ITU Training on Conformance and Interoperability
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# EMC fundamentals

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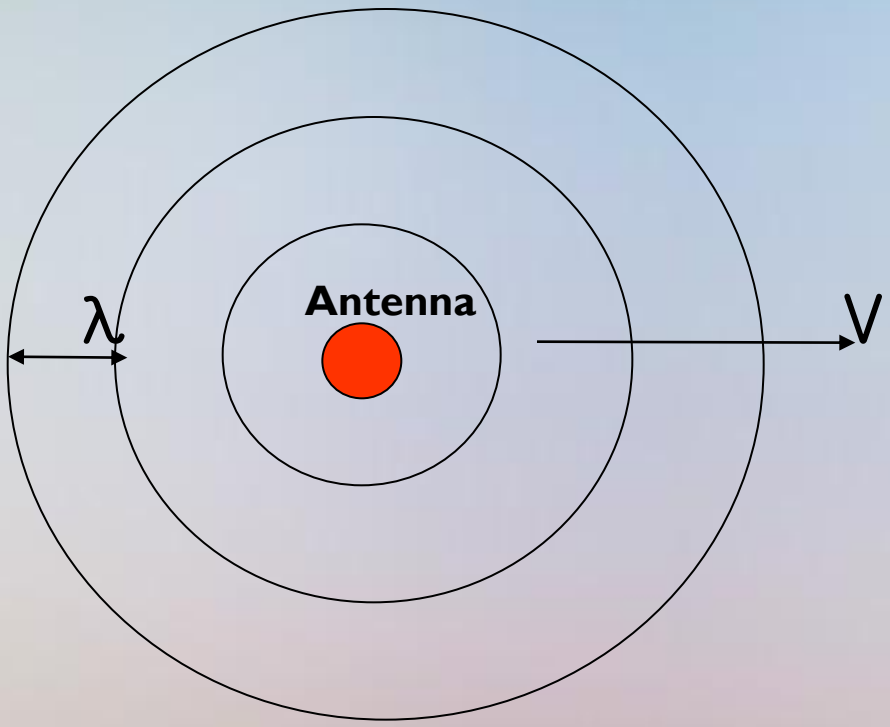
# Basics of electromagnetics

# Electromagnetic waves

A wave is a moving vibration




$$\lambda\ (m) = c(m/s) / F(Hz)$$

# Definitions

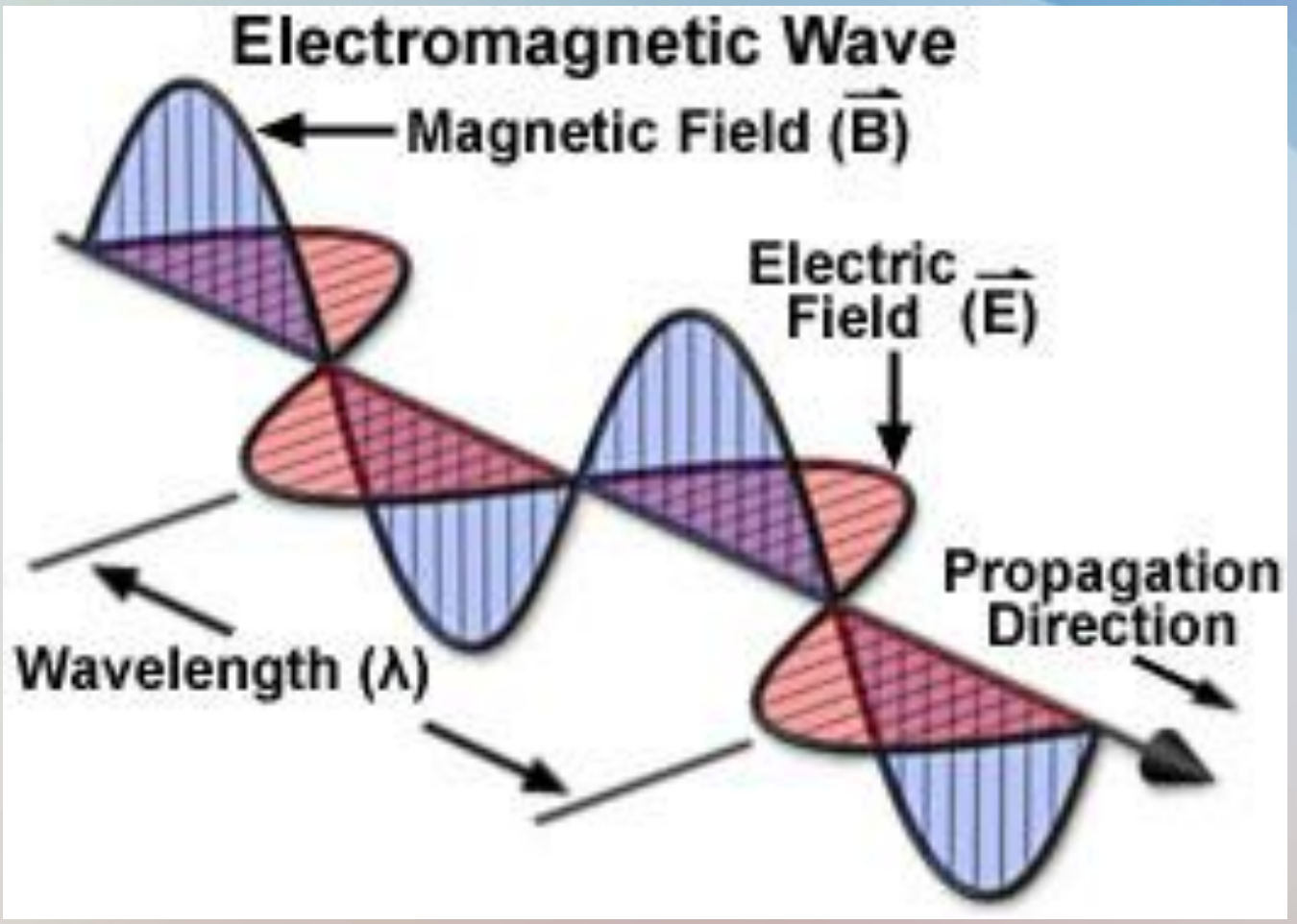
- The wavelength is the distance traveled by a wave in an oscillation cycle
- Frequency is measured by the number of cycles per second and the unit is Hz . One cycle per second is one Hertz.

# Electromagnetic waves (2)

- An electromagnetic wave consists of:
  - ✓ an electric field E (produced by the force of electric charges)
  - ✓ a magnetic field H (produced by the movement of electric charges)
- The fields E and H are orthogonal and are m oving at the speed of light

  $c = 3.\ 10^8$ m/s

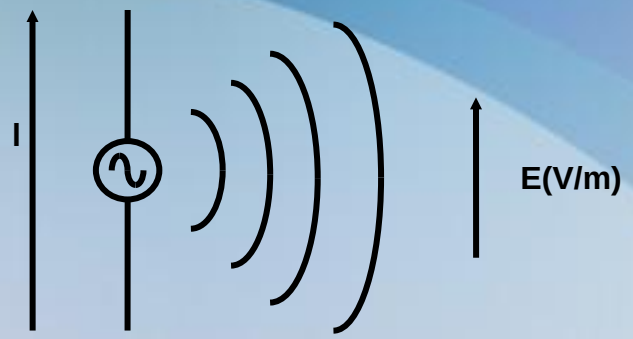
# Electromagnetic waves (3)



# E and H fields

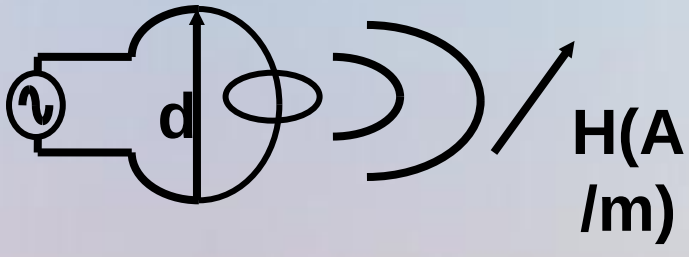
**Electric field**

The field amplitude is expressed in (V/m).




**Magnetic field**

The field amplitude is expressed in (A/m).



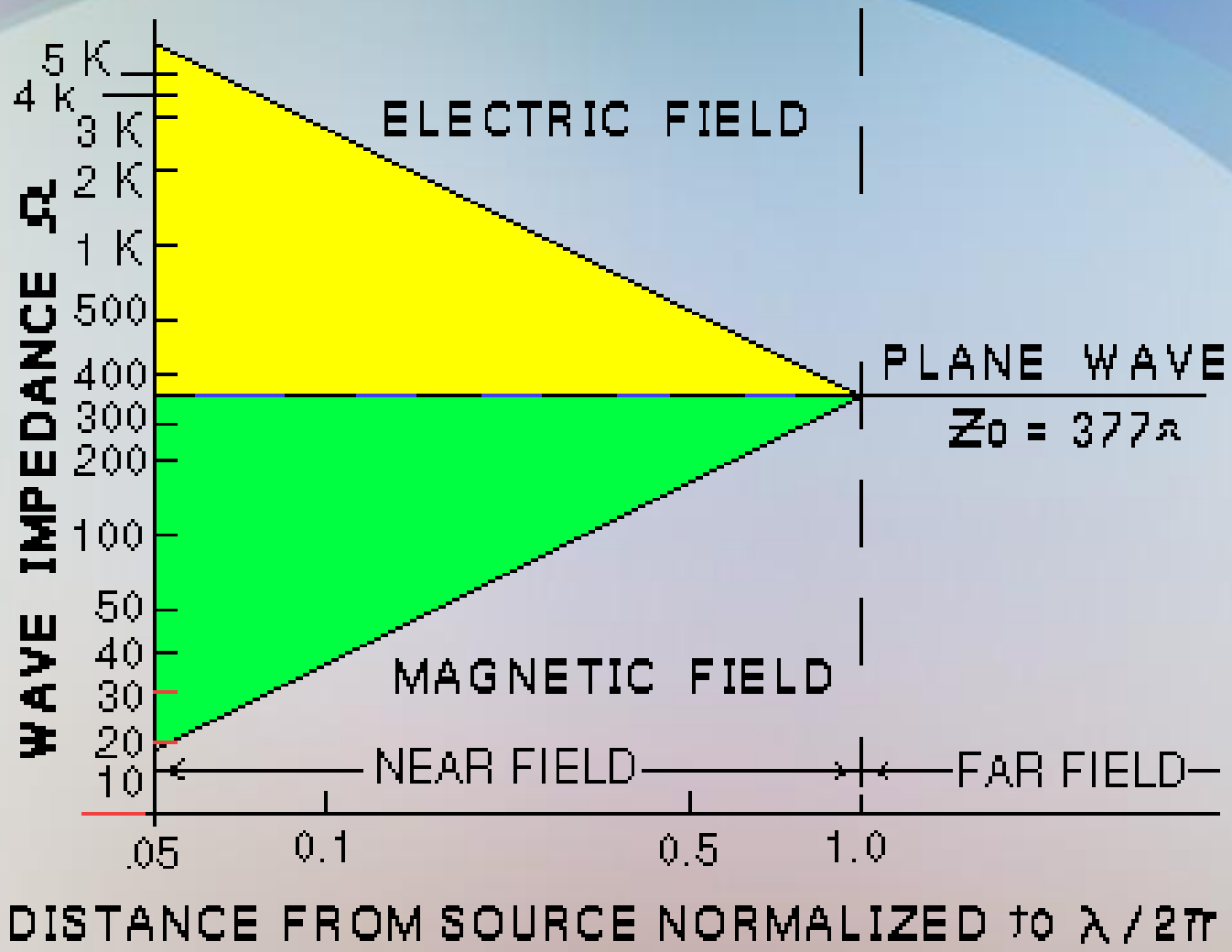

**Power density**

Radiated power is perpendicular to a surface, divided by the area of the surface. The power density is expressed as S (W / m²), or (mW /cm ²) , or (µW / cm ²).

# E and H fields

- Near a whip, the dominant field is the E field. The impedance in this area is Zc > 377 ohms.
- Near a loop, the dominant field is the H field. The impedance in this area is Z c <377 ohms.

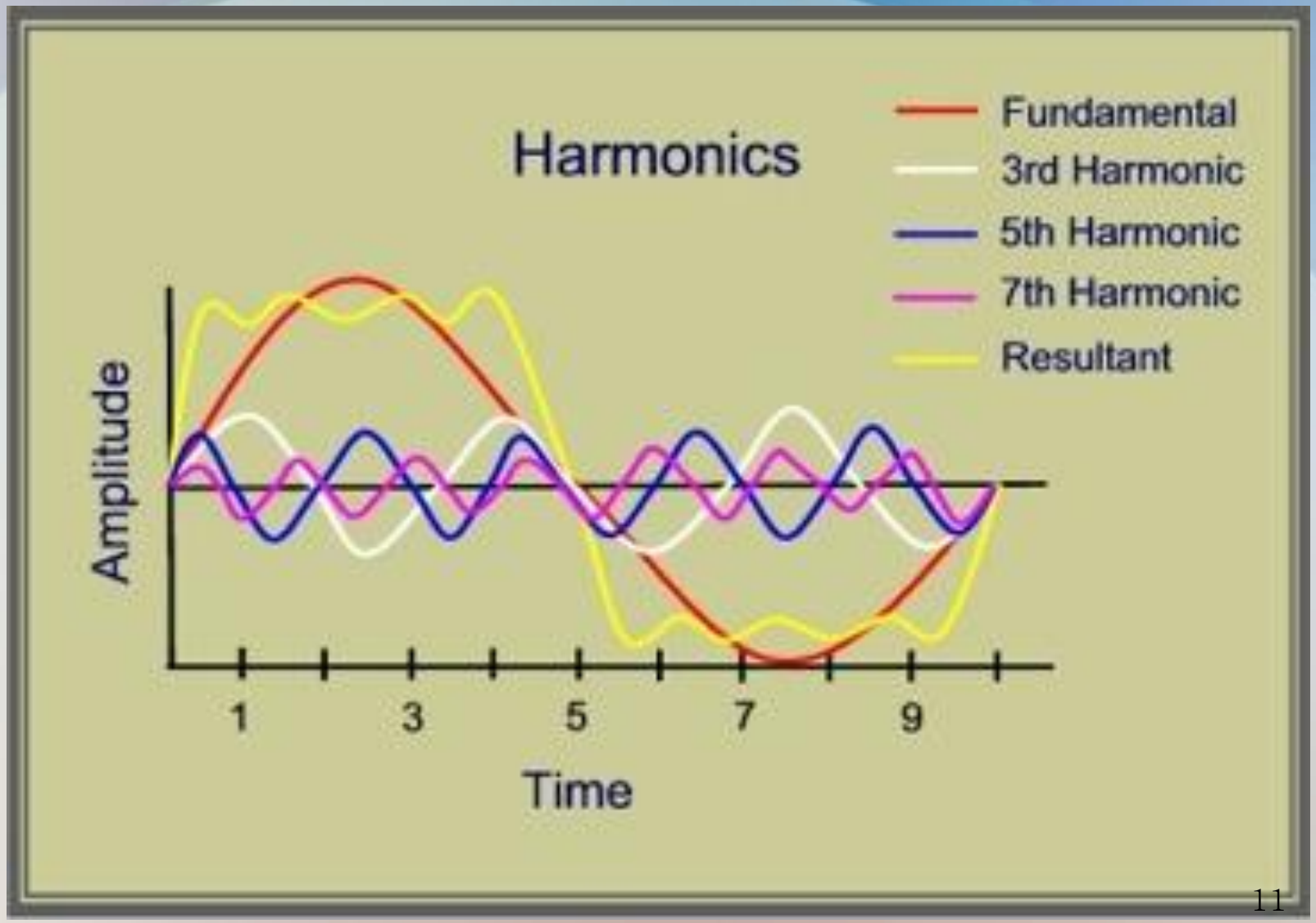
# Plane wave


5 K
4 K
3 K
2 K
1 K
500
400
300
200
100
50
40
30
20
10
WAVE IMPEDANCE Ω
ELECTRIC FIELD
PLANE WAVE
Z0 = 377Ω
MAGNETIC FIELD
NEAR FIELD
FAR FIELD
.05
0.1
0.5
1.0
DISTANCE FROM SOURCE NORMALIZED to λ/2π

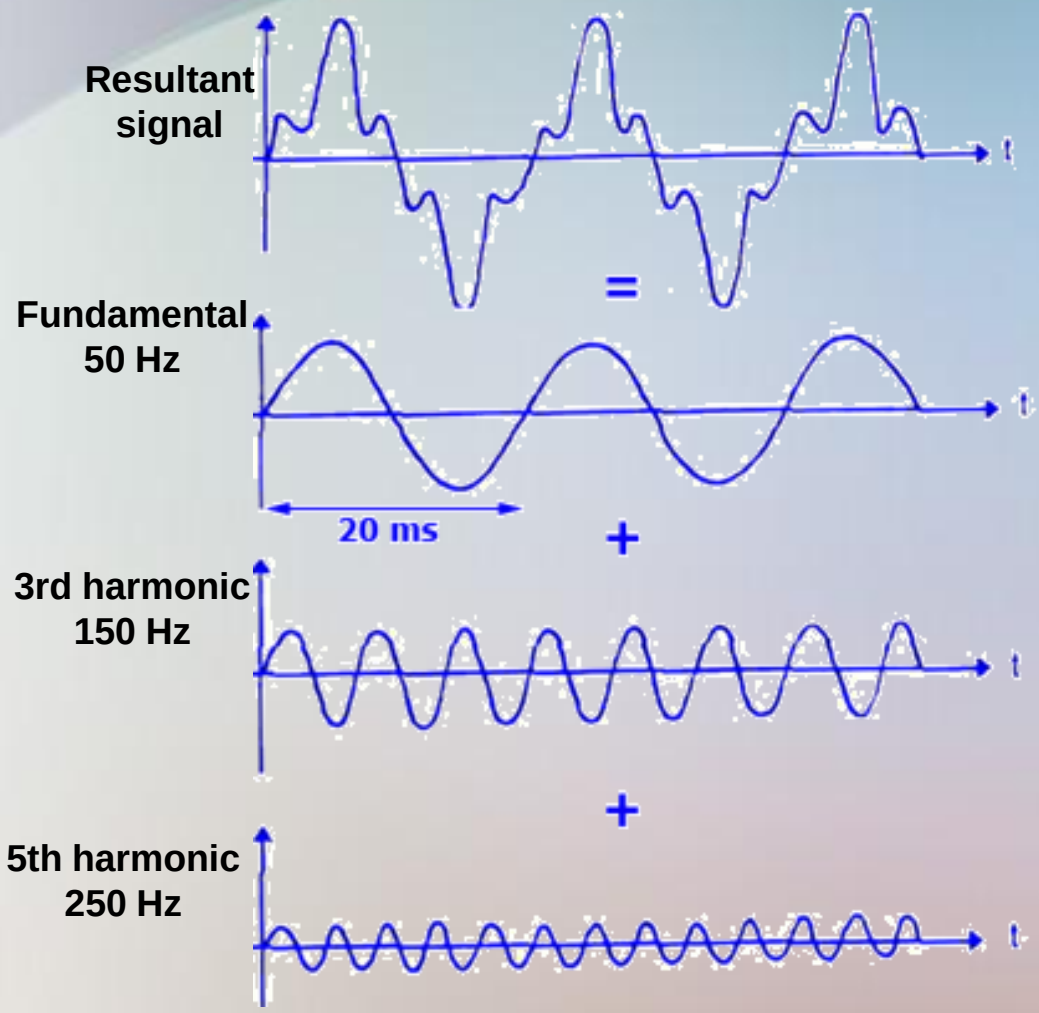
# The EMC way of thinking

| *Electrical domain* | *Electromagnetic domain* |
|---|---|
| Voltage V (Volt) | Electric Field E (V/m) |
| Current I (Amp) | Magnetic field H (A/m) |
| Impedance Z (Ohm) | Characteristic impedance Z0 (Ohm) |
| Z=V/I | Z=E/H |
| $P=I^2 \times R$ (watts) | $P=H^2 \times 377$ (watts/$m^2$)<br>*far field conditions* |

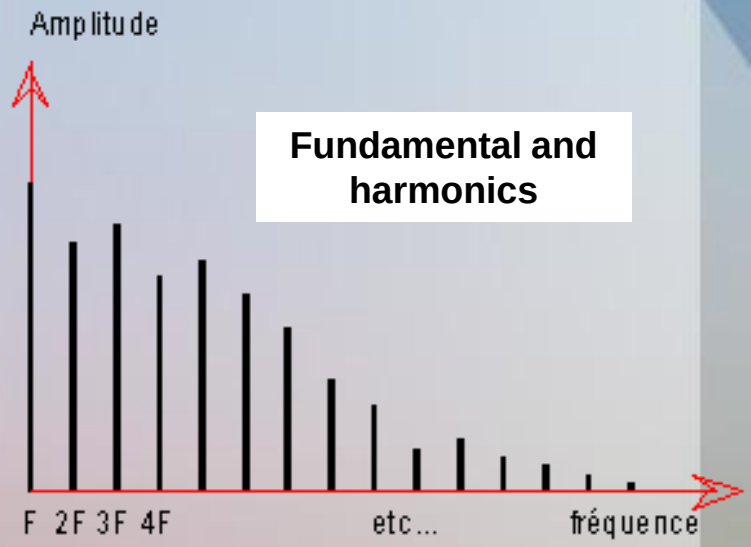
# Harmonics


Harmonics
Fundamental
3rd Harmonic
5th Harmonic
7th Harmonic
Resultant
Amplitude
1
3
5
7
9
Time

# Harmonics




Time domain




Frequency domain

# EMC results

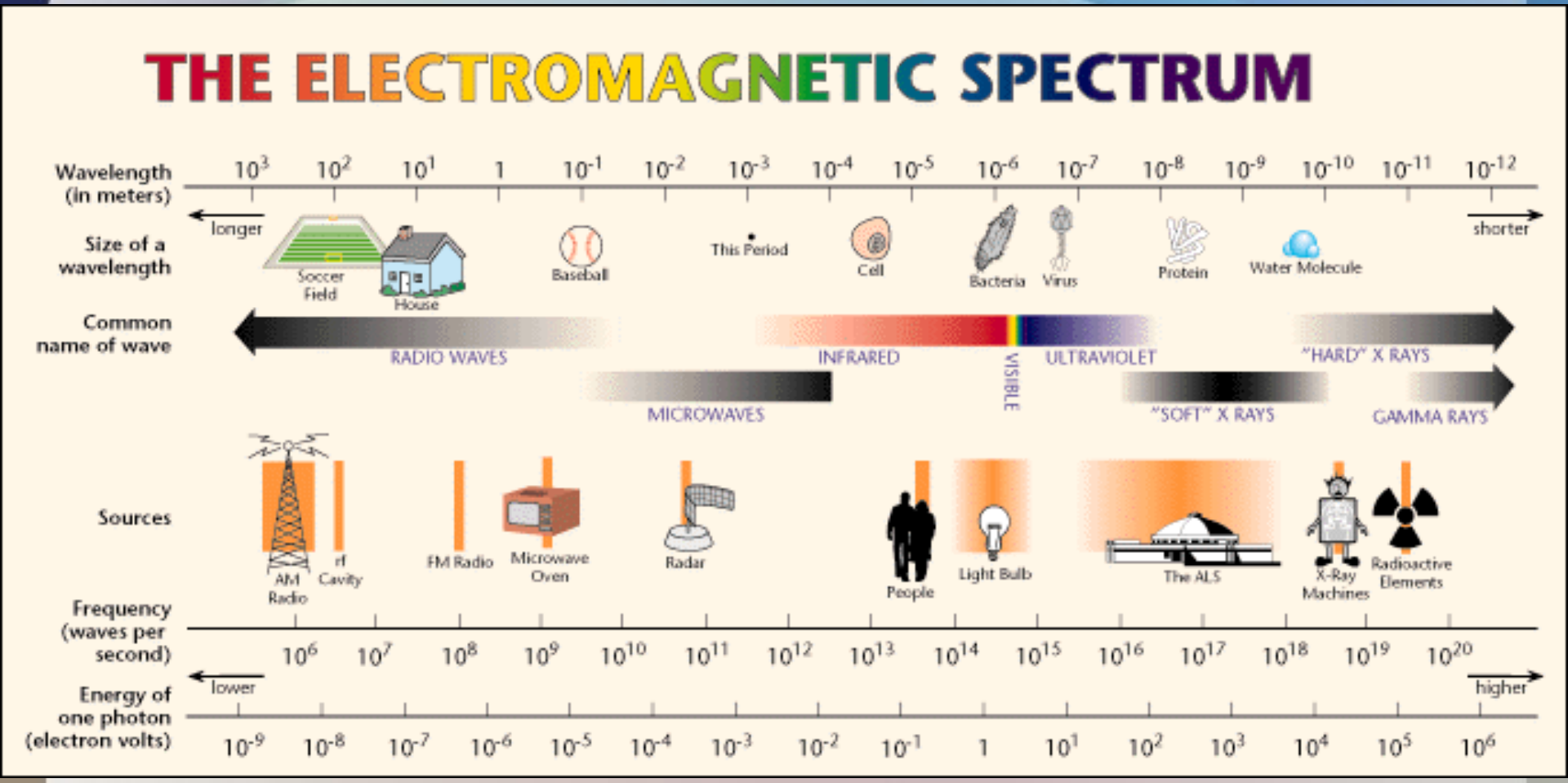
## Why in frequency domain (Hz) ?

- Time domain aspect is dominated by the major frequency harmonics
- Distinguish contributions of each harmonics, even small ones

## Why in logarithm scale (dB) ?

- Signals are composed of high and low amplitude harmonics
- Very large dynamic (from µV to several mV)
- Logarithm scale is requested

# Electromagnetic spectrum



# Frequencies

| Frequency | Wavelength | Metric designation | Current designation | Abreviations | |
|---|---|---|---|---|---|
| 3 kHz à 30 kHz | 100 km à 10 km | myriamétric waves | Very Low Frequencies | VLF | O.Mm |
| 30 kHz à 300 kHz | 10 km à 1 km | kilometric waves | Low Frequencies | LF | O.km |
| 300 kHz à 3 MHz | 1 km à 100 m | Hectometric waves | Mid Frequencies | MF | O.hm |
| 3 MHz à 30 MHz | 100 m à 10 m | Decamétric waves | High Frequencies | HF | O.dam |
| 30 MHz à 300 MHz | 10 m à 1 m | metric waves | Very High Frequencies | VHF | O.m |
| 300 MHz à 3 GHz | 1 m à 10 cm | décimetric waves | Ultra High Frequencies | UHF | O.dm |
| 3 GHz à 30 GHz | 10 cm à 1 cm | Centimetric waves | HyperFrequencies | SHF | O.cm |
| 30 GHz à 300 GHz | 1 cm à 1 mm | Millimetric waves | | EHF | O.mm |

# EM wave Propagation

- In an isotropic and homogenuous area, wave propagation is modeled by Maxwell equations:

$$\text{rot } H = E(\sigma - j\omega_0\varepsilon) \qquad \text{rot } E = j\omega_0\mu H$$
$$\text{div } \varepsilon E = \rho \qquad \text{div } \mu H = 0$$

H (A/m), Magnetic field
E (V/m), electric field
ε (F/m), Dielectric constant (permettivity)
μ (H/m), magnetic permeability
σ (ohms-1/m), conductibility

# physical quantities

| Grandeur | Symbol | Unit | Symbol |
|---|---|---|---|
| **Frequency** | *f* | Hertz | Hz |
| **Wavelength** | $\lambda$ | Metre | m |
| **Electric field** | *E* | Volt per metre | V/m |
| **Magnetic field** | *H* | Ampere per metre | A/m |
| **Magnetic flow density** | *B* | Tesla | T |
| **Power density** | *S* | Watt per square metre | $W/m^2$ |
| **intrinsic impedance** | *Z* | Ohm | $\Omega$ |
| **Antenna's highest dimension** | *D* | Metre | m |

# Wave impedance

- At several wavelengths from the antenna, wave impedance is expressed as:

$$Z_0 = \frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}}$$

Intrinsic impedance of the propagation environment (in ohms)

# Near field

- For distances to the source below $\lambda / 2\pi$ we consider that we are in near field conditions.
  Electric dipole: E varies as $1/r^3$ , H varies as $1/r^2$ , So Z varies as 1/r.

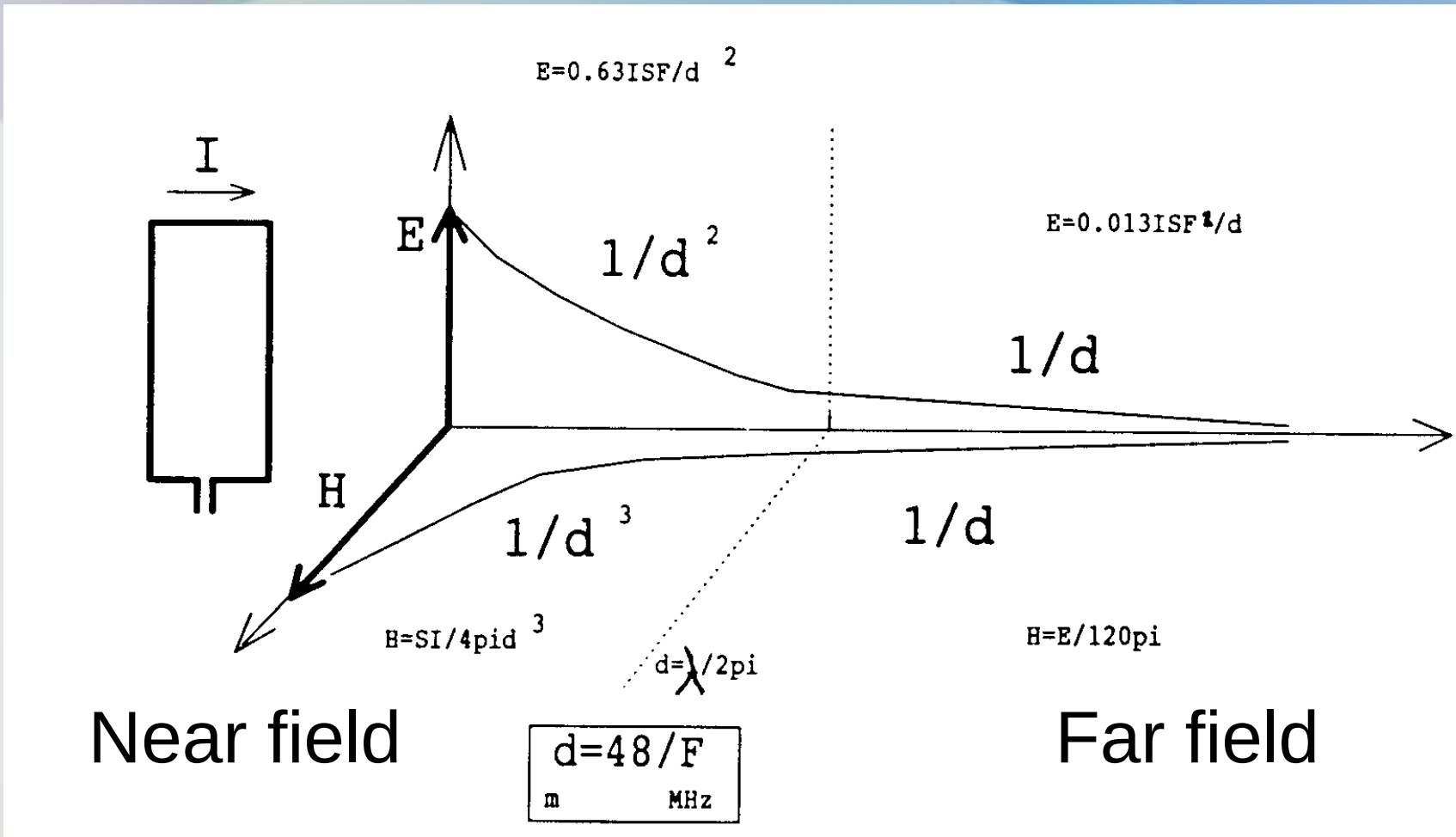
  At short distance from the dipole radiates mainly in field E.
- Magnetic dipole: E varies as $1/r^2$, $1/r^3$ H, Z varies as r

  At short distance loop radiates mainly in field H.

# Far field

- E and H decrease as 1/r , Z=Cte=377Ω (empty environment impedance)
- The EM field has the caracteristics of a plane wave
- For the majority of radio tests, only electric component is measured as the tests are carried out in far field conditions

# Relations field/distance



# Radiated field

- Radiated field (in V/m)

$$E = \frac{1}{d}\sqrt{30.P.G}$$

d: distance from the transmitter (in m)

P: power t the output of the transmitter in W

G: Antenna gain (in dB)

# Exercice

- FM Emetter
- Output power: 100 Watts
- Antenna gain : 5
- Frequency 100 Mz

- Compute the electric field at 50 m?

# Solution

- G = 10*log 5 = 6.98
- Field at 50m = 2.89 V/m

# Specific units

## Voltage Units

Wide dynamic range of signals in EMC → use of dB (decibel)

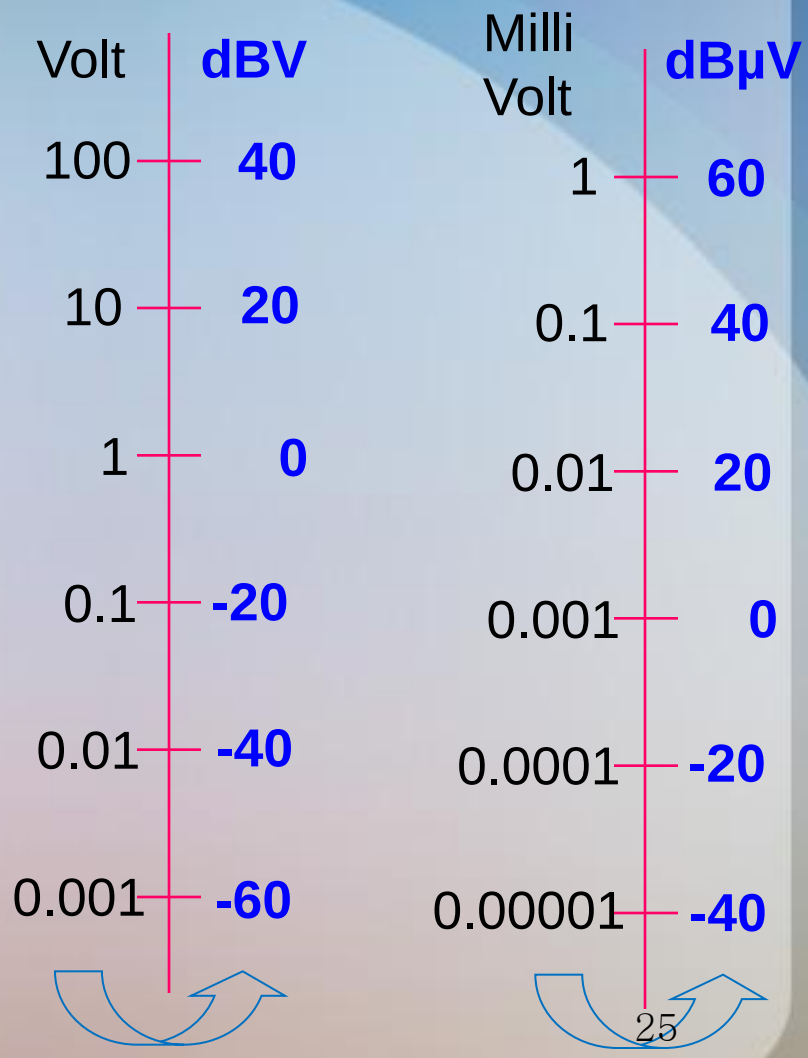
For example dBV, dBA :

$$dBV = 20 \times \log(V)$$

$$dBA = 20 \times \log(A)$$

Extensive use of **dBµV**

$$V_{dB\mu V} = 20 \times \log\left(\frac{V}{1\mu V}\right) = 20 \times \log(V) + 120$$



# Specific units

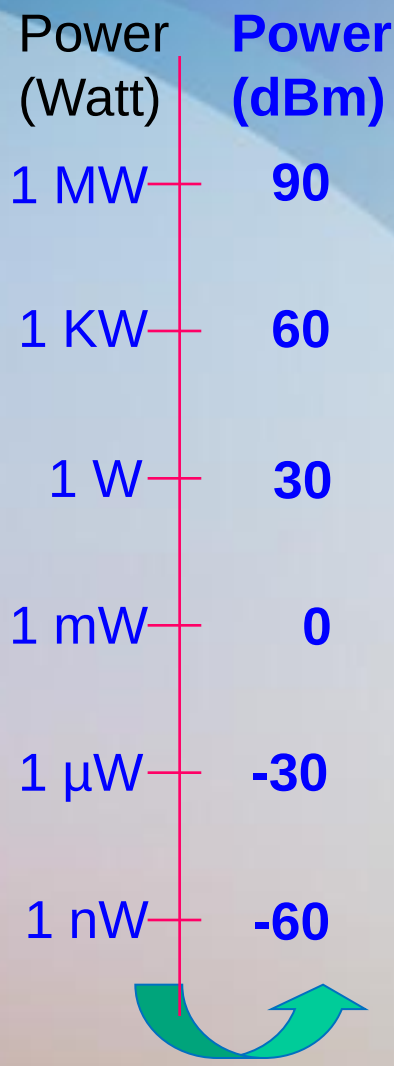
## Power Units

The most common power unit is the "**dBm**" (dB milli-Watt)

$$P_{dBmW} = 10 \times \log\left(\frac{P_W}{1mW}\right) = 10 \times \log\left(P_W\right) + 30$$

*Exercise: Specific units*

1 mV = ___ dBµV
1 W = ___ dBm



| dB | Voltage or current ratio | Power ratio | dBm (50Ω, column 1 in dBμV) |
|---|---|---|---|
| -20 | 0.1 | 0.01 | -127 |
| -10 | 0.3162 | 0.1 | -117 |
| -6 | 0.501 | 0.251 | -113 |
| -3 | 0.708 | 0.501 | -110 |
| 0 | 1.000 | 1.000 | -107 |
| 0.5 | 1.059 | 1.122 | -106.5 |
| 1 | 1.122 | 1.259 | -106 |
| 2 | 1.259 | 1.585 | -105 |
| 3 | 1.413 | 1.995 | -104 |
| 4 | 1.585 | 2.512 | -103 |
| 5 | 1.778 | 3.162 | -102 |
| 6 | 1.995 | 3.981 | -101 |
| 7 | 2.239 | 5.012 | -100 |
| 8 | 2.512 | 6.310 | -99 |
| 9 | 2.818 | 7.943 | -98 |
| 10 | 3.162 | 10.000 | -97 |
| 12 | 3.981 | 15.849 | -95 |
| 14 | 5.012 | 25.120 | -93 |
| 16 | 6.310 | 39.811 | -91 |
| 18 | 7.943 | 63.096 | -89 |
| 20 | 10.000 | 100.00 | -87 |
| 25 | 17.783 | 316.2 | -82 |
| 30 | 31.62 | 1000 | -77 |
| 35 | 56.23 | 3162 | -72 |
| 40 | 100 | 10,000 | -67 |
| 45 | 177.8 | 31,623 | -62 |
| 50 | 316.2 | $10^5$ | -57 |
| 55 | 562.3 | $3.162 \cdot 10^5$ | -52 |
| 60 | 1000 | $10^6$ | -47 |
| 65 | 1778 | $3.162 \cdot 10^6$ | -42 |
| 70 | 3162 | $10^7$ | -37 |
| 75 | 5623 | $3.162 \cdot 10^7$ | -32 |
| 80 | 10,000 | $10^8$ | -27 |
| 85 | 17,783 | $3.162 \cdot 10^8$ | -22 |
| 90 | 31,623 | $10^9$ | -17 |
| 95 | 56,234 | $3.162 \cdot 10^9$ | -12 |
| 100 | $10^5$ | $10^{10}$ | -7 |
| 110 | $3.162 \cdot 10^5$ | $10^{11}$ | 3 |
| 120 | $10^6$ | $10^{12}$ | 13 |

# Conversion

| | Amplitude | Power |
|---|---|---|
| 3 dB | x 1,41 | x 2 |
| 6 dB | x 2 | x 4 |
| 10 dB | x 3,16 | x 10 |
| 20 dB | x 10 | x 100 |

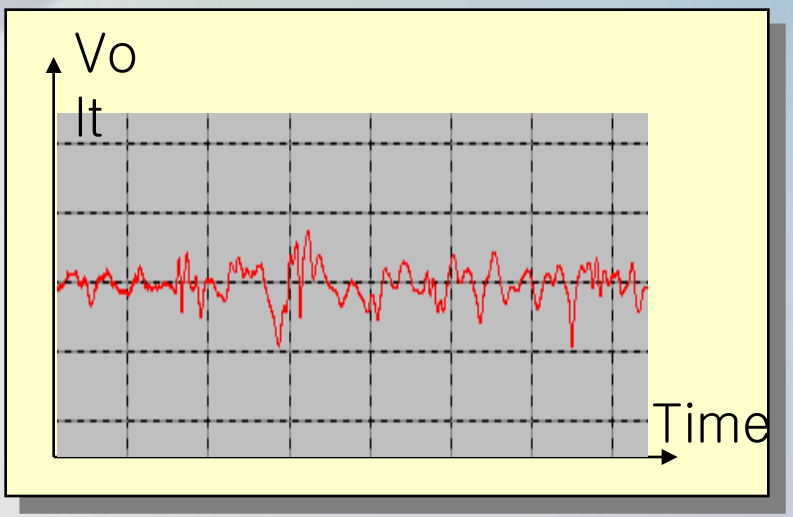
Example:

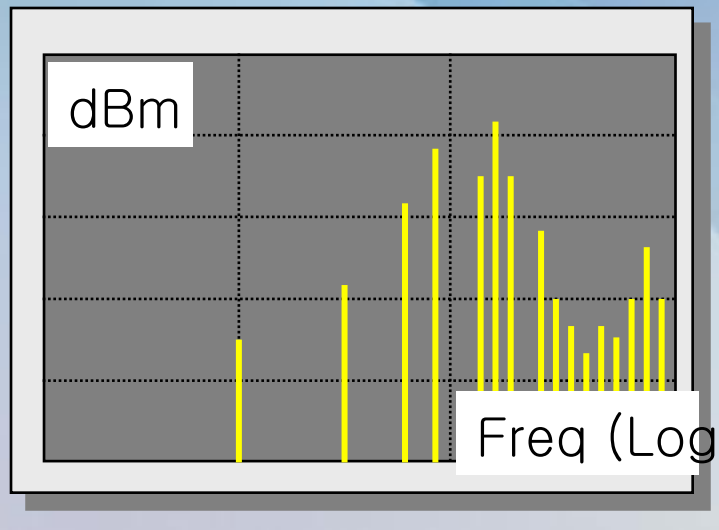
46 dBµV = 20 + 20 +6 dBµV

= 10 x 10 x 2 µV

= 200 µV

# Specific units




*Fourier transform*

Time domain measurement → Frequency measurement

*Invert Fourier transform*

Oscilloscope

Spectrum analyser

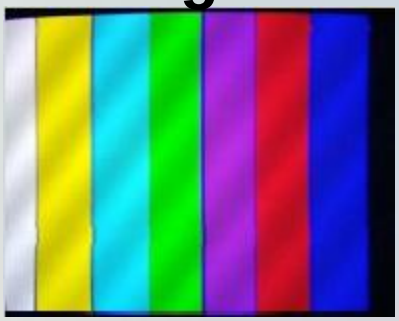
# Electromagnetic compatibility

# Electromagnetic interference

- Electric and electronic systems are not isolated fro m their environment.
- Electromagnetic energy can unintentionally cross their borders:
  - ✓to enter,
  - ✓or to escape.
- This energy is called stray electromagnetic interference.

# Example of perturbation

**Analogue video signal**



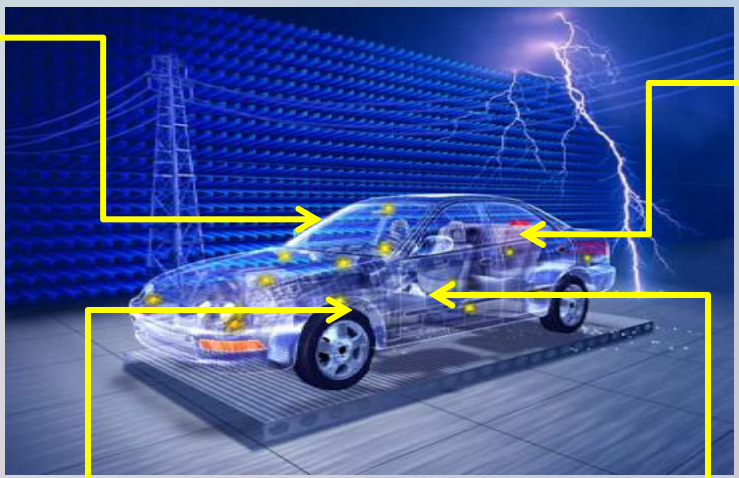
- ✓Moire
- ✓loss of luminance, contrast
- ✓loss of color
- ✓loss of synchronization

**Digital video signal**

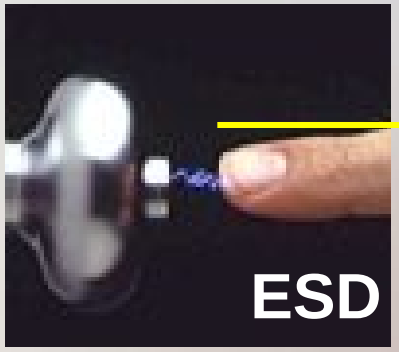
- ✓block effect
- ✓cessation of movement
- ✓black screen

# Sources of perturbation

RF transmitters



Mobile phones



ESD

- External Impacts
- Internal Impacts
- Human Impacts

Orago
ns

# EMC (1)

Electric equipment:

1. Victim of its environment:
   - ✓Malfunction
   - ✓Temporary malfunction or permanent

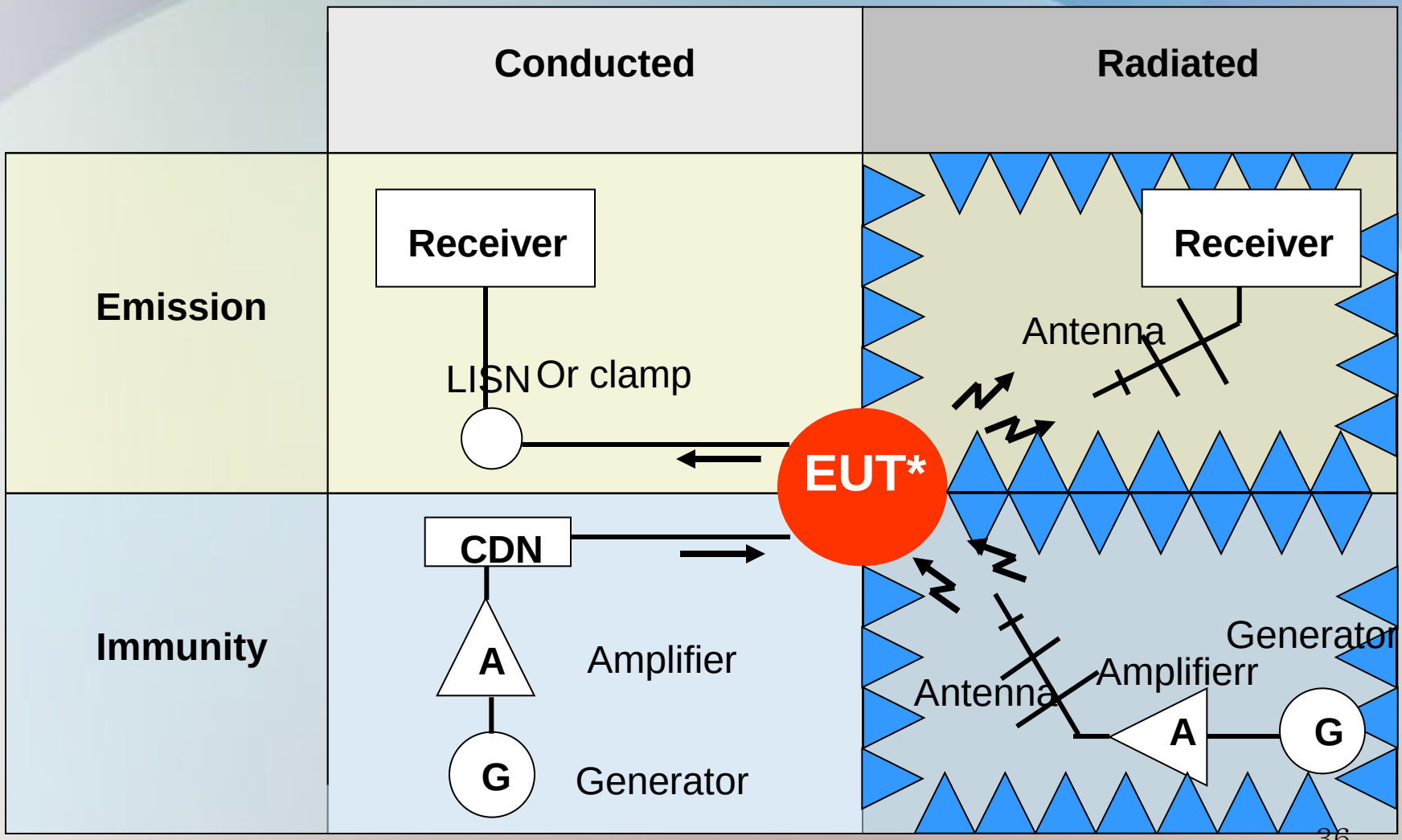
2. Source of disturbance in its environment

# EMC (2)

According to the european directive 2004/108/CEE, EMC refers to:

- the ability of an equipment or a system to perform satisfactorily in its electromagnetic environment
- without introducing intolerable interference into any thing in that environment.

# EMC (3)



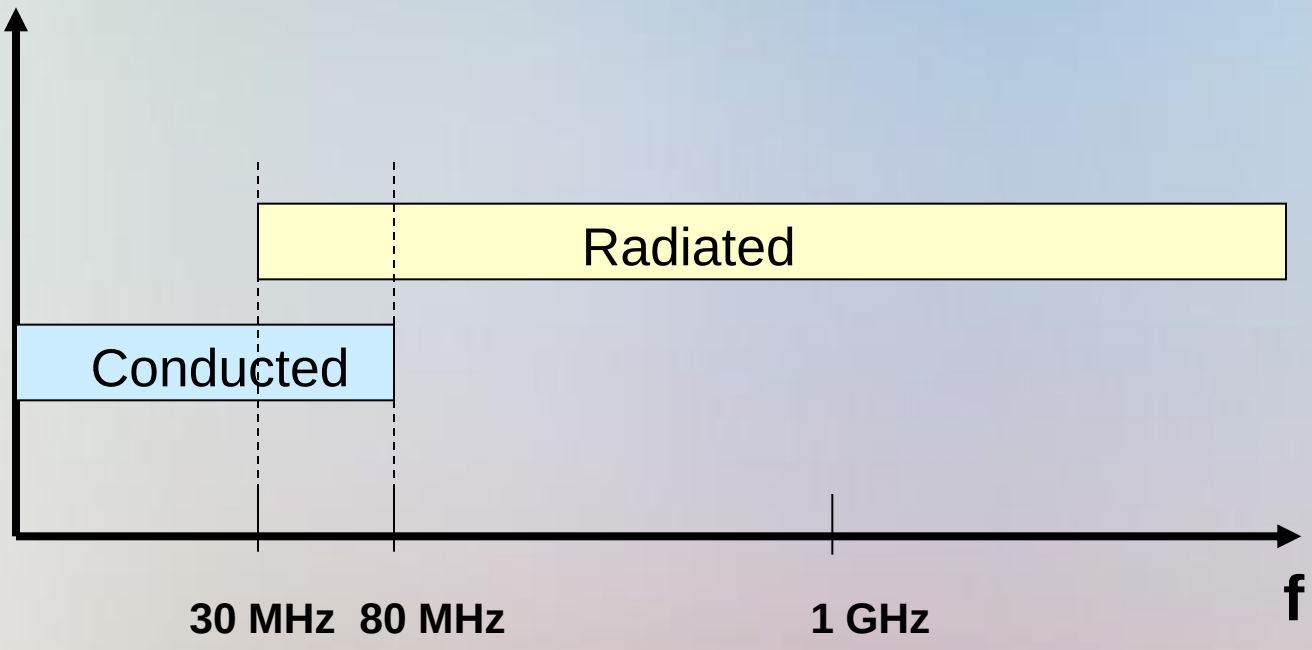

*EUT = Equipement Under Test

# Conducted/Radiated

- The parasites circulating currents and voltages in cables or equipments will radiate.
- The radiated power will also induce currents and stray voltages in the different interconnections.

  => The conducted and radiated disturbances are closely coupled.

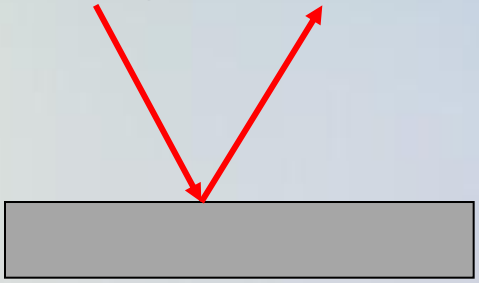
# Conducted/radiated (2)



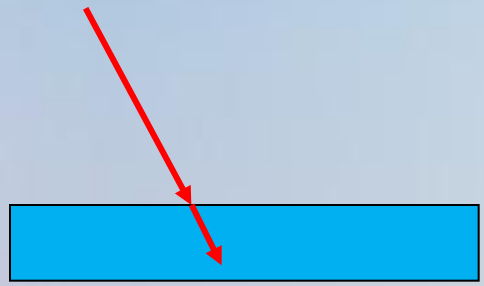
# Test sites

# Reflectivity

Electromagnetic wave



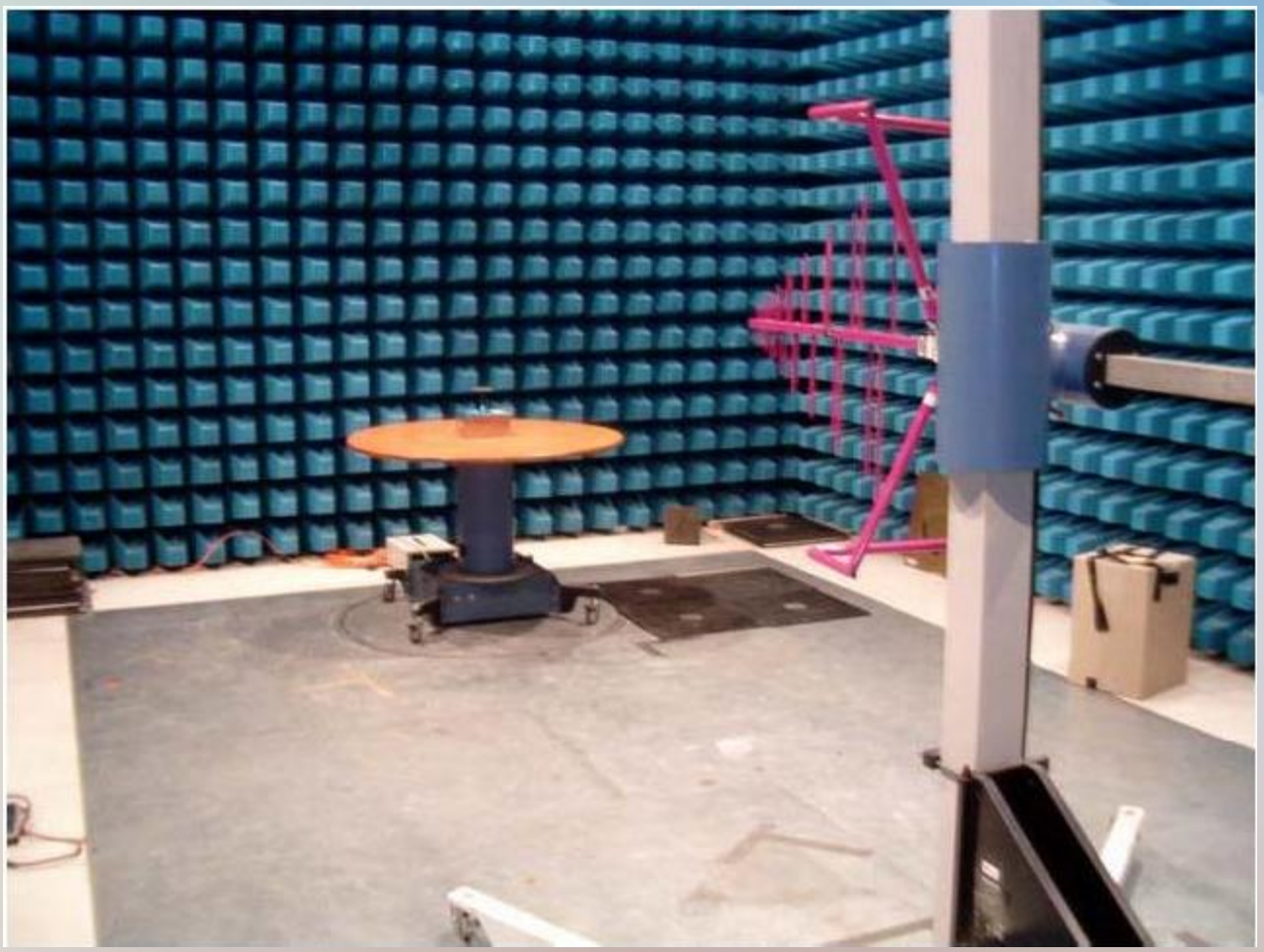
Metal



Absorber

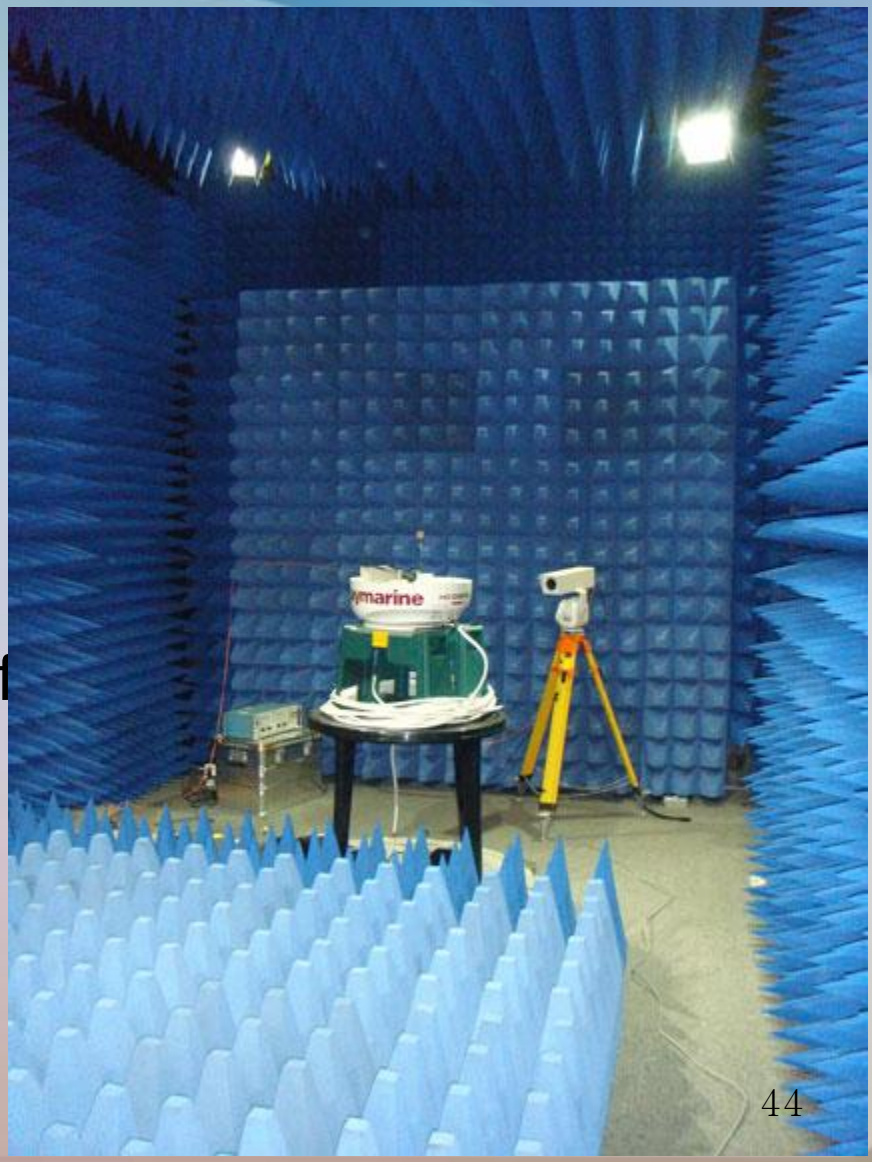
# Semi anechoic chamber SAC (1)

# Semi anechoic chamber SAC (2)



# Fully anechoic chamber (FAC)

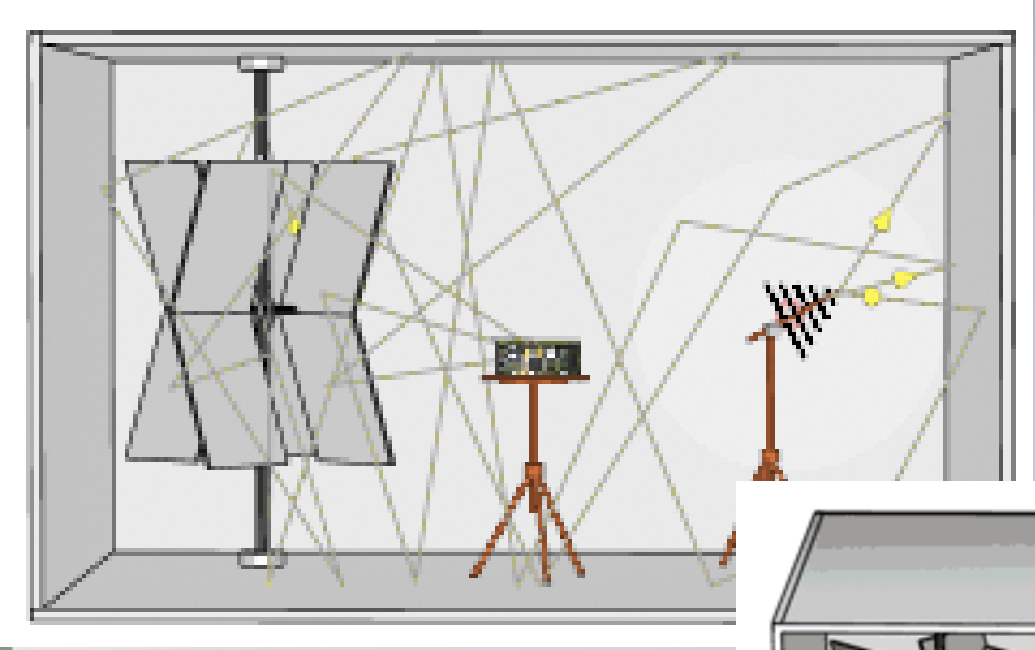
- Fully anechoic shielded enclosure
- Provided with radio frequency absorbent on its entire inner surface
- Emission measurements of direct radiation of radio frequency transmitters.
- Complies with ETSI standards

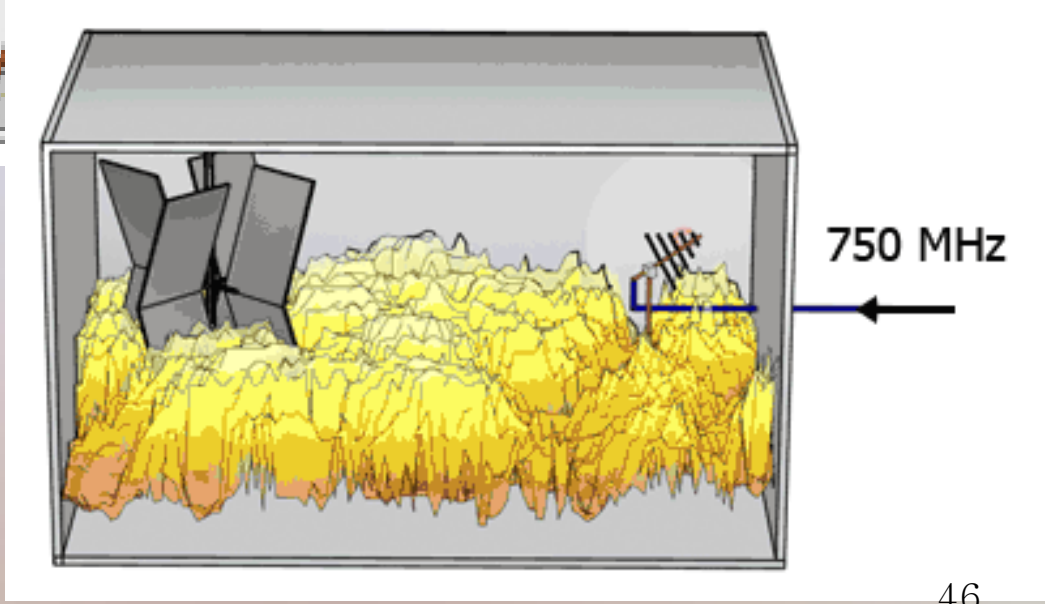


# Mode stirred reverberation chambers

- Shielded enclosure, sin gle or double wall, with metal stirrer
- Measures of radiated im munity and emission
- EN 61000-4-21.

# Mode stirred reverberation chambers





# TEM Cells

- Closed cell loaded onto a characteristic impedance
- Measures radiated emission and immunity.
- EN61000-4-20

# Open Area test sites

- The reference CISPR test site
- Radiated fields measures
- Great distance measures (10m – 30m).

# Open Area test sites

# Performance of measure sites

| | Low distance faraday cage | Open area test site | Sami or fully anechoic chamber |
|---|---|---|---|
| Advantages | Isolating EUT from external EM noise | Correct field measurements | Correct field measurements |
| drawbacks | •Walls reflexions<br>•Near field measure | Electromagnetic noise | •Degradation of absorbers performance<br>•high cost |

# EMC standards

# Fundamental standards

- These are standards or guidelines that define the general requirements for the "EMC" (phenomena, testing ...).
- They apply to all products and are used as references to develop specific standards.
- They include:
  - ✓ the description of electromagnetic phenomena
  - ✓ the characteristics of measuring instruments and of generation of test signals
  - ✓ the implementation of testing
  - ✓ the recommendations of severity levels
  - ✓ general criteria for proper operation.

# Fundamental standards

| | |
|---|---|
| **EN 61000.4.2** | Electrostatic discharge immunity test |
| **EN 61000.4.3** | Radiated, radio-frequency, electromagnetic field immunity test |
| **EN 61000.4.4** | Electrical fast transient/burst immunity test |
| **EN 61000.4.5** | Surge immunity test |
| **EN 61000.4.6** | Immunity to conducted disturbances, induced by radio-frequency fields |
| **EN 61000.4.8** | Power frequency magnetic field immunity test |
| **EN 61000.4.9** | Pulse magnetic field immunity test |
| **EN 61000.4.11** | Voltage dips, short interruptions and voltage variations immunity tests |
| **EN 61000-3-2 et EN 61000-3-3** | Limits for harmonic current / flicker emissions (equipment input current ≤ 16 A per phase) |

# Product standards

| | |
|---|---|
| **EN 55011** | Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement |
| **EN 55014** | Requirements for household appliances, electric tools and similar apparatus<br>Part 1: Emission.<br>Part 2: Immunity |
| **EN 55022** | Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement |
| **EN 55024** | Information technology equipment - Immunity characteristics - Limits and methods of measurement. |
| **ETSI EN 300-330** | Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD);<br>Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; |

- These standards define, for products or product families , the special design, characteristics, methods and test levels.
- Where available, these standards take precedence over generic standards.
- They use the fundamental standards.
- They define:
  - ✓ tests to be performed
  - ✓ levels of severity of tests
  - ✓ the criteria for proper operation

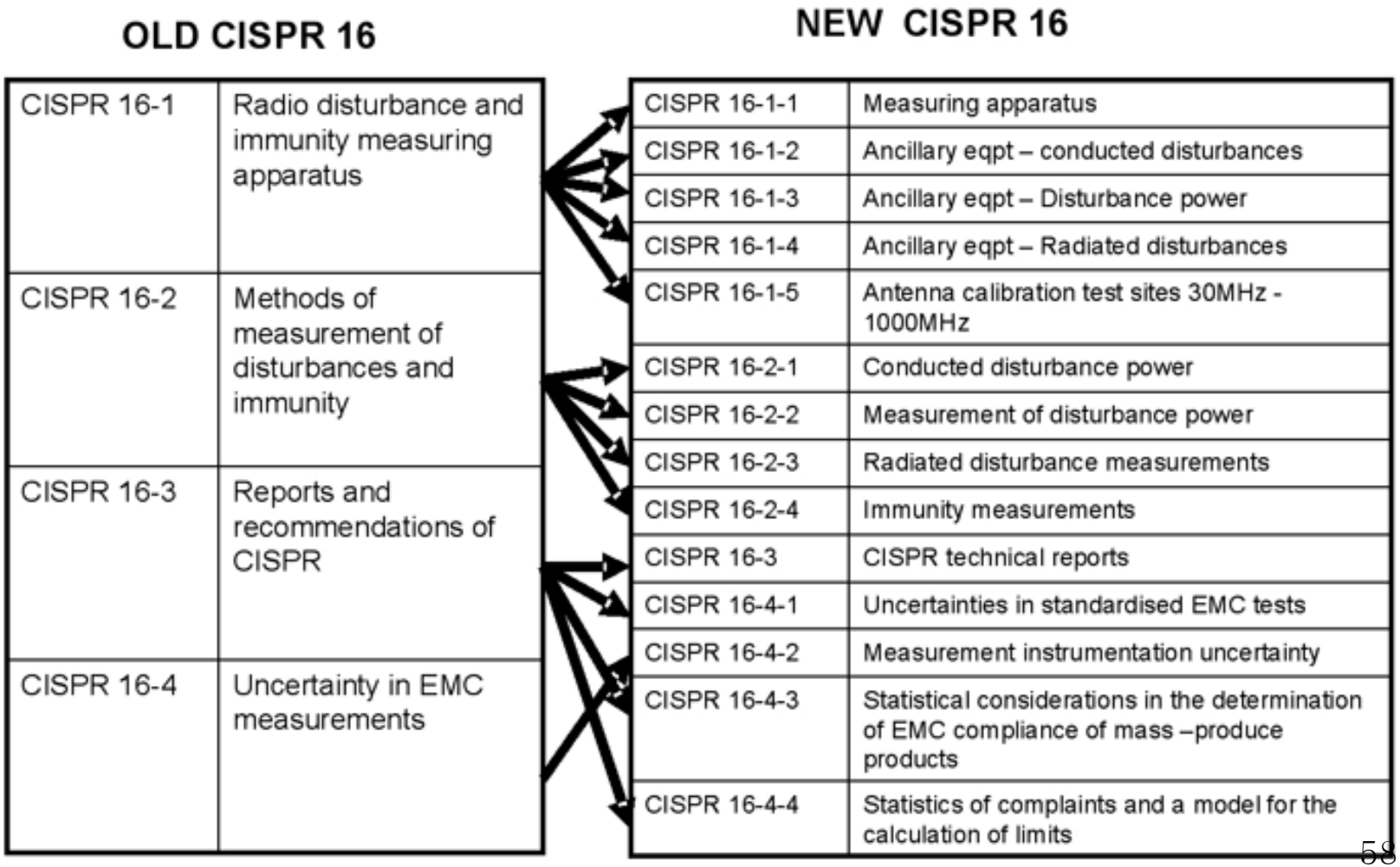
# Generic standards

- These standards define the essential require ments in terms of level to be maintained by type of test
- In the absence of product or family product standards, they apply to products installed in a defined environment (industrial, residential).
- They use the fundamental standards.
- They define:
  - ✓ the environment (residential, industrial ...)
  - ✓ tests to be performed
  - ✓ levels of severity of tests
  - ✓ the performance criteria

# Generic standards

| | |
|---|---|
| **EN 61000-6-1: .** | Immunity for residential, commercial and light-industrial environments |
| **EN 61000-6-2** | Immunity for industrial environments |
| **EN 61000-6-3:** | Emission standard for residential, commercial and light-industrial environments |
| **EN 61000-6-4:** | Emission standard for industrial environments |

# CISPR 16 standards



**OLD CISPR 16**

| | |
|---|---|
| CISPR 16-1 | Radio disturbance and immunity measuring apparatus |
| CISPR 16-2 | Methods of measurement of disturbances and immunity |
| CISPR 16-3 | Reports and recommendations of CISPR |
| CISPR 16-4 | Uncertainty in EMC measurements |

**NEW CISPR 16**

| | |
|---|---|
| CISPR 16-1-1 | Measuring apparatus |
| CISPR 16-1-2 | Ancillary eqpt – conducted disturbances |
| CISPR 16-1-3 | Ancillary eqpt – Disturbance power |
| CISPR 16-1-4 | Ancillary eqpt – Radiated disturbances |
| CISPR 16-1-5 | Antenna calibration test sites 30MHz - 1000MHz |
| CISPR 16-2-1 | Conducted disturbance power |
| CISPR 16-2-2 | Measurement of disturbance power |
| CISPR 16-2-3 | Radiated disturbance measurements |
| CISPR 16-2-4 | Immunity measurements |
| CISPR 16-3 | CISPR technical reports |
| CISPR 16-4-1 | Uncertainties in standardised EMC tests |
| CISPR 16-4-2 | Measurement instrumentation uncertainty |
| CISPR 16-4-3 | Statistical considerations in the determination of EMC compliance of mass –produce products |
| CISPR 16-4-4 | Statistics of complaints and a model for the calculation of limits |

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# EMC fundamentals

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