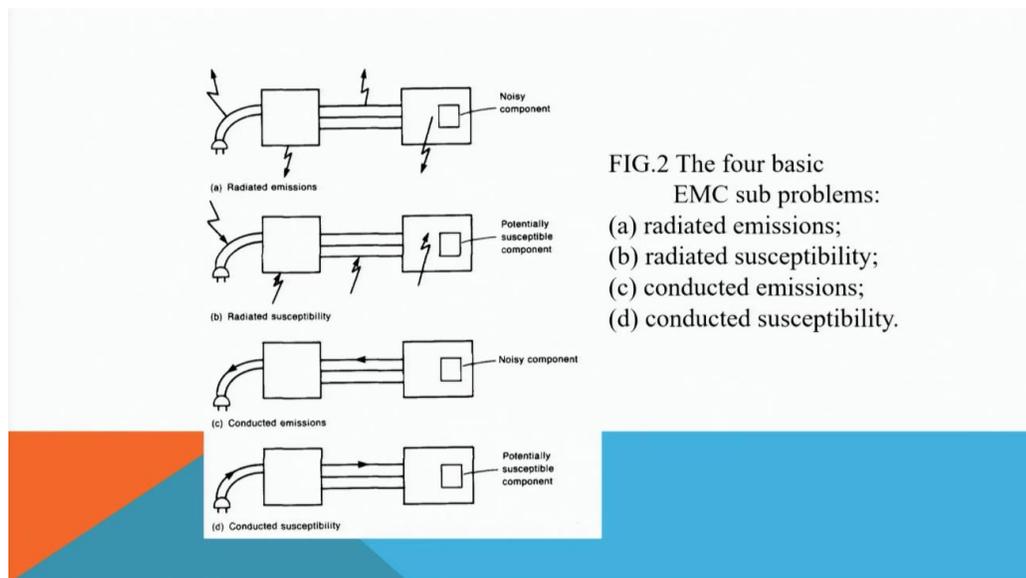


Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
Professor name: Prof. Amitabha Bhattacharya
Department name: Electronics and Electrical Communication Engineering
Institute name: IIT Kharagpur
Week :10
Lecture 48: Conducted emission and susceptibility

Welcome to the 48th lecture of the course on EMIMC and Signal Integrity Principles, Techniques and Applications. Now, till the last class we were seeing Radiated Susceptibility Problems, today we will see Conducted Problems. So, please refer to the this figure which we have introduced at the beginning of the course. So, radiated emission and radiated susceptibility we have done the next two that conduct the C and D conducted emission and conducted susceptibility. So, this is the conducted emission problem that this is the device under test which is connected to the power network. Now, this device should not send any emission through this conducted path to the power net, also in conducted susceptibility the power net should not give any power to this device which is under test.



Now, what is conducted emission? Every digital device is connected to power network. Now, on the other side of the power network various electrical equipment AC,

refrigerator etcetera there and some of them have a strong reactive load. So, whenever these loads are switched on or off and interference come in or goes from the digital device.

What is Conducted Emission?

- Every digital device is connected to power network
- Various electrical equipment is connected to the other side of the powernet.
- Some of them have a strong reactive load, like AC machine
- Whenever these loads are switched on or off, an interference comes in or goes from the digital device



So, this interference may have several higher order significant harmonics disturbing the functioning of the digital device we have seen the digital device definition. So, this conducted emission they have though they are supposed to be of 50 hertz, but due to that reactive load they may have frequency dependent harmonics which can disturb them. So, the functioning of the digital device may be impaired. To mitigate this problem an equipment called line impedance stabilization network LISN is employed. LISN can mitigate both conducted emission and conducted susceptibility problems. So, we will throughout this lecture we will just try to understand what an LISN is.

What is LISN?

- This interference may have several higher order significant harmonics disturbing the functioning of the digital device
- To mitigate this interference, an equipment called **Line Impedance Stabilisation Network (LISN)** is employed.
- LISN can mitigate both conducted emission and conducted susceptibility problems.



So, this what we will call this dotted rectangle that is the LISN, LISN comes in a box. So, it is a three phase circuit. So, one side it is connected to the product under test. So, with three wires so, one is the phase wire another is the neutral wire and the third one is basically a ground or also called green wire. Now LISN is basically comprises of an inductance and two capacitances. So, you see that between phase and ground there is a capacitance C_1 as well as a capacitance C_2 and on each similarly from neutral to ground there is C_1 and C_2 and on the line on the phase line there is a series inductance L_1 on neutral line there is a series inductance L_1 . Also between with C_1 there is a R_1 and a measuring device. So, that measuring device is again shown as dotted here it may be a spectrum analyzer it may be any signal analyzer etcetera. So, we have called it 50 ohm now sometimes that measuring device is not connected, but always this one this R_1 is connected. So, and finally, this V_p across these and V_n across these spectrum analyzers are measured to see whether conducted emission problems or conducted susceptibility problems are there ok. The other side is connected to AC power net. So, you see that product under test without LISN it should have been connected to AC power net 3 phase, but for LISN which mitigates the problem of conducted emission and conducted susceptibility it comes between the product and the AC power net. So, this bigger rectangle that is the LISN and as I describe that main functioning is done by this L_1 and also by this C_2 R_1 50 ohm etcetera.

Line Impedance Stabilisation Network (LISN) for the measurement of conducted emission

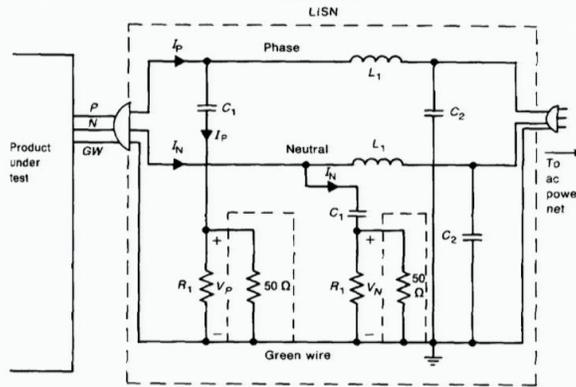


FIGURE . 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, we will understand what it will do. Similarly, LISN should LISN. So, this AC power net is giving you 50 hertz sinusoidal AC that should be passed through the LISN to the product otherwise the product would not function. Every product every digital device needs this 50 hertz 230 volt AC connection ok. So, that so, LISN lets 50 hertz pass through it. So, you see for that the value of L_1 is chosen actually according to the CISPR limit this is one example of LISN. LISN may be change different values may be used, but this is one typical example with which we will see what is LISN. So, in our example L_1 is 50 micro handy ok. So, how we are saying that LISN lets 50 hertz pass through it, its impedance if you calculate at 50 hertz this impedance of LISN L_1 is 15.7 milliohm. So, from AC power net the current is coming now it is seeing two paths one is through L_1 another is through C_2 then it is getting grounded. So, which one it will take L_1 has an impedance of 15.7 milliohm .

LISN lets 50 Hz pass through it

- Value of L_1 is 50 μH
 - It's impedance at 50 Hz is 15.7 $\text{m}\Omega$

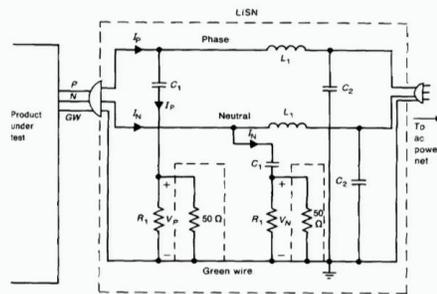


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



what about C_2 value of C_2 in our example is 1 micro farad. So, its impedance at 50 hertz is 3.18 kilo ohm. So, you see that one is in milliohm L_1 's impedance is 15.7 or roughly 16 milliohm and this is 3.18 kilowatt. So, a good portion of the current will pass through L_1 then from L_1 it will go here. So, that will be called I_p , but here the arrow of I_p is as if product is sending that. So, that will come later, but if we are considering that 50 hertz should pass then that current will go like this then through this phase where it will go to the product. Another thing for neutral all these L_1 's are same value all the C_2 's are same value. So, that means, through L_1 the 50 hertz phase line that sinusoidal current that is going through neutral the 50 hertz that current is going, but you can ask me that you are saying these, but full current is not passing for there is some

amount of current will also go through 3.18 kilo ohm that means, through C 2 path yes because this L i s n is designed now values of L 1 C 2 etcetera are for a judicious choice now for all frequency it cannot give you the total current that 50 hertz will pass through it.

LISN lets 50 Hz pass through it

- Value of C_2 is $1 \mu\text{F}$
 - It's impedance at 50 Hz is $3.18 \text{ K}\Omega$

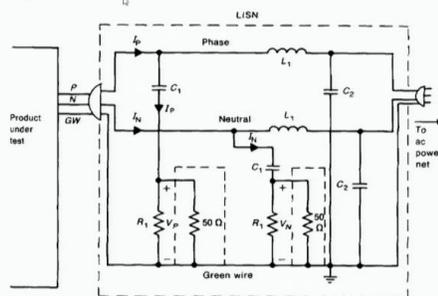


FIGURE . 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, we can calculate how much portion of that passes through L 1. So, 230 volt 50 hertz AC passes from the power net through L 1 of phase and neutral to the product and the test that is ok, but how much.

LISN lets 50 Hz pass through it

- So, 230 V 50 Hz AC passes from the powernet through L_1 of phase and neutral to the product under test so that it can function properly

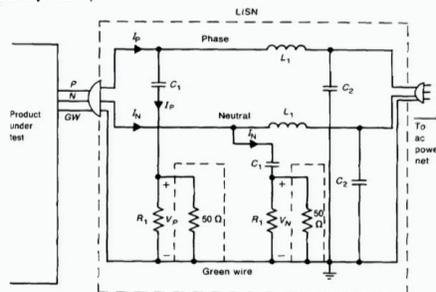


FIGURE . 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, there you can calculate that by how much percentage it will go that will be 3.18 by 3.18 into or 3.18 by 3.18 plus 0.005 so that means, 3.18 by 3.185. So, I think at 50 hertz almost all the current at least greater than 99 percent of the current is flowing through L₁ and going to the product. So, this part is now understood that at 50 hertz L i s n lets the current to pass.

LISN lets 50 Hz pass through it

- Value of C₂ is 1 μF
 - It's impedance at 50 Hz is 3.18 KΩ

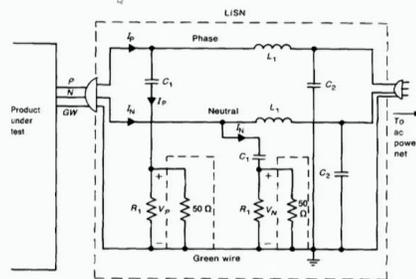


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



Now, L i s n blocks noises from power net noises or interference from those higher order harmonics in the frequency range 150 kilohertz to 30 megahertz because this range is specified by CEM that conducted emission test you should do for 150 kilohertz that means, 50 hertz. So, 150 kilohertz means it is I think 3000 harmonics to 30 megahertz will be some 20000 or something harmonics they should not have any component. So, who blocks that that is the L₁ C₂ part that this one is in series another in shunt that L₁ C₂ blocks the interference actually this heading should not be noises L i s n blocks interference from power net.

LISN Blocks noises from power net in the frequency range 150 KHz to 30 MHz

- L₁ and C₂ does this job
- Both in Phase and neutral they are present

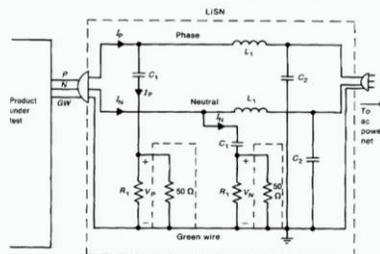


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



How value of L_1 is already I said 50 microhenry. So, at 150 kilohertz its impedance will be $47 \text{ ohm } j \omega L$ then value of C_2 is 1 micro farad this is the first time I am saying value of C_2 its impedance at 150 kilohertz if you calculate it will be 1.06 ohm. So, how much interference current it has passed. So, most of the 150 kilohertz noise will be diverted by C_2 to ground that means, this is 1.06 ohm and the previous one is 47 ohm.

LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- Value of L_1 is 50 μH
 - It's impedance at 150 KHz is 47Ω

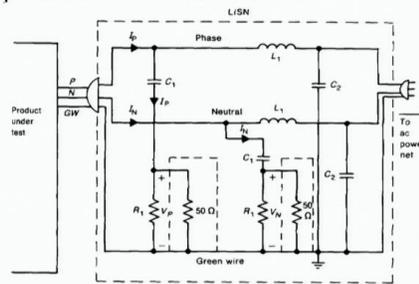


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- Value of C_2 is 1 μF
 - It's impedance at 150 KHz is 1.06 Ω

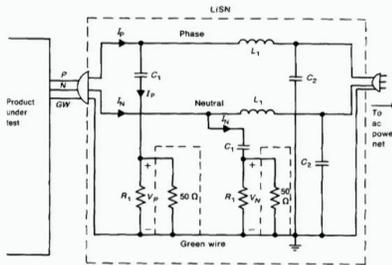


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- So most of the 150 KHz noise will be diverted by C_2 to ground.

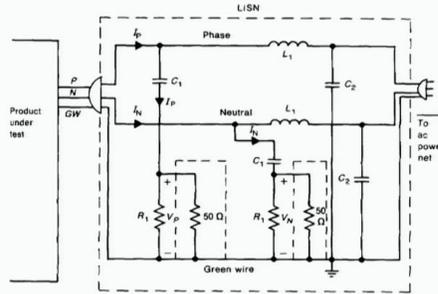


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, the current is coming seeing a 47 ohm path and a 1.06 ohm path now obviously, it should come here. So, how much is going through L 1 that will be this 1.7 divided by 1.7 plus 47. So, which is a good value. So, it will pass that. So, what portion would be flowing through L 1 to the product under test that will be $1.06 / (47 + Z_{in} \text{ of the product under test})$ fraction of the. So, otherwise it come most of it goes through C 2 to here. Now, Z_{in} of U T if you assume even 50 ohm that U T's input impedance at 150 kilohertz that will be a very small number 1 you can say 1 divided by 97 that is almost like 0.2. So, 1.0 is 1 by 47 plus 50. So, 1 by 100 not 0.2 that will be 0.01. So, 1 percent current is going.

LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- Only $1.06 / (47 + Z_{IN \text{ of EUT}})$ fraction of the 150 KHz noise current would be flowing through L_1 to the product under test

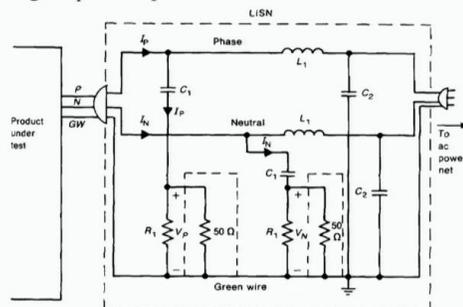


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



Now let us see the other end the 30 megahertz what is happening. So, impedance of L_1 is 9.42 kilo ohm there and impedance of C_2 is 5.31 milli ohm very very small impedance. So, most of the 30 megahertz interference will be diverted by C_2 to ground.

LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- Value of L_1 is $50 \mu\text{H}$
 - It's impedance at 30 MHz is $9.42\text{K}\Omega$

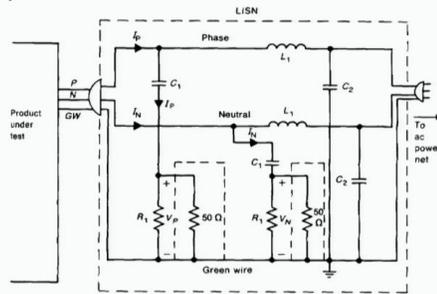


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- Value of C_2 is $1 \mu\text{F}$
 - It's impedance at 30 MHz is $5.31\text{m}\Omega$

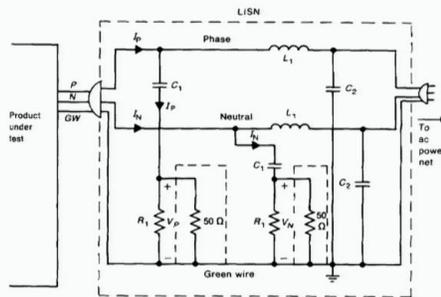


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- So most of the 30 MHz noise will be diverted by C_2 to ground

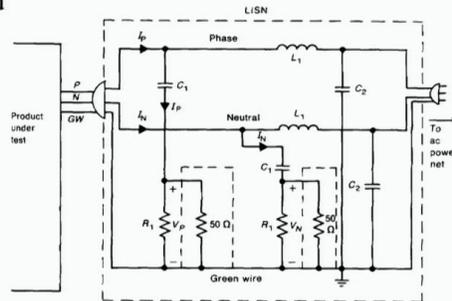


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, only if you calculate a very very small fraction of the 30 megahertz noise current would be flowing through L_1 to the product under test. So, you see throughout this range 150 kilohertz to 30 megahertz we can say that the LISN is blocking the interference from power net to go to the device. So, it is doing a susceptibility thing that it has prevented the device under test to be susceptible to the power net interference.

LISN Blocks noises from powernet in the frequency range 150 KHz to 30 MHz

- Only 5.64×10^{-6} fraction of the 30 MHz noise current would be flowing through L_1 to the product under test

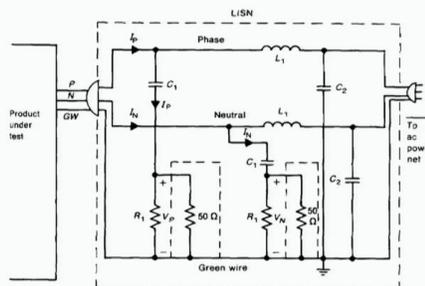


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, we can say LISN primary purpose is to prevent noise external to the test from contaminating the measurement. So, that when you are testing the product it is as if the power net noise or interference is not there. Basically all these will be interference, but while preparing someone has made the mistake.

LISN's primary purpose

To prevent Noise External to
the test from contaminating
the Measurement



Now, there is also a second purpose of LISN actually for that its name is its name derived from the second purpose to provide uniform impedance for the conducted emission measurement to provide uniform impedance.

LISN's second purpose

To provide uniform
impedance for the conducted
emission measurement



Why the question of AC impedance seen looking at the power net varies from site to site why? Because you see that if a AC machine is powered on there will be one impedance if it is not powered on there will be another impedance because reactive load is changing. Emission current from a PUT measured at one side for this reason that impedance is changing will be different at different measurement time because we measure current from voltage divided by impedance. So, that will be different also it will differ from site to site some in some site the power net may be supporting 3 AC machines in some site may be 10 AC machines and if all the 3 are on and in other case all the 10 are on. So, obviously, their impedance will be different. So, the same device that will show different emissions at two different sites. So, measurement will not contain correlation. So, LISN gives a stabilized impedance that is why the name line impedance stabilization network.

AC Impedance seen looking at the power net varies from site to site

- Emission current from a PUT measured at one site will be different at different measurement time
- Also it will differ from site to site
- Measurements will not maintain correlation

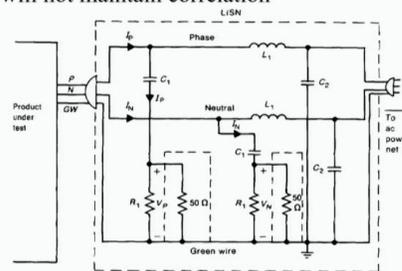


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



Then we will see that who does this job basically C 1 in series with parallel combination of R 1 and 50 ohm that is the measuring instrument that does this stabilization. R C is same impedance between phase and ground and also neutral and ground looking towards is power cord. You see in the bottom part that is R 1 and R 1 is 1 kilo ohm and sometimes the spectrum analyzer or the measuring device may be connected sometimes may not be connected. So, but still its value will be either 1050 ohm sorry near about something more than 50 ohm and sometimes it is 1 kilo ohm. But that is known at different frequencies the value of C 1 will change.

LISN stabilises the AC Impedance of the Powernet

- C_1 and $R_1 \parallel 50 \Omega$ does this job
- They are present in both phase and neutral
- Product sees same impedance between phase and ground and also neutral and ground looking towards its power cord

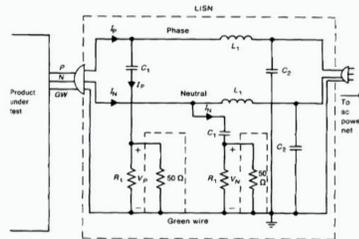


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, let us see that. We have assumed 50 ohm is the input impedance of the measuring device that is spectrum analyzer value of R_1 is 1 kilo ohm its job is to provide a discharge path for current coming through C_1 in the event the receiver is disconnected.

LISN stabilises the AC Impedance of the Powernet

- 50Ω is the input impedance of the conducted emission measuring receiver
- Value of R_1 is 1 $K\Omega$
- Its job is to provide a discharge path for C_1 in the event the receiver is disconnected

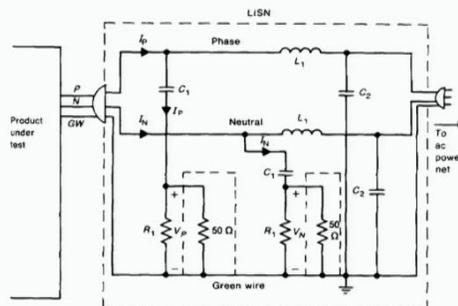


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



Value of C_1 is 0.1 micro Farad it first blocks any DC coming to 50 ohm receiver its impedance at 150 kilo hertz is 10.6 ohm. So, that means, there is a where is this is 10.6 ohm this is 1 kilo ohm.

LISN presents same impedance from 150 KHz to 30 MHz

- Value of C_1 is 0.1 μF
- It blocks any dc coming to 50 Ω receiver
 - It's impedance at 150 KHz is 10.6 Ω

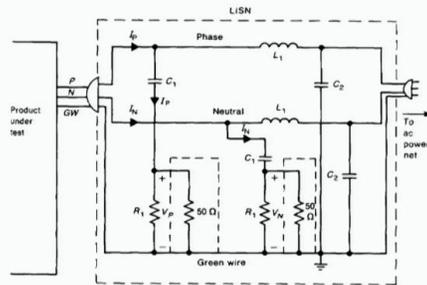


FIGURE 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



So, total impedance of this path if you calculate that as I said that it will be slightly higher than 50 ohm and so, 50 in parallel that means, R_1 and measuring device in parallel that will be slightly greater than 50 greater than it will be slightly less because 50 into 1000 by 50 plus 1000. So, that will be slightly less something like 47 ohm etcetera plus this 10.6 ohm. So, that comes to 58.22 ohm whereas, impedance of the $L_1 C_2$ path.

Does LISN presents same impedance from 150 KHz to 30 MHz ?

- Value of C_1 is 0.1 μF
- It's impedance at 150 KHz is 10.6 Ω
- So, total impedance of this path is 58.22 Ω
- Impedance of the $L_1 - C_2$ path is 48.06 Ω
- 45% Emission current enters receiver
- $0.45 I_p \times 47.62 = V_p$
- $I_p = V_p / 21.43$
- Error of 7.36 dB!



So, there is this current that is coming it can go either here or it can also go to this L 1 C 2 path. So, that we are calculating that impedance of the L 1 C 2 path is 48. So, 45 percent emission current enters receiver so that means, 45 percent emission current in per enters receiver. You see that the spectrum analyzer is measuring V p spectrum analyzer can measure for current also, but let us say that we are selected the spectrum analyzer in the voltage mode. So, 0.45 into I p I p is the current that is coming from the device. So, 45 percent is coming to this 50 ohm receiver. So, 0.45 I p into this is the parallel combination of 50 ohm into 1 kilo ohm that is 47.62. So, that will be V p. So, I p will be V p by 21.43. So, obviously, some error has been committed why because I p should have been V p divided by 50, but it is at 150 kilo hertz it is giving you instead of 50 it is giving you 21.43. So, how much is the error that you can easily calculate and the error is quite high 7.36 dB at 150 kilo hertz.

LISN presents same impedance from 150 KHz to 30 MHz

- Value of C_1 is $0.1 \mu\text{F}$
- It blocks any dc coming to 50Ω receiver
 - It's impedance at 150 KHz is 10.6Ω

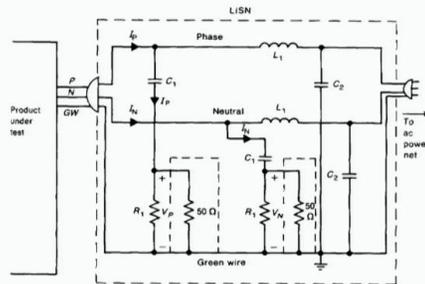


FIGURE . 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.



What about 450 kilo hertz again do all these calculations and that shows that error has come down to 3.1 dB.

What about 450 KHz?

- Value of C_1 is $0.1 \mu\text{F}$
- It's impedance at 450 KHz is 3.54Ω
- So, total impedance of this path is 51.16Ω
- Impedance of the L_1 - C_2 path is 141.37Ω
 $+0.35 \Omega = 141.72 \Omega$
- 73% Emission current enters receiver
- $I_p = V_p / 35$
- Error of 3.1 dB!



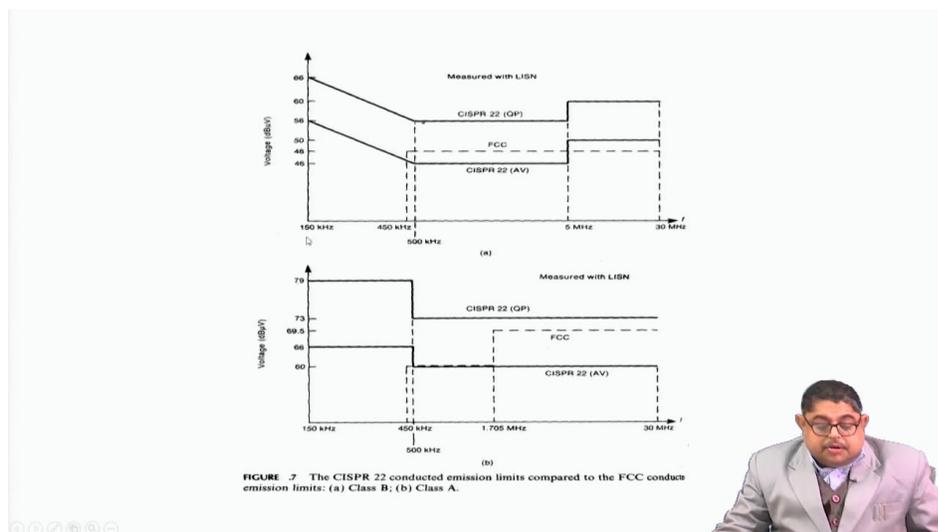
What about 500 kilo hertz error of 2.85 dB?. These frequencies are important actually I have not arbitrarily taken them 150 kilo hertz, 450 kilo hertz, 500 kilo hertz, but error is being shown, but later we will see the significance of those frequencies.

What about 500 KHz?

- Value of C_1 is $0.1 \mu\text{F}$
- It's impedance at 500 KHz is 3.19Ω
- So, total impedance of this path is 50.81Ω
- Impedance of the L_1 - C_2 path is 157.08Ω
 $+0.315 \Omega = 157.4 \Omega$
- 75.6% Emission current enters receiver
- $I_p = V_p / 36$
- Error of 2.85 dB!



And now you see that the CISPR voltage limits they extend from 150 kilo hertz to 500 kilo hertz and FCC conducted emissions starts from 450 and both of them go up to 30 mega hertz that is why I checked at 150 kilo hertz at 450 kilo hertz at 500 kilo hertz at 30 mega hertz. Now you see in FCC the lower limit starts from 450 and it is the limit is same up to 30 mega hertz. Whereas CISPR they understood that at the lower from 150 kilo hertz to 500 mega hertz there is a need to adjust because ELISN for all the frequencies are not same. So, they have given roughly a 10 dB margin for 150 kilo hertz. So, you see our at 150 kilo hertz our error was 7.36 dB it is within the CISPR limit because CISPR has said that you can go up to 10 dB. So, it is a very good ELISN and whatever I talked is about class B, class A the values are different, but the frequency choice is same there also you see that for class B CISPR has given a almost you can say 7 dB clearance between 150 kilo hertz and 500 milli kilo hertz.



Now lower limit for conductor dimension is not 150 kilo hertz that I already said that FCC lower limit starts from 450 kilo hertz for CISPR lower limit starts from 150 kilo hertz, but the permissible level is raised by 10 dB.

Now measuring receivers measures V_A , V_P and V_N respectively. So whatever we have explained for phase the same thing happens in neutral part also. So sometimes the V_P and V_N may be different due to some problem in the device etcetera. So, that also can be found out with LISN.

LISN presents same impedance from 150 KHz to 30 MHz

- Measuring Receivers measure V_P and V_N respectively

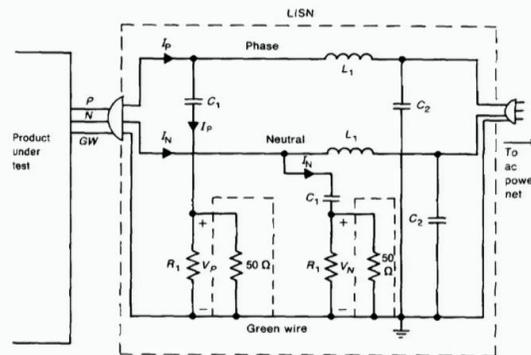


FIGURE . 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.

This is again that you see that at 30 megahertz we can roughly say that I_p is equal to V_p by 50 and I_n is equal to V_N by 50.

LISN presents same impedance from 150 KHz to 30 MHz

- So, $I_p = V_p / 50$
- And $I_N = V_N / 50$

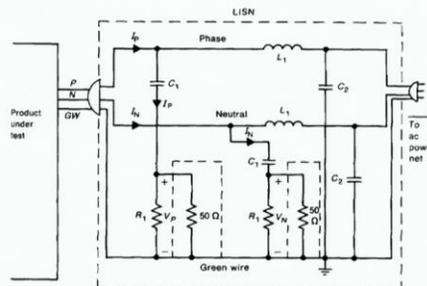
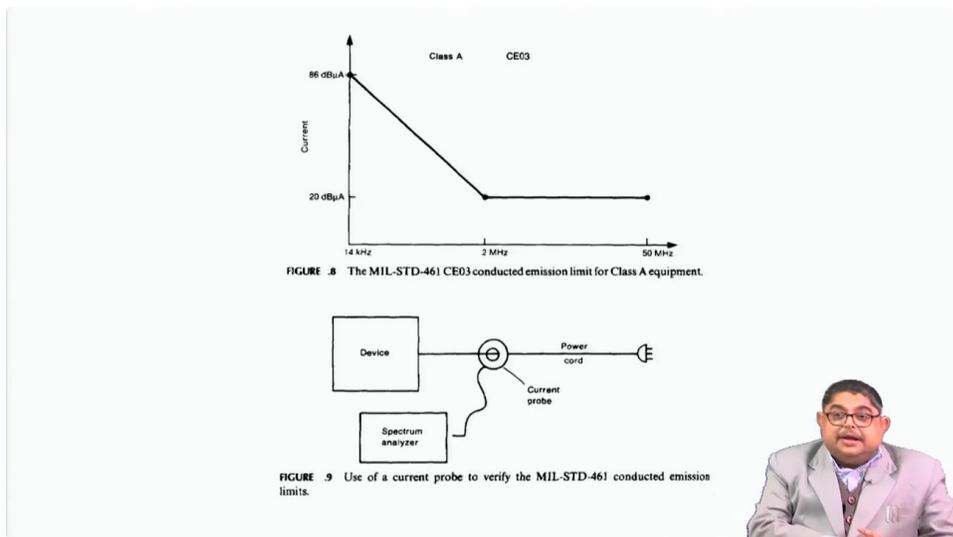
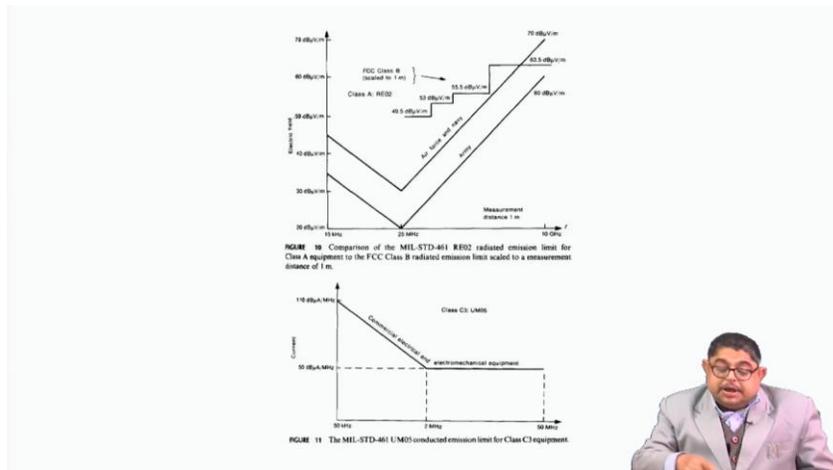


FIGURE . 15 The line impedance stabilization network (LISN) for the measurement of conducted emissions.

Now there is another standard that is MIL standard that is a military standard. So, we have not studied, but if you study MIMC from a military organization this one you will have to study very elaborately that is CE 03, but the thing that is to be noted you see the specification y axis is voltage. So, CFSER and FCC both this civilian standard say that you measure voltage. So, the measuring device will measure voltage, but military standard they measure current, but for that they need this current probe which we have already introduced. So here this extra this device will be required. So then you can easily measure through the current probe. So, this is called MIL standard 461 and the report name is CE 03 conducted emission test.



So, here is a comparison between class A and class B MIL standard. So, you see that FCC class B that is in type of steps a band of frequencies it is constant whereas, the military standards they are rising sharply. So, for every frequency rise there is no band concept from 25 megahertz to 10 gigahertz it is going. You see it is starting from 15 kilohertz it is giving a relaxation up to 25 megahertz relaxation of roughly you can say 15 dB micro volt per meter, but after that it should be the higher you go the limit is going higher continuously. And this is class 3 another equipment is there for that it is somewhat like civilian standard it is flat.



So, MIL standard conducted limit conducted emission limit is based on current this we have already said it starts from 50 kilohertz and goes up to 50 megahertz for class C 3 devices that is all. So, thank you in the next class we will. So, this 4 subclasses has been covered in detail from the next class we will start shielding another way of mitigating interference. Thank you.

MIL standard conducted emission limit is based on Current

- It starts from 14 KHz and goes up to 50 MHz for Class A devices
- It starts from 50 KHz and goes up to 50 MHz for Class C3 devices