Chapter 2

EMC Requirements for Electronic Systems

National Taiwan University of Science and Technology

Chun-Long Wang

Outline

- Preview
- Governmental Requirements
- Additional Product Requirements
- Design Constraints for Products
- Advantages of EMC Design

Preview

- Categories of EMC Requirements
  - Those Mandated by Governmental Agencies
    - Legal requirements and generally cannot be waived.
    - This do not guarantee that the product will not cause interference.
    - A product can not be legally sold if it does not comply with this requirement.
  - Those Imposed by the Product Manufacturer
    - They are imposed for the purpose of ensuring a reliable, quality product in order to result in customer satisfaction.

Governmental Requirements

- Sectors of Governmental Requirements
  - Products Marketed in the USA
    - The Federal Communications Commission (FCC) is charged with the regulation of radio and wire communications.
  - Products Marketed outside the USA
    - The International Special Committee on Radio Interference (CISPR), which is a committee of the International Electrotechnical Committee (IEC), is in charge of this.

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Introductions
    - Range of radio frequency: 9kHz to 3000GHz
    - Part 15 of the FCC Rules and Regulations contained in Title 47 of the Code of the Federal Regulations applies to the radio-frequency devices.
    - Any electronic device that has digital circuitry and uses a clock signal in excess of 9kHz must obey this rule.

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Class A of FCC Regulations
    - Digital devices that are marketed for use in a commercial, industrial, or business environment.
  - Class B of FCC regulations
    - Digital devices that are marketed for use in a residential environment.
    - The Class B limits are more stringent than the Class A limits since we are not likely to have expertise or financial resources in residential environment.

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Conducted Emissions
    - Currents that are passed out through the unit's ac power cord
    - Frequency range: 150kHz ~ 30MHz
    - Measured with a line impedance stabilization network (LISN)
  - Radiated Emissions
    - Frequency range: 30MHz ~ 40GHz
    - Measured in a semianechoic chamber (SAC) or at an open-field test site.
    - Data for Vertical and Horizontal Polarizations are both required.

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - FCC and CISPR 22 Conducted Emission Limits for Class B Digital Devices

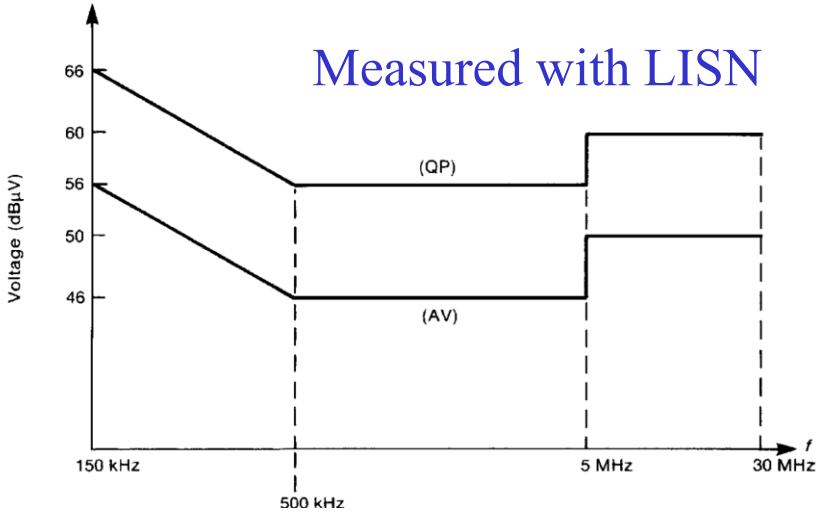
Frequency (MHz)	μV QP (AV)	dBμV QP (AV)
0.15	1995 (631)	66 (56)
0.5	631 (199.5)	56 (46)
0.5–5	631 (199.5)	56 (46)
5–30	1000 (316)	60 (50)

  - FCC and CISPR 22 Conducted Emission Limits for Class A Digital Devices

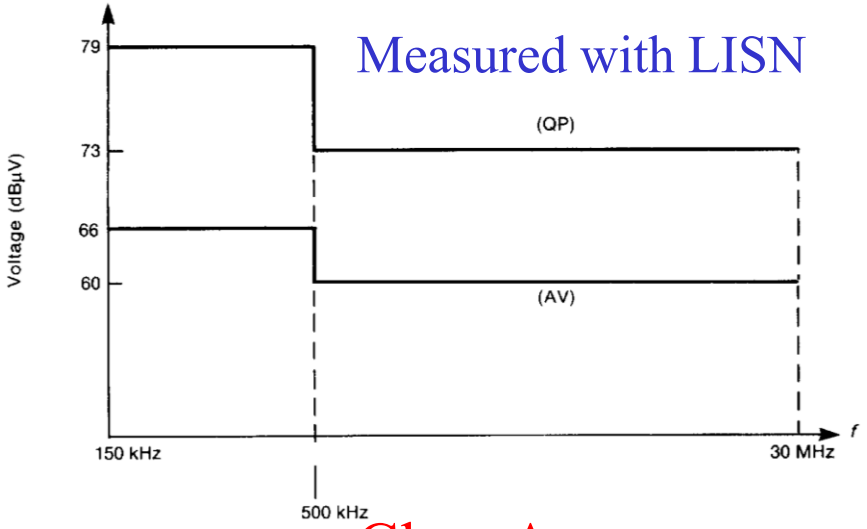
Frequency (MHz)	μV QP (AV)	dBμV QP (AV)
0.15–0.5	8912.5 (1995)	79 (66)
0.5–30	4467 (1000)	73 (60)

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Conducted Emissions of FCC Regulations



Class B



Class A

QP: a quasi-peak detector in the measurement receiver
AV: an average detector in the measurement receiver

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Upper Limit of Measurement Frequency

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

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - FCC Emission Limits for Class B Digital Devices

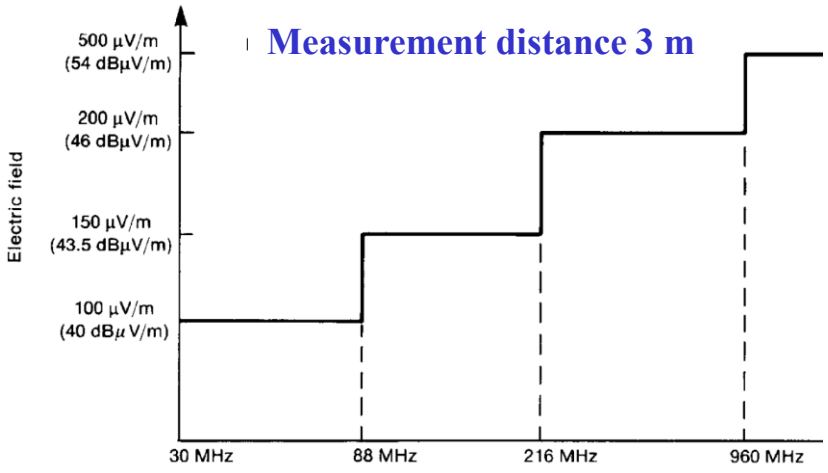
	Measured at 3 m	
Frequency (MHz)	μV/m	dBμV/m
30–88	100	40
88–216	150	43.5
216–960	200	46
>960	500	54
>1 GHz	500 (AV)	54 (AV)
	5000 (PK)	74 (PK)

  - FCC Emission Limits for Class A Digital Devices

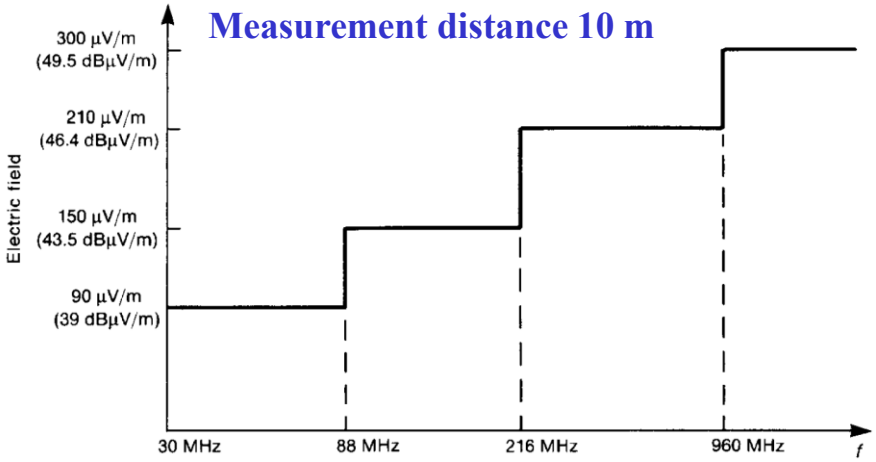
	Measured at 10 m	
Frequency (MHz)	μV/m	dBμV/m
30–88	90	39
88–216	150	43.5
216–960	210	46.4
>960	300	49.5
>1 GHz	300 (AV)	49.5 (AV)
	3000 (PK)	69.5 (PK)

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Radiated Emissions of FCC Regulations



Class B

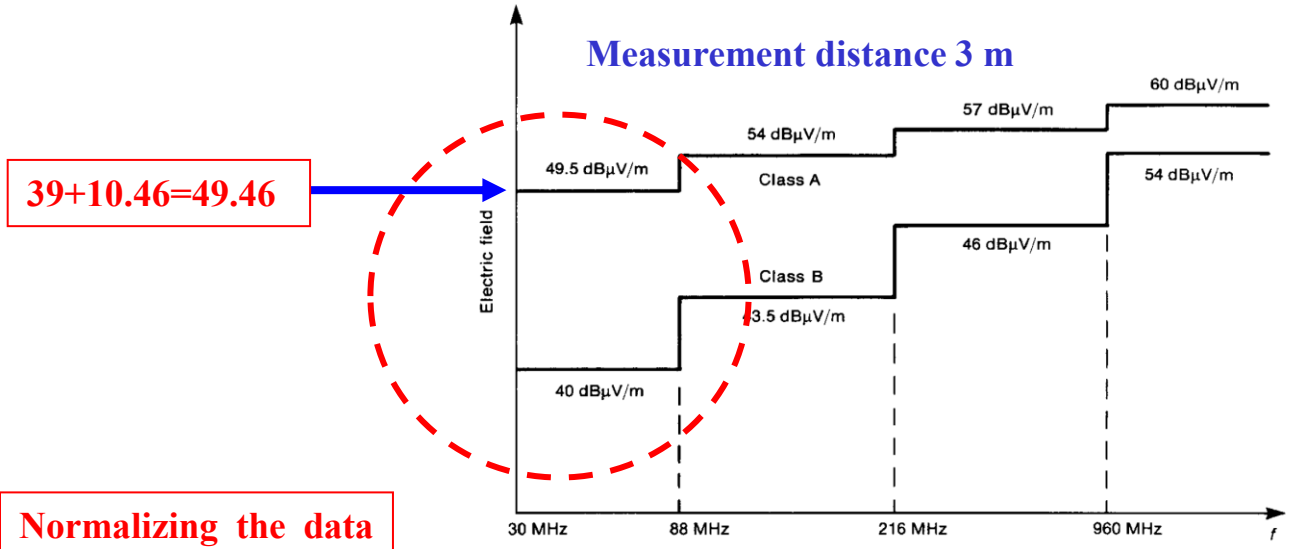


Class A

The antenna must be elevated above the ground-plane distances of 1-4 m and the maximum emission recorded.

Governmental Requirements

- Requirements for Commercial Products Marketed in the United States
  - Radiated Emissions of FCC Regulations
    - Comparison between Classes B and A



The data for class A are normalized to those with a distance of 3 m.
The normalized data in the lower frequency part are not reliable. (not far-field)

Normalizing the data of class A from 10 m to 3m results a increase of 20log(10/3) dB (= 10.46 dB)

The class A limits are some 10dB less stringent than the class B limits.

Governmental Requirements

- Requirements for Commercial Products Marketed outside the United States
  - CISPR 22 Radiated Emission Limits for Class B ITE Equipment (10 m)

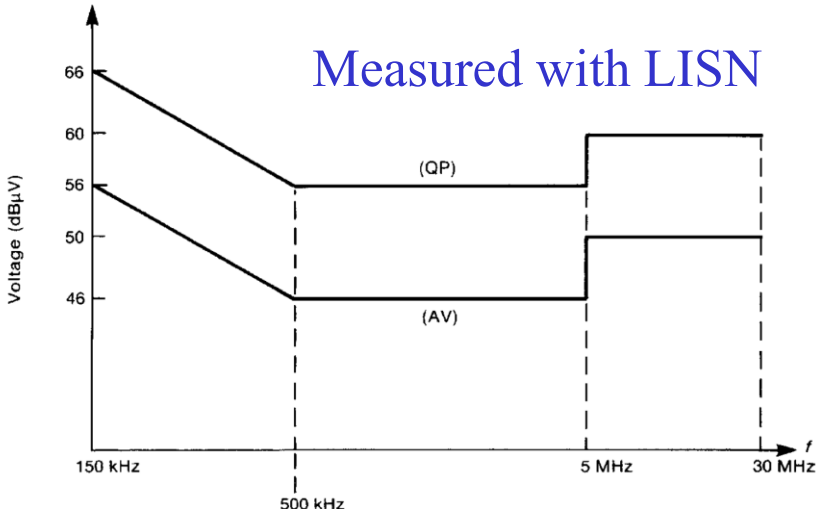
Frequency (MHz)	μV/m	dBμV/m
30–230	31.6	30
230–1000	70.8	37

  - CISPR 22 Radiated Emission Limits for Class A ITE Equipment (10 m)

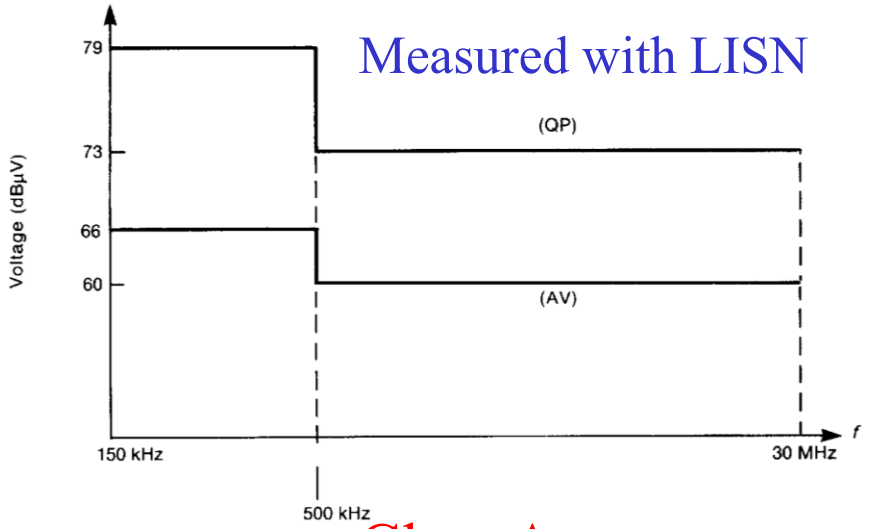
Frequency (MHz)	μV/m	dBμV/m
30–230	100	40
230–1000	224	47

Governmental Requirements

- Requirements for Commercial Products Marketed outside the United States
  - Conducted Emissions of CISPR 22 Regulations
    - The same as those of FCC regulations



Class B

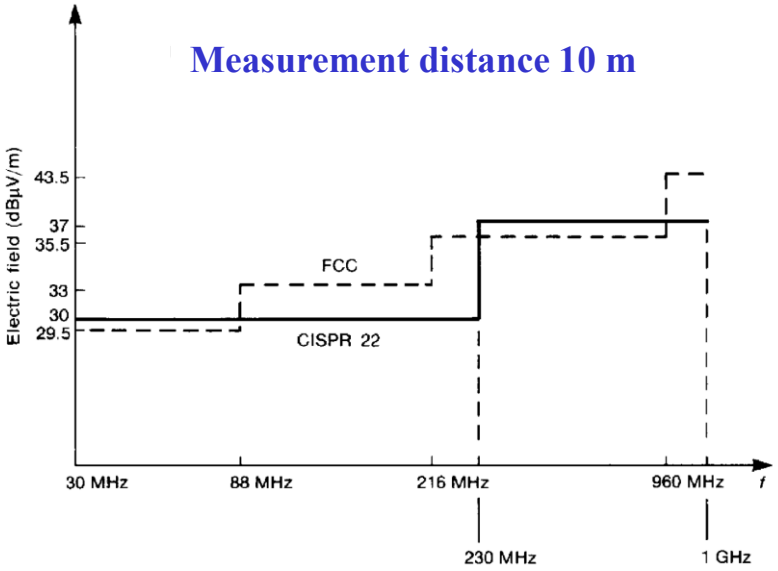


Class A

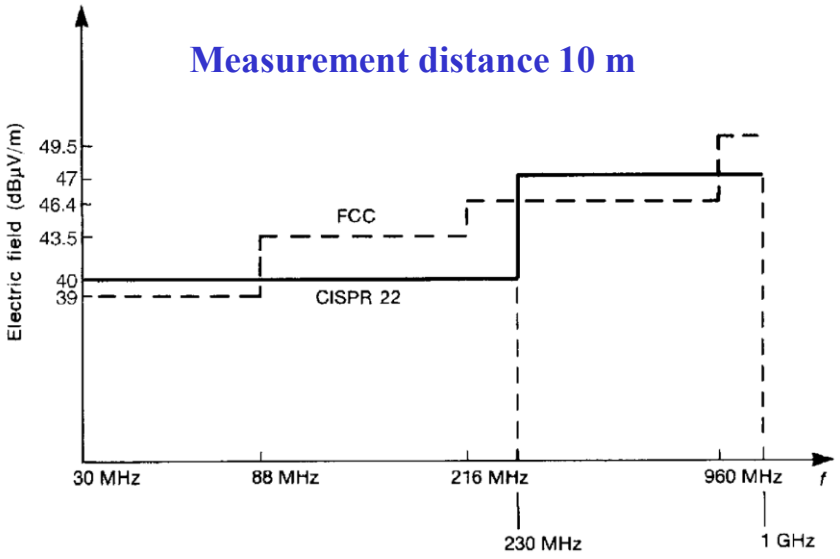
QP: a quasi-peak detector in the measurement receiver
AV: an average detector in the measurement receiver

Governmental Requirements

- Requirements for Commercial Products Marketed outside the United States
  - Radiated Emissions of CISPR 22 Regulations
    - Only up to 1 GHz



Class B



Class A

The European EMC Directive was the first one to mandate the susceptibility (immunity) for commercial products.

Governmental Requirements

- Requirements for Military Products Marketed in the United States
  - The Military Standard MIL-STD-461E:1999
    - The limits and applicability are much more complicated and span much larger frequency ranges than do those of the FCC or CISPR 22.
    - The requirements can be waived and/or tailored.

Governmental Requirements

- Requirements for Military Products Marketed in the United States
  - The Military Standard MIL-STD-461E:1999

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

Governmental Requirements

- Requirements for Military Products Marketed in the United States
  - 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.

Governmental Requirements

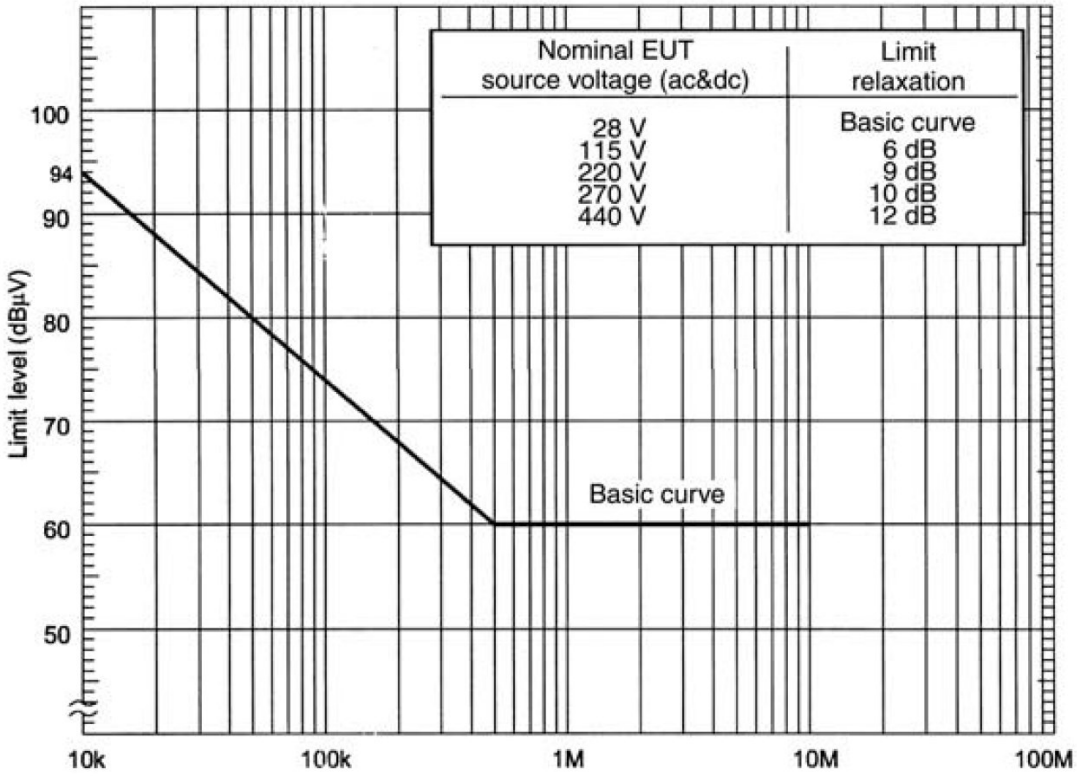
- Requirements for Military Products Marketed in the United States
  - RS103 Limits[a]

Frequency Range	Platform	Limit Level (V/m)[a]							
		Aircraft (External or Safety-Critical	Aircraft Internal	All Ships (above Decks) and Submarines (External)[b]	Ships (Metallic) (below Decks)	Ships (Nonmetallic) (below Decks)	Submarines (Internal)	Ground	Space
2–30 MHz	A	200	200	200	10	50	5	50	20
	N	200	200	200	10	50	5	10	20
	AF	200	20	—	—	—	—	10	20
30 MHz–1 GHz	A	200	200	200	10	10	10	50	20
	N	200	200	200	10	10	10	10	20
	AF	200	20	—	—	—	—	10	20
1–18 GHz	A	200	200	200	10	10	10	50	20
	N	200	200	200	10	10	10	50	20
	AF	200	60	—	—	—	—	50	20
18–40 GHz	A	200	200	200	10	10	10	50	20
	N	200	60	200	10	10	10	50	20
	AF	200	60	—	—	—	—	50	20

[a] *Key:* A = Army; N = Navy; AF = Air Force.
[b] For equipment located external to the pressure hull of a submarine but within the superstructure, use "Ships (Metallic) (below Decks)."

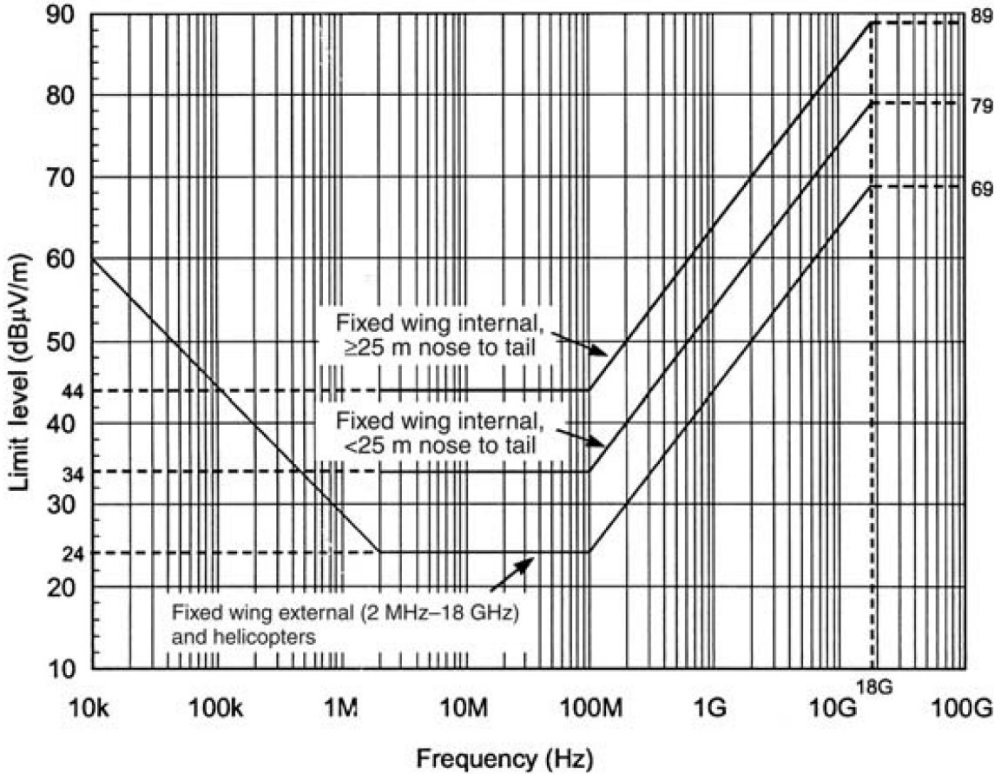
Governmental Requirements

- Requirements for Military Products Marketed in the United States
  - MIL-STD-461E CE102 limit (EUT power leads, ac and dc) for all applications



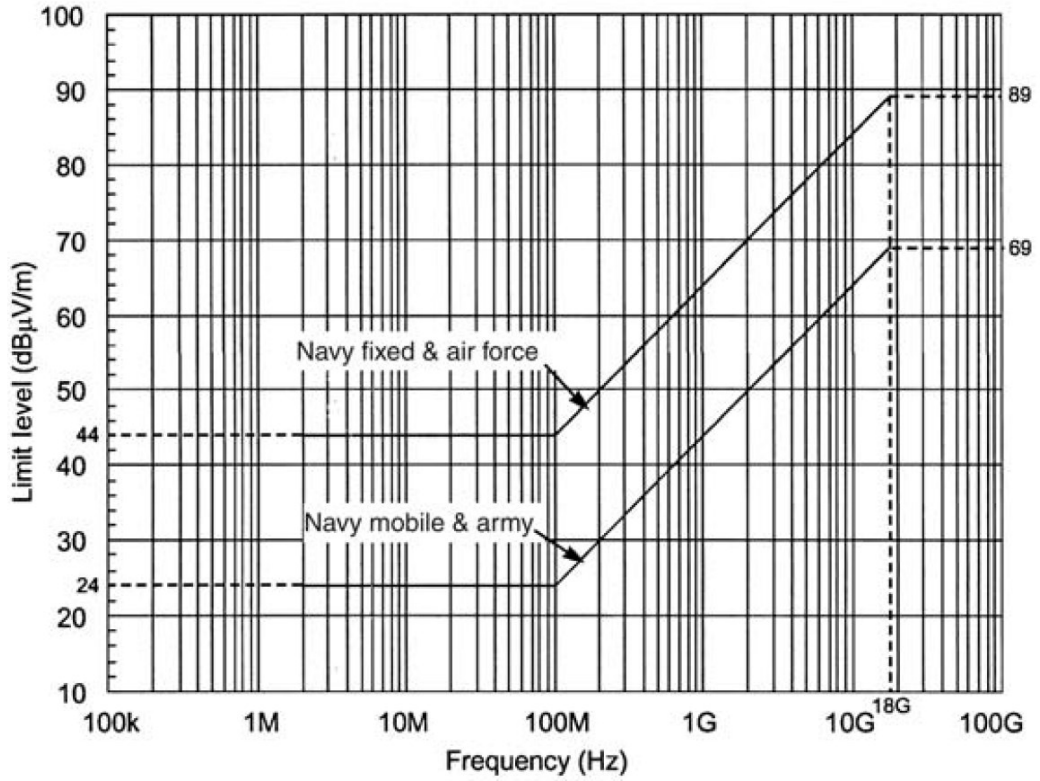
Governmental Requirements

- Requirements for Military Products Marketed in the United States
  - MIL-STD-461E RE102 limit for aircraft and space system applications



Governmental Requirements

- Requirements for Military Products Marketed in the United States
  - MIL-STD-461E RE102 limit for ground applications



Governmental Requirements

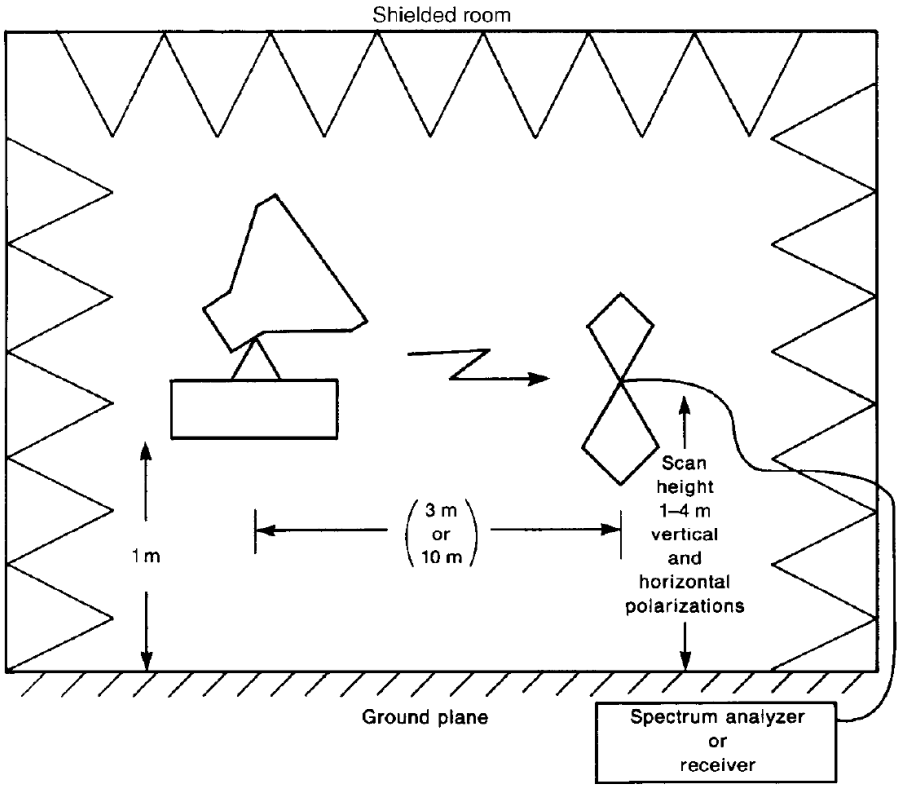
- Measurement of Emissions for Verification of Compliance
  - Introduction
    - Every standard that sets out limits on radiated and conducted emissions (FCC, CISPR22, and MIL-STD-461) clearly defines how the data are to be measured. This includes test procedure, test equipment, bandwidth, and test antennas.
    - Thus, the governing agency as well as the product manufacturer can be assured that the product's emissions comply with the limits.

Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Radiated Emissions
    - The radiated electric fields for the commercial tests (FCC and CISPR22) are to be measured either at an open-area test site (OATS) or in a semianechoic chamber (SAC).
    - While the OATS is preferred, the SAC provides all weather measurement capability as well as security.
    - In the following slides, we will introduce the measurement setup of SAC.

Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Radiated Emissions
    - SAC

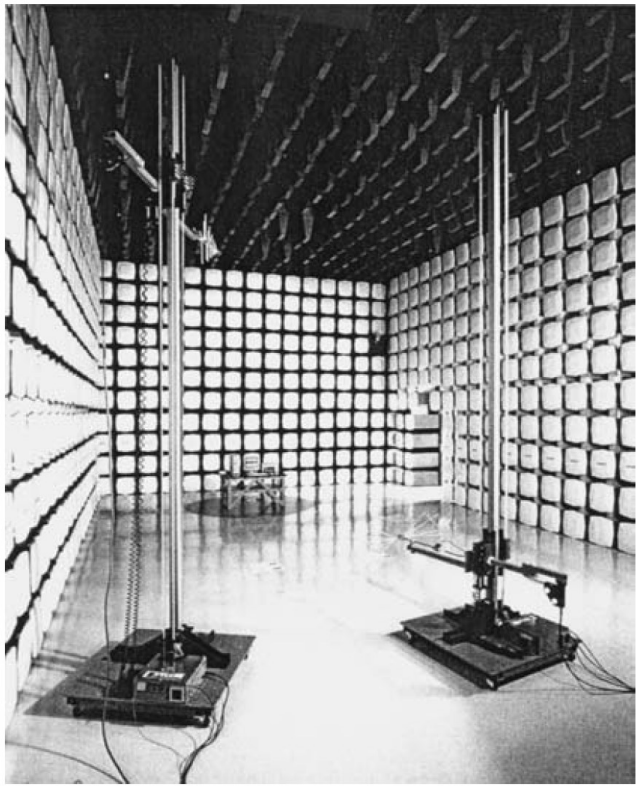


Top: Absorber
Sides: Absorber
Floor: Ground plane

Receiver for
FCC: quasi-peak
CISPR: quasi-peak
MIL: peak

Governmental Requirements

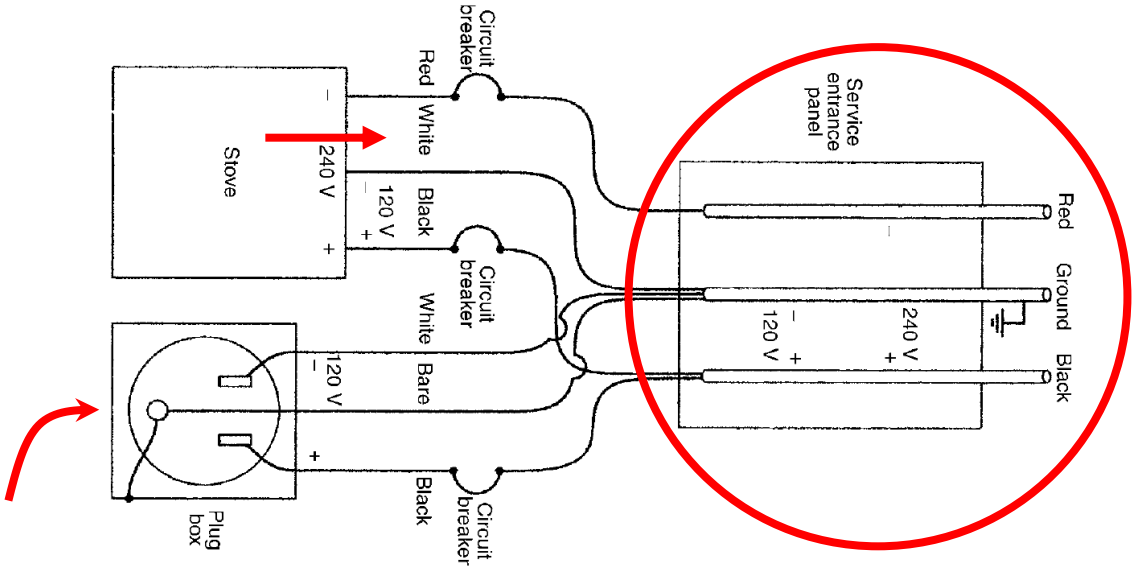
- Measurement of Emissions for Verification of Compliance
  - Radiated Emissions
    - SAC



•Antenna for FCC and CISPR:
Biconical antenna: 30~200 MHz
Log-periodic antenna: 200 MHz ~ 1 GHz
•Antenna for MIL-STD-461E:
104-cm rod dipole antenna: 10 kHz ~ 30 MHz
Biconical antenna: 30~200 MHz
Double-ridge horn antenna: above 200 MHz

Governmental Requirements

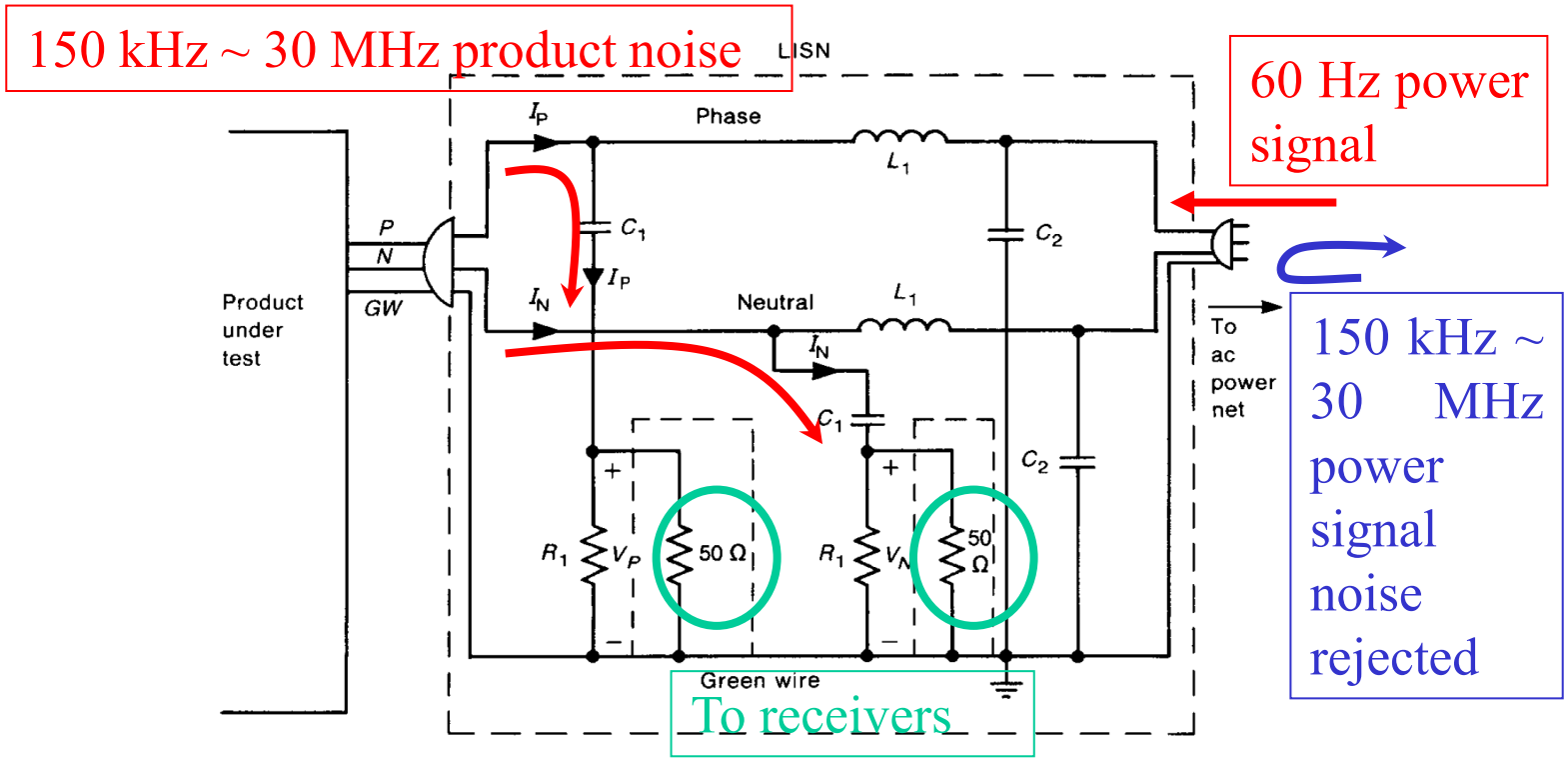
- Measurement of Emissions for Verification of Compliance
  - Conducted Emissions
    - A typical household power distribution system



    - We want to measure the conducted noise current passing back to the power system.

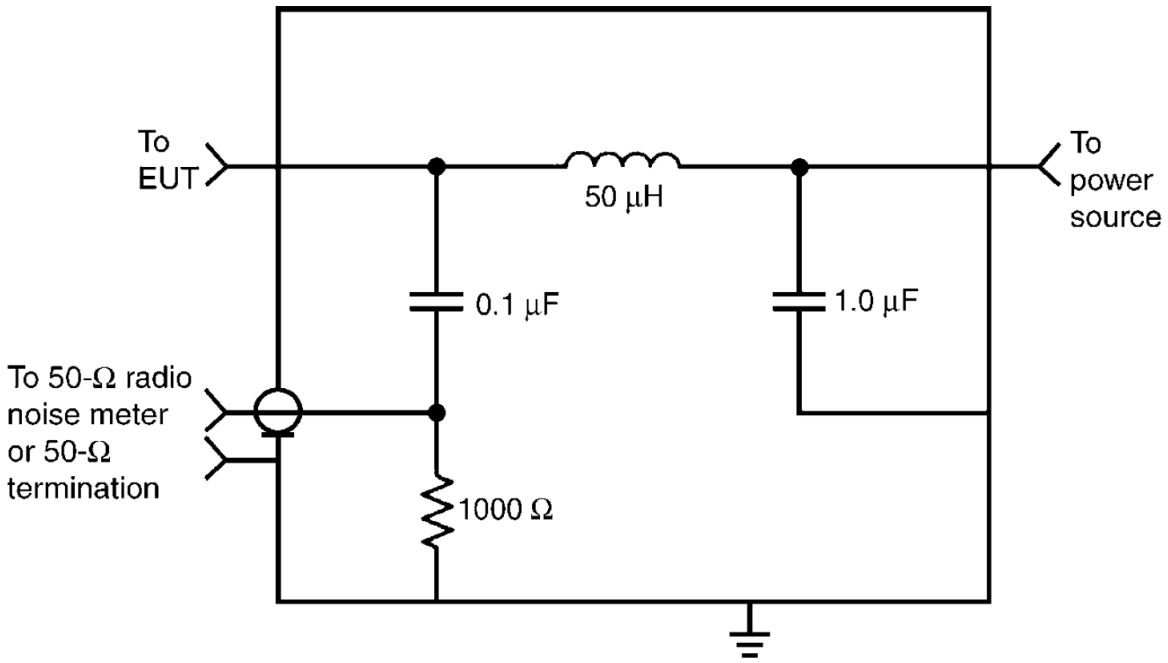
Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Conducted Emissions
    - The measurement setup is shown below



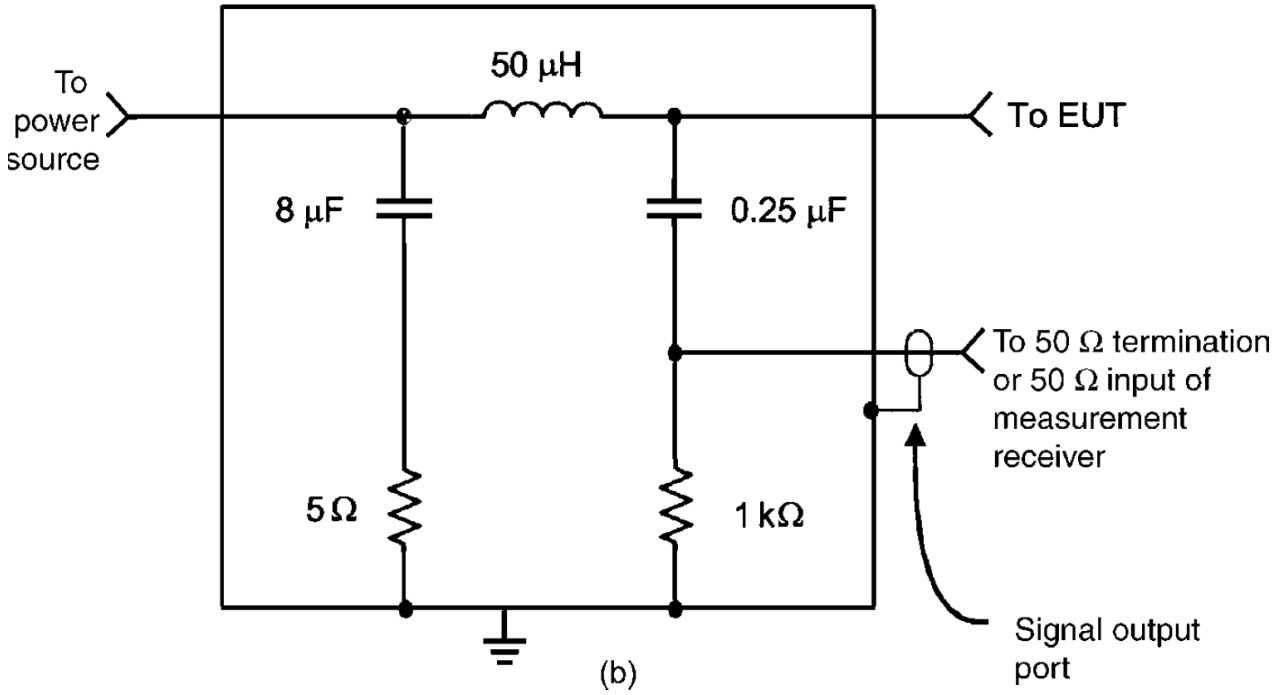
Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Conducted Emissions
    - LISN element values for (a) FCC and CISPR 22 conducted emission tests



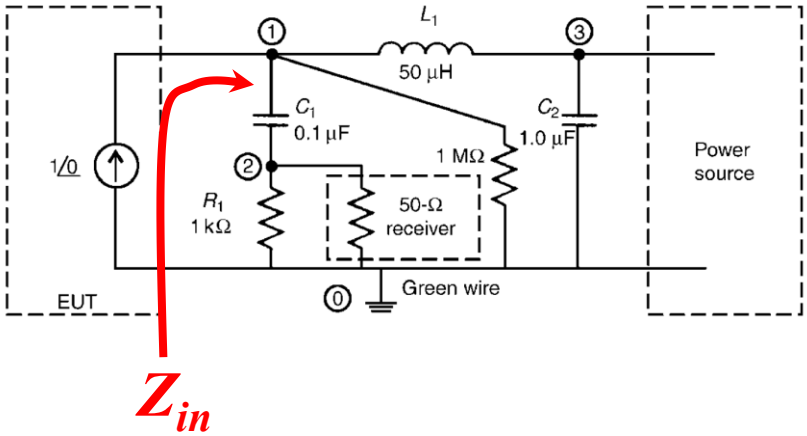
Governmental Requirements

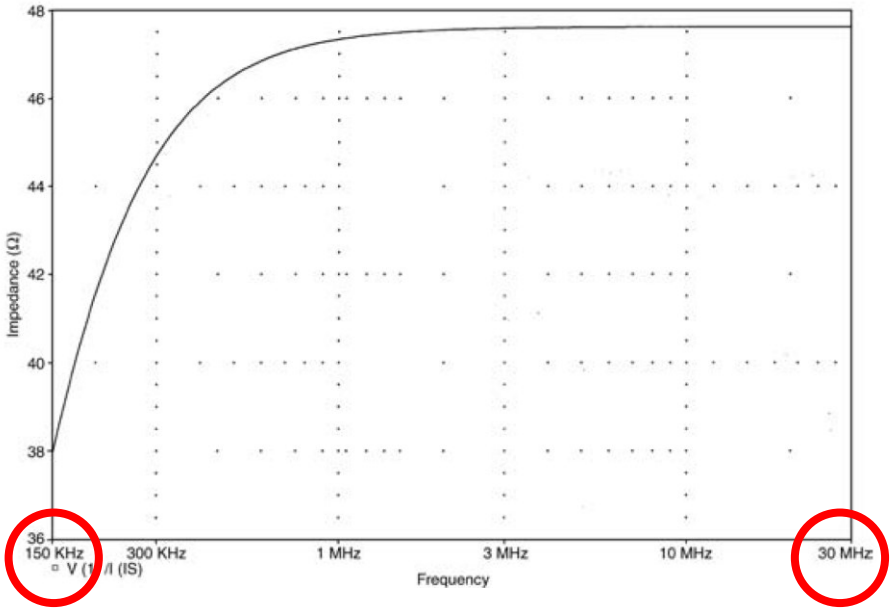
- Measurement of Emissions for Verification of Compliance
  - Conducted Emissions
    - LISN element values MIL-STD-461E conducted emission tests.



Governmental Requirements

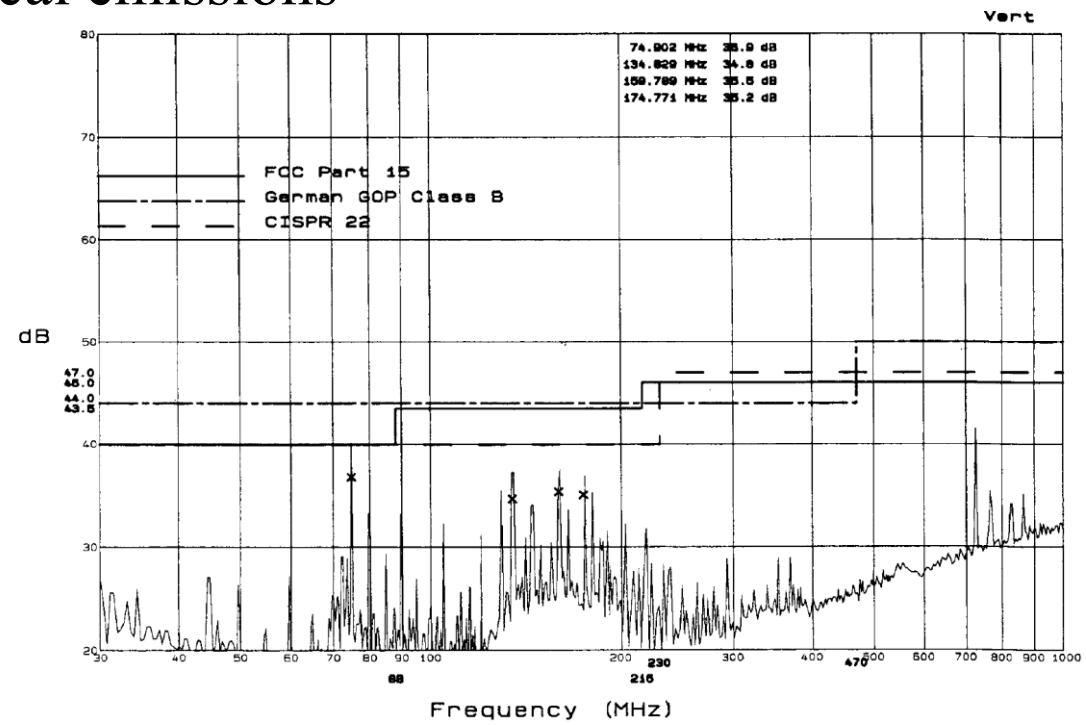
- Measurement of Emissions for Verification of Compliance
  - Example-Using PSPICE to Simulate
    - An important purpose of the LISN is to present a constant (50Ω) impedance.





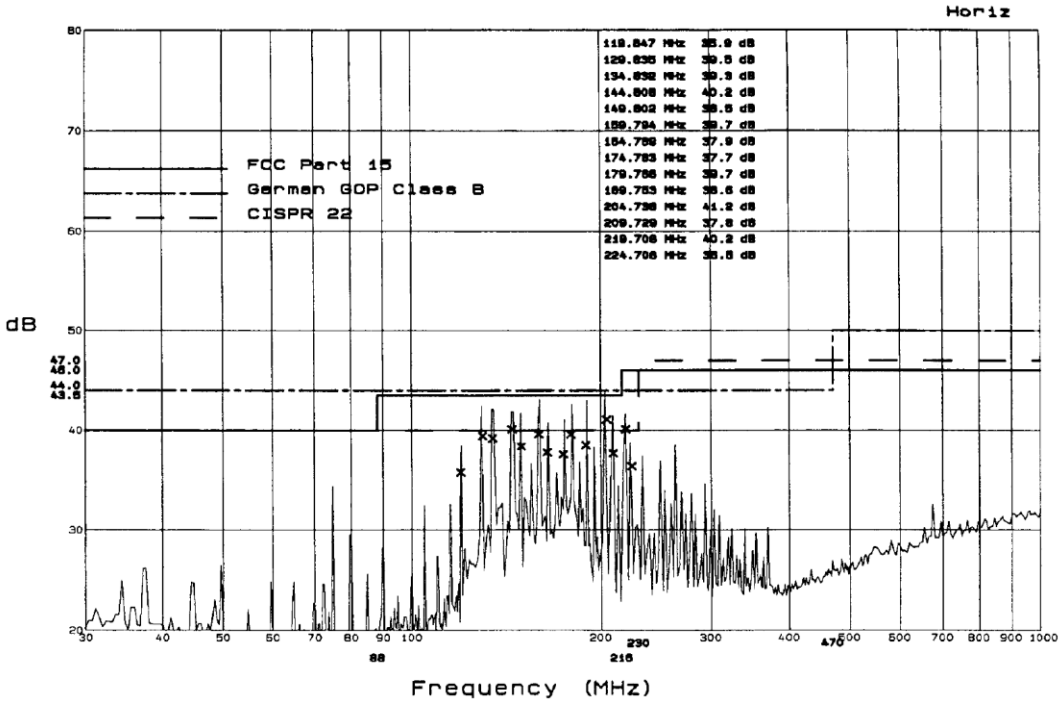
Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Typical Product Emissions
    - Radiated emissions of a typical digital product: (a) vertical emissions



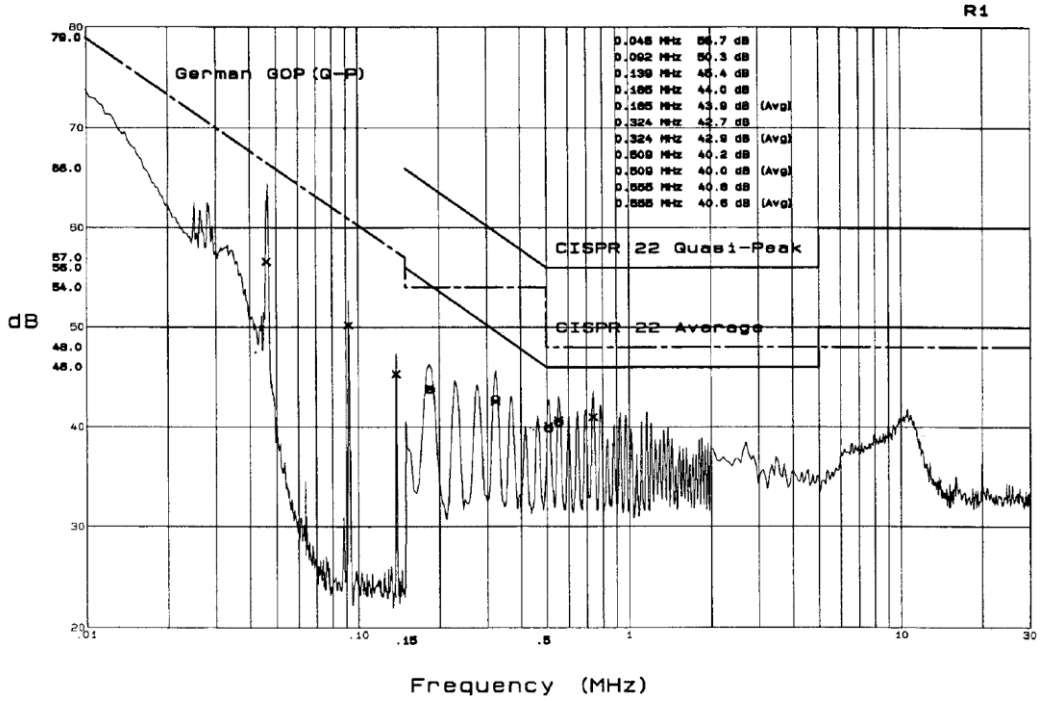
Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Typical Product Emissions
    - Radiated emissions of a typical digital product: (b) horizontal emissions



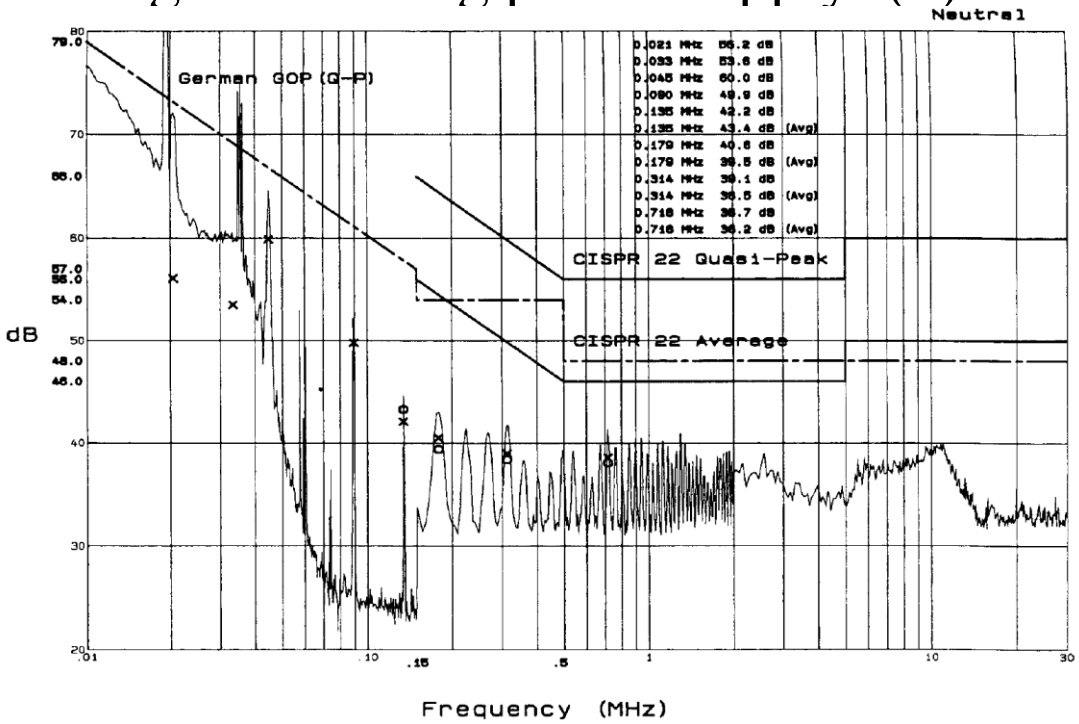
Governmental Requirements

- Measurement of Emissions for Verification of Compliance
  - Typical Product Emissions
    - Conducted emissions of a typical digital product containing a switching power supply: (a) phase



Governmental Requirements

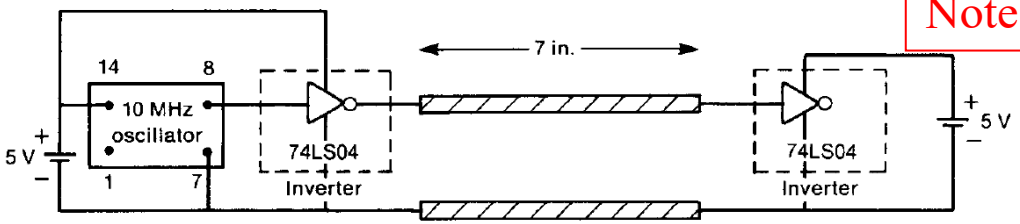
- Measurement of Emissions for Verification of Compliance
  - Typical Product Emissions
    - Conducted emissions of a typical digital product containing a switching power supply: (b) neutral



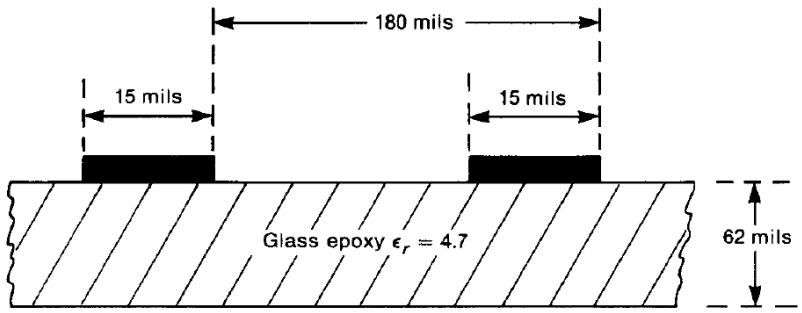
Governmental Requirements

- Difficulty in Meeting the Regulatory Limits
  - Example-Typical PCB Layout
    - The oscillator is in dual inline package in order not to produce interference.
    - Also, an internal battery is used to prevent from illumination from general power system.

Note: f=30GHz → λ=10 mm



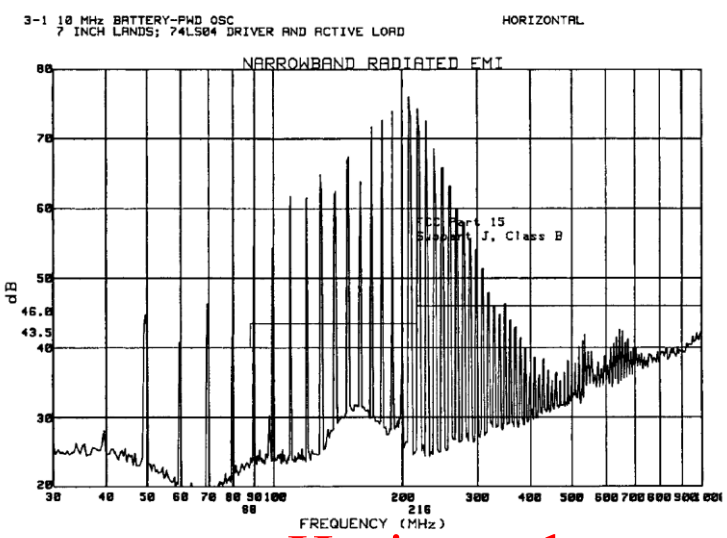
(a)



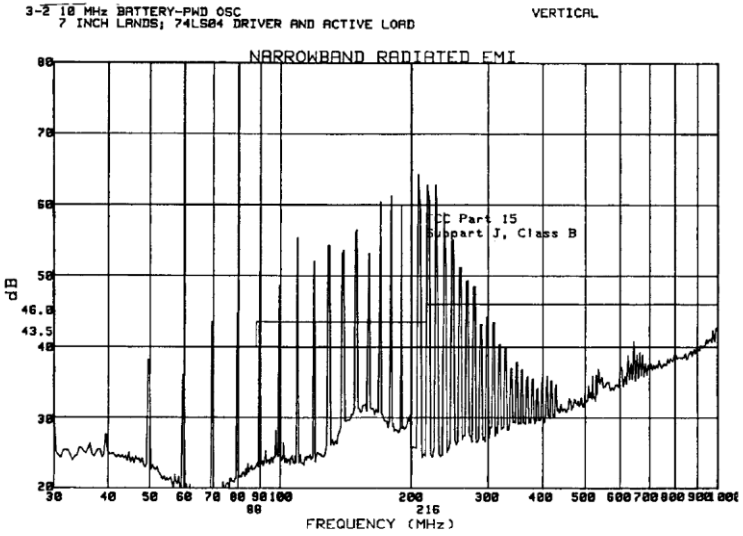
L=7 in.=7*2.54cm=17.78cm
f=1GHz →λ=300mm=30cm

Governmental Requirements

- Difficulty in Meeting the Regulatory Limits
  - Example-Typical PCB Layout



Horizontal



Vertical

The horizontal emissions exceed the FCC Class B limit by as much as 30 dB.
Even though the board is placed parallel to the ground plane of the chamber, the vertical emissions also exceed the FCC Class B limit, but only by some 15 dB.

Additional Product Requirements

- Radiated Susceptibility (Immunity)
- Conducted Susceptibility (Immunity)
- Electrostatic Discharge (ESD)
  - The static voltage can approach 25 kV in magnitude.
- Requirements for Commercial Aircraft
  - For commercial aircraft and airborne electronic system
- Requirement for Commercial Vehicles
  - For onboard electronics of Vehicles

Design Constraints for Products

- Product Cost
- Acceptability by the Consumer
- Be Easily Handled by the Automatic Assembly Process
- Product Development Schedule
  - Delays Affect the Marketability and Increase Costs
    - Determine the primary or dominant source of the emission so that a fix can be efficiently made and unnecessary cost is not added.

Advantages of EMC Design

- Minimizing Product Cost
- Minimizing Development Schedule Delays
- Minimizing Customer Complaints
  - How to Follow the Rules
    - Early and consistent attention to EMC will minimize cost and schedule delays and will provide the best chance for complying with the regulatory requirements. (Paper work before layout)
    - Assume that some EMC suppressions will be needed for compliance and provide the ability to implement it if it is needed. (Prepare holes for capacitors and resistors)