Electromagnetic Compatibility (EMC)

Topic 2

EMC Requirements and Regulations

Mohammad S. Sharawi, PhD. , P.E.

EMC requirements and Regulations

- EMC regulations and requirements are living documents that are constantly being changed. You need to keep checking and design against the latest regulation.
- Need to check the requirements within the USA or outside.
- In the **USA**, the Federal Communications Commission (**FCC**) is responsible for the regulations for radio and wire communications.
- **Out the USA**, the International Special Committee on Radio Interference (Comité International Spécial des Perturbations Radioélectriques) **CISPR** is responsible for the regulations and EMC standards.
- If you are designing an electronics system/device, it has the satisfy the requirements in the regions it will be used or sold. Usually, the FCC and CISPR requirements apply. So, **Pay extra attention**!

FCC rules and regulations

- **FCC part 15** covers Radio Frequency Devices.

  - A radio frequency device is any device that in its operation is capable of emitting radio-frequency (RF) energy by radiation, conduction or other means.

  - RF energy covers the band from 9 KHz – 3000 GHz

  - They have two fold purpose:

  (1) to provide for the operation of low-power transmitters without a radio license

  (2) to control interference to authorized radio communications services that might be caused by the equipment emitting RF energy or noise. This include digital electronics with more than **9000 pulses/cycles** per second (**all electronics today!**).
- **FCC part 18** covers industrial, scientific and medical (ISM) equipment
- **FCC part 68** covers protection of telephone networks.

FCC part 15

- **Part 15** is organized into 6-parts
  - Subpart-A: General
  - **Subpart-B**: Unintentional radiators (***Contains EMC regulations for electronic equipment***)
  - Subpart-C: Intentional radiators
  - Subpart-D: Unlicensed personal communication devices
  - Subpart-E: Unlicensed national information infrastructure
  - Subpart-F: Ultra-wide-band operation
- **Digital devices** are covered in Part 15, Subpart-B.
  - **Class A**: A digital device that is marketed for use in a commercial, industrial, or business environment (§15.3(h))
  - **Class B**: A digital device that is marketed for use in a residential environment (§15.3(i))
- Because **Class B** digital devices are more likely to be located in a closer proximity to radio and television receivers, the emission limits of these devices are **about 10dB more restrictive** than those of **Class A** devices.

FCC part 15

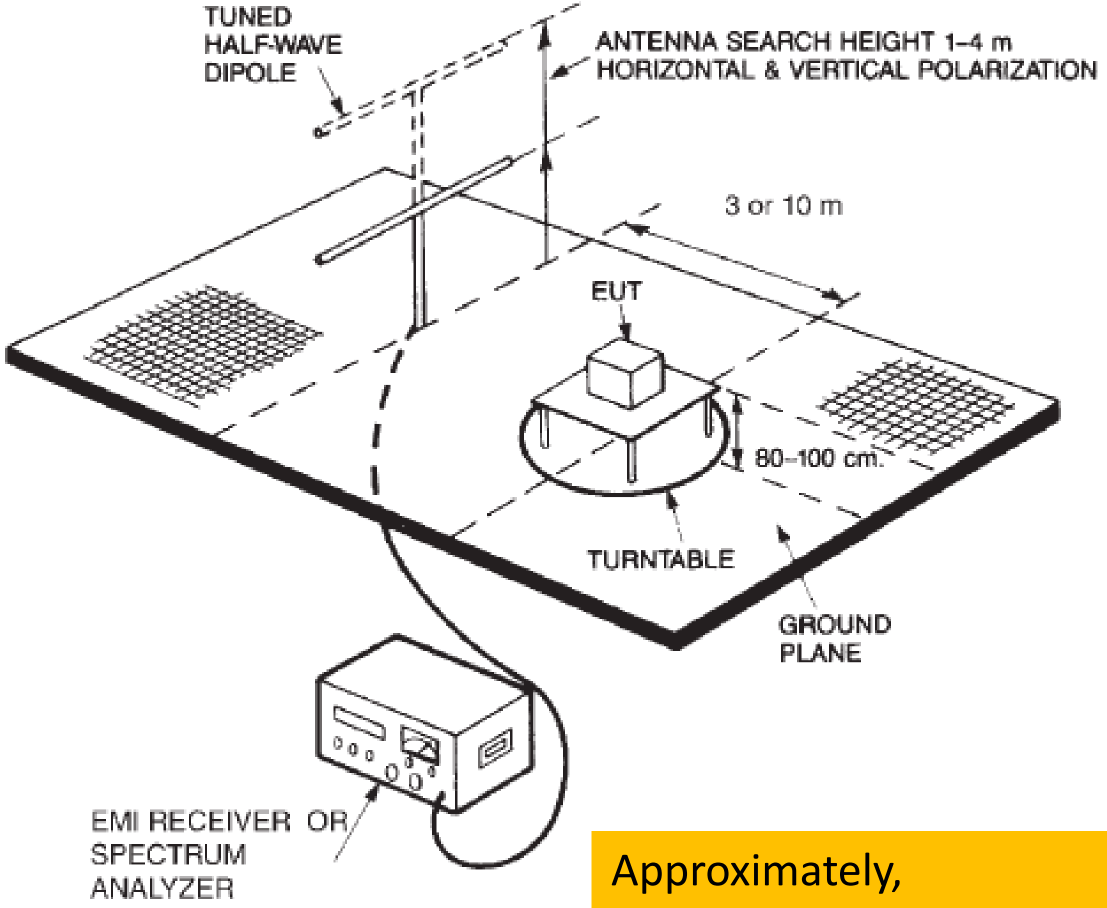
- For **personal computers** and **their peripherals** (sub category in Class B), the manufacturer can demonstrate compliance with the requirements via a Declaration of Conformity. This is a procedure where the manufacturer takes the steps required (measurements) to ensure that the equipment complies with standards without the need to submit a unit for testing to the FCC unless specified otherwise ($\S 2.1071$ – 2.1077)
- For **ALL other products** (Class A or Class B), the manufacturer must verify compliance by testing against the standard before marketing. Verification is a self-certification procedure where nothing is submitted to the FCC unless specifically requested by the commission, which is similar to the Declaration of Conformity ($\S 2.951$ – 2.956)
- Pre-compliance testing and EMC measurements can help shorten the compliance testing via ensuring the limits are satisfied.
- To have high degree of confidence in the final compliance test,
    (1) Apply proper EMC design principles and recommendations throughout the design phases
    (2) Conduct pre-compliance testing on sub-assemblies and with early design phases

Compliance tests for Part 15

- Measurements and compliance tests have set some limits for EMC levels based on specific test procedures that the manufacturers have to replicate to pass compliance levels.
- For **Part 15** (digital devices), measurements must be performed according to the procedures described in the **ANSI standard C63.4-1992** entitled "Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range **of 9 KHz to 40 GHz**" (§15.31(a)(6))
- The tests should be conducted on a **complete system** (with cables and with a configuration maximizing emissions)
- FCC Part 15 regulations limit the maximum allowable conducted emission on **the AC power line in the range of 0.15 – 30 MHz**, and the maximum **radiated emission in the frequency range of 30MHz – 40 GHz**.
- Conducted emissions are measured with the utilization of a **line impedance stabilization network** (**LISN**) into the unit AC power cord.

Radiated Emissions test

- The measurement procedure is specified in an open area test site (OATS)
- The measurement is conducted over a GND plane with a tuned Dipole antenna or other correctable linearly polarized antenna.
- A Dipole is used between 30 – 1000 MHz
- A linearly polarized Horn antenna is used for above 1000 MHz measurements
- **EUT**: Equipment Under Test.
- Tables show the FCC radiated emissions limits (§15.109)



Approximately, the **Far-field** of the antenna starts around **3λ**.

Radiated Emissions test

- In reality, a **semi-anechoic chamber (SAC)** is used for the radiated emissions tests, for two reasons:

  (1) to prevent electromagnetic emissions from outside the room from contaminating the test (shielded room)

  (2) RF absorbers cover all the interior to represent free space except for the floor that should represent a GND and reflections are considered.

- **Bi-conical** antennas can cover 30-200 MHz
- **Log-periodic** antennas can cover 200MHz – 1GHz
- For **FCC** and **CISPR** tests, antennas should scan 1-4m above GND in both vertical and horizontal polarizations, and maximum recorded emissions from **both polarizations and within all locations should meet the standard levels**.

FCC Radiated emission limits

FCC Class A Radiated Emission Limits Measured at 10 m.

Frequency (MHz)	Field Strength (μV/m)	Field Strength (dB μV/m)
30–88	90	39.0
88–216	150	43.5
216–960	210	46.5
>960	300	49.5

FCC Class B Radiated Emission Limits Measured at 3 m.

Frequency (MHz)	Field Strength (μV/m)	Field Strength (dB μV/m)
30–88	100	40.0
88–216	150	43.5
216–960	200	46.0
>960	500	54.0

FCC Class A and Class B Radiated Emission Limits Measured at 10 m.

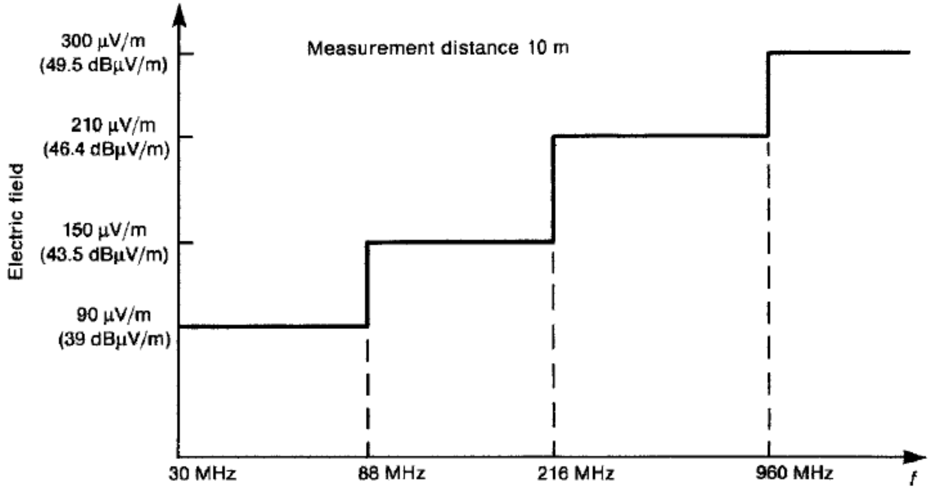
Frequency (MHz)	Class A Limit (μV/m)	Class B Limit (dB μV/m)
30–88	39.0	29.5
88–216	43.5	33.0
216–960	46.5	35.5
>960	49.5	43.5

Upper Frequency Limit for Radiated Emission Testing.

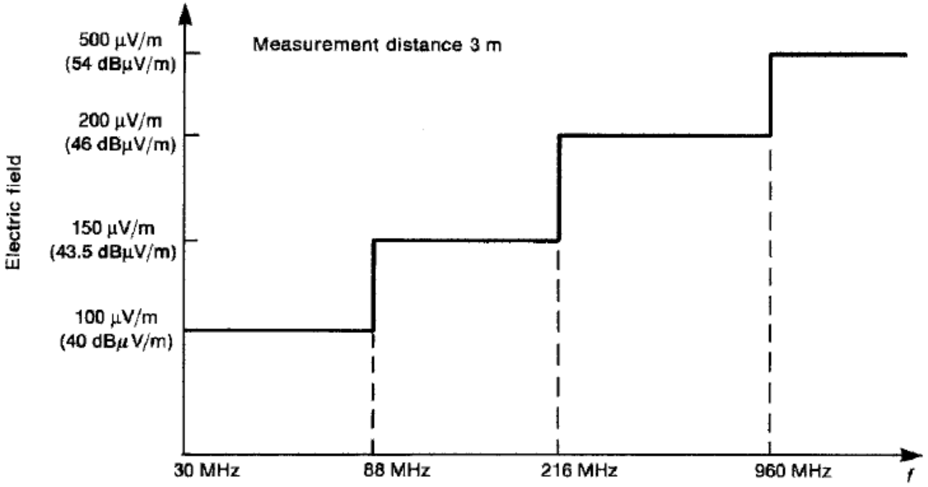
Maximum Frequency Generated or Used in the EUT (MHz)	Maximum Measurement Frequency (GHz)
< 108	1
108–500	2
500–1000	5
> 1000	5^{th} Harmonic or 40 GHz, whichever is less

- Since Class A and Class B are specified at two distances, we can use the **inverse distance method**, to have limits scaled to the distance of interest.
- Thus, emissions at 3m are assumed to reduce by 3/10 at a distance of 10m (radiated field intensity in proportional to 1/r).
- Moving Class B measurements from 3m to 10m to compare with Class A at 10m, we would add **$20\log_{10}(3/10) \approx -10.5$ dB**

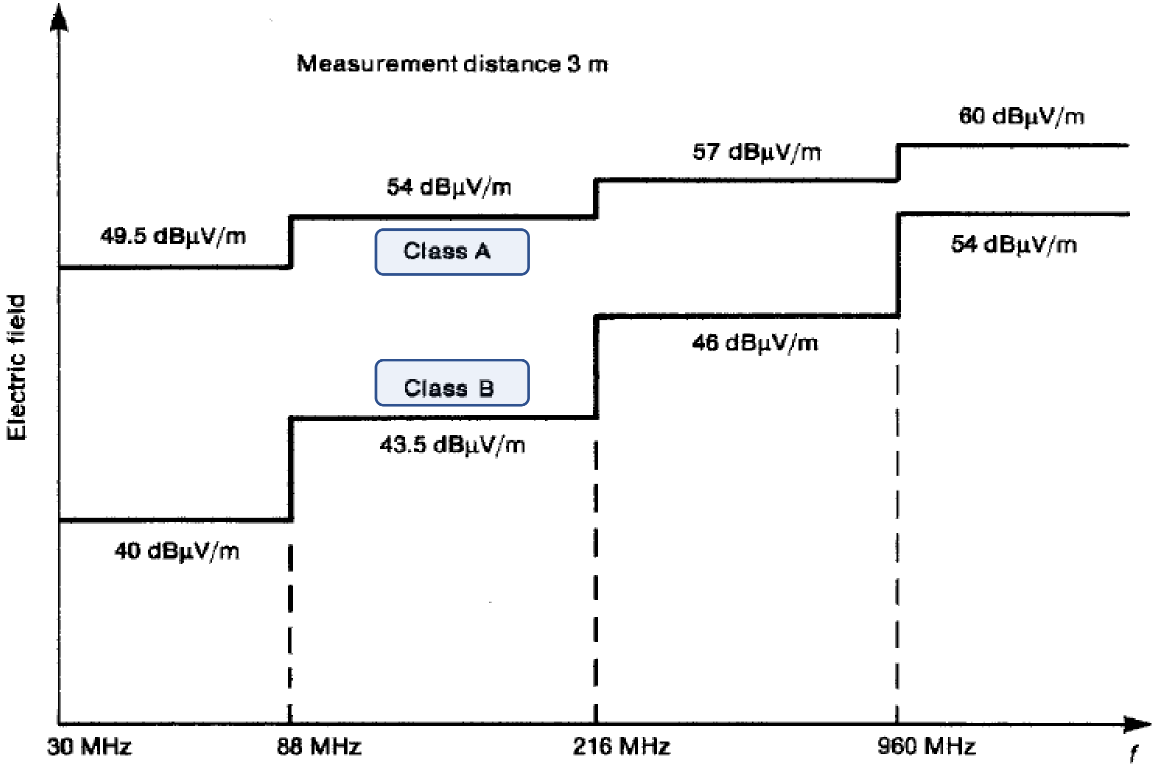
FCC radiated emission limits



Class A



Class B



→ Apply the inverse distance method to bring Class A to 3m from 10m, i.e. ADD **$20\log_{10}(10/3) \approx 10.5$ dB**

CISPR 32 radiated emission limits

- CISPR is a committee of International Electrotechnical committee (**ICE**)
- The **CISPR 32** standard sets the limits on the radiated and conducted emissions of multimedia equipment (MME) including information technology equipment (**ITE**).

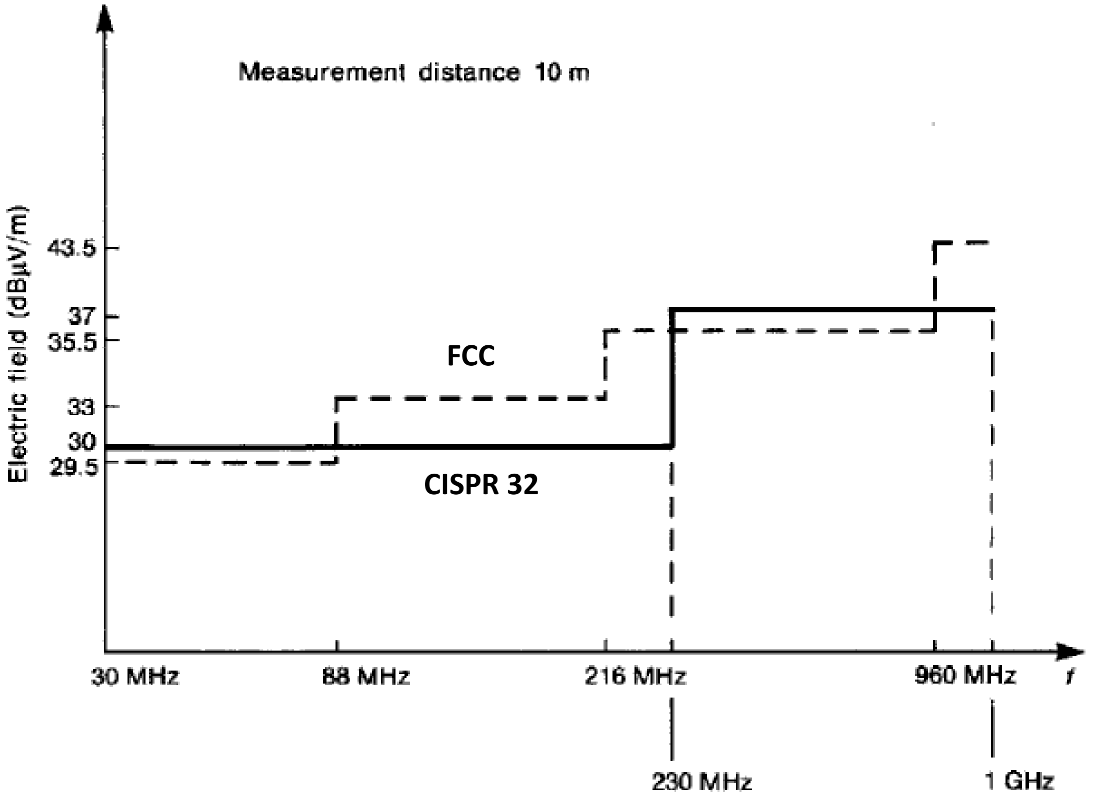
CISPR 32 radiated Emission Limits for Class A ITE

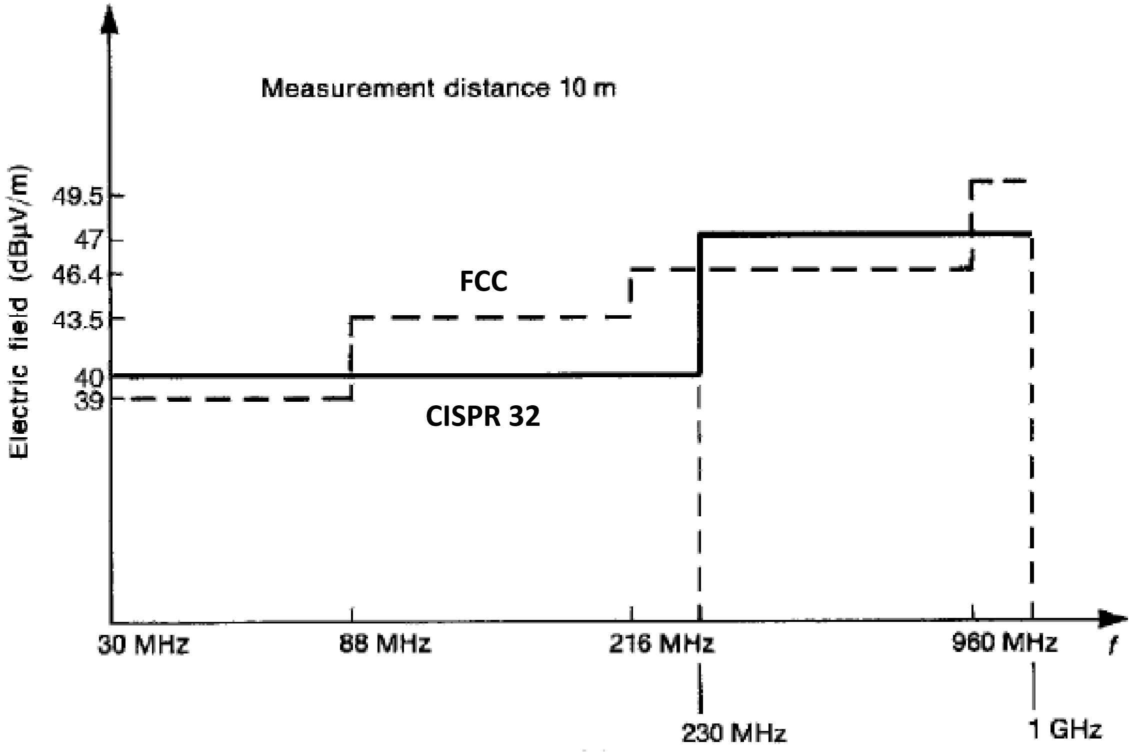
Frequency (MHz)	μV/m	dBμV/m
30–230	100	40
230–1000	224	47

CISPR 32 radiated Emission Limits for Class B ITE

Frequency (MHz)	μV/m	dBμV/m
30–230	31.6	30
230–1000	70.8	37

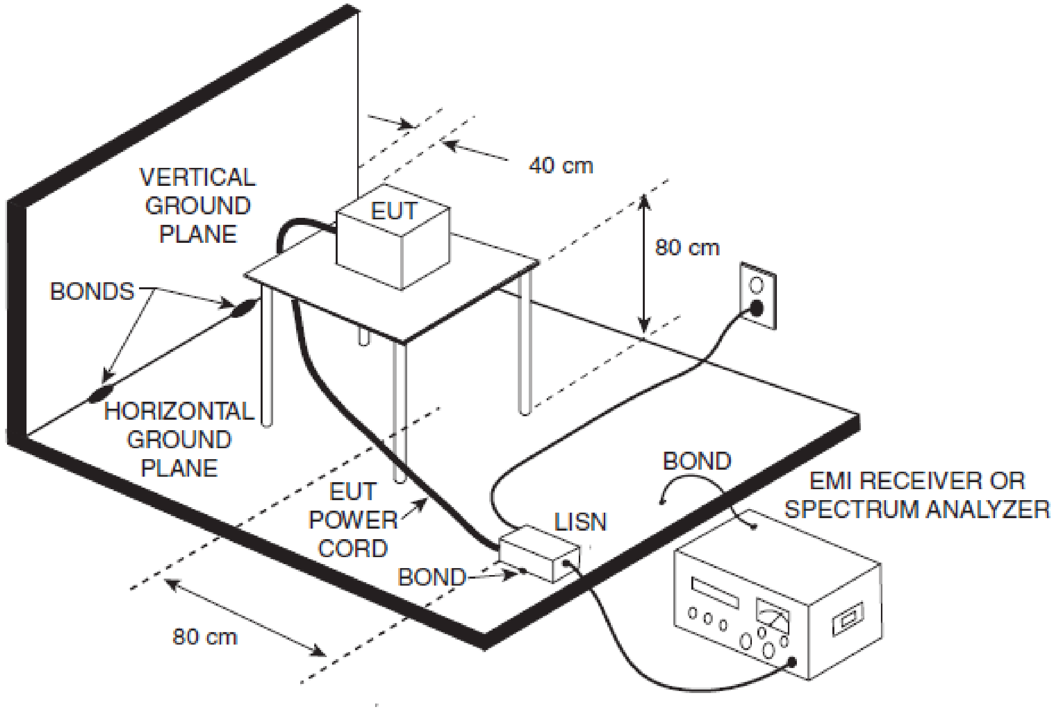
FCC part 15 and CISPR 32 radiated limits





FCC conducted emissions

- Conducted emission regulations limit the voltage that is conducted back onto the AC powerline in the frequency range of 150 KHz – 30 MHz.
- The **FCC Part 15** conducted emission limits (§15.107) are similar to their **CISPR 32** counterpart
- The voltage levels are measured common-mode (hot to GND and neutral to GND) on the AC power line using a 50Ω / 50 μH **LISN**.
- **QP**: Quasi-peak detector in measurement receiver. Representative of noise from **narrowband noise sources** (i.e. clocks)
- **AV**: Average detector in measurement receiver. Representative of **broadband noise sources**

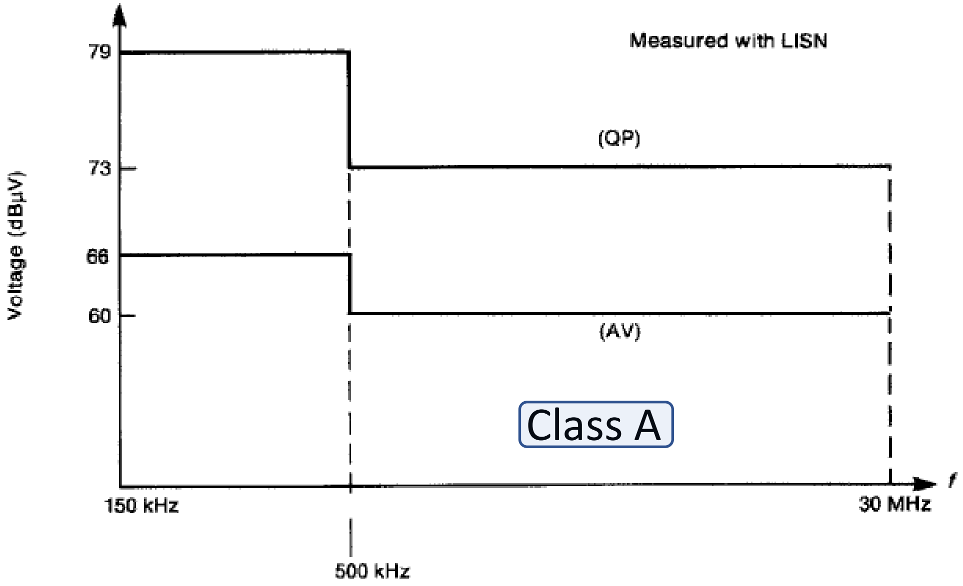


BOND METER, LISN AND GROUND PLANES TOGETHER

FCC/CISPR 32 conducted emission limits

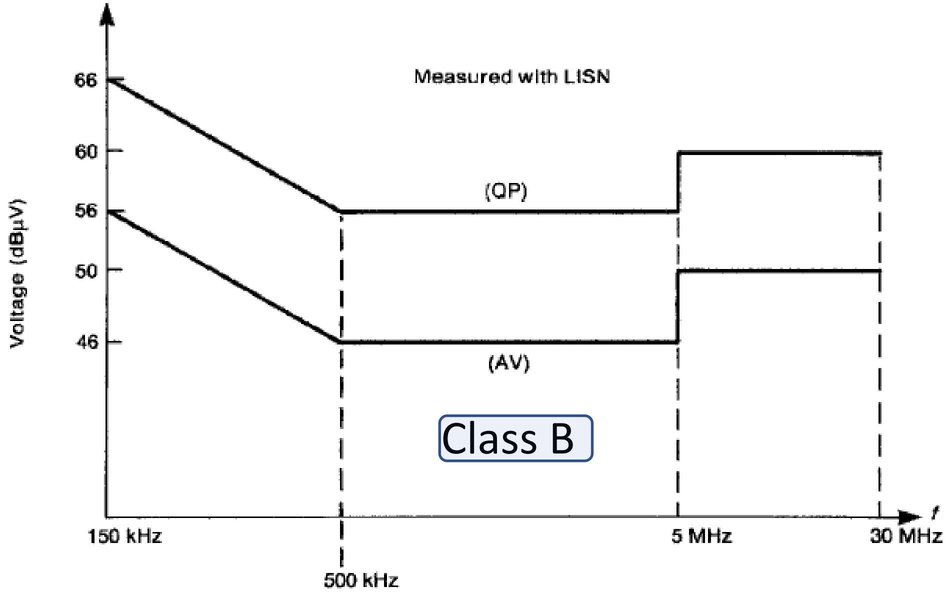
FCC and CISPR 32 Conducted Emission Limits for Class A Digital Devices

Frequency (MHz)	μV QP (AV)	dBμV QP (AV)
0.15–0.5	8912.5 (1995)	79 (66)
0.5–30	4467 (1000)	73 (60)



FCC and CISPR 32 Conducted Emission Limits for Class B Digital Devices

Frequency (MHz)	μV QP (AV)	dBμV 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)



Class B are 13 – 23 dB more stringent than Class A

Administrative procedures

- A tested product must be labeled for compliance (§15.19) and information must be provided to the user on its interference potential (§15.105) .
- The FCC has **exempted eight subclasses** of digital devices (§15.103) from meeting the standards, they are: (*note that some might be following other limits*)
  - Digital devices in transportation vehicles (cars, planes, boats)
  - Industrial control systems in plants, factories, public utilities
  - Industrial, commercial or medical test equipment
  - Digital devices used in appliances (microwave, oven, dryer, air conditioner…)
  - Special medical devices that are under supervision of health care professional
  - Devices with power consumption less than 6nW (digital watch)
  - Joystick controllers (mice)
  - Devices with highest frequency below 1.705 MHz and does not use AC power line
- All FCC rules are in the Code of Federal Regulations, Title 47 (telecommunications), parts 0 – 300. check www.fcc.gov

Susceptibility

- No legal susceptibility requirements exist for commercial equipment in the **United States**
- A reasonable minimum immunity level objective might be 2-3 V/m
- (**Canada**) The Electromagnetic Compatibility Advisory Bulletin (EMCAB-1) defined the grades and immunity for electronic equipment as
  (1) Products that meet GRADE 1 (1V/m) are likely to experience performance degradation
  (2) Products that meet GRADE 2 (3V/m) are unlikely to experience performance degradation
  (3) Products that meet GRADE 3 (10V/m) should experience performance degradation only under very arduous circumstances.
- (**Europe**) The IEC has set the immunity (susceptibility) standards under the 61000 series and adopted it as the EN 61000-4-xxx standards. They considered ESD, electrical fast transients, bursts, surge immunity tests, pulsed magnetic fields, etc…

Electrostatic Discharge (**ESD**) can build up static voltage up to 25kV!

Other Regulations

- **Medical Equipment**
  - Most medical equipment (other than those under Part 18 Rules) is exempt from FCC Rules
  - The federal drug administration (**FDA)** regulates medical equipment in the **USA**.
  - **FDA** EMC standards started with **MDS-201-0004 in (1979)**
  - Manufacturers are encouraged to follow **IEC 60601-1-2** that provides limits on both emissions and immunity (including **ESD** and **transients**) for medical equipment.
- **Telecom**
  - Central office (network) equipment are **exempt** from **FCC Part 15** rules as long as they are installed in a dedicated building or large room (owned or leased by operator)
  - **Telecordia GR-1089** is the standard that applied to telecommunication network equipment in the USA which covers both emissions and susceptibility (similar to European one)
  - This standard is often referred to as New Equipment Building standard (**NEBS**)

Other Regulations

- **Automotive**
  - Most (if not all) electronics built in transportation vehicles **are exempt from the FCC** Part 15 Rules.
  - Regulations in automotive follow **CISPR**, International Organization for Standardization (**ISO**) and the Society of Automotive Engineers (**SAE**).
  - The **SAE-J551** is a **vehicle** level EMC standard. The **SAE-J1113** is a **component**/module level EMC standard. Both cover emissions and susceptibilities and are close to the military EMC ones.
  - Vehicular EMC **emission** standards are among toughest due to close proximity of various types of sub-systems (~ **40dB more stringent** than FCC Part 15 class B limits), due to presence of high-voltage discharges, wiring, motors and inductive harnesses located near radio modules and among each other.
  - Radiated **immunity** tests are specified up to an electric field (E-field) strength of **200V/m** or higher (compared to 3V/m or 10V/m for non automotive standards)
  - (**Europe and outside USA**) use **CISPR 12** and **CISPR 25**.

Other Regulations

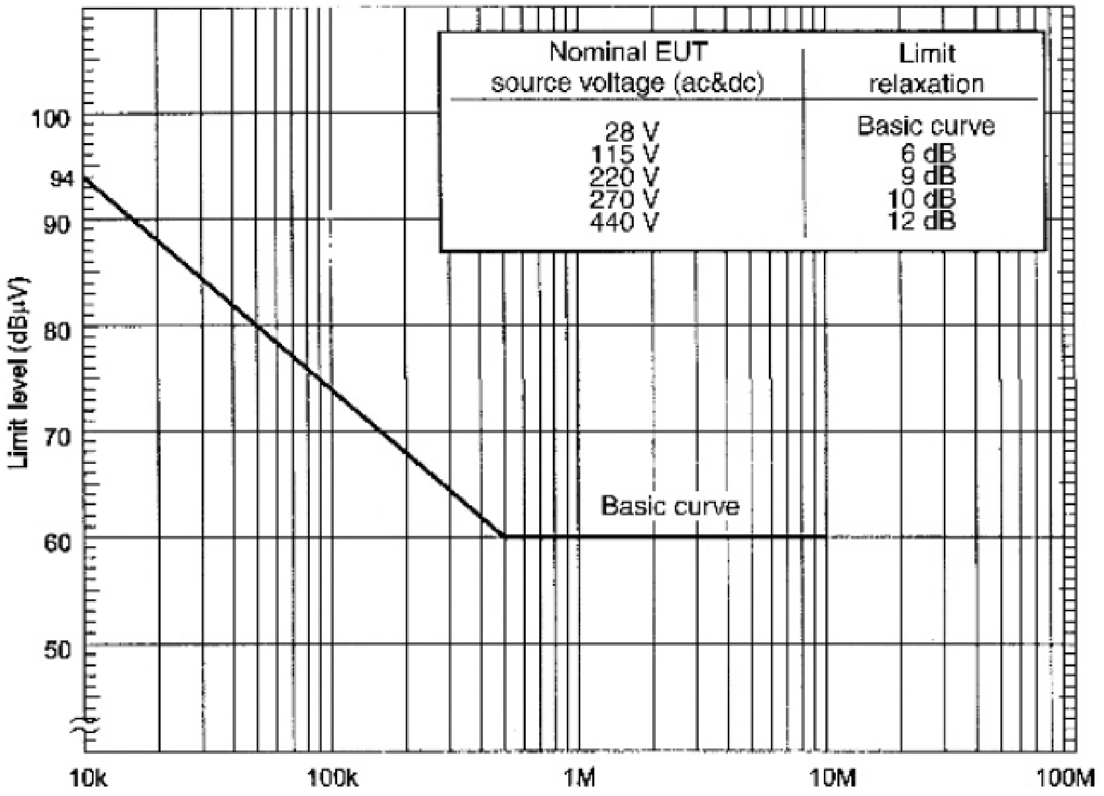
- **Avionics**
  - Commercial Avionics industry has its own EMC standards (similar to military ones)
  - The Radio Technical Commission for Aeronautics (**RTCA**) creates these standards for the Avionics industry
  - An example is the **RTCA/DO-160E** “Environmental conditions and Test Procedures for Airborne Equipment”, where Sections 15 – 23 cover EMC issues. It covers emissions and susceptibility (ESD, lightning, etc)
  - Such standards are **contractual**, **not legal**, **requirements**, and thus can be negotiated

Military standard (MIL-STD-461G)

- The **US Department of Defense** comes up with the rules and regulations applicable to military and aerospace equipment
- MIL-STD-461 specifies the limits that needs to be met, and **MIL-STD-462** specifies the procedures for conducting these tests contained in **MIL-STD-461**.
- MIL EMC requirements are **more stringent than FCC**, cover immunity and emissions in the **30 Hz – 40 GHz** bands.
- Again, **MIL-STDs are not legal, but contractual** ones
- The latest is **MIL-STD-461G**
- For radiated emissions, **MIL-STD specifies SAC tests**, and for conducted emissions testing, MIL-STD measures current while commercial tests measure voltage. Later, **MIL-STD adopted the LISN voltage** based conducted emissions tests following commercial procedures.

Emission and Susceptibility Requirements of MIL-STD-461E

Requirement	Description
CE101	Conducted emissions, power leads, 30 Hz–10 kHz
CE102	Conducted emissions, power leads, 10 kHz–10 MHz
CE106	Conducted emissions, antenna terminal, 10 kHz–40 GHz
CS101	Conducted susceptibility, power leads, 30 Hz–150 kHz
CS103	Conducted susceptibility, antenna port, intermodulation, 15 kHz–10 GHz
CS104	Conducted susceptibility, antenna port, rejection of undesired signals, 30 Hz–20 GHz
CS105	Conducted susceptibility, antenna port, cross-modulation, 30 Hz–20 GHz
CS109	Conducted susceptibility, structure current, 60 Hz–100 kHz
CS114	Conducted susceptibility, bulk cable injection, 10 kHz–200 MHz
CS115	Conducted susceptibility, bulk cable injection, impulse excitation
CS116	Conducted susceptibility, damped sinusoidal transients, cables and power leads, 10 kHz–100 MHz
RE101	Radiated emissions, magnetic field, 30 Hz–100 kHz
RE102	Radiated emissions, electric field, 10 kHz–18 GHz
RE103	Radiated emissions, antenna spurious and harmonic outputs, 10 kHz–40 GHz
RS101	Radiated susceptibility, magnetic field, 30 Hz–100 kHz
RS103	Radiated susceptibility, electric field, 2 MHz–40 GHz
RS105	Radiated susceptibility, transient electromagnetic field

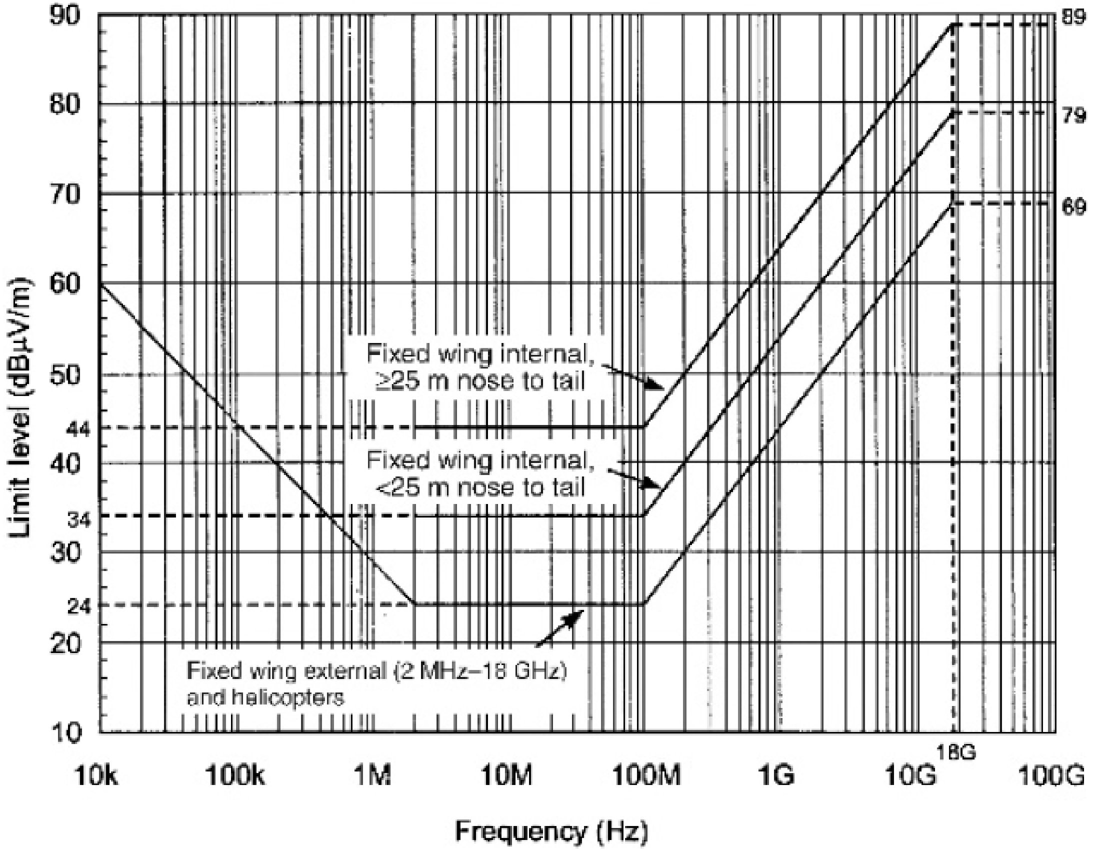


MIL-STD-461E CE102 limit (EUT power leads, ac and dc) for all applications

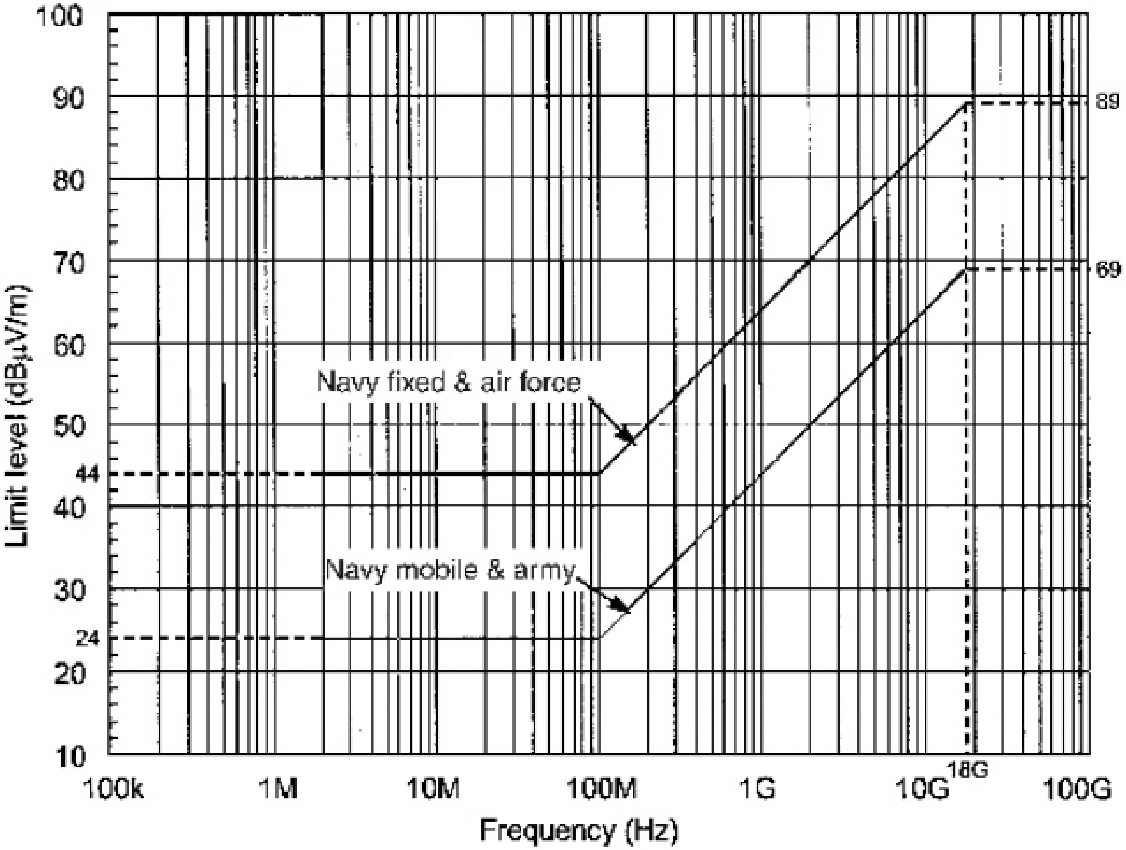
Requirement Matrix of MIL-STD-461E[a]

Equipment and Subsystems Installed in, on, or Launched from the Following Platforms or Installations	Requirement Applicability																
	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS109	CS114	CS115	CS116	RE101	RE102	RE103	RS101	RS103	RS105
Surface ships		A	L	A	S	S	S		A	L	A	A	A	L	A	A	L
Submarines	A	A	L	A	S	S	S	L	A	L	A	A	A	L	A	A	L
Aircraft, army, including flight line	A	A	L	A	S	S	S		A	A	A	A	A	L	A	A	L
Aircraft, navy	L	A	L	A	S	S	S		A	A	A	L	A	L	L	A	L
Aircraft, air force		A	L	A	S	S	S		A	A	A		A	L		A	
Space systems, including launch vehicles		A	L	A	S	S	S		A	A	A		A	L		A	
Ground, army		A	L	A	S	S	S		A	A	A		A	L	L	A	
Ground, navy		A	L	A	S	S	S		A	A	A		A	L	A	A	L
Ground, air force		A	L	A	S	S	S		A	A	A		A	L		A	

[a] *Legend:* A—applicable; L—limited as specified in the individual sections of this standard; S—procuring activity must specify in procurement documentation.



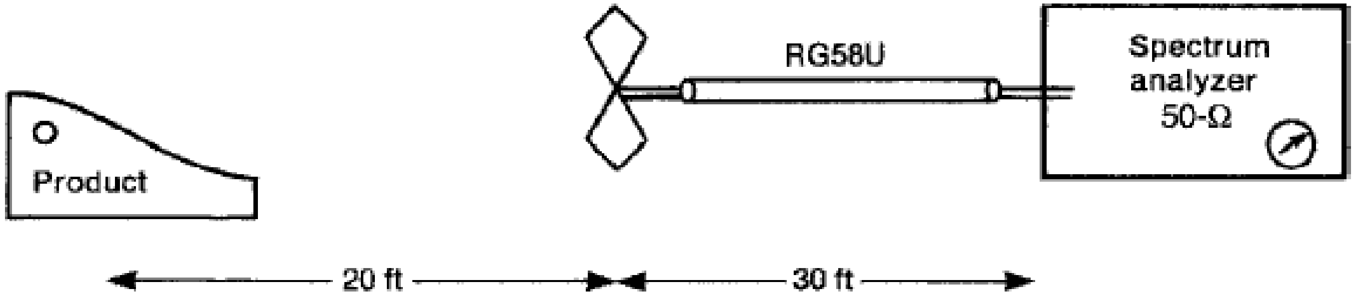
MIL-STD-461E RE102 limit for aircraft and space System applications



MIL-STD-461E RE102 limit for ground applications

Example 1

A product is tested for FCC Class B radiated emission compliance as shown in the figure. The distance between the measurement antenna and the product is 20 ft. The spectrum analyzer is connected to the measurement antenna with 30 ft of RG58U coaxial cable that has a loss of 4.5 dB/100 ft at 100 MHz. The receiving antenna provides an output voltage at 100 MHz of 6.31 V for each V/m of incident electric field. If the spectrum analyzer indicates a level of 53 dBμV at 100 MHz, (a) determine the level of received electric field at the antenna. (b) Determine whether the product will pass or fail the FCC Class B test, and by how much.



Sol.

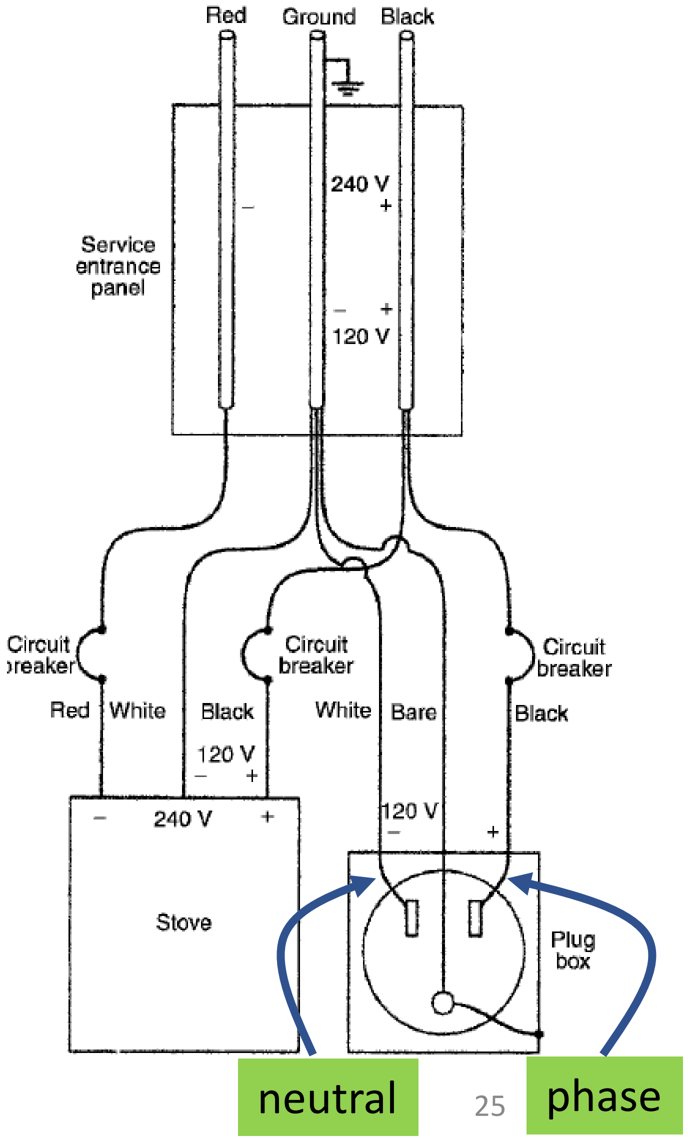
ON THE BOARD!

Measurement of conducted emissions

- We have outlined the measurement procedure and the limits for conducted emissions.
- The intent of conducted emission limits is to reduce noise currents pass out of the product’s AC power cord.
- The common power net of an installation is an array of connected wires in the walls, which will act as an efficient large antenna that will radiated high levels of interference.
- We will measure the conducted emissions in volts (FCC and CISPR) via a line impedance stabilization network (LISN) in series with the product power cord.
- Now we will dig a little deeper into the process.

Typical Household power distribution system in the USA

- Voltage of 120V_{RMS} with 60 Hz between either wire and the GND. Voltage between RED and Black is 240 V_{RMS}.
- Service voltage is between either RED or Black and GND to provide 120 V_{RMS}.
- A third **safety** wire (Green/Bare) is carried with the other two carrying 120 V_{RMS} and 60 Hz. These two wires are called the **Phase** and **Neutral**.
- Thus we need to **measure** the **currents** on the **phase** and **neutral** lines for **conducted emissions**.
- An **LISN** will serve two purposes:
  (1) It will prevent (like a shielded room) the contamination of the measurement from external noise (on common AC power net)
  (2) Ensure that the measurements on one site can be correlated with another (present a constant impedance)



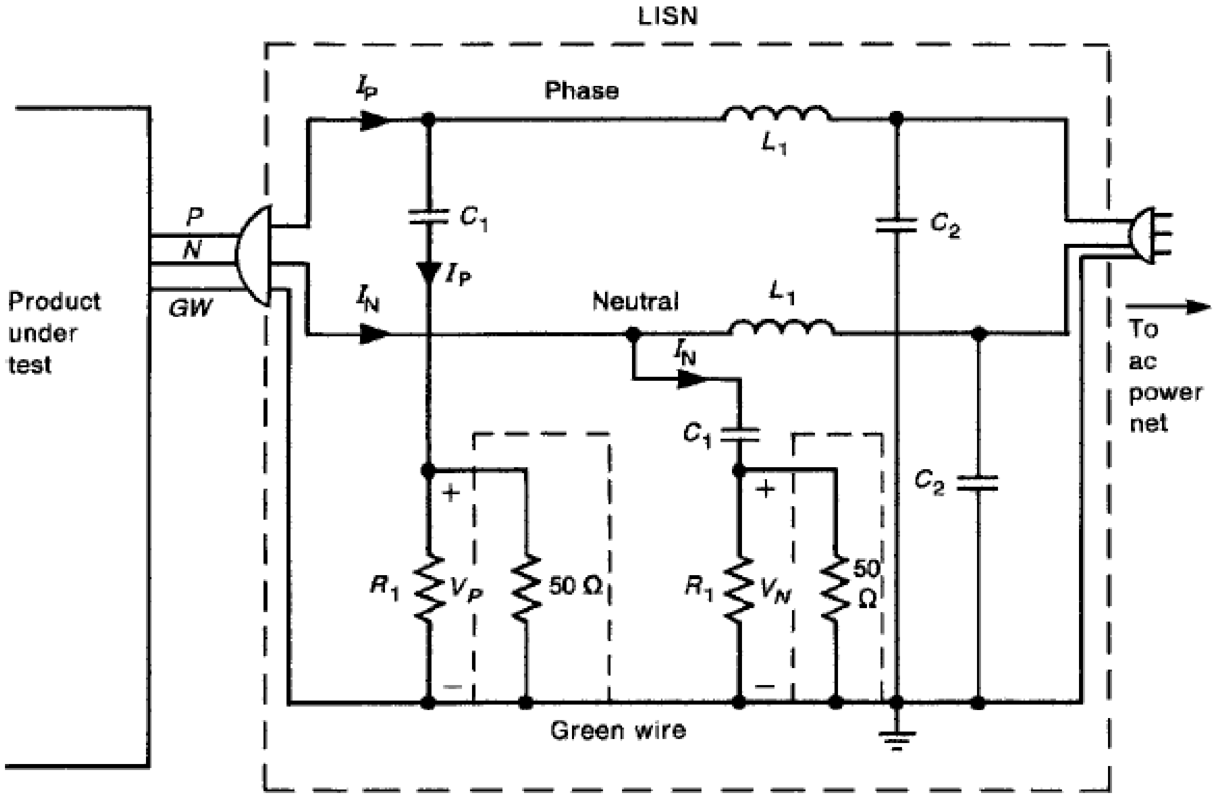
LISN

Purpose 1

- **L_1 blocks the noise**. Its value is 50 µH, thus its Z_{L1} is 47 – 9425 Ω between 150KHz and 30 MHz.
- **C_2 will divert the noise**. Its value is 1 µF, thus its Z_{C2} is 1.06 – 0.005 Ω between 150KHz and 30 MHz.
- L_1 and C_2 will pass 60 Hz signal.

Purpose 2

- Impedance seen by product looking into the power cord should be same from site to site. C_1 and 50 Ω resistor represent the input impedance of product (receiver). C_1 will prevent DC from overloading receiver, R_1 = 1K Ω is used to discharge C_1 if 50 Ω is disconnected
- C1 = 0.1 µF, thus Z_{C1} is 10.6 – 0.05 Ω in the above frequency rage.
- Currents I_P and I_N pass through C1 and 50 Ω because L_1 and C_2 will block signals in the 150 KHz – 30 MHz bands.
- Thus impedance seen by product (P-GW or N-GW) is 50 Ω. **Both** measurements should pass limits.



- Thus, Measured voltages are representatives of the noise currents via:

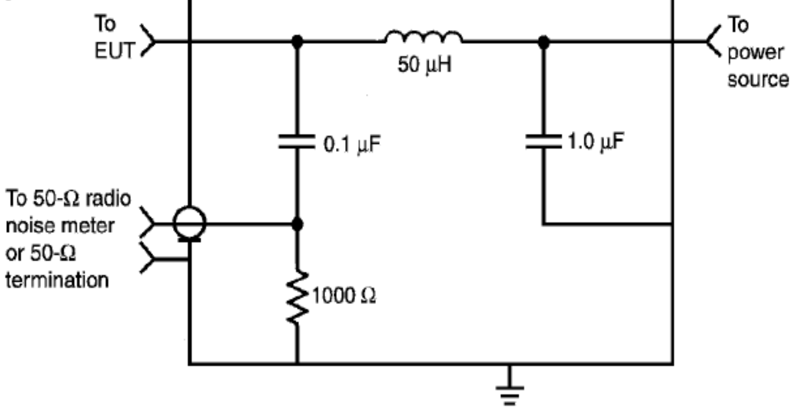
$$I_P = \frac{V_P}{50}$$

$$I_N = \frac{V_N}{50}$$

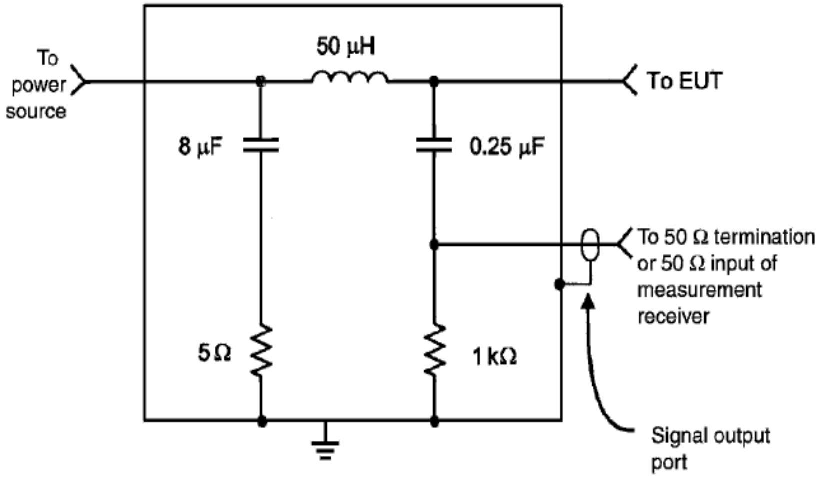
LISN example

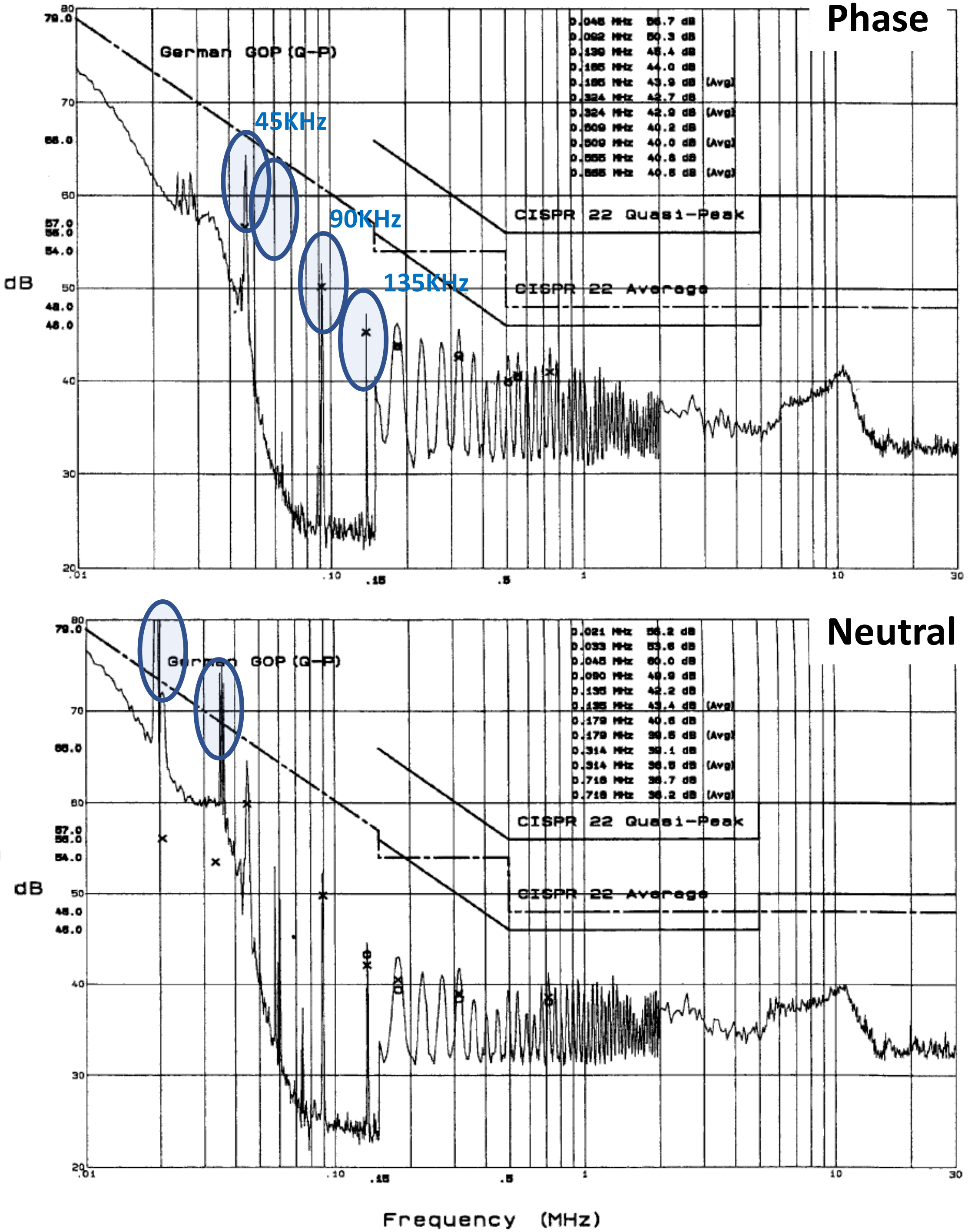
- **Measurement** example for **conducted emissions** of a product with a 45KHz switching power supply.
- Note peaks at 45KHz, 90KHz and 135KHz.
- 45KHz was chosen so that the 3rd harmonic occurs before the 150KHz limit of CISPR
- Measurements show that **this device is not regulated** as emissions will exceed the standard levels (see levels at Neutral line)

FCC/CISPR 32



MIL-STD-461G

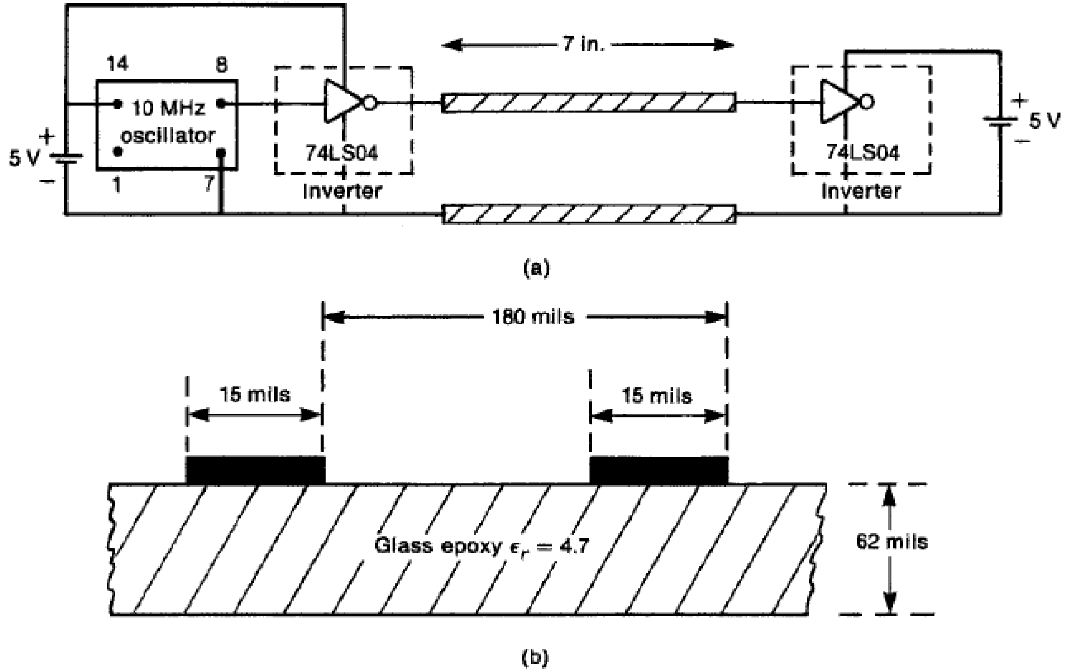


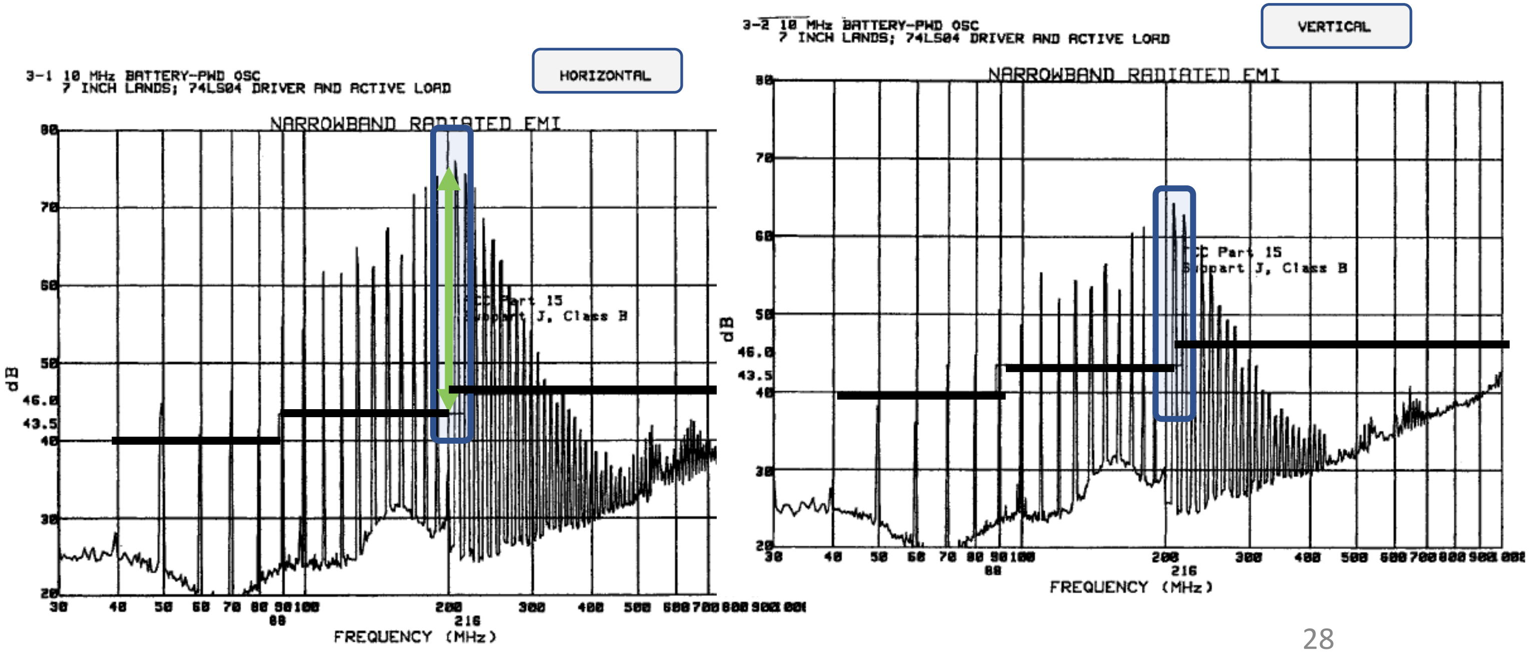


Radiated example

- A simple experiment to demonstrate the difficulty in complying with the radiated emission limits: (a) schematic and dimensions of device tested; (b) cross-sectional dimensions of the printed circuit board (**PCB**).
- 5V supplies are coming from a 9V source and a 7805-regulator chip (not shown).
- Both supplies were compact (less than 2x2 in^2) and were not connected to the commercial power system.
- Measured radiated emissions show that they exceed FCC Class B limits by **30dB** and **15dB** for the **horizontal** and **vertical** emissions, **respectively**!!

→ Getting the trace and its return bath closer together as well as improving the impedances and having a low GND current, common GND paths are essential for reducing EMC issues in PCB (more later!)





Design constraints for Products

- To reduce emissions and improve susceptibility, we can use batteries to avoid the main AC line, we can enclose the equipment in a metallic enclosure (to shield it), but this is not always possible or even permitted.
- The use of **suppression components** is another way to reduce levels of emissions. But such components might require extra **cost** that is another important factor for manufacturers.
- **Manufacturability** of the product is another important issue, thus such components should be compatible with the manufacturing process
- **Marketability** is important, thus the shape and enclosure of such products are important and some EMC reduction techniques (i.e. shielding via an enclosure) might not be the best way to go.
- **Product development schedule** is by far the most important. It is important not to miss the schedule so that you do not miss the market share. Thus, make sure you account for EMC issues early on so that you do not suffer from delays trying to solve them later.
- It is important to follow a **preventive** measures to EMC issues via following recommended practices for emission reduction. If it happens and levels are high, determining the source of the emission becomes the most important so that

    (1) a fix is made fast

    (2) unnecessary cost is not added due to fixes that are not substantial to emission reduction

Advantages of EMC Design

- The primary advantages of adequate EMC Design are:

  (1) minimizing the additional cost required by suppression elements or redesign in order to satisfy limits

  (2) maintaining the product development and announcement on schedule

  (3) ensures that the product will operate satisfactorily in the presence of inevitable external noise sources at its operating location
- Early and consistent attention to EMC will minimize cost and schedule delays and will provide the best chance for complying with the regulators.
- Always assume that some EMC suppression will be needed for compliance and provide the ability to implement it as needed

Next …

- Time-Domain and Frequency-Domain Analysis …