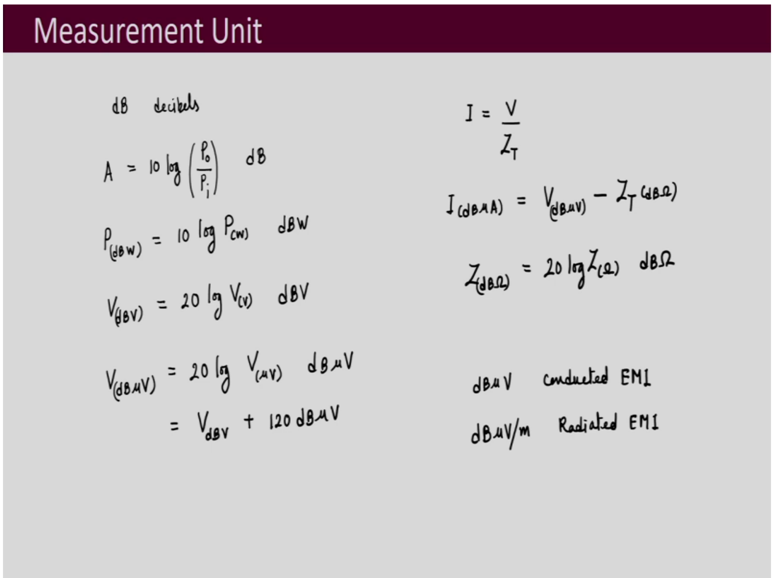
Design of Power Electronics Converters
Professor Doctor Shabari Nath
Department of Electronics and Electrical Engineering
Indian Institute of Technology Guwahati
Lecture 55
EMI Measurements

Welcome to the course on Design of Electronic Converters. We had started with the module of introduction to electromagnetic interference and in the last lecture I had given an introduction. Those are electromagnetic interference and its different types and the frequency range, it's importance from perspective of EMI. Now, let us go further and let us see how it is measured.



EMI is measured with the unit of *dB*. You may be already familiar with this unit. This is a logarithmic unit. So, if we have output power P_o and input power P_i, then

$$A = 10\log\left(\frac{P_0}{P_i}\right) \quad dB$$

So, now, this is a ratio. But then if we want to express the power in *dB*. We have power in *W*. So, that will be

$$P_{(dBW)} = 10\ \log P_{(W)} \quad dBW$$

So, we know that power is proportional to V^2. So, if you want to write voltage in *dB*, that will be

$$V_{(dB\mu V)} = 20\ \log V_{(\mu V)} \quad dB\mu V$$

Now, for EMI purpose it is basically noise measurement and those are very small voltages. So, that unit will be *dBμV*.

Now if we are going to measure in *V* and if we know *dBV*, that will

$$= V_{dBV} + 120\ dB\mu V$$

Now, you might have already guessed it from where this *120* is coming. Because when you convert the ratio of *V* to *µV* into *dB*, that will be *120*. So, that's why we are adding *120* to it and this is logarithmic unit. So, multiplication will become addition. Then, further if we want to express current, now the current is voltage by the impedance.

$$I = \frac{V}{Z_T}$$

So let us say this is Z_T, the transfer impedance. For probe current probe you may be using the termination impedance. So, if we want to express this in *dBµA*, that will be given as

$$I_{(dB\mu A)} = V_{(dB\mu V)} - Z_{T(dB\Omega)}$$

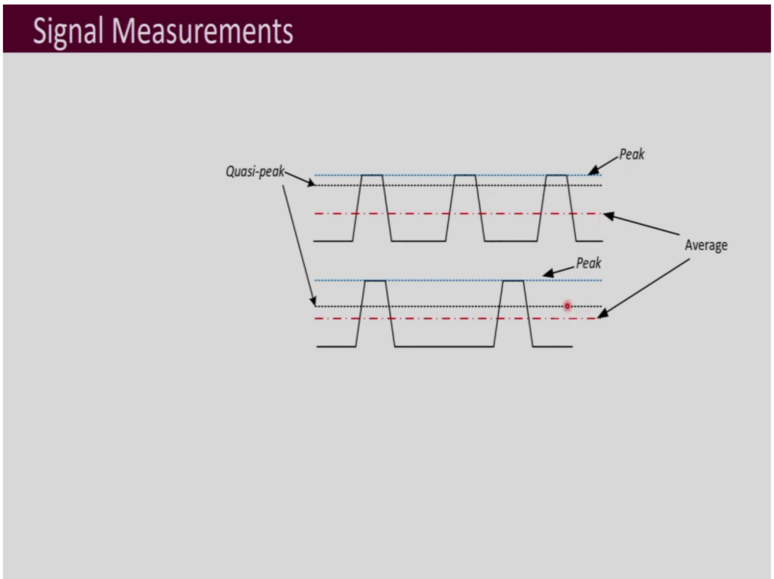
What is this *dB*Ω? So, that is

$$Z_{(dB\Omega)} = 20 \log Z_{(\Omega)} \quad dB\Omega$$

The unit is *dB*Ω. So, these are the measurement units, like *dB*, *dBµV*, *dBµA* or *dBµW*. The units for impedance will be generally *dB*Ω.

If we have conducted EMI being measured, it will be mostly *dBµV* because it is transferred through cables and the noise in the voltage can be measured. Then also if you wish, you can calculate the corresponding current using the impedance of the probe that you are going to use for measurement.

Further it may be *dBµV/m*, when it is radiated EMI. Because those are mostly electromagnetic fields which are going to be measured using antennas and so, this per meter is going to come. It is not only just going to be the voltage measurement, but per meter or the per unit distance part will also come in the measurement unit.



Now, we sa the unit of the measurement. But what are the quantities of a signal which needs to be measured for EMI? So, let us say we have two signals, this is one signal and this is another signal. So, we can measure the peak of these signals using some peak detectors. So, we can have a peak being measured.

Now, the peak is going to be the same for both of them because the peak value is same and we can also measure the average of these signals. That means you can record the full signal in the oscilloscope and then from that you can calculate the average. So, for a certain time period, we see that the average of both of these two signals are also same. So, if we just measure peak and if we measure average, although both of these two signals are different, the signal quantities which we are measuring they will give us the same value. So that means these two quantities are not sufficient for measurement, because we have to distinguish these two signals. These two signals will create different types of interferences. So, you might be familiar with (RMS) root mean square.

So, root mean square of the signal is

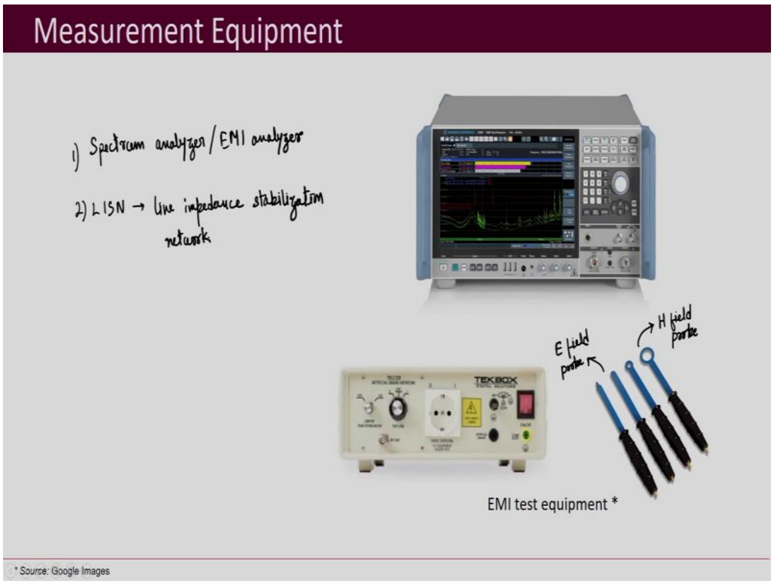
$$V_{RMS} = \left[\frac{1}{T}\int_0^T v^2\, dt\right]^{\frac{1}{2}}$$

So that is RMS quantity which we talk about.

Now, this is mostly associated with the heating effect, where it is RMS value. Now RMS value is used in power engineering a lot. Now, that value is not measured here. We are not talking about the heating effect here. But we are talking about its capability to create disturbance with other systems on the same system. So, it is the peak or the transients which are more important for us to observe or its frequency has to be noted down. So, for that there is another term which is used, is called quasi peak and this is another quantity. Now, this is something like RMS but it is not RMS quantity.

So, this is basically dependent on how many times we have the peak coming in and also associated with the value of the peak. So, you can see here, that the quasi peak will be detected by the instrument which you will be using. That will be of this level for this signal.

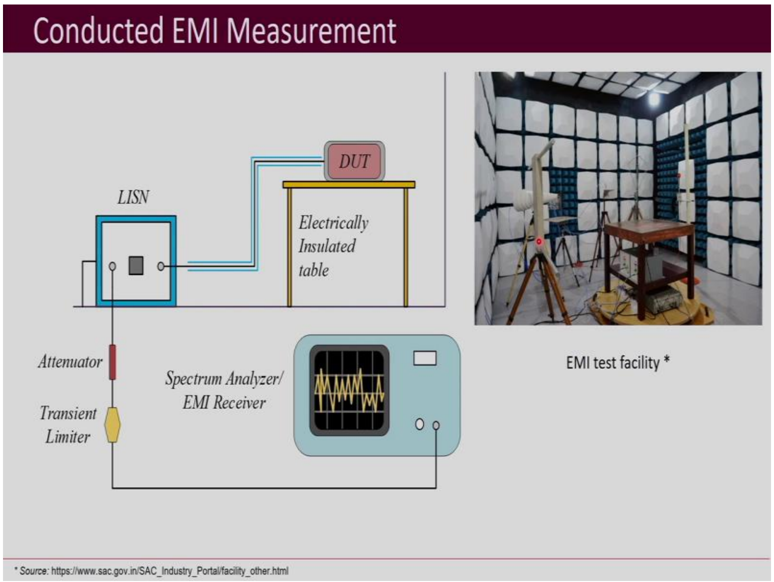
For this second signal, the quasi peak will be detected lower because here the number of times of the peak is coming lesser than this. So, in this way you can use the quasi peak quantity, and you can distinguish between these two signals. So, the peak, quasi peak and average are the three quantities which may be measured for EMI.



Now, what are the measuring equipment? So, first you see that here is a spectrum analyser. Sometimes people also call it as EMI analyser. This is the equipment. So, what it is measured? This spectrum analyzer or EMI analyzer is going to measure only the noise or the disturbance voltages with respect to the frequency, or for different frequencies the level of the disturbance.

Then further there are different types of probes, which are used for EMI measurements. So, these are called as near field probes and this is used for measuring the magnetic fields. So, it is also called as the H field probe. Then these are the E field probes that is measuring the electric fields. So, these kinds of probes are also used for EMI testing and measurement.

Then further this is the picture of a LISN, Line Impedance Stabilization Network. Now, it's action is like that of a filter. It does not let the disturbance or the noise coming from the supply side to enter into the device and this is going to be tested and it does not let the device noise go to the supply. So, its action is similar to that of a filter.

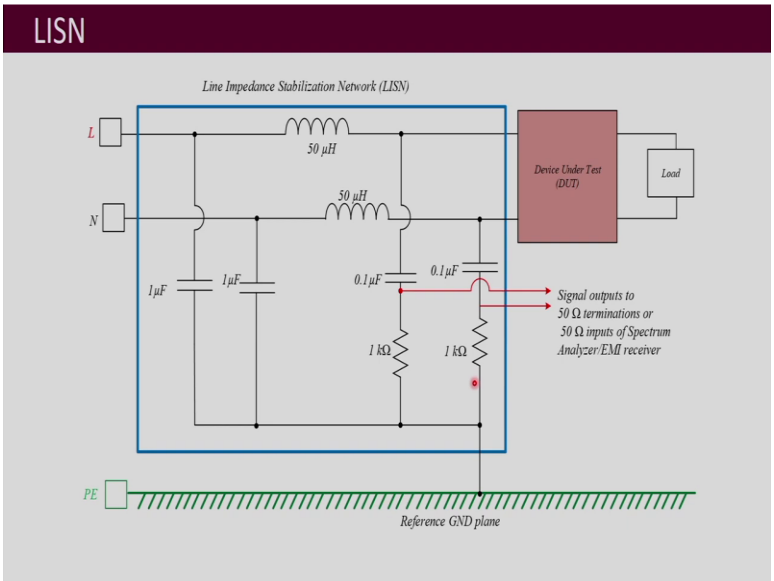


Now, let us see how do we test it. So, this is a picture of EMI test facility. So, this is the table. Here this device which is going to be tested, is kept and then these are LISN, line impedance stabilization networks and the source is actually outside this room. So, this room is called as the screen room or a shielded room. So, this is the room which is completely shielded from any sort of electromagnetic wave. There is no possibility of entering it.

So, for example, if you enter in these kind of screen rooms with the cell phones, you will not be getting any signal. So, it is a completely electromagnetically shielded room and supply is in outside. Through wires it comes, and it goes to the LISN. So, this picture shows you that supply maybe in outside. It first goes to the LISN and then it goes through the LISN to the electrical connection.

So, the cables reaches to the device which has to be tested. DUT is device under test and this is an electrically insulated table and this actually shows the screen room and then to the probes these measurements of the LISN can be done and then actually this is the spectrum analyser, which is also kept outside the screen room.

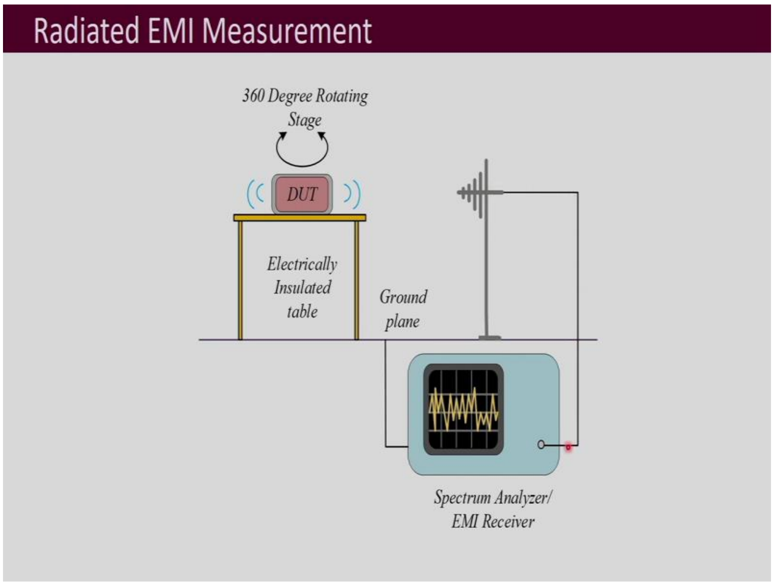
Further, this is for conducted EMI testing, where we do not need antennas, and when we will be measuring radiated EMI, then we will be needing antennas. So those antennas can also be kept inside the room. So, here you can see that in this picture different types of antennas are kept. So depending on the requirement, the type of antenna can be chosen and that particular antenna can be kept and then that can be used for testing the radiated EMI.



So, this is the diagram of inside LISN. So as I told you, it is something like a filter. So here you see that this is like a CLC filter. So this is the supply which is going to come through L and N points, then this part will be filtering out. The noise may be coming from there and it would not let it go to the device which is under test and the high frequency noise may be generated by the device that will be confined by these capacitors in this area.

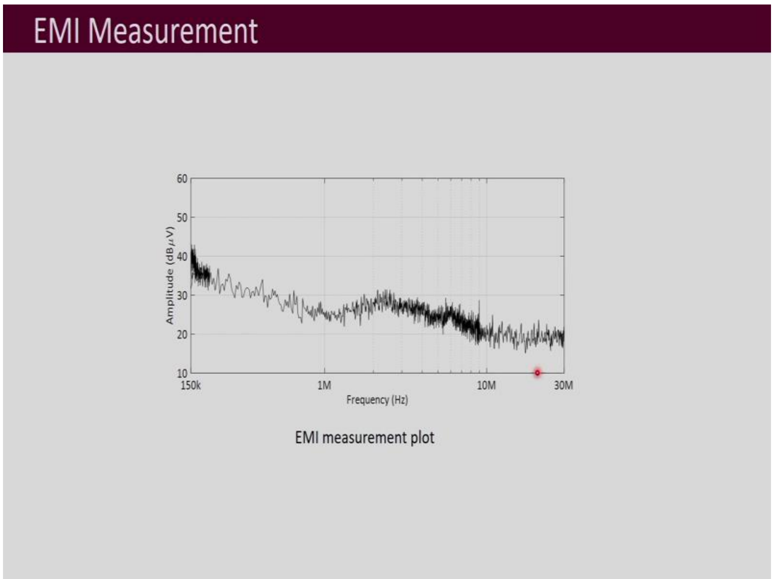
So, then the corresponding voltages can be measured at this point and then these are the ones which are connected to the probes and then it go to the spectrum analyser. The probes that we use, are usually a $50\ \Omega$ termination. So, it is always intended that the impedance seen by the probes over here because of the LISN is also $50\ \Omega$.

So, then there will be no reflection in the signals and of course, you would like to measure all corresponding to the ground plane which is Earth there and also the differential voltages that may be present. So, that's why this is also connected to this point. This is connected to ground which is inside LISN and this is used for the measurement of conducted EMI.



Then in radiated EMI, I already explained you some part of it. So, inside the screen room we will keep the antenna and the antenna has to be chosen properly. The type of antenna required for the corresponding radiated EMI measurement depends on the standards which we want to pass and in that it is specified about the antenna to be used for the measurement and further you keep the device under the test on the table and the device can be kept in different angles that means you can rotate the table and keep the device at different angles with respect to the antenna.

The antenna here it is shown as a vertical, but it need not be always vertical. The antennas position might also be changed. It can also be kept in the horizontal position and then also the measurements can be made. So, the induced waves here are received by the antenna. So, then through the probes, they are taken out of the screen room and then they are measured by the spectrum analyzer. So, in this way radiated EMI measurement takes place.



So, you will be obtaining in a radiated or conducted EMI measurement something like this. You will be getting amplitudes in *dBμV*. Now I have shown you here that this is used for conducted EMI.

So, that's why this is *dBμV*. If it is for radiated, the unit will become *dBμV/m* because in radiated EMI distance plays an important role. How far we are keeping the antenna from the source, is important. So, antenna may be kept at *3 m* distance or *5 m* distance or *10 m*. Whatever the distance may be specified, on that distance the measurement is being done. So, that distance has to be accounted for. So, it will become *dBμV/m*.

So, then I had already shown you the frequency range in the last lecture for conducted EMI which is *150 kHz* to *30 MHz*. So, you may be doing these measurements and then you may be getting this kind of jittery waveform on the spectrum analyzer.

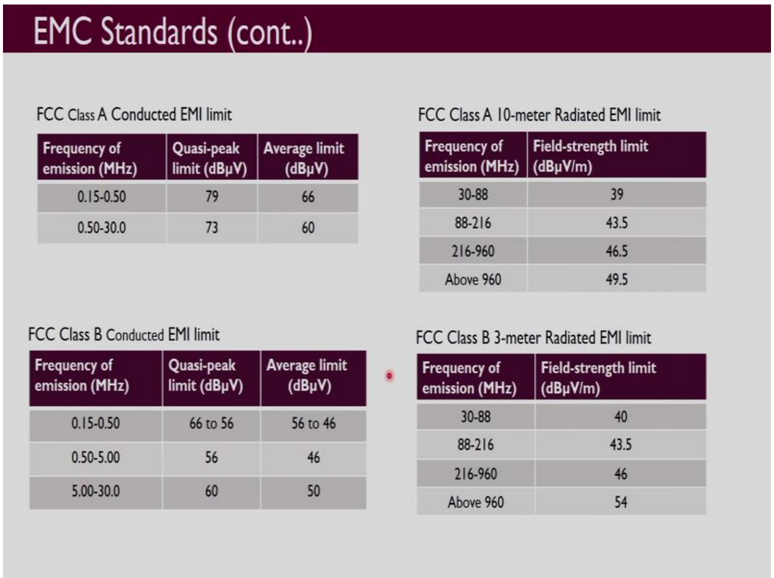
Now, you may be thinking that, all these measurements are done. Then how do we know that whatever you have designed the converter and whatever the system is under test, whether its performance is satisfactory or not, or whether it is going to create the disturbance with others/ itself or not. How do you know that? So, for that there are limits specified by different organizations.

If the measurements are below those limits, you have passed the EMI test. So, EMI test certificates have to be acquired by different product manufacturers. For that they will be able to launch the product in the market. They have to mention the EMC standard that they have followed or they have passed.

So the different organizations which make these EMC standards, many of them are there. So, few of them are listed here. CISPR, this is one international organization which makes the standards for EMC and then another is FCC, Federal Communications Commissions. They also make it. I have just written here names of some of the standards that are made by these organizations.

There may be many of them like here. There is CISPR 25, CISPR 32, FCC part 15. So, there may be different parts that may be specified by the particular standard making organization and that may be one part which may be relevant for one particular type of product. Then European standards is another one.

So, one of their standards is named as EN 55 101. Then ISO standards are there. Then International Electrotechnical Commission is also another organization which makes the standards for EMC and one of their standard is named like IEC 61000. So, again these different names maybe there for different standards, depending on the system for what it is intended. It has to get a certificate for that particular part, a number for which the application is relevant.



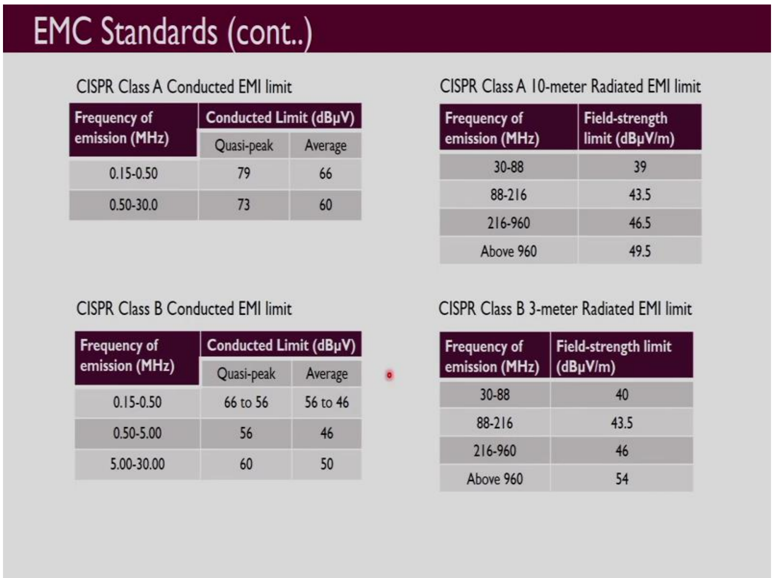
Now, how the standards look like? So, this is shown here. So, this is FCC class A conducted EMI limit. So, you see here that the frequency range is provided first *15 kHz* to this *0.5 MHz*. Here, the limit is given as *79*, which is the quasi peak limit and if you are measuring the average limit, that should come as *66 dBμV* and then for *0.5* to *30 MHz*, it is *73 dBμV* for quasi peak and for average it is *60*.

Further for that same FCC class A 10 meter radiated EMI limit, note that this *10 m* is important because this is radiated EMI limit. So, the distance by the antenna kept for measurement is specified by this. So, for *30* to *88 MHz*, *39* is the limit and the unit is noted down here, which is *dBμV/m*, and for *88* to *216 MHz*, *43.5* is the limit. For *219* to *960* it is *46.5* and above *960* that means close to *1 GHz*, the limit is *49.5 dBμV/m*.

Then, for class B FCC conducted EMI limits, those are also given here. Now, what is this class A and class B? So, class A are the devices or the systems which are going to be used for commercial applications and they may be used in a business environment or in industrial environment and class B are the ones which are going to be used for residential environments. So, obviously, class B limits are more stringent than class A limits.

So, you can compare here that for *0.15* to *0.5 MHz* the quasi peak limit is 66 to 56. Whereas, here this limit was *79* which was higher and also you can see the average which is *56* to *46* and here it was *66 dBμV* in case of class A. Then, for *0.5* to *5 MHz*, *56* is the limit for quasi peak, *46* is for average and for *5* to *30 MHz*, *60* is the quasi peak limit and *50* is the average limit and for class B in this radiated EMI limit the distance given is *3 m*.

So, the antenna that has to be kept for measurement is going to be *3 m* from the device under test. So, here again you can see that similarly the limits are again provided for class B products.



EMC Standards (cont..)

CISPR Class A Conducted EMI limit

Frequency of emission (MHz)	Conducted Limit (dBμV)	
	Quasi-peak	Average
0.15-0.50	79	66
0.50-30.0	73	60

CISPR Class A 10-meter Radiated EMI limit

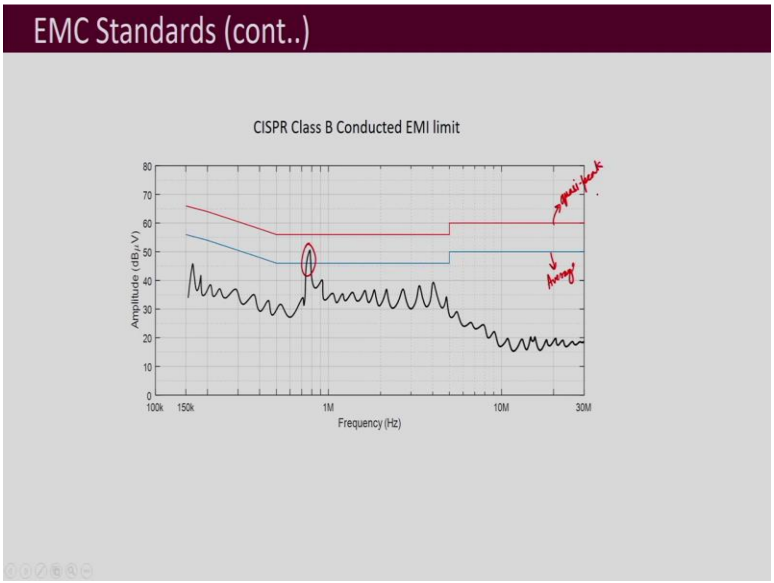
Frequency of emission (MHz)	Field-strength limit (dBμV/m)
30-88	39
88-216	43.5
216-960	46.5
Above 960	49.5

CISPR Class B Conducted EMI limit

Frequency of emission (MHz)	Conducted Limit (dBμV)	
	Quasi-peak	Average
0.15-0.50	66 to 56	56 to 46
0.50-5.00	56	46
5.00-30.00	60	50

CISPR Class B 3-meter Radiated EMI limit

Frequency of emission (MHz)	Field-strength limit (dBμV/m)
30-88	40
88-216	43.5
216-960	46
Above 960	54



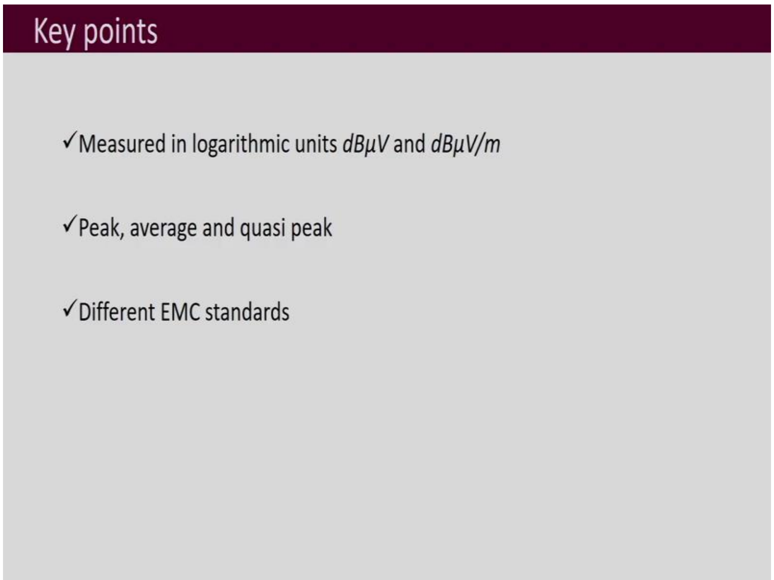
Now, if we plot these limits, because this is shown in the table or it can also be plotted, you will be getting something like this. This is shown for CISPR class B conducted EMI limit. So, the unit is *dBμV*. So, here first it decreases linearly and then this is the limit which is given from *0.5 MHz* to *5 MHz* and then from *5 MHz* to *30 MHz* these are the limits which are given.

So, one is for class A and another is for class B conducted EMI limit. So, average and quasi peak both are given over here. So, this is shown for CISPR class A conducted EMI limit. So, these are similar tables as we saw for FCC limits. EMC standards are given.

So, these were class A conducted EMI limits and class B conducted EMI limits. Here for radiated EMI class A and class B the distances are at *10 m* and *3 m*. The limits are tabulated here. Now there may be small little differences between two standards that you may be following. But, there are many similarities also between them and I already showed you. If you plot it for quasi peak and average, you will be observing the nature of the limit.

So, when this spectrum analyzer or EMI analyzer is used, then you may be observing this kind of waveform. So, you have to see that it is not crossing those standards or the limits that are given. So, for example, here if it is crossing quasi peak and average limit, we see that quasi peak limit is higher and average limit is lower. So, this is for average and this one is for quasi peak.

So, depending on the time-period to measure the quasi peak or the average, you can check the limits there and in the waveform or the frequency spectrum you measure the noise using the spectrum analyser. You can check whether it is crossing at any point those limits or not. If it is not crossing that means you pass the EMI. If you have not, then you have to do some changes in the design or you have to design the enclosure or some EMI filter or you have to do some measures to reduce the noise which is the disturbance being generated by the designed device.



So, the key points of this lecture are that the measurement units are logarithmic units and conducted EMI is measured in *dBμV* and radiated EMI is measured in *dBμV/m*. Then, three quantities are important. One is peak average and a quasi peak limits are given by different organizations. This makes the EMC standards. For that you have to see while testing EMI, whether these are below those limits or not. Thank you.