



# Electromagnetic Compatibility

Véronique Beauvois  
2020-2021



# Electromagnetic Compatibility

## Introduction

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## 0. Introduction - ULiège

- EMC activities are included in research unit ACE (Applied and Computational Electromagnetics)
- Prof. Christophe Geuzaine
- Véronique Beauvois, Ir.
- 1 PostDoc, 2 technicians
- EMC laboratories



## 0. Introduction - ULiège

**1996**

- Directive 89/336/CEE
- Walloon companies (especially SMEs) are searching for an EMC laboratory (competent, nearby, independent, accredited)
- Funding: Europe & Walloon Region





## 0. Introduction - ULiège

### July 1997

- Building of a semi-anechoic chamber 9 x 6 x 6 m
- Equipment
- Budget ~ 1.500.000 €

### March 1998

Official opening

### 2003

Initial BELAC Accreditation ISO 17025





# 0. Introduction - ULiège



In 20 years, more than 150 companies





## 0. Introduction - ULiège

**2009**

- New needs for military & spatial applications
- Reverberating Chamber
- High electric fields and larger frequency band
- Budget ~ 1.600.000 € (SPW)



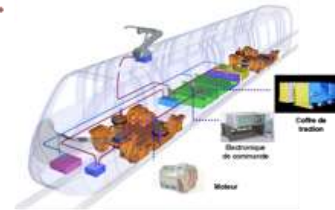
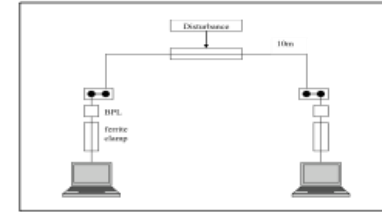
# 0. Introduction - ULiège



## Research activities

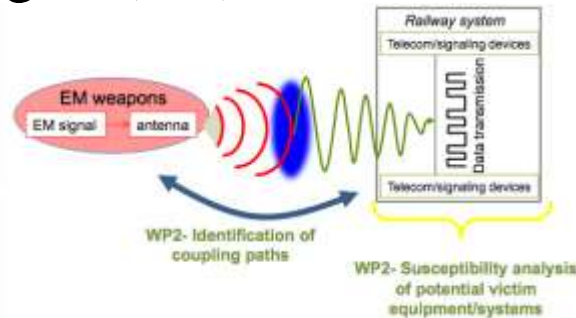
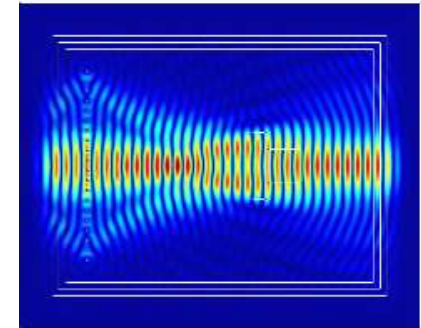
Previously

- On site measurements
- PLC
- Near-field measurements
- Railway applications
- Smart-Pod (FN)



Currently

- EM field control
- Electric tommy gun (FN)







# 1. Introduction

## *A little bit of history (1)*

- 19<sup>th</sup> century: lightning strikes on ships, buildings and power supplies, short-circuit failures lead to the development of output circuit breakers on power stations and input fuses in buildings and appliances
- Beginning of the 20<sup>th</sup> century: advent of radio communications, with first radio interference problems (especially related to electrical motors sparks)
- Electrostatic discharge (ESD) problems in hazardous environments lead to development of safe working practice
- Germany 1924: high-frequency committee from VDE (*Verband der Elektrotechnik*)
- Netherlands 1931: *Radiostoringscommissie*
- England 1933: Institution of Electrical Engineers (IEE) creates a Radio Frequency Interference (RFI) committee
- 1933: International Electrotechnical Commission (IEC) creates CISPR (International Special Committee on Radio Interference) to develop standards to limit interferences



# 1. Introduction

## *A little bit of history (2)*

- 2<sup>nd</sup> World War: Electronic and radio communication equipment (radio, navigation, radar) developments increase and the number of reported interference problems also (e.g. air navigation)
- From then on increasingly rapid evolution of electronics: transistors, integrated circuits, high density components, microprocessors, ... combined with enlarged frequency spectrum to increase information transfer capacity
- 1967: aircraft carrier Forrestal was destroyed during Vietnam war. An on-board radar disturbed the firing system of rockets under a plane, the rocket was launched accidentally, hit a plane which exploded and set the deck on fire
- 1982: HMS Sheffield missile destroyer was destroyed by an Exocet missile because the antimissile detection system was off, related to interference with the satellite communication system (Falklands war – Argentina vs United Kingdom)
- 1996: All products to be put on the European market should be in conformity with emission and susceptibility requirements, in order to protect communication systems



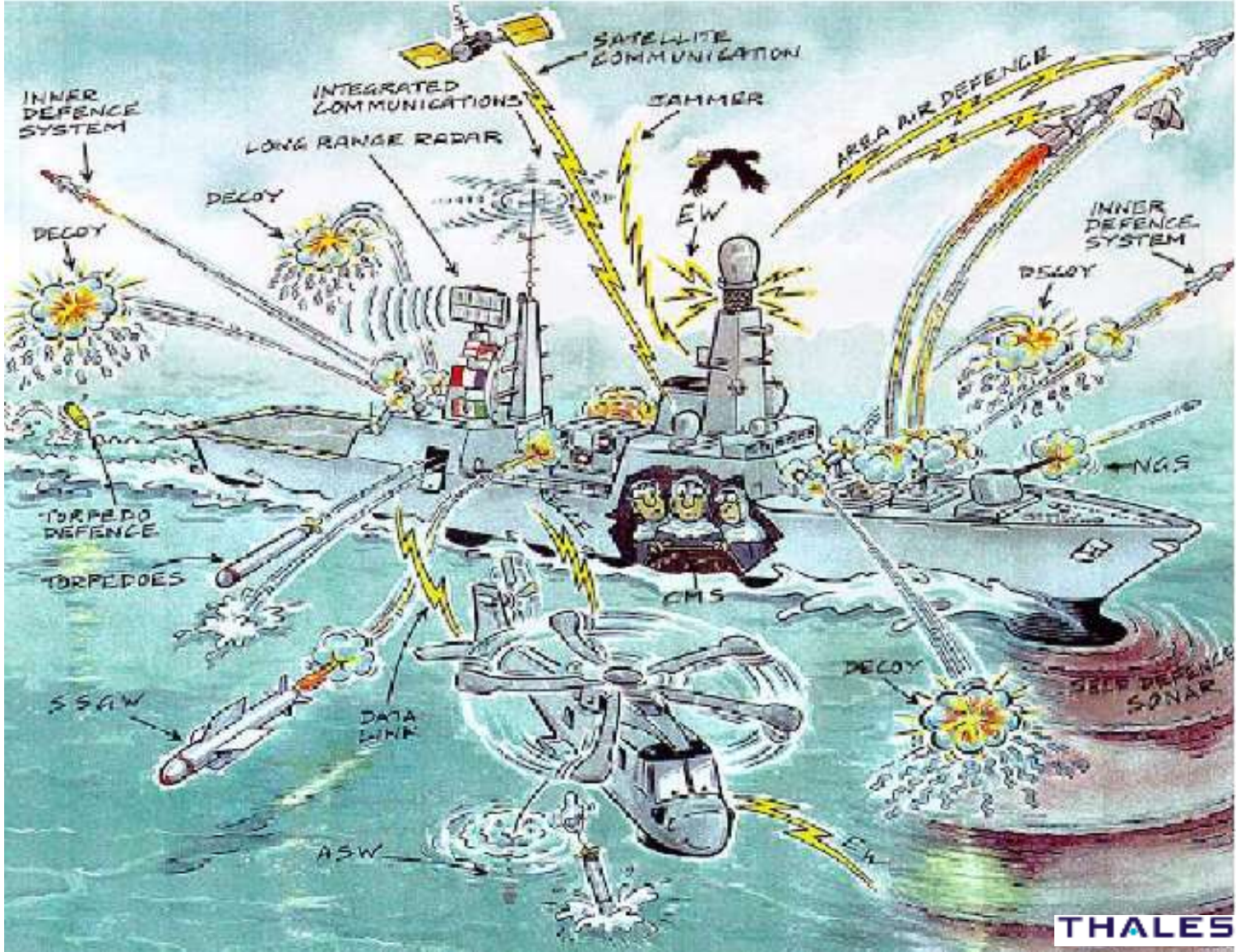


# 1. Introduction

Numerous modern technological developments highlight the importance of correctly dealing with electromagnetic interferences: ABS and electronics on board of automotive vehicles, mobile phones and electronic equipment on airplanes or in hospitals, medical implants such as pacemakers and hearing aids, etc.



# 1. Introduction





# 1. Introduction

## *Interference Classification*

Natural

Artificial



non intentional

intentional

- thunderstorm/lightning
- solar activities
- cosmic noise
- electrostatic discharges





# 1. Introduction

Electromagnetic interferences



Electromagnetic Compatibility (EMC)

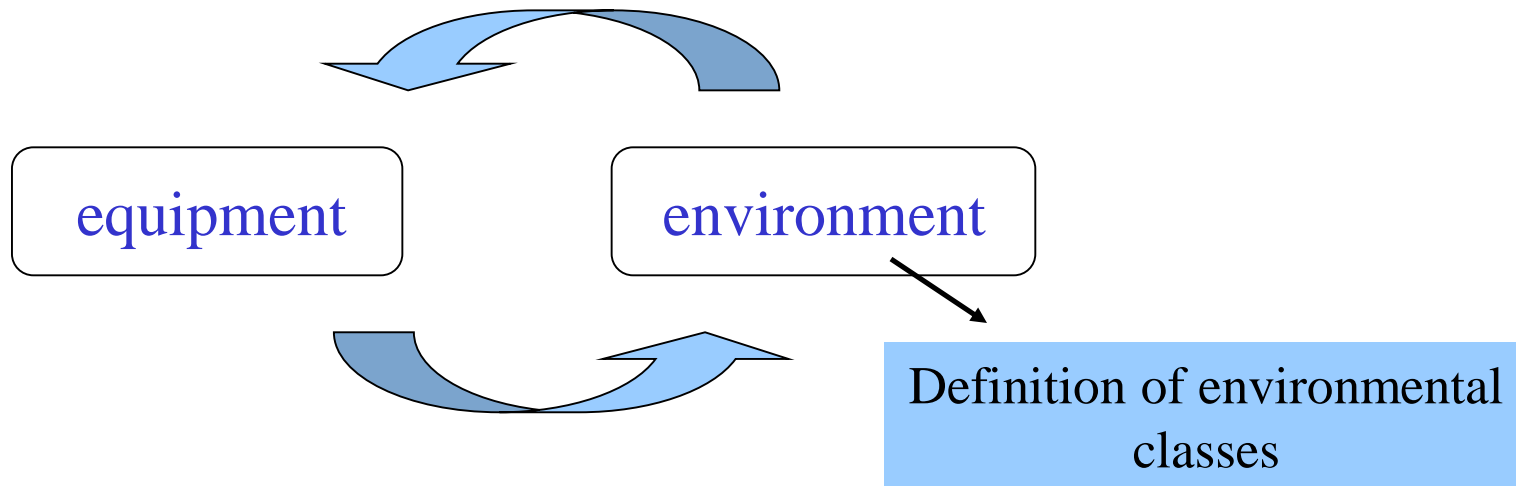


What is EMC?



According to the European Directive (2014/30/EU)

EMC (electromagnetic compatibility) means the ability of equipment to function **satisfactorily** in its electromagnetic environment without introducing **intolerable** electromagnetic disturbances to other equipment in that environment.

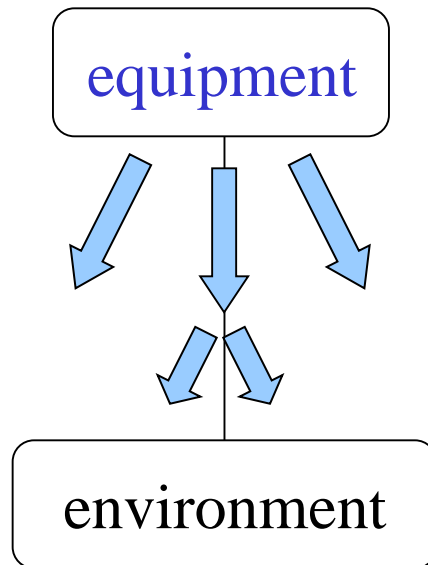




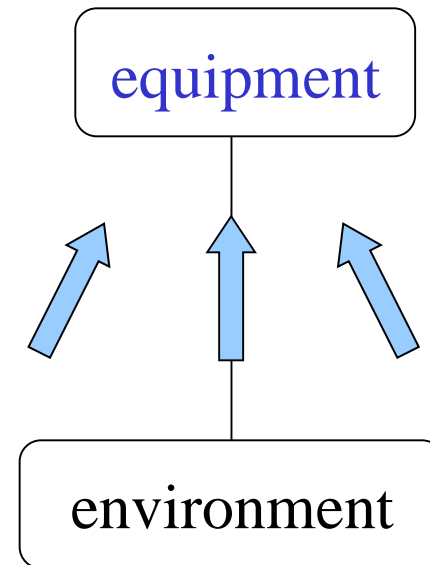
## What is EMC?

### Two-way phenomena

#### Emission



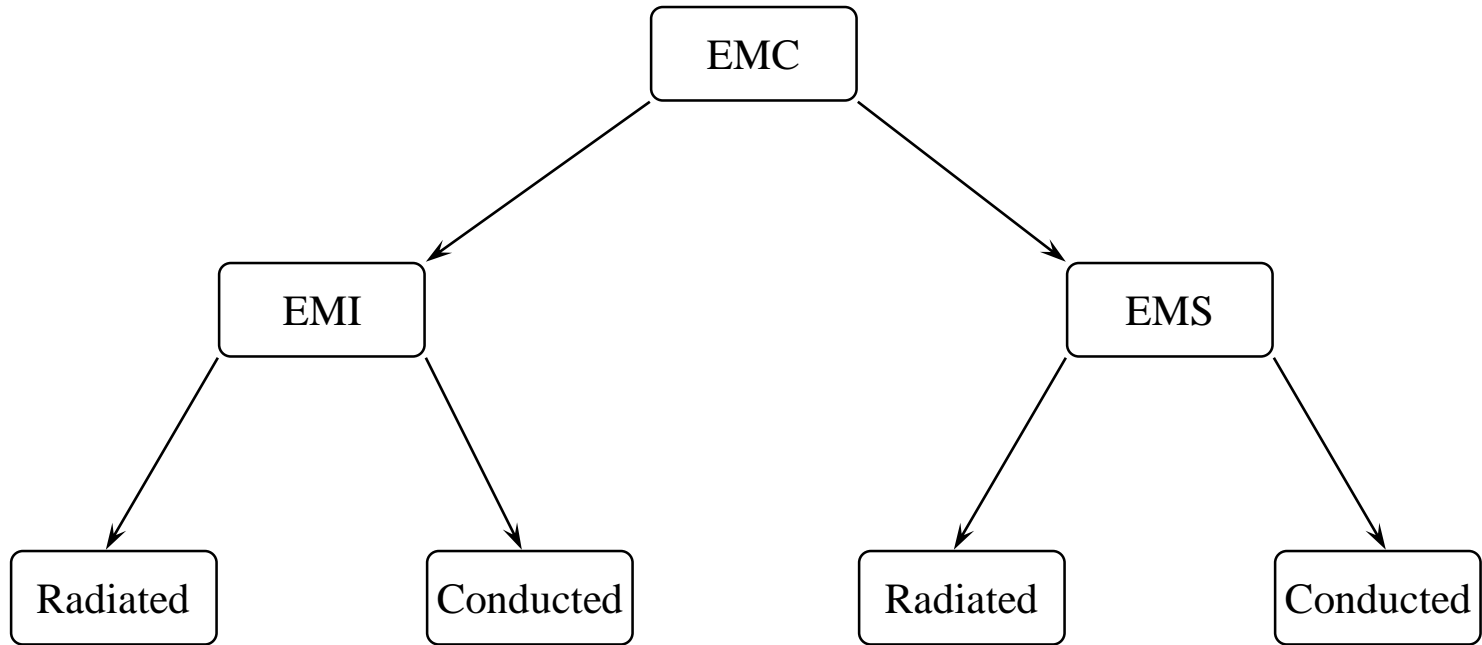
#### Susceptibility/Immunity







# What is EMC?



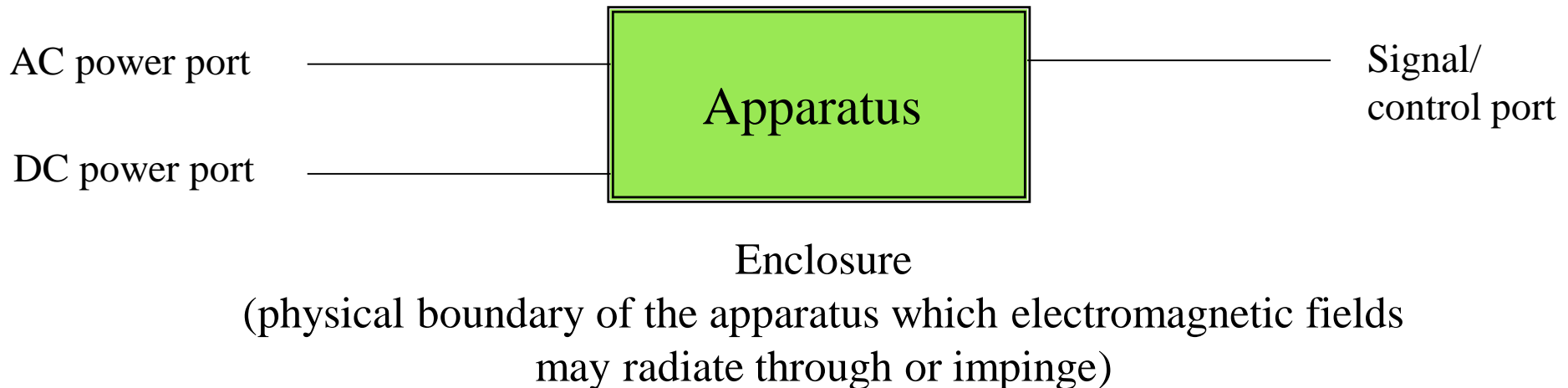
**EMI** = ElectroMagnetic Interference

**EMS** = ElectroMagnetic Susceptibility



## What is EMC?

### Equipment - Ports

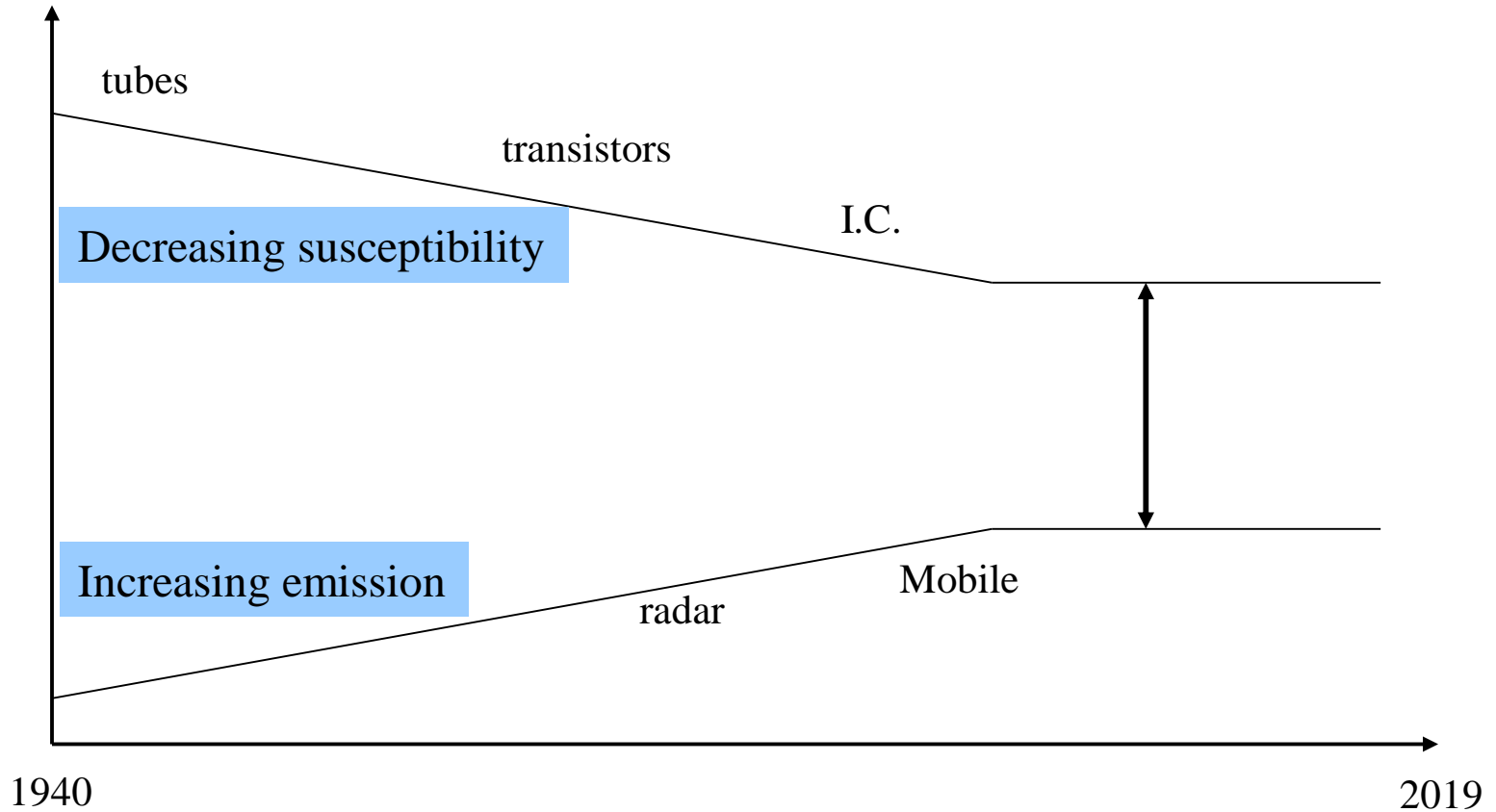


EMC tests are related to these different ports: enclosure (electric and magnetic fields at low and high frequencies, ESD), power supply ports (AC/DC), signal/control ports (Ethernet, RS-232, ...)



# What is EMC?

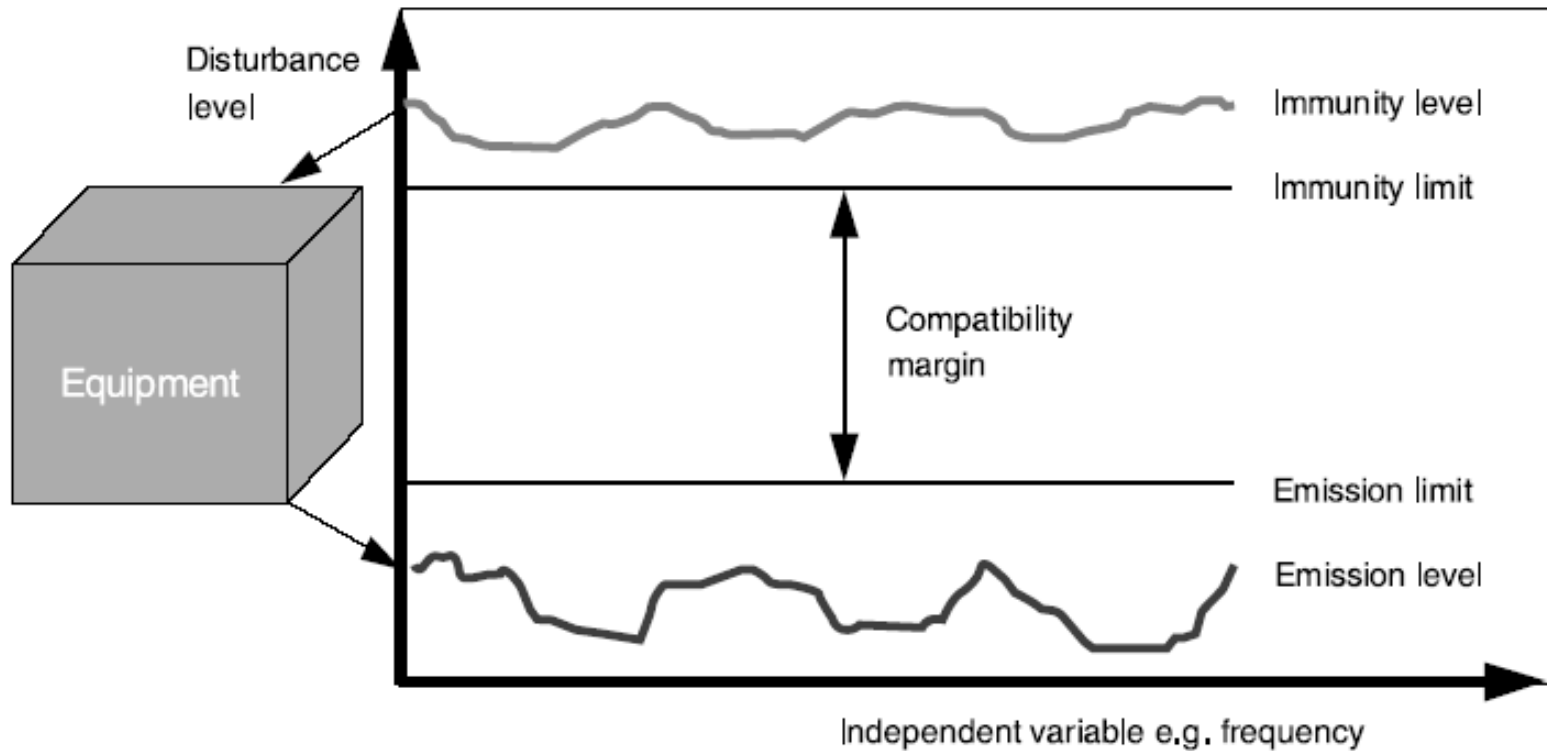
## Electromagnetic compatibility gap





# What is EMC?

## Compatibility margin





# Electromagnetic Compatibility

## Basic concepts

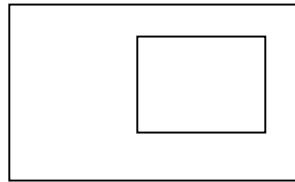
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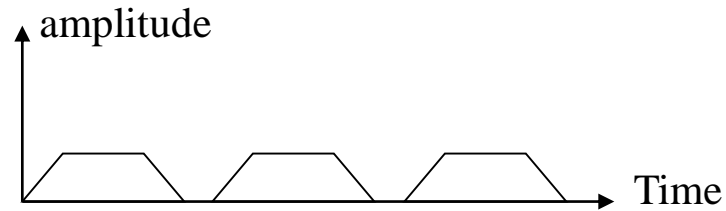
## Basic concepts

There are 2 common ways to represent a signal

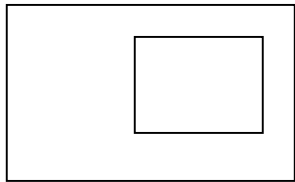
### Time Domain



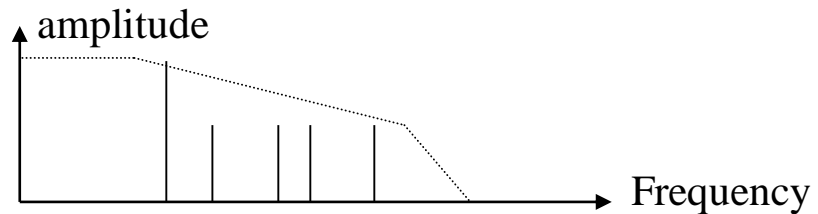
Scope



### Frequency Domain



Spectrum Analyser



**How to convert?**



# Mathematical Conversion Time vs Frequency

## Periodic signal – Fourier Serie

$s(t)$  period  $T$  :  $s(t) = s(t+kT) \quad \forall k$  integer

$s(t) = \sum c_n \exp^{j2\pi nt/T}$  linear comb. of complex exponential functions

where  $c_n = 1/T \int s(t) \cdot \exp^{-j2\pi nt/T} \cdot dt$

### Examples

\*  $A \cos(\omega t)$

\* Rectangular signal amplitude  $A$ , duty cycle  $1/2$  and period  $T$



## Mathematical Conversion Time vs Frequency

### Non periodic signals – Fourier Transform

Non periodic signal = periodic signal with  $T \rightarrow \infty$

Discrete spectrum  $\rightarrow$  continuous spectrum (gap  $\rightarrow 0$ )

$$f(t) = \int F(f) \exp^{j2\pi ft} df$$

$$F(f) = \int f(t) \exp^{-j2\pi ft} dt$$





## Examples

- **Pulse  $i(t)$  width  $\tau$  and amplitude  $A$**
- **Dirac pulse  $d(t)$  (limit of  $i(t)$  when  $\tau \rightarrow 0$ ) amplitude  $A$**
- **Single pulse ESD ( $\tau_r$  1ns /  $\tau$  60ns)**
- **...**

# Basic concepts



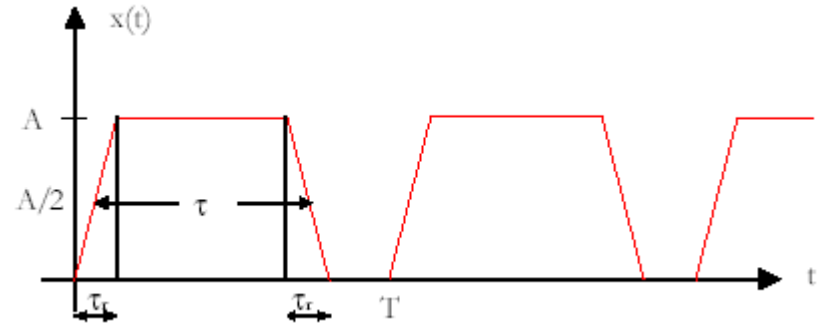
**$\mu\text{P}$  clock 8MHz,  $t_r = 5\text{ns}$ ,  
 $\tau = 62,5\text{ns}$  (duty cycle  $\tau/T$ )**

**$f_{c1} = 1/\pi\tau = 5,1\text{MHz}$ ,**

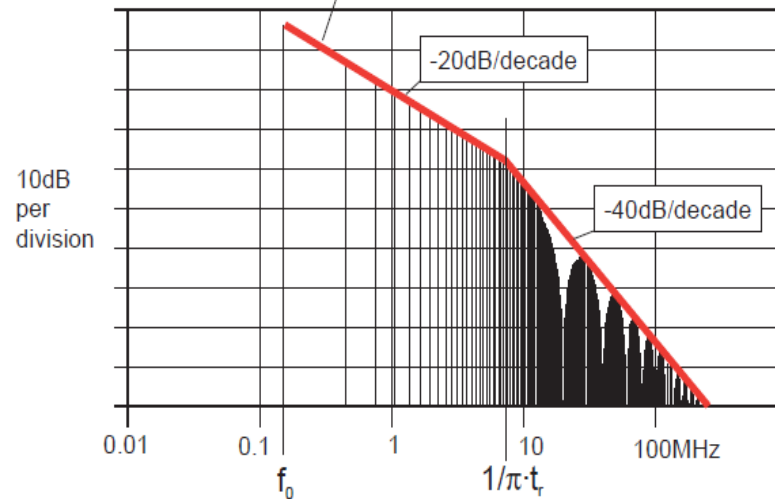
**then -20dB/dec.**

**$f_{c2} = 1/\pi t_r = 63,7\text{MHz}$ ,**

**then -40dB/dec.**



Envelope of maximum harmonic amplitudes

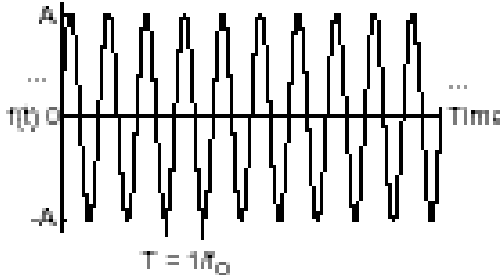
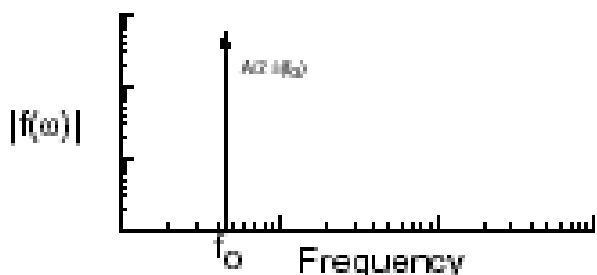
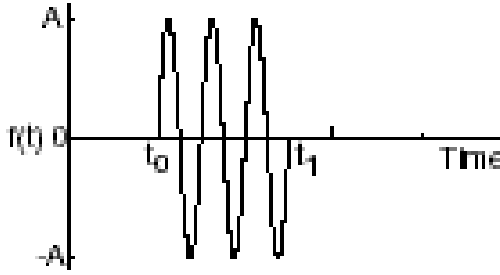
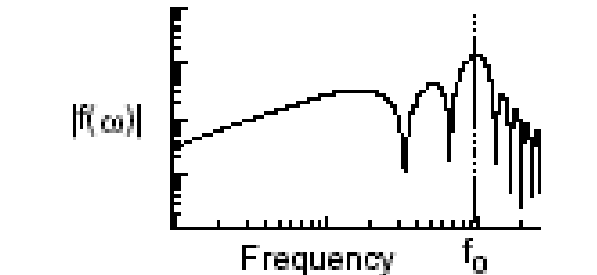
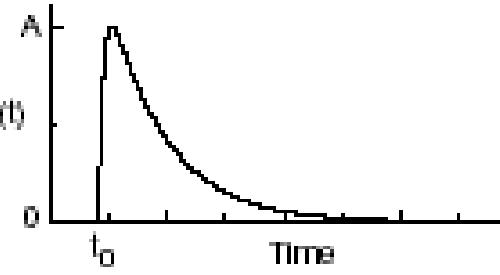
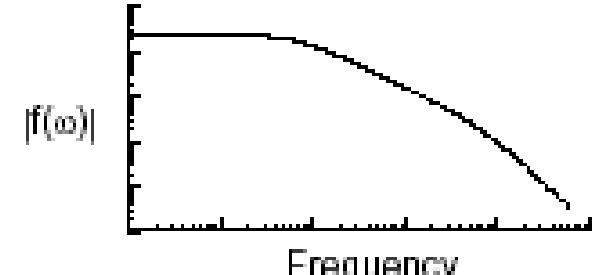


Frequency domain

$f_0 = 150\text{kHz}$   
 $t_r = 40\text{ns}$

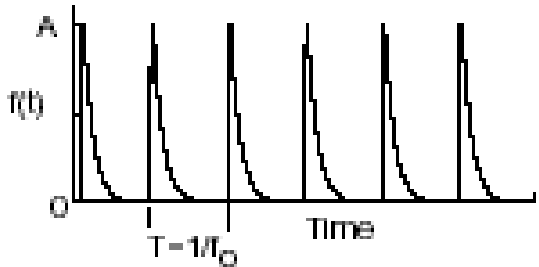
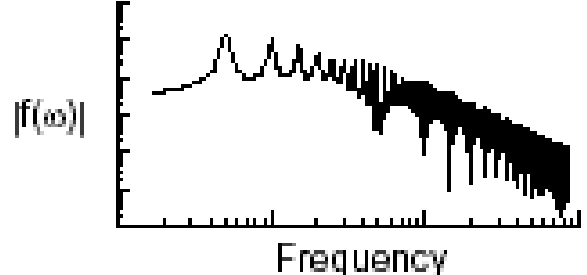
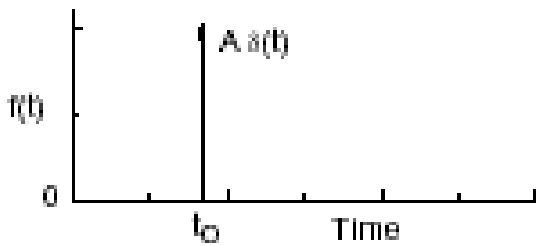
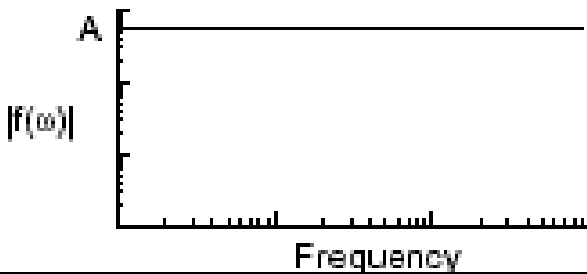
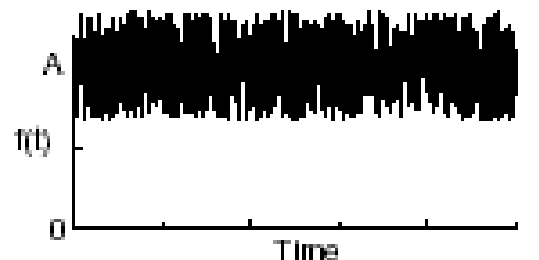
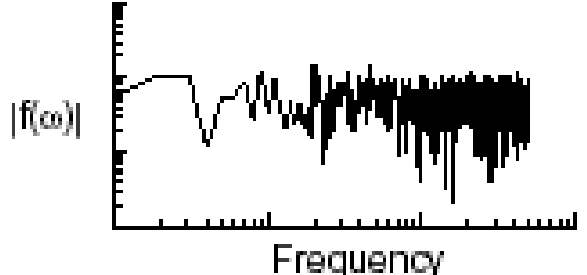


# Basic concepts

Signal	Forme d'onde	Spectre
1. Sinusoïde		
2. Impulsion sinusoïdale		
3. Impulsion unique		

# Basic concepts



Signal	Forme d'onde	Spectre
4. Train d'impulsions		
5. Impulsion de Dirac		
6. Bruit avec une composante DC		



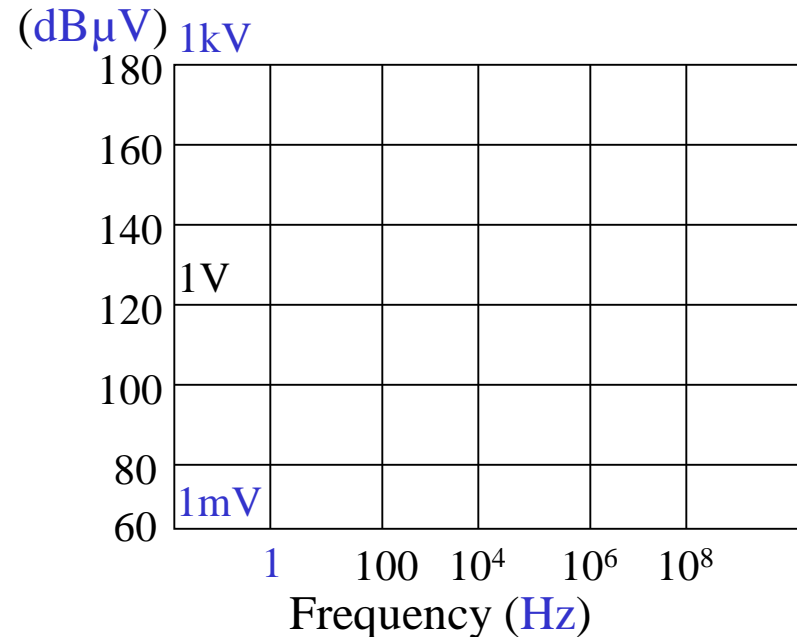
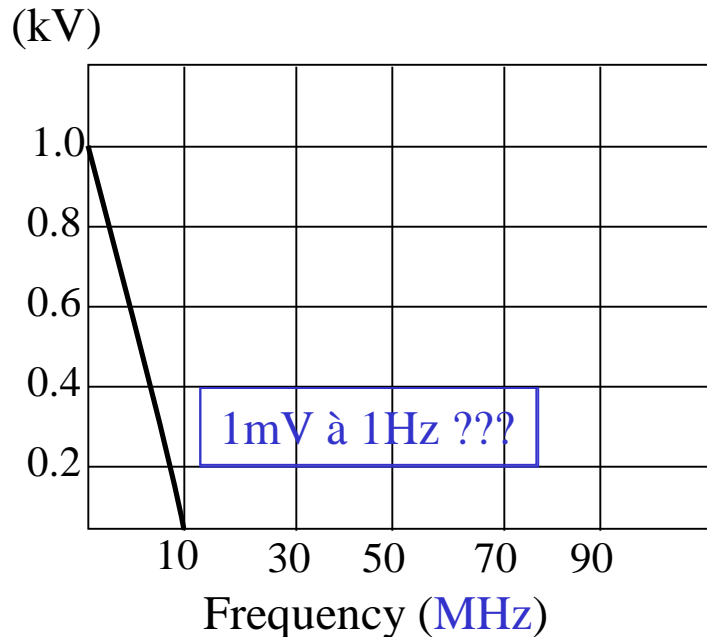
# Basic concepts

Units in EMC? Why **dB** and **logarithmic scales**?

**1mV @ 1 Hz and 1kV @ 10MHz on the same graph?**

**-Linear scale (f in MHz and V in kV)**

**-Log scale (f in Hz and V in dB $\mu$ V)**





## Basic concepts

### Units in EMC?

$$\log (ab) = \log a + \log b$$

$$\log (a/b) = \log a - \log b$$

$$\log (1/a) = - \log a$$

$$\log a^n = n \log a$$

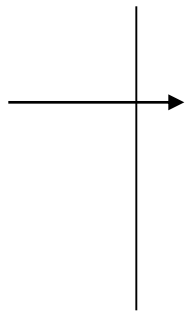


# Basic concepts

## Units in EMC? dB

= logarithmic division between 2 quantities (without units)

Power (initially)  
 $dB = 10 \log (P_{1Meas}/P_{2Ref})$   
 $dBW > P_2 = 1 \text{ Watt}$   
 $dBm (dBmW) > P_2 = 1 \text{ mW}$



Voltage ( $P_i = V_i^2/Z$ )  
 $dB = 20 \log (V_{1Meas}/V_{2Ref})$   
 $dBV > V_2 = 1 \text{ V}$   
 $dB\mu V > V_2 = 1 \mu V$

	dB(P)	dB(V)
1	0	0
2	3	6
10	10	20



## Exercises

Convert 50W in dBW

$$50\text{W} = 10 \times 10 / 2 \text{ W} > 10 + 10 - 3 = 17 \text{ dBW}$$

Convert 50W in dBm (1mW as reference)

$$50\text{W} \times 1000 \text{ mW/W} > (10 \times 10 / 2) \times 10^3 > 10 + 10 - 3 + (3 \times 10) = 50 - 3 = 47 \text{ dBm}$$

Relationship V(dB $\mu$ V) - P(dBm) for any value of Z and for Z 50 $\Omega$

$$P = V^2 / Z$$

$$10 \log P / 1\text{W} = 10 \log P / 10^3 \text{mW} = 10 \log P / 1\text{mW} - 30 = 20 \log V / 1\text{V} - 10 \log Z$$

$$= 20 \log V / 10^6 \mu\text{V} - 10 \log Z = 20 \log V / 1 \mu\text{V} - 120 - 10 \log Z$$

$$P(\text{dBm}) = V(\text{dB}\mu\text{V}) - 90 - 10 \log Z$$

If Z=50 $\Omega$

$$V(\text{dB}\mu\text{V}) = P(\text{dBm}) + 107 \text{ dB}$$





# Basic concepts

## Units in EMC?

<u>Power</u>	<u>Voltage</u>	<u>Current</u>
W	V	A
dBW	dBV	dBA
→ <b>dBm</b>	EMI → <b>dBμV</b>	<b>dBμA</b>
dBm/kHz	dBμV/MHz	dBμA/MHz

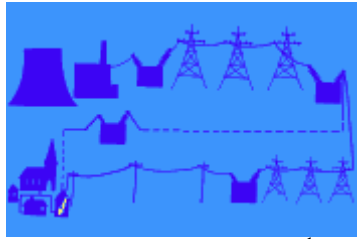
EMS → <u>E</u>	<u>H</u>
<b>V/m</b>	A/m
dBV/m	dBA/m
EMI → <b>dBμV/m</b>	<b>dBμA/m</b>
dBμV/m/MHz	dBμA/m/MHz



## Frequency / Wavelength

$$\lambda = c/f$$

$$c = 3 \cdot 10^8 \text{ m/s}$$



← 50Hz

6000km

EMI-V

150kHz

2km

1MHz

300m

30MHz

10m

EMI-F

300MHz

1m

900MHz →

33.3cm

1GHz

30cm



← 2.4GHz

12cm

18GHz

1.67cm