

Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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Week :01
Lecture 3: EMC Standards

Welcome to the third lecture of the course on EMI, EMC and Signal Integrity Principles, and Techniques. Now, today we will see that what are the restrictions imposed by various agencies for electromagnetic interference for various subsystems that four subsystems or sub class of problems that we discussed in the last class. So, EMC requirements for electronic systems some of the requirements are mandated by governmental agencies for controlling electromagnetic pollution . every government has that agency in our country the controlling agency you know that ISO - Indian Standard Organization they have some of these requirements also for signals our the whole signal spectrum allocation etcetera covered by WPC wireless planning commission.

EMC Requirements for Electronic Systems

- Requirements mandated by governmental agencies:
 - for controlling electromagnetic pollution
- Requirements imposed by the product manufacturer:
 - Intended for customer satisfaction



So, some of the signal problems they also do, but ultimately everything is covered by ISO. Similarly, every manufacturer of electronic system they have their in house EMC requirements because suppose a TV manufacturer has produced a TV, but if a scooter is started nearby that means its ignition plug is made on the there may be a flicker. So, people people will next time say that I would not buy that TV because other TVs they do not have that problem, but my TV has that problem. So, whenever a scooter is started nearby or some of that type of thing lightning goes on my TV has a flicker. So, I get disturbance that is why every manufacturer on their own tried to impose some in house things, but they do not disclose it to outside. So, this is for customer satisfaction.

Requirements for Commercial Products Marketed in the United States

- Federal Communication commission (FCC)
 - Charged with the regulation of Radio and Wire Communication



Now, actually we will be discussing as you know that we are third world countries. So, we always follow whatever America or Europe is doing and for America and Europe there are two different standards. So, first I will discuss the American standards because they were the pioneers in enforcing these requirements on a mandatory basis. Before that it was voluntary basis, but throughout the world USA was the pioneer for making these requirements on a mandatory basis that is why we will first start with that then we will go to Europe. Europe had started work on developing those standards much earlier than USA, but they did not make it mandatory before USA. So, that is why these USA standards created a lot of furrow in 80s. So, that we will see in the passing I may note that our ISO standard is simply a cut and paste of Europe standard not this American standard. Now, we will also see a comparison between US standard and European standard during this lecture. Now, Federal Communication Commission FCC in USA they are charged with the regulation of radio and wire communication. So, since EMI problems mainly come in radio systems also come in wired systems. So, it comes under the purview of Federal Communication Commission or FCC.

FCC Rules and Regulations

- Title 47 of the code of Federal regulations
 - Several Parts applicable to Non-licensed electronic Equipment
 - Part 15 applies to radio frequency devices



So, Title 47 so they have several codes. So, Title 47 of the code of federal regulations you know why it is called federal because throughout the USA this is valid this is part of federal thing. So, this is not part of a single state of California or single state of Michigan etc. So, several parts of this code is applicable to non licensed electronic equipment. You know there are electronic equipment some of them are licensed some of them are non licensed.

For license you will have to take all the permissions, but if you want to play radio you do not require permission. In our country in our childhood even to have a radio you required license even to have a TV you required license even I think within last even 2-3 years back if you want to have a car radio you needed to have a license now for last 2-3 years it has been webbed up. So, the so these Title 47 applies to non licensed electronic equipment and in that Title 47 part 15 applies to radio frequency devices. These FCC regulations are available in website you can go to the website and see it yourself what is that that is why I am giving this thing the Title 47 part 15 they applies to these.

Because of the increasing occurrence of digital system interference with wire and radio communication, the **Federal Communications Commission (FCC)** in the US published a regulation in 1979 that required the electromagnetic emissions of all “**digital devices**” to be below certain limits. The intent of this rule was to try to limit the “electromagnetic pollution” of the environment in order to prevent, or at least reduce, the number of instances of EMI. Because no “digital device” could be sold in the US unless its electromagnetic emissions met these limits imposed by the FCC, the subject of EMC generated intense interest among the manufacturers of commercial electronics ranging from digital computers to electronic typewriters.



Because of the increasing occurrence of digital system interference with wire and radio communication FCC published a regulation in 1979 that required the electromagnetic emissions of all digital devices to be below certain limits. What a digital device is we will see in the next slide. The intent of this rule was to try to limit the electromagnetic pollution of the environment in order to prevent or at least reduce the number of instances of EMI. We have seen various case studies so there were lot of EMI case problems. So, to reduce that number this was done because no digital device could be sold in the US unless its electromagnetic emissions made these limits the subject of EMC

generated intense interest among the manufacturers of commercial electronics ranging from digital computers to electronic typewriters.

The FCC defines a digital device as

Any unintentional radiator (device or system) that generates and uses timing pulses at a rate in excess of 9000 pulses (cycles) per second and uses digital techniques.....

Any electronic device that has digital circuitry and uses a clock signal in excess of 9 KHz is covered under the rule, although there are a limited number exemptions. This rule includes, for examples, electronic typewriters, calculators, point of sale terminals, printers, modems, etc. as well as personal computers.



This is the definition of digital device according to FCC. Any unintentional radiator that generates and uses timing pulses at a rate in excess of 9000 pulses per second and uses digital techniques. That means if any electronic device has digital circuitry and uses a clock whose frequency is more than 9 kilohertz then it will be covered under the rule. So, this rule includes all those things and very importantly your personal computers. Actually if you look at the backside of computers you will see that there is either a symbol of FCC or a symbol of C is written in all the devices your printers your computers your keyboard everything. So, that they are compliant with these rules.

Punishment for violation

- It is illegal to market a digital device unless
 - It's radiated and conducted emissions have been measured and within the limits set by regulations
 - Violators can be fined or jailed



Now this is very important that FCC introduced punishment for violation. In our country till today it is not a punishable thing. If you violate this also there would not be any punishment. But in USA it is illegal to market a digital device unless it is radiated and conducted emissions have been measured and within the limits set by regulations. Violators can be fined or even jailed. So, that is the that is why manufacturers started to comply with this standard.

Classes of Digital Device

- Class A
 - Marketed for use in a commercial, industrial or business environment
- Class B
 - Marketed for use in a residential environment, notwithstanding their use in a commercial, industrial or business environment



Now according to FCC there are two types of digital device class A and class B. Class A is for industrial use, commercial use, business use and class B is for your household use. Class B devices may be also used in commercial thing like your personal computer that is used in industrial environment that is also used in your household things. But it will be called a class B device because it is used in residential environment.

So, anything in class B is residential meant for also residential use. Now can you tell which why this classification? The classification is because the environment, the resources etcetera different in these two classes. Now which one will be more stringent class A or class B?

Class B limits are more stringent

- Interference from the device in an industrial environment can be more easily corrected
- In residential environment emitter and receptor are in close proximity
- Owner of the interfering device in a residential environment has less expertise or financial resource to correct problem



Answer is let us see class B limits are more stringent. The reason is interference from the device in an industrial environment can be more easily corrected. But in residential environment the emitter and receptor are in close proximity. So, there is more chance of AMI. Owner of the interfering device in a residential environment has less expertise. Suppose some AMI problem is coming in your device in your home now you may not have sufficient expertise to handle that or you may not have financial resource to correct for the problem. But in an industrial environment they can have more resources also their distance between emitter and receptor are generally larger etcetera that is why they can easily correct it. So, for them that is why the thing is a bit relaxed but for class B it is stringent quite stringent.

Personal Computers and peripherals

- Subcategory of Class B Digital devices
- They must be tested by the manufacturer and test data to be submitted to FCC for certification
- For all other digital devices, test data need not be submitted to the FCC
- FCC does random checking to ensure compliance



Now personal computers is one thing which is given special emphasis by FCC it is a subcategory of class B digital devices. Now what is special about them you see that they must be tested by the manufacturer and test data to be submitted to FCC for certification. For all other digital class B devices test data need not be submitted to the FCC, FCC does some random checking. But personal computers the manufacturers should submit the test data because a personal computer is nowadays a very important part of a residential daily life. So, any malfunction there may cause huge loss of something maybe your data maybe your photos maybe your memories. So, that is why for them the rule is very stringent.

TABLE 1

Highest Frequency Generated or Used in the Device or on Which the Device Operates or Tunes (MHz)	Upper Frequency of Measurement Range (MHz)
< 1.705	30
1.705–108	1000
108–500	2000
500–1000	5000
> 1000	5th harmonic of highest frequency or 40 GHz, whichever is lower

TABLE 2 FCC Emission Limits for Class B Digital Devices.

Radiated Emissions (3 m)

Frequency (MHz)	$\mu\text{V}/\text{m}$	$\text{dB}\mu\text{V}/\text{m}$
30–88	100	40
88–216	150	43.5
216–960	200	46
> 960	500	54

Conducted Emissions

Frequency (MHz)	μV	$\text{dB}\mu\text{V}$
0.45–30	250	48

TABLE 3 FCC Emission Limits for Class A Digital Devices.

Radiated Emissions (10 m)

Frequency (MHz)	$\mu\text{V}/\text{m}$	$\text{dB}\mu\text{V}/\text{m}$
30–88	90	39
88–216	150	43.5
216–960	210	46
> 960	300	49.5

Conducted Emissions

Frequency (MHz)	μV	$\text{dB}\mu\text{V}$
0.45–1.705	1000	60
1.705–30	3000	69.5



Now this is a in table form actually all these are given in different rule books. So, I tried to make it shorter actually in Clayton Paul's book this is available that if highest clock frequency in your electronic system is less than 1.7 megahertz you see that any clock giving suppose clock frequency is F_C now it will have various harmonics. So, those harmonics also should be within the limit now up to which harmonic will go that guideline is the table 1 that if your clock frequency is less than 1.7 megahertz then you should test it up to 30 megahertz. That means roughly you can say that it is what I will say that $(30 / 1.7)$. So, it is less than 20 harmonic it is some 17, 18 harmonic up to that you should test. Then if your clock frequency is between 1.7 to 108 then you should test it up to 1 gigahertz. Next one says up to 2 gigahertz. So, then finally if your clock frequency is more than 1 gigahertz which nowadays is very common then fifth harmonic of highest frequency. So, suppose you are having 10 gigahertz. So, that means fifth harmonic will be 50 gigahertz or 40 gigahertz whichever is lower because more than 40 gigahertz the test systems etcetera they become very costly. So, that is why they are saying that up to 40 gigahertz you need to check. Now, table 2 gives you FCC emission limits for class B digital devices. For class B you see we have already said that class B is the distance between the emitter and receptor they are small. So, FCC said that it is the test should be done at 3 meters whereas for class A since the distance is more the all the tests should be done at 10 meter distance. You see how minutely all these things have been included in the regulations. So, radiated emission you remember the first subclass is radiated emission for them if your clock frequency is within 30 to 88 megahertz, below

30 you need not check because that is not so problematic but 30 to 88 megahertz it should be within 100 micro volt per meter not more than that it is an electric field. Obviously in wireless things you have fields you do not have voltage or currents. So, electric field should be within 100 micro volt per meter. I am not seeing the third column that we will learn later that how to convert it in dB scale. Now if your frequency is 88 to 216 then it should not at 3 meter distance the electric field should be within 150 micro volt per meter 216 to 960 it is 200 micro volt per meter. But if it is more than 960 megahertz then it should be less than 500 meter. So, whatever may be your highest frequency but it should be less than 500 micro volt per meter. The third sub problem conducted emission for it is not so much dangerous because it is having through lines we will discuss that. So, for conducted emission if your frequency is within 0.5 to 30 megahertz it is generally your clock frequency is not more than that in conducted emission places. So, it is 250 micro volt per meter. you can see the corresponding limits for class A device for the same things the numbers are here. So, it may appear apparently that table 2 and table 3 though we have said in earlier slide that class B is more stringent but it does not appear always from this table because you see that for you look at 88 to 216 in class B also it is 150 in class A also it is 150. 216 to 960 class B is 200 class A is slightly relaxed 210 greater than 960 it is 500 for class B it is 300 for class A. So, it appears class A is more stringent let us see that actually you cannot compare these two directly because in one case the distance of measurement is from the source to the receptor the measurement distance is 3 meter in another case it is 10 meter. So, you cannot have that measurement actually you know that the field with distance it has a variation. So, you will have to take into account that that we will see but before going there first let us see that those numbers now look meaningful with this graph that the first figure 3 is within 30 megahertz to 88 megahertz it is constant this limit.

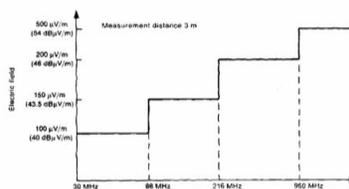


FIGURE 3 The FCC radiated emission limits for Class B digital devices.

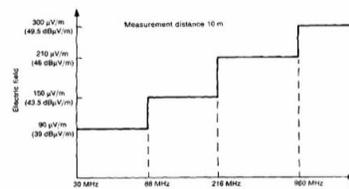


FIGURE 4 The FCC radiated emission limits for Class A digital devices.



From 88 megahertz to 216 this is actually how they have selected this range actually they have studied various electronic systems for class B devices and then saw that this is a group this is another group next is another group next is another group. So, in one group you have this another group you have this so it is actually a staircase type of thing and as you go higher and higher in frequency you see you are given more relaxation because at higher frequency it is more difficult to control the radiated emission. So, your range or your limit has been increased steadily. So, at higher frequency is this and when you are crossing 1 gigahertz sort of clock actually that you will have to comply with 500 micro volt per meter because it is very very difficult to control it at higher frequency. Now, this is for class A digital device. So, you see that here measurement distance is kept 10 meter as per the standard and here also it is like the steps but as I said that you may think that class A is more stringent. So, let us see the comparison with same distance.

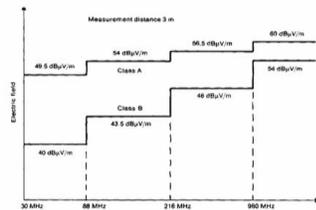


FIGURE 5 A comparison of the FCC Class A and FCC Class B radiated emission limits for a measurement distance of 3 m.

TABLE 4 CISPR 22 Radiated Emission Limits Class B Digital Devices (10 m).

Frequency (MHz)	$\mu\text{V}/\text{m}$	$\text{dB}\mu\text{V}/\text{m}$
30-230	31.6	30
230-1000	70.8	37



So, we have made both class A and class B at 3 this 3 meter distance what will happen it is an simple extrapolation and then you see that class B is more stringent because throughout this staircase is lower than this staircase at every frequency range it is lower than the class A by quite a good amount. Obviously, at higher frequency the gap is reduced but still class B stringent it is clear from this. So, since in case of class A it is the distance of measurement is higher that is why the apparently it looks that the standard is not so stringent but that is not so.

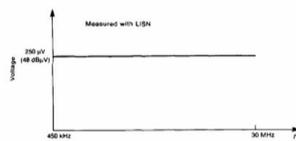


FIGURE 1 The FCC conducted emission limits for Class B digital devices.

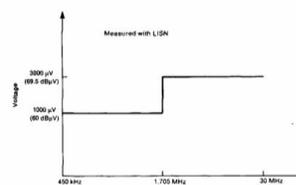


FIGURE 2 The FCC conducted emission limits for Class A digital devices.



Then this is the FCC conducted emission conducted emission is the third sub class problem. So, there you see that from 450 kilohertz to 30 megahertz it is it should be less than 250 micro volt .you see here it is measured with LISN and here it is a voltage type of thing we will discuss all of these what is LISN actually LISN is a network it is for stabilizing the conducted emission is full form is line impedance stabilization network. we will in detail discuss this. Similarly, the figure 2 is for class A device.

Requirements for Commercial Products Marketed in the Europe



Now, let us come to Europe standard requirements for commercial products marketed in the Europe.

- In 1933 a meeting of the International Electrotechnical Commission (IEC) in Paris recommended the formation of the [International Special Committee on Radio Interference \(CISPR\)](#) to deal with the emerging problem of EMI.
- The CISPR reconvened after World War II in London in 1946. Subsequent meetings yielded various technical publications, which dealt with measurement techniques as well as recommended emission limits. Some European countries adopted versions of CISPR's recommended limits.
- The FCC rule was the first regulation for digital systems in the US, and the limits follow the CISPR recommendations with variations peculiar to the US environment. Most manufacturers of electronic products within the US already had internal limits and standards imposed on their products in order to prevent "field problems" associated with. However, the FCC rule made what had been voluntary a matter of compliance.



You see that FCC made its rule made in 1979 but from 1933 there was a meeting of the international electro technical communication and UN body in Paris and it recommended the formation of the international special committee on radio interference in French this is called CISPR to deal with the emerging problem of EMI. After that world war came the CISPR recommend after world war 2 in London subsequent meetings yielded various technical publications which dealt with measurement techniques as well as recommended emission limits. some European countries adopted versions of CISPR recommended limits in Europe some countries as their own limit but more or less the structure is CISPR structure our country also adopted generally third world countries also adopted this because this is an UN body so generally. However, the FCC rule was the first regulation for digital systems and the limits follow the CISPR recommendations with variations peculiar to the US environment. Most manufacturers of electronic products within the US already had internal limits and standard imposed on their products in order to prevent field problems associated with EMI. However, the FCC rule made what had been voluntary a matter of legal compliance.

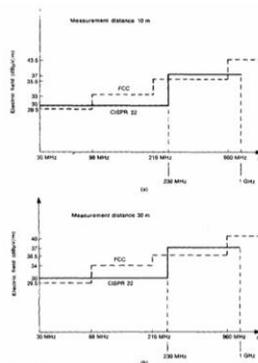


FIGURE 4 The CISPR 22 radiated emission limits compared to the FCC radiated emission limits (a) Class B, (b) Class A.

Frequency (MHz)	$\mu\text{V/m}$	$\text{dB}\mu\text{V/m}$
30-230	31.6	30
230-1000	70.8	37



Now, again you see that this is a comparison of FCC and CISPR for measurement distance 10 meter you see at some zone that means at lower frequency CISPR is more stringent than FCC but at higher frequency FCC is or a within certain zone FCC is against stringent and for measurement distance 30 meter the next figure is for class A device actually in case of CISPR for class B their

measurement distance is 10 meter and for class A their measurement distance is 30 meter that shows that the European homes etcetera are larger than American homes.

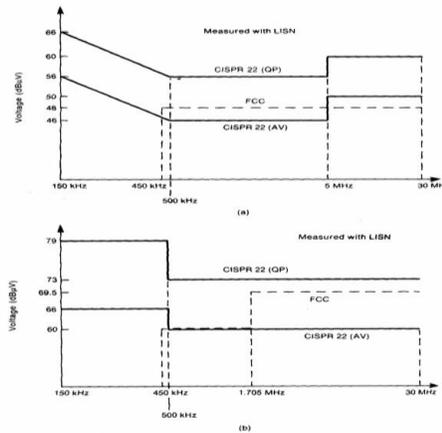


FIGURE 7 The CISPR 22 conducted emission limits compared to the FCC conduct emission limits: (a) Class B, (b) Class A.



Now, this is the conducted emission limits comparison between FCC and CISPR. The upper graph is for class A device there you see that CISPR 22 that is the version and there is written QP another one written AV now QP stands for quasi periodic average AV stands for average we will discuss all these later and FCC. So, here you see that FCC is more stringent than CISPR in class B and here the FCC is generally more stringent than CISPR, CISPR is a bit relaxed compared to FCC in radiation limits.

TABLE 2.6 CISPR 22 Conducted Emission Limits for Class B Digital Devices.

Frequency (MHz)	μV QP(AV)	$\text{dB}\mu\text{V}$ QP(AV)
0.15	1995(631)	66(56)
0.5	631(199.5)	56(46)
0.5–5	631(199.5)	56(46)
5–30	1000(316)	60(50)

TABLE 2.7 CISPR 22 Conducted Emission Limits for Class A Digital Devices.

Frequency (MHz)	μV QP(AV)	$\text{dB}\mu\text{V}$ QP(AV)
0.15–0.5	8912.5(1995)	79(66)
0.5–30	4467(1000)	73(60)



These are the values so quasi peak average so there are different values for them and frequency wise also this is conducted emission but this is up to 30 megahertz in both FCC and CISPR.

CISPR 22 standards. MIL-STD-461 covers systems ranging from electric hand drills to sophisticated computer systems.

The frequency ranges and types of limits are as follows :

b

CONDUCTED EMISSIONS

- CE01 - dc – 15 kHz
- CE03 - 15 kHz – 50 MHz
- CE06 - 10 kHz – 26 GHz
- CE07 - Spikes, time domain

CONDUCTED SUSCEPTIBILITY

- CS01 - 30 Hz – 50 kHz
- CS02 - 50 kHz – 400 MHz
- CS03 - Intermodulation, 15 kHz – 10 GHz
- CS04 - Rejection of undesired signals, 30 Hz – 20 GHz
- CS05 - Crossmodulation, 30 Hz – 20 GHz
- CS06 - Spikes
- CS07 - Squelch circuits
- CS09 - Common-mode currents, 60 Hz – 100 kHz
- CS10 - Damped sinusoidal transients, pins and terminals, 10 kHz – 100 MHz
- CS11 - Damped sinusoidal transients, cables, 10 kHz – 100 MHz



Now there is also a mil standard actually military has its own standard which space also follows space has some of their own standards but mil standard is generally followed in very critical systems like military systems they should not fail due to EMI in case of field operations or space things if your this Bikram etcetera they fail then it is a loss of prestige to all our national tempo that is why the space things are tested very very rigorously for this EMC compliance. Now these are the various documents these are available in your internet these are CISPR standard you see that for conducted emissions the code is CE, CE01, CE03, CE06, CE07 etcetera conducted susceptibility code is CS .

RADIATED EMISSIONS

- RE01 - Magnetic field, 30 Hz – 50 kHz
- RE02 - Electric field, 14 kHz – 10 GHz
- RE03 - Spurious emissions and harmonics

RADIATE SUCCEPTIBILITY

- RS01 - Magnetic field, 30 Hz – 50 kHz
- RS02 - Magnetic induction, spikes, power frequency
- RS03 - Electric field, 14 kHz – 40 GHz
- RS05 - EMP transients

MISCELLANEOUS

- UM03 - Radiated emissions, tactical and special purpose vehicles and engine-driven equipment
- UM04 - Conducted emissions and radiated emissions and susceptibility, engine generators, and associated components, UPS and MEP equipments
- UM05 - Conducted and radiated emissions, commercial electrical and electromechanical equipments.



Similarly if the radiated emission the code that document will start with RE if it is radiated susceptibility the document will start from radiated susceptibility you see RE01 it is for magnetic field RE02 for electric field RE03 for spurious emissions etcetera similarly for RS and there are miscellaneous ones. So you can all go through these documents if you like those are huge documents but every procedure how to take a measurement at what environment you will take the measurement everything is given there.

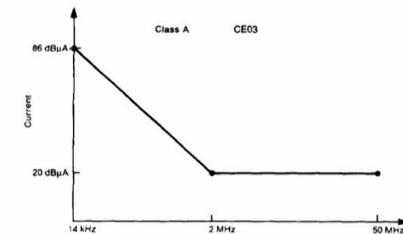


FIGURE 8 The MIL-STD-461 CE03 conducted emission limit for Class A equipment.

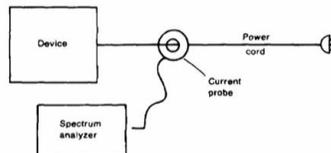


FIGURE 9 Use of a current probe to verify the MIL-STD-461 conducted emission limits.



this is the mil standard conducted emission limit here you see instead of voltage it is in current that also we will discuss later also this is a current probe by which how much current is passing through a device that is measured actually you see that this is a novel thing that current probe you see it is not breaking the circuit actually in low frequency classes in our labs we never measured the current we always measured voltage and we assume there is a resistance so from that resistance we calculate the current but the resistance may not be there or in field problems how to take that resistance etcetera so this one we will see that how a current probe is made it is an electro on electromagnetic principle basically Maxwell's equation principle this is made Faraday's law and by that non destructively you can measure current so on any current carrying where you can measure current this is this was never taught in undergraduate or postgraduate courses we will see that .

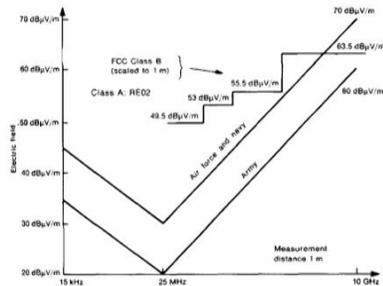


FIGURE 10 Comparison of the MIL-STD-461 RE02 radiated emission limit for Class A equipment to the FCC Class B radiated emission limit scaled to a measurement distance of 1 m.

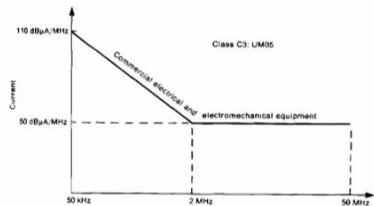


FIGURE 11 The MIL-STD-461 UM05 conducted emission limit for Class C3 equipment.



this is the comparison of mil standard for class A to FCC class B you see that army has the standard air force has the standard and the staircase one that is for our FCC so you see that compared to FCC the mil standard is very very stringent you see how stringent it is also you see that below certain frequency range below 20 megahertz etcetera our commercial products they do not have any limit but mil standards they have limit from 15 kilohertz not megahertz and they are very stringent then you see throughout they are very stringently measured whereas commercial products are not so stringent.

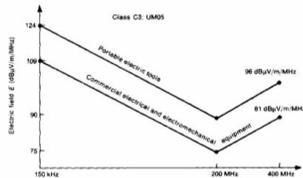


FIGURE 12 The MIL-STD-461 UM05 radiated emission limit for Class C3 equipment.

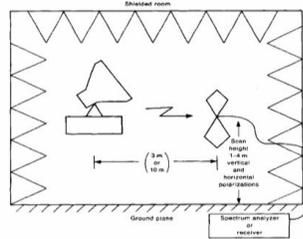


FIGURE 13 Illustration of the use of a semi-anechoic chamber for the measurement of radiated emissions.



this is the diagram of an anechoic chamber actually measurement of radiated emission this is a semi anechoic because the floor is metal if there were absorbers here there are some very good anechoic chambers where the floor is there that is called fully anechoic these are absorbers these are phenomenal absorbers basically some carbon type of

material is there and wave when it hits there wave goes inside and then gets absorbed by the carbon etcetera so in that environment there are no electromagnetic environment so you have source here ,you have a probe that probe is kept at a height so that this test device the here this is the test device the left side that is the test device the distance is either 3 meter or 10 meter according to whether this device is class A or class B and then it is taken to a spectrum analyzer or a very good radio receiver with a very very high dynamic range so that you get that signal what is received so what you are receiving is simply from this source so there are no other interference actually whole this chamber is shielded there is a metal shield outside you see the full thing is a metal box then there are absorbers so that internally if anything goes generated that also is getting absorbed so what you are getting this is in a quiet zone you are getting this thing so this is the measurement recommended for making radiated emission in a for this EMI measurement .I think with this we are over for the time being with the standards now we will start our model our EMC model before that in the class first next class I will start talking about the dv conversion the electromagnetic unit then we will go to the model development or some of the signal integrity problems thank you.