 T} e^{-jn\omega_0 \frac{\tau}{2}} (e^{-jn\omega_0 \frac{\tau}{2}} - e^{jn\omega_0 \frac{\tau}{2}})$$

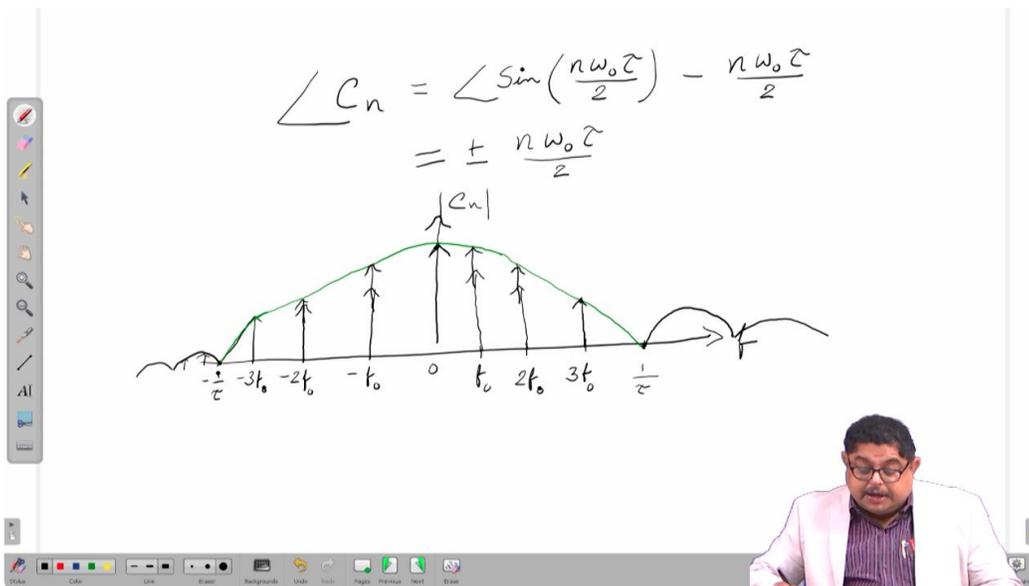
$\omega_0 = \frac{2\pi}{T}$

This is to make it more compact.

$$\begin{aligned}
 C_n &= \frac{A}{jn\omega_0 T} e^{-jn\omega_0 \frac{\tau}{2}} \sin\left(\frac{n\omega_0 \tau}{2}\right) \times 2j \\
 &= \frac{2A}{n\omega_0 T} e^{-jn\omega_0 \frac{\tau}{2}} \sin\left(\frac{n\omega_0 \tau}{2}\right) \\
 &= \frac{2A}{n2\pi} e^{-jn\omega_0 \frac{\tau}{2}} \sin\left(\frac{n\omega_0 \tau}{2}\right) \\
 &= A \frac{\tau}{T} e^{-jn\omega_0 \frac{\tau}{2}} \frac{\sin\left(\frac{n\omega_0 \tau}{2}\right)}{\left(\frac{n\omega_0 \tau}{2}\right)} \\
 |C_n| &= A \frac{\tau}{T} \left| \frac{\sin\left(\frac{n\omega_0 \tau}{2}\right)}{\frac{n\omega_0 \tau}{2}} \right|
 \end{aligned}$$

So this is the spectrum you see considerable time and effort was required to find these now  $C_n$  is a complex number because of presence of this  $e$  to the power term so it will have magnitude and phase so at discrete points that means multiple number of  $\omega_0$  it will have magnitude where I am giving magnitude here also because  $\sin$  may have positive or negative things.

similarly it will have phase so phase will be that phase of  $\sin$  because  $\sin$  is positive or negative so it will have.



so I can plot the magnitude spectrum, if I plot it versus frequency so this is my  $C_n$  this is magnitude spectrum so at it will be this at 0 then at next component will come at  $f_0$  naught the next component  $2f_0$  the next component  $3f_0$  etcetera ultimately depending on the value so this will be like this will be reducing this will be further reducing and similarly here. So it is a the envelope is sinusoidal but the spectrum is discrete. all are discrete spectrum these are  $-f_0, -2f_0, -3f_0, -1/T$  etcetera so this is the magnitude spectrum and the phase spectrum  $C_n$  versus  $f$  that will be this so this will be the phase spectrum. So this will be repetitive and magnitude and phase spectrum of the rectangular periodic pulse is like this we will discuss more on this next day so today we can end here thank you.

