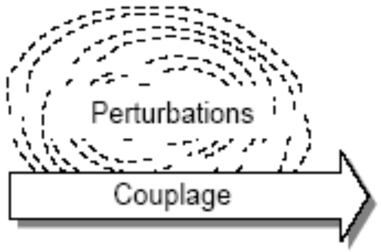
Coupling modes

Véronique Beauvois, Ir.
2015-2016

General problem in EMC = a trilogy

Parameters
• Amplitude
• Spectrum



Source (disturbing) → **Victim (disturbed)**

propagation
Coupling modes

Source (disturbing)	propagation / Coupling modes	Victim (disturbed)
• lightning • electrostatic discharges • motors, converters • etc.	• conducted (I / U) • radiated (cables, slot, shielding defect,…)	• receivers • sensors • amplifiers • µC • etc.

General solution in EMC = a trilogy

Source (disturbing) → Victim (disturbed)

propagation
Coupling mode

To act on the source (not always possible)

To reduce the efficiency of the coupling mode = frequently only solution

To act on the victim (increasing immunity – reducing susceptibility)

or different combined solutions

Remark : reciprocity (to improve emission frequently improve also immunity)

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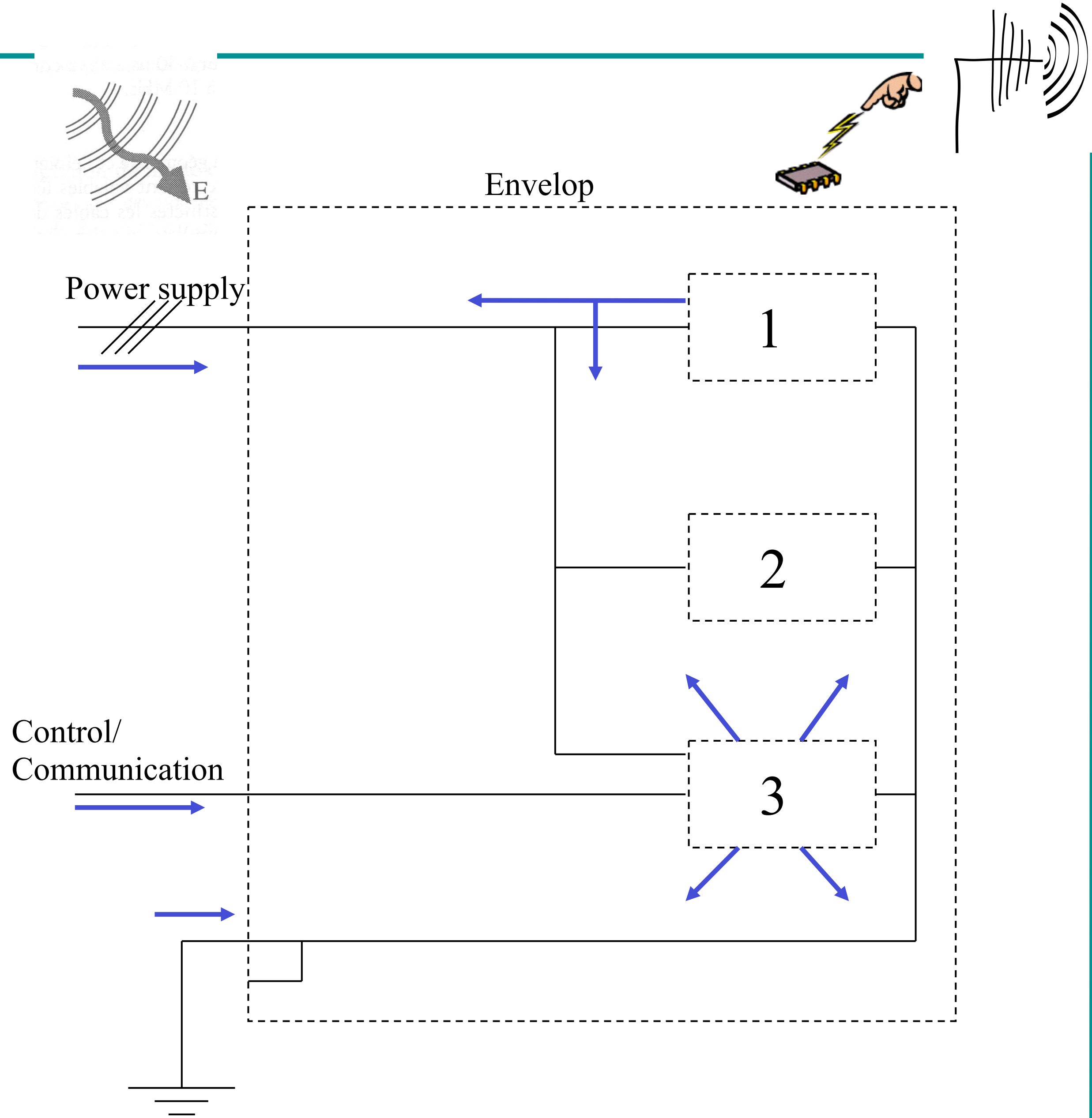
1st step: to identify the disturbing elements

⇩

Protections

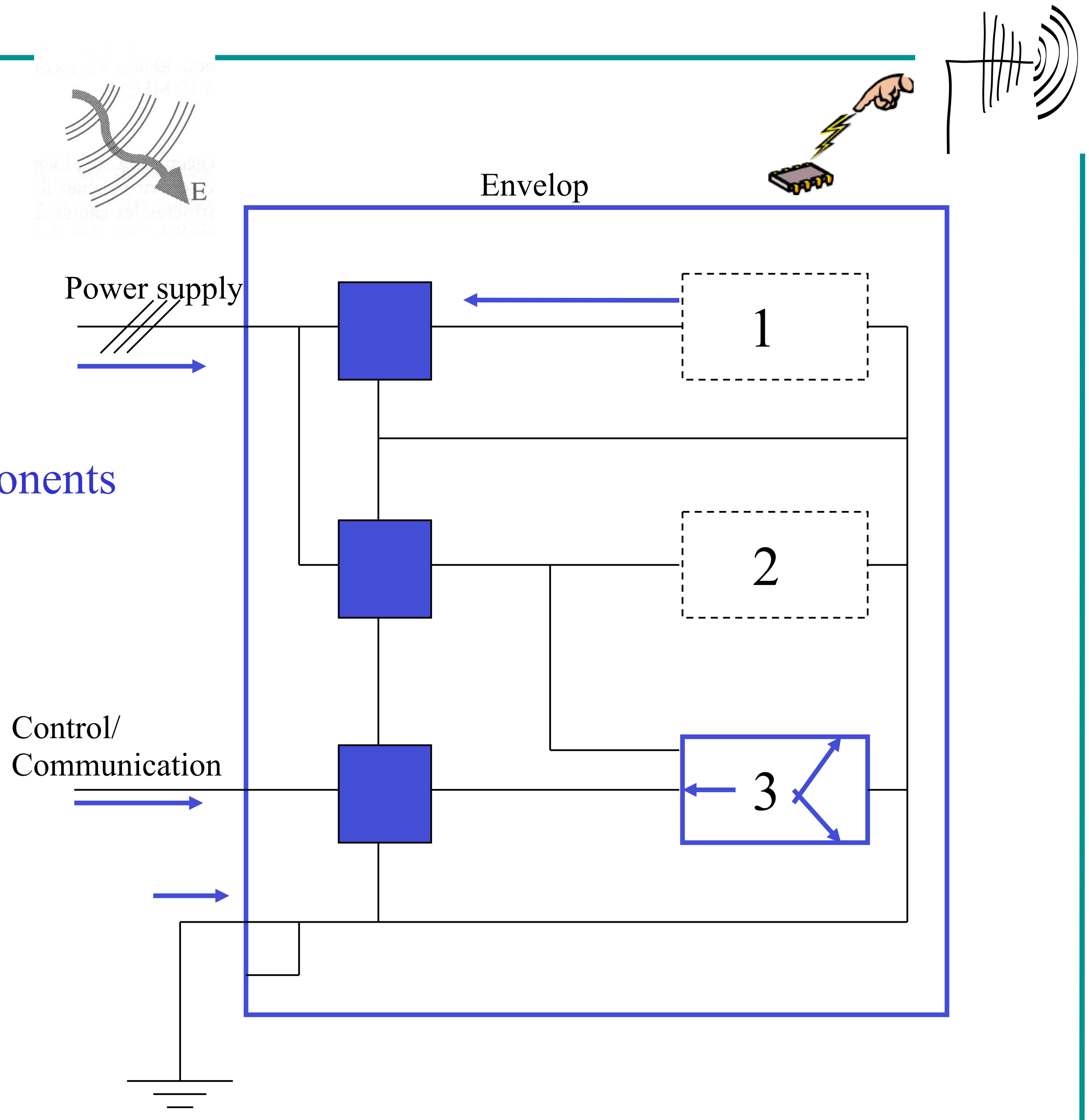
- for inter-system
- for intra-system

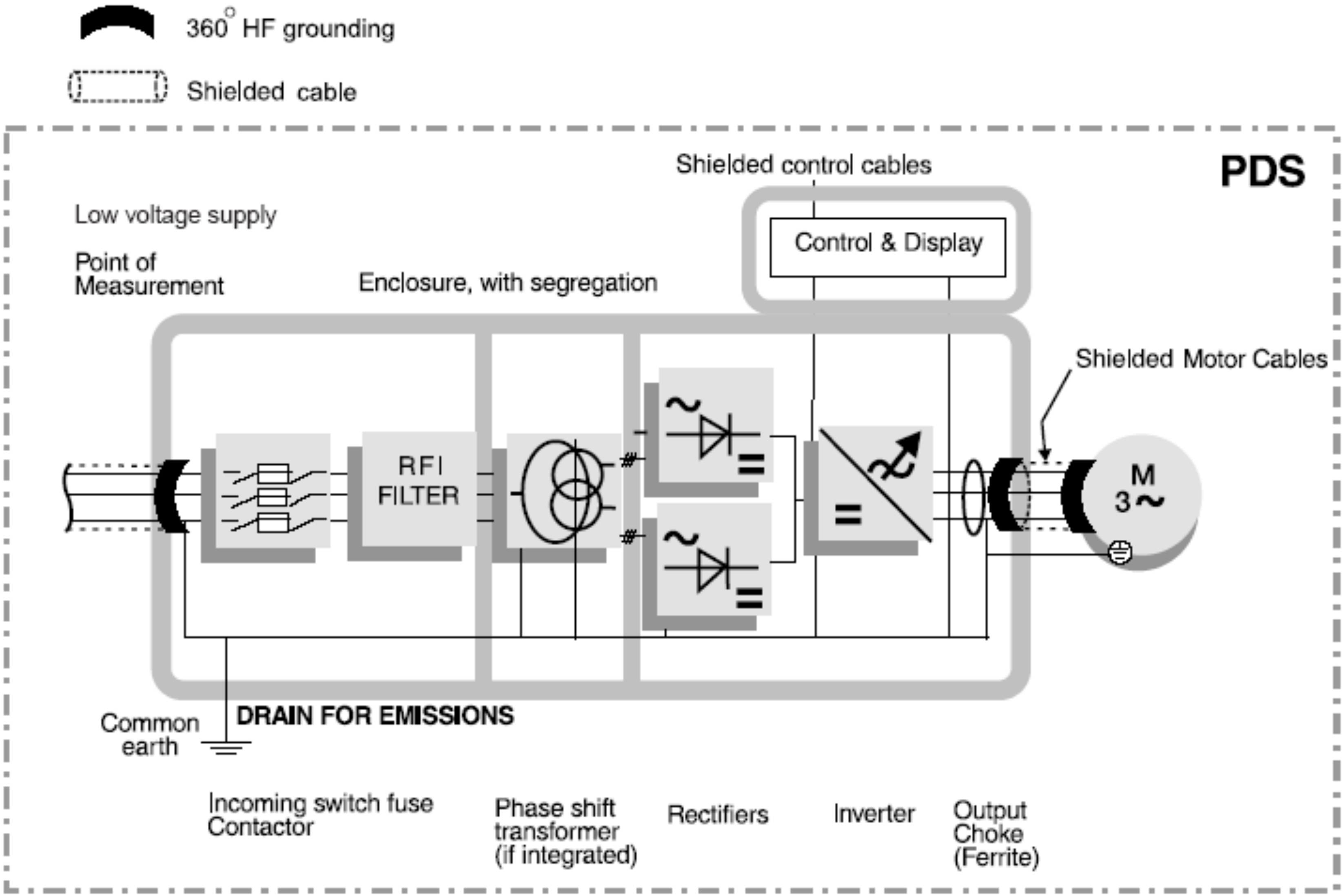
= source & victim
inside the same system



To identify the disturbing elements, the coupling paths, …

To add elements/components to reduce some effects




360° HF grounding
Shielded cable
PDS
Shielded control cables
Low voltage supply
Point of Measurement
Enclosure, with segregation
Control & Display
Shielded Motor Cables
RFI FILTER
M
3~
Common earth
DRAIN FOR EMISSIONS
Incoming switch fuse Contactor
Phase shift transformer (if integrated)
Rectifiers
Inverter
Output Choke (Ferrite)

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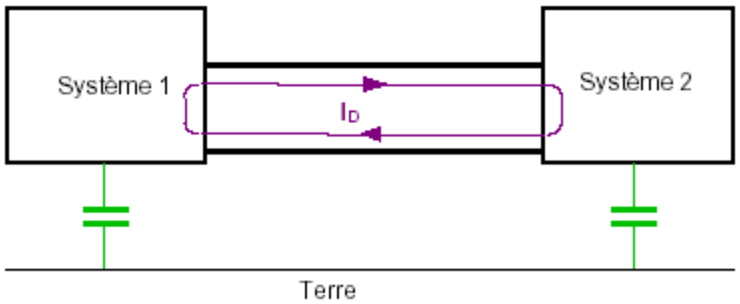
Coupling modes

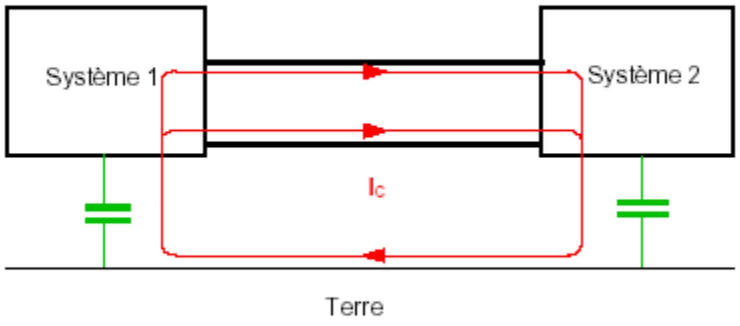
The coupling modes between source and victim could be classified according to:

- Common mode
- Differential mode



Differential mode (DM)
(or symetrical) : current is on one conductor in one direction and in phase opposition on the second conductor (e.g. power supply, RS-485, CAN, USB).

Coupling modes



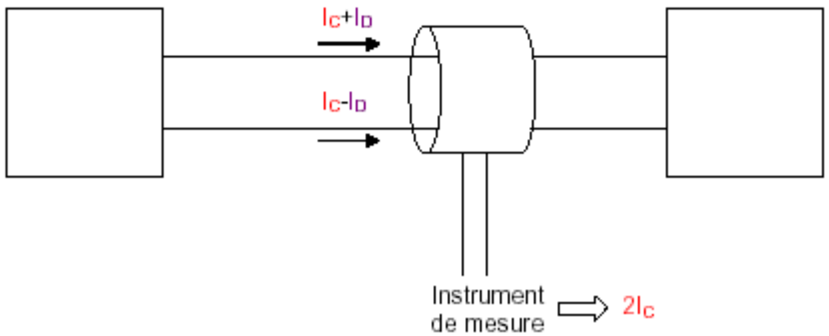
Common Mode (CM) (or asymetrical or longitudinal) : current on both conductors in the same direction.

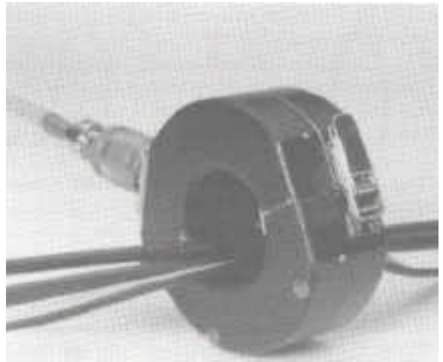
The EM disturbances are weakly coupled in DM as conductors are nearby. On the other hand, in CM, current could be induced by an external field.

Coupling modes

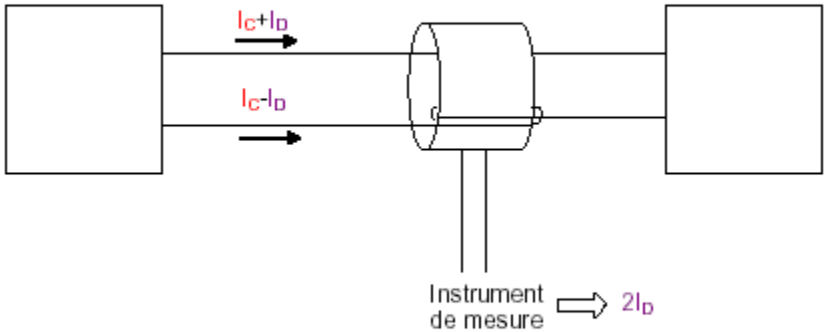
How to measure CM and DM?
With a current clamp

CM





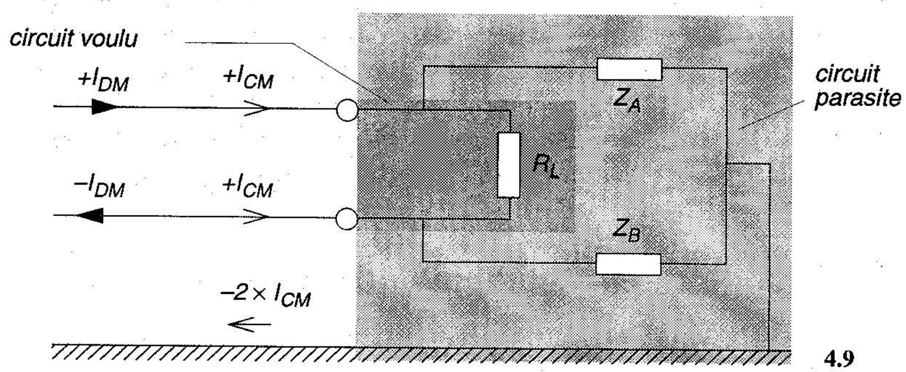
DM



Coupling modes

Conversion between DM and CM

Related to the parasitic impedances of different values



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Origin? When 2 conductors have a different impedance regarding earth (parasitic capacitors)

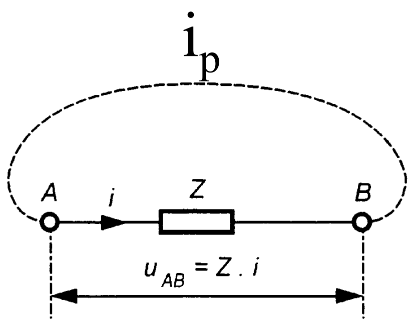
If $Z_A = Z_B$, there is no voltage accross R_L due to I_{CM}

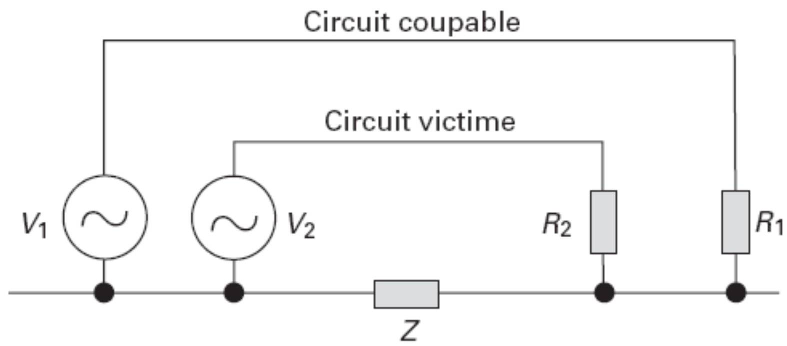
If $Z_A \neq Z_B$, $V_{charge(CM)} = I_{CM}.(Z_A - Z_B)$

Coupling modes

A. Common impedance coupling (conducted coupling)
= common conductor

Considering a conductor AB, impedance Z(f) ($\neq$0) :





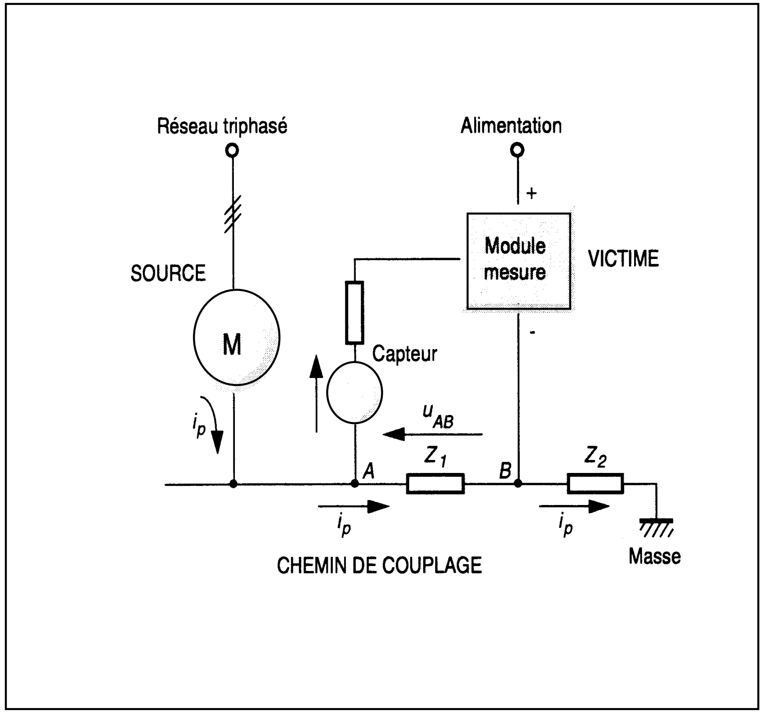
Z impédance commune aux deux circuits

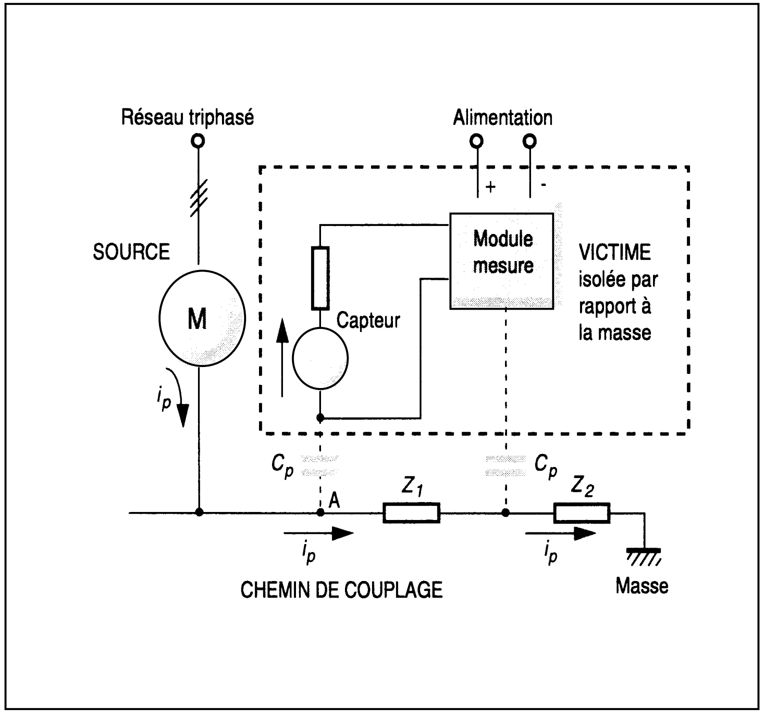
Solutions:

- to decrease Z (coupling)
- to decrease i_p (source)

Coupling modes

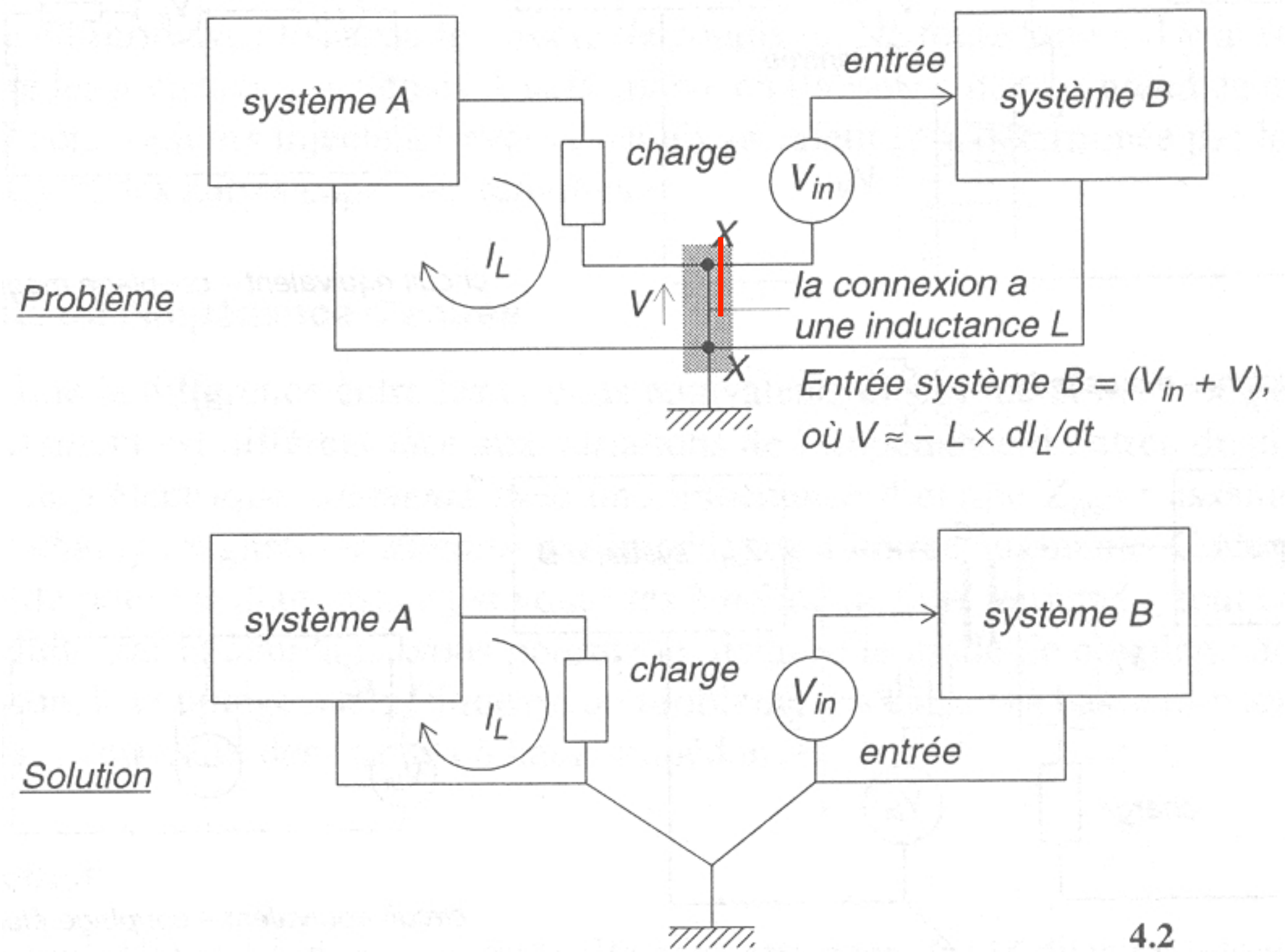
A. Common impedance coupling (conducted coupling) = common conductor





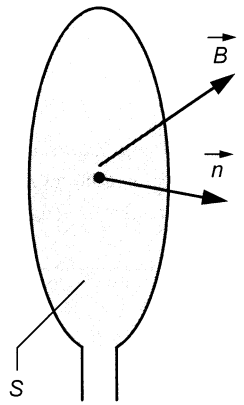
Coupling modes

A. Common impedance coupling (conducted coupling)
= common conductor



Coupling modes

B. Inductive Coupling



The circulation of a current in a conductor creates a magnetic field, which could couple with a nearby circuit, and induced a voltage.

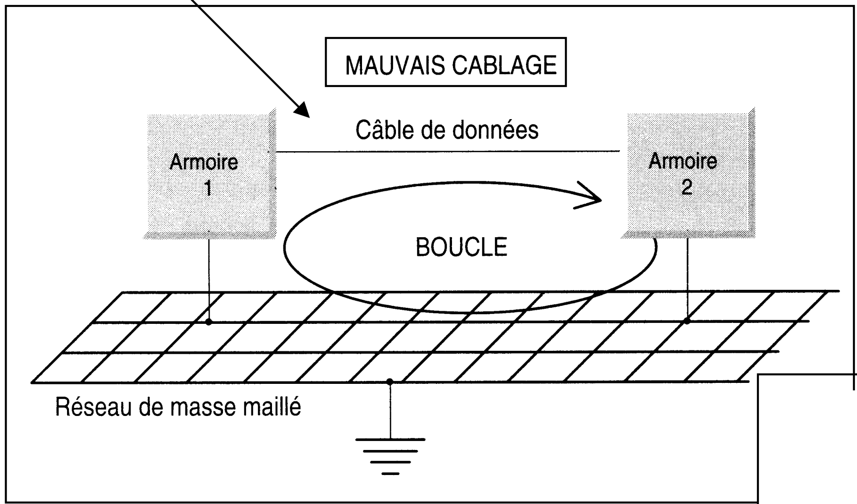
Solutions:

- source: to decrease dB/dt
- victim: to decrease S or modify orientation
  (n and B perpendicular, B // loop)
- coupling: to increase distance or add a magnetic screen

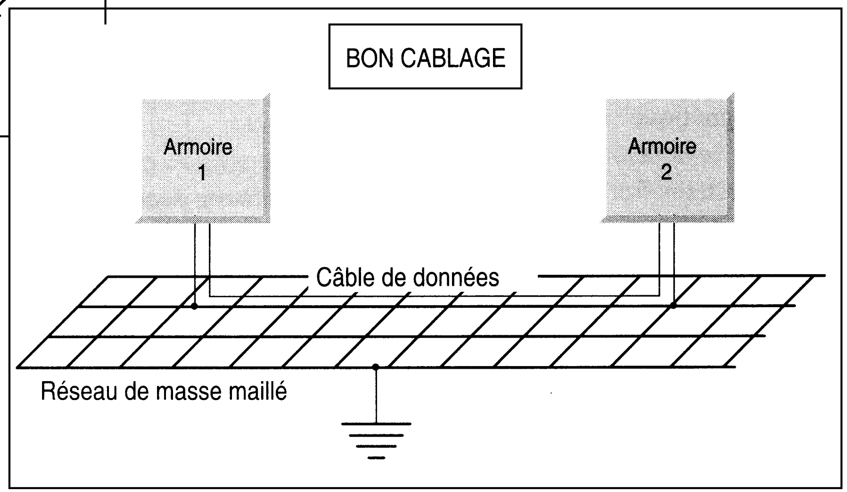
Coupling modes

B. Inductive Coupling

External disturbance



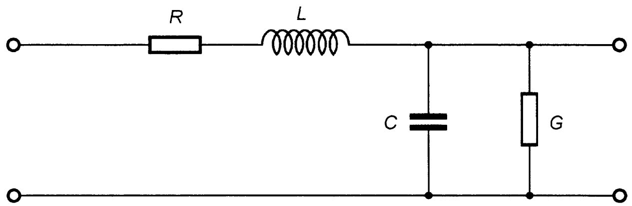
To reduce S loop

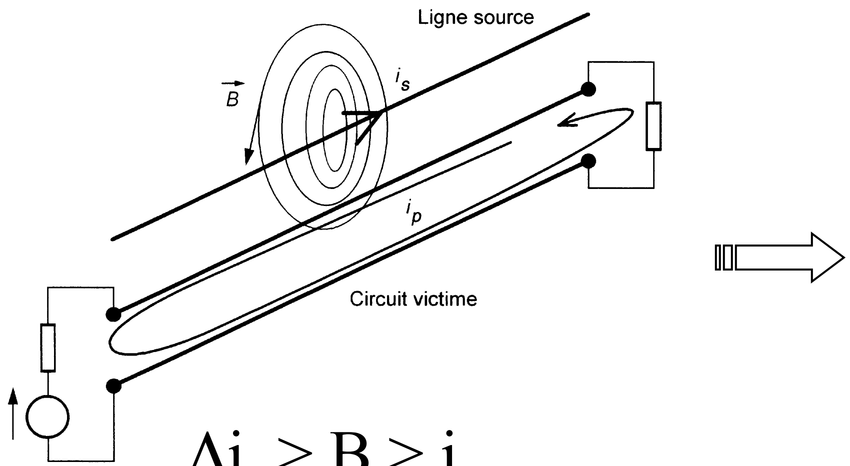


Coupling modes

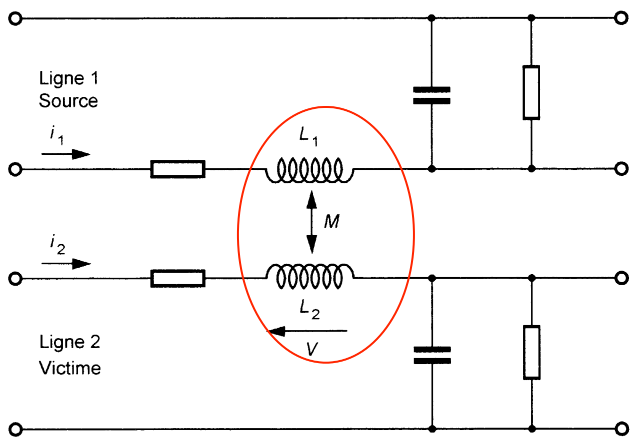
B. Inductive Coupling

Inductive diaphony



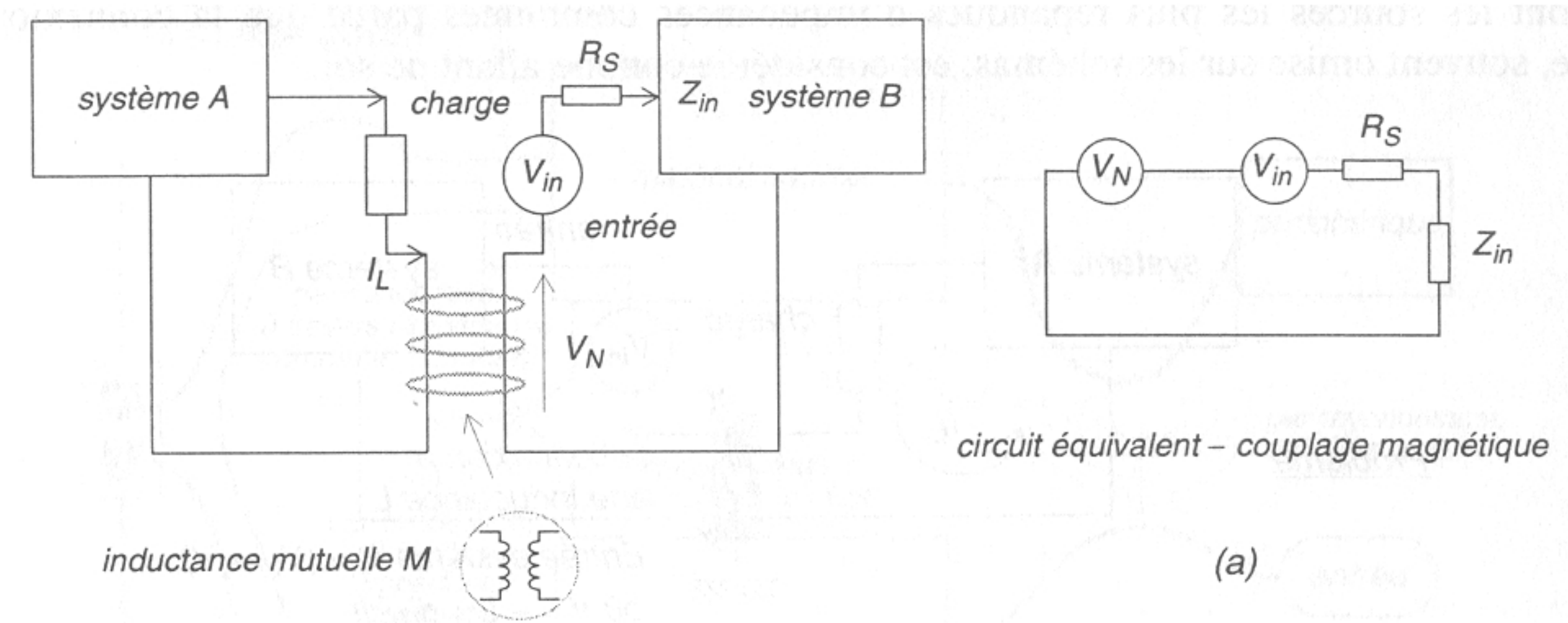


$$\Delta i_s > B > i_p$$



$$V = L_2 di_2/dt + M di_1/dt$$

B. Inductive Coupling

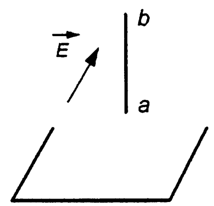


$$V_N = - M \times dI_L/dt$$

Coupling modes

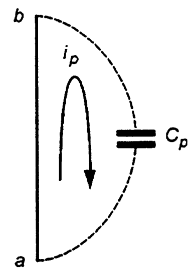
C. Capacitive Coupling

dU/dt > E electric field could couple with a nearby conductor and generate a voltage



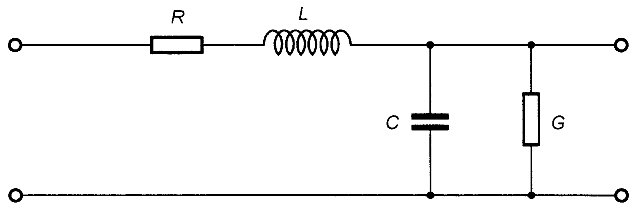
Solutions:

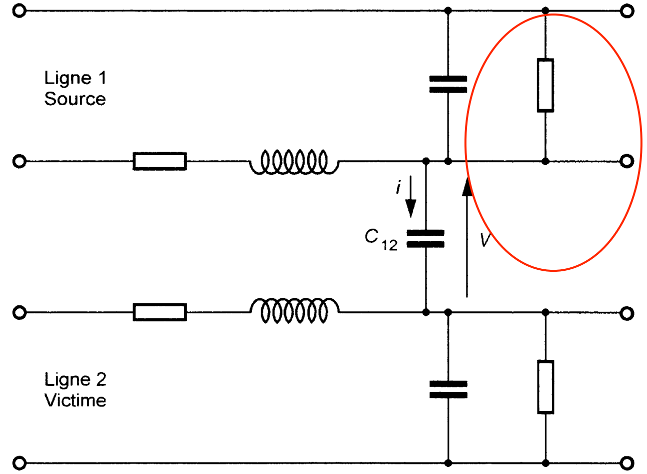
- source: to reduce dU/dt
- coupling: to increase distance



C. Capacitive Coupling

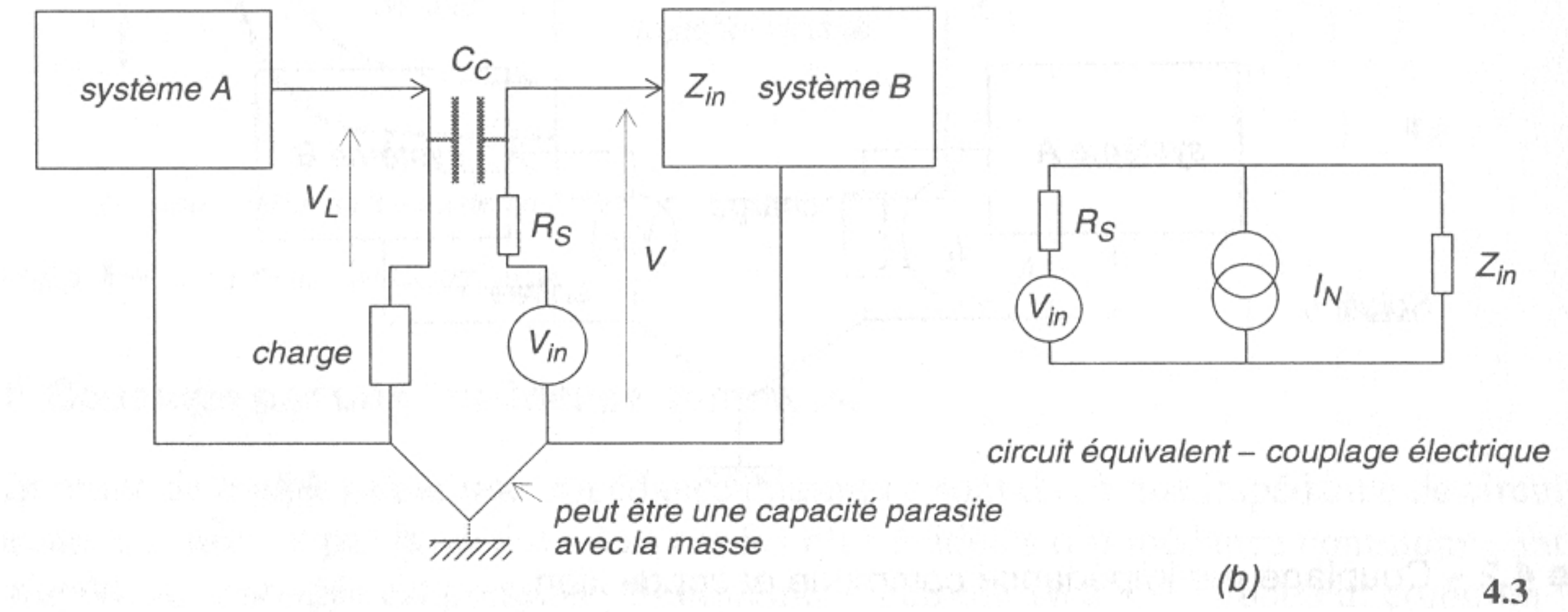
Capacitive diaphony





Coupling modes

C. Capacitive Coupling

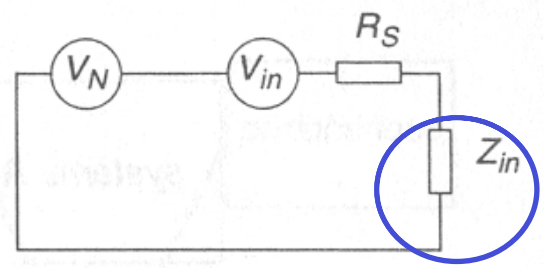


$$V = C_C \times dV_L/dt \times \underbrace{(Z_{in} \,//\, R_S)}_{}$$

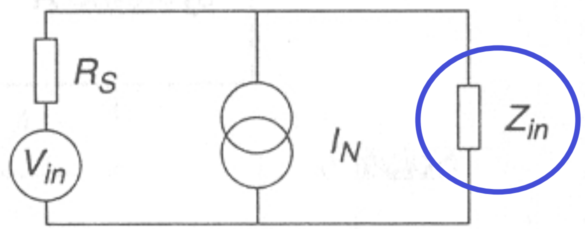
Impedance of victim circuit to ground

Coupling modes

Input impedance?



circuit équivalent – couplage magnétique

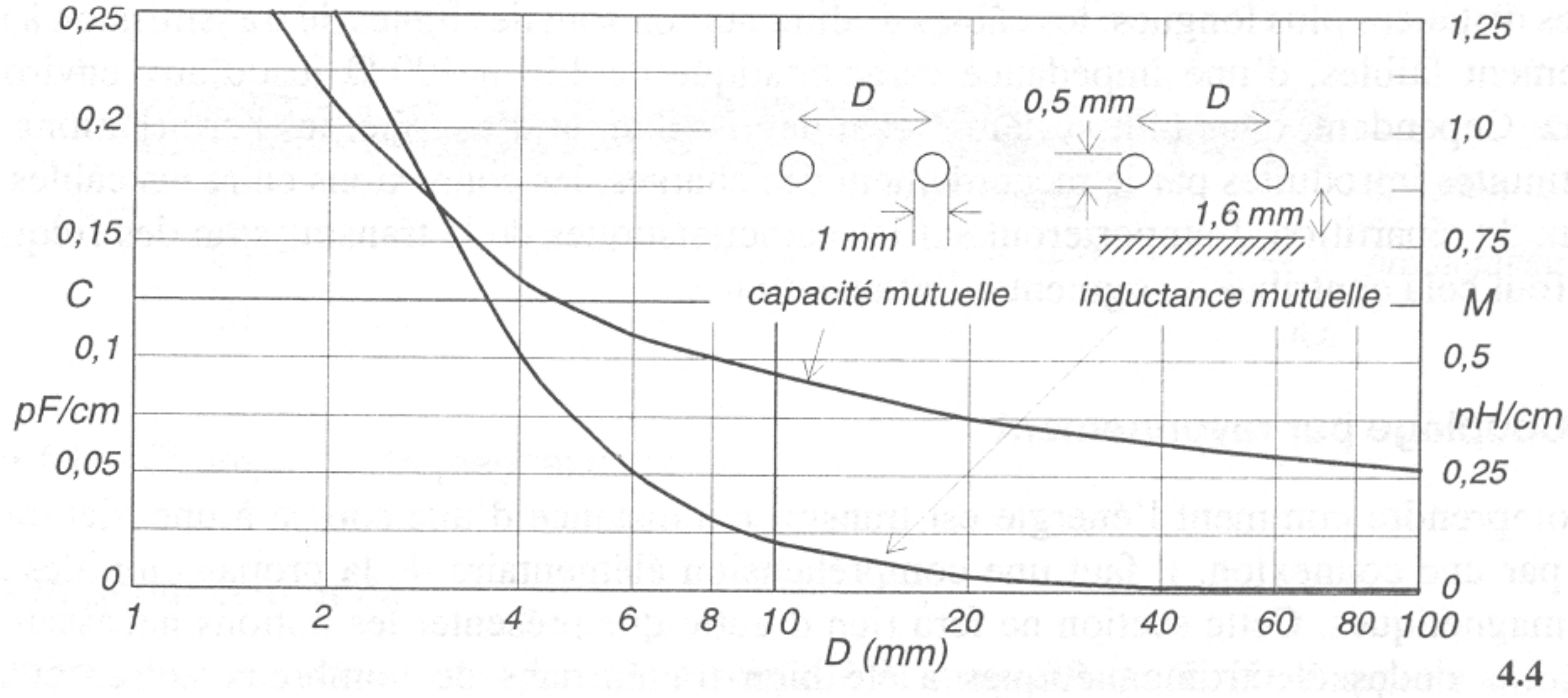


circuit équivalent – couplage électrique

Electric coupling *increases with* Z_{IN} growing whereas magnetic coupling *decreases*.
For the same reason, magnetic coupling is related to circuits with low input impedance as electric coupling to high input impedance.

Coupling modes

Relationship distance - L and C



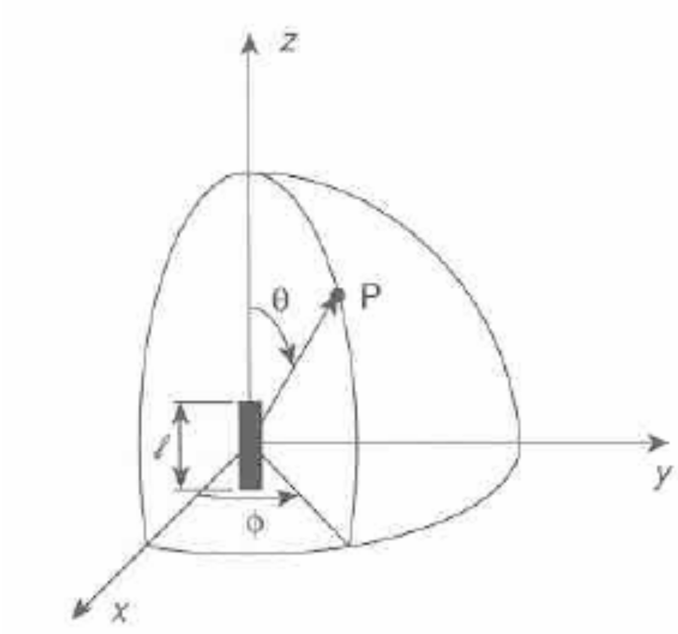
Coupling modes

D. Radiated Coupling

- H-field (field to loop)
- E-field (field to conductor)

D. Radiated Coupling

1. Electromagnetic field of short electric dipole



Conductor length *l* with a current *I*o

l <<< λ of the field

So *I*o is constant on *l*

1. Electromagnetic field of short electric dipole

Electromagnetic fields (in spherical coordinates) is evaluated at an observation point P at a distance *r* from the origin:

$$E_r = \frac{Z_o}{2\pi}\frac{I_o l \cos\theta}{r^2}\left(1+\frac{1}{jkr}\right)\exp(-jkr)$$

$$E_\theta = \frac{jZ_o k}{4\pi}\frac{I_o l \sin\theta}{r}\left(1+\frac{1}{jkr}-\frac{1}{(kr)^2}\right)\exp(-jkr)$$

$$H_\phi = \frac{jk}{4\pi}\frac{I_o l \sin\theta}{r}\left(1+\frac{1}{jkr}\right)\exp(-jkr)$$

où

$$k = 2\pi/\lambda = 2\pi f/c$$

$$Z_o = \sqrt{\mu/\varepsilon}$$

1. Electromagnetic field of short electric dipole

We have to consider 3 cases:

- $r >> \lambda/(2\pi)$ or $kr >> 1$

  far-field

- $r << \lambda/(2\pi)$ or $kr << 1$

  near-field

- $r \approx \lambda/(2\pi)$ or $kr \approx 1$

  intermediate zone

Far-field

For θ=0°, no electromagnetic wave,
consider θ=90° (maximum of radiation):

$$E_r = 0$$

$$E_\theta = \frac{jZ_o k}{4\pi}\frac{I_o l}{r}\exp(-jkr)$$

$$H_\phi = \frac{jk}{4\pi}\frac{I_o l}{r}\exp(-jkr)$$

Caracteristic Impedance

$$Z_w = \left|\frac{E_\theta}{H\phi}\right| = Z_o = \sqrt{\frac{\mu}{\varepsilon}}$$

Dans le vide,

$$Z_o = 120\pi \cong 377\ \Omega$$

1. Electromagnetic field of short electric dipole

Near-field

$$E_r = \frac{Z_o}{2\pi jk}\frac{I_o l\cos\theta}{r^3}\exp(-jkr)$$

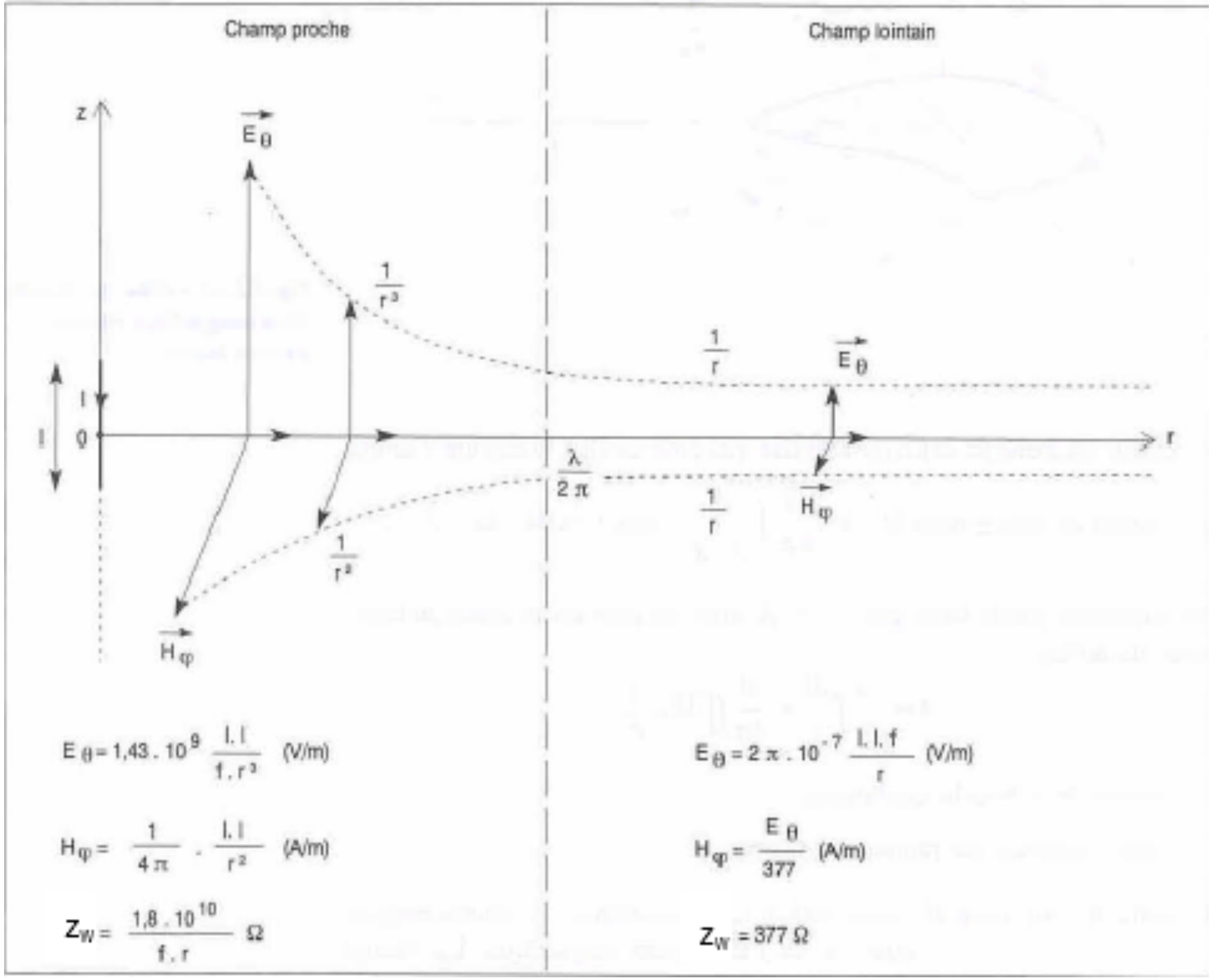
$$E_\theta = -\frac{jZ_o}{4\pi k}\frac{I_o l\sin\theta}{r^3}\exp(-jkr)$$

$$H_\phi = \frac{1}{4\pi}\frac{I_o l\sin\theta}{r^2}\exp(-jkr)$$

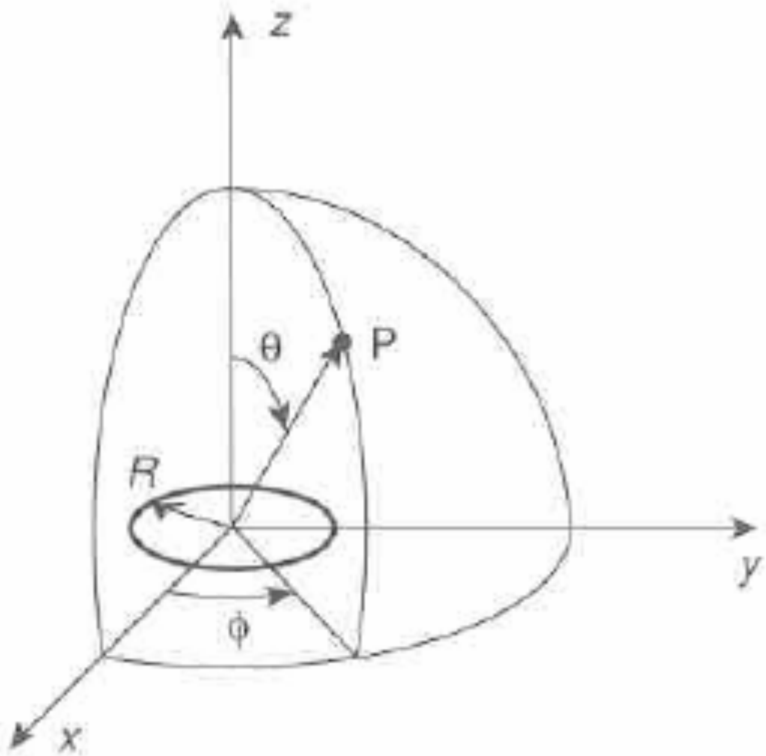
Caracteristic Impedance

$$Z_w = \left|\frac{E_\theta}{H_\phi}\right| = \frac{Z_o}{kr}$$

1. Electromagnetic field of short electric dipole



D. Radiated Coupling
2. Electromagnetic field of magnetic dipole



Consider a loop with *I*o

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2. Electromagnetic field of magnetic dipole

Electromagnetic fields (in spherical coordinates):

$$H_r = \frac{jk}{2\pi}\frac{\pi R^2 I_o \cos\theta}{r^2}\left(1+\frac{1}{jkr}\right)\exp(-jkr)$$

$$H_\theta = \frac{-k^2}{4\pi}\frac{\pi R^2 I_o \sin\theta}{r}\left(1+\frac{1}{jkr}-\frac{1}{(kr)^2}\right)\exp(-jkr)$$

$$E_\phi = \frac{Z_o k^2}{4\pi}\frac{\pi R^2 I_o \sin\theta}{r}\left(1+\frac{1}{jkr}\right)\exp(-jkr)$$

2. Electromagnetic field of magnetic dipole

Far-field ($r >> \lambda/(2\pi)$)

For θ=90°:

$$H_r = 0$$

$$H_\theta = \frac{-k^2}{4\pi}\frac{\pi R^2 I_o}{r}\exp(-jkr)$$

$$E_\phi = \frac{Z_o k^2}{4\pi}\frac{\pi R^2 I_o}{r}\exp(-jkr)$$

Caracteristic Impedance

$$Z_w = \left|\frac{E_\phi}{H_\theta}\right| = Z_o = \sqrt{\frac{\mu}{\varepsilon}}$$

2. Electromagnetic field of magnetic dipole

Near-field ($r << \lambda/(2\pi)$)

$$H_r = \frac{1}{2\pi}\frac{\pi R^2 I_o \cos\theta}{r^3}\exp(-jkr)$$

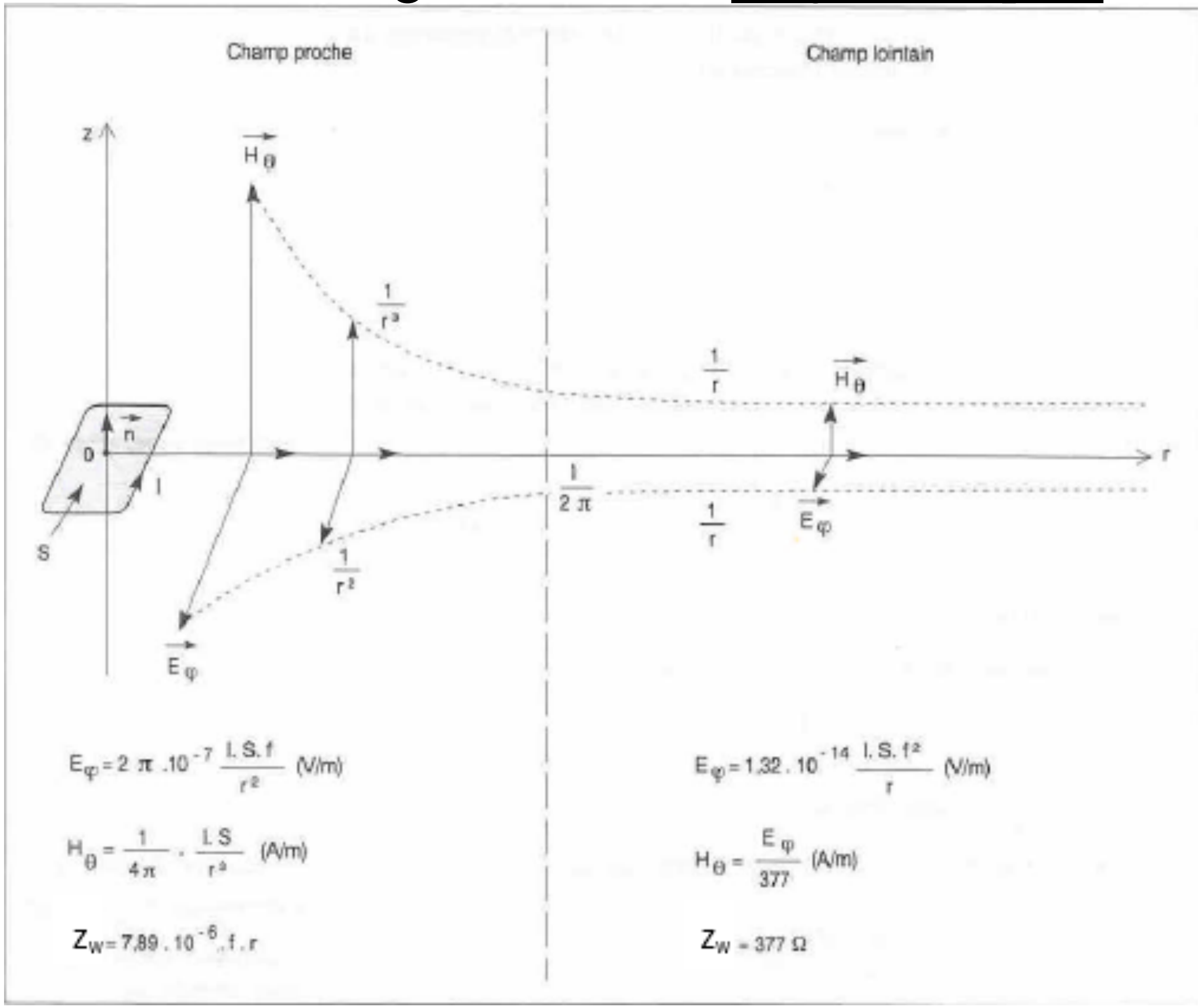
$$H_\theta = \frac{1}{4\pi}\frac{\pi R^2 I_o \sin\theta}{r^3}\exp(-jkr)$$

$$E_\phi = \frac{Z_o k}{4\pi}\frac{\pi R^2 I_o \sin\theta}{r^2}\exp(-jkr)$$

Caracteristic Impedance

$$Z_w = \left|\frac{E_\phi}{H_\theta}\right| = Z_o kr$$

2. Electromagnetic field of magnetic dipole



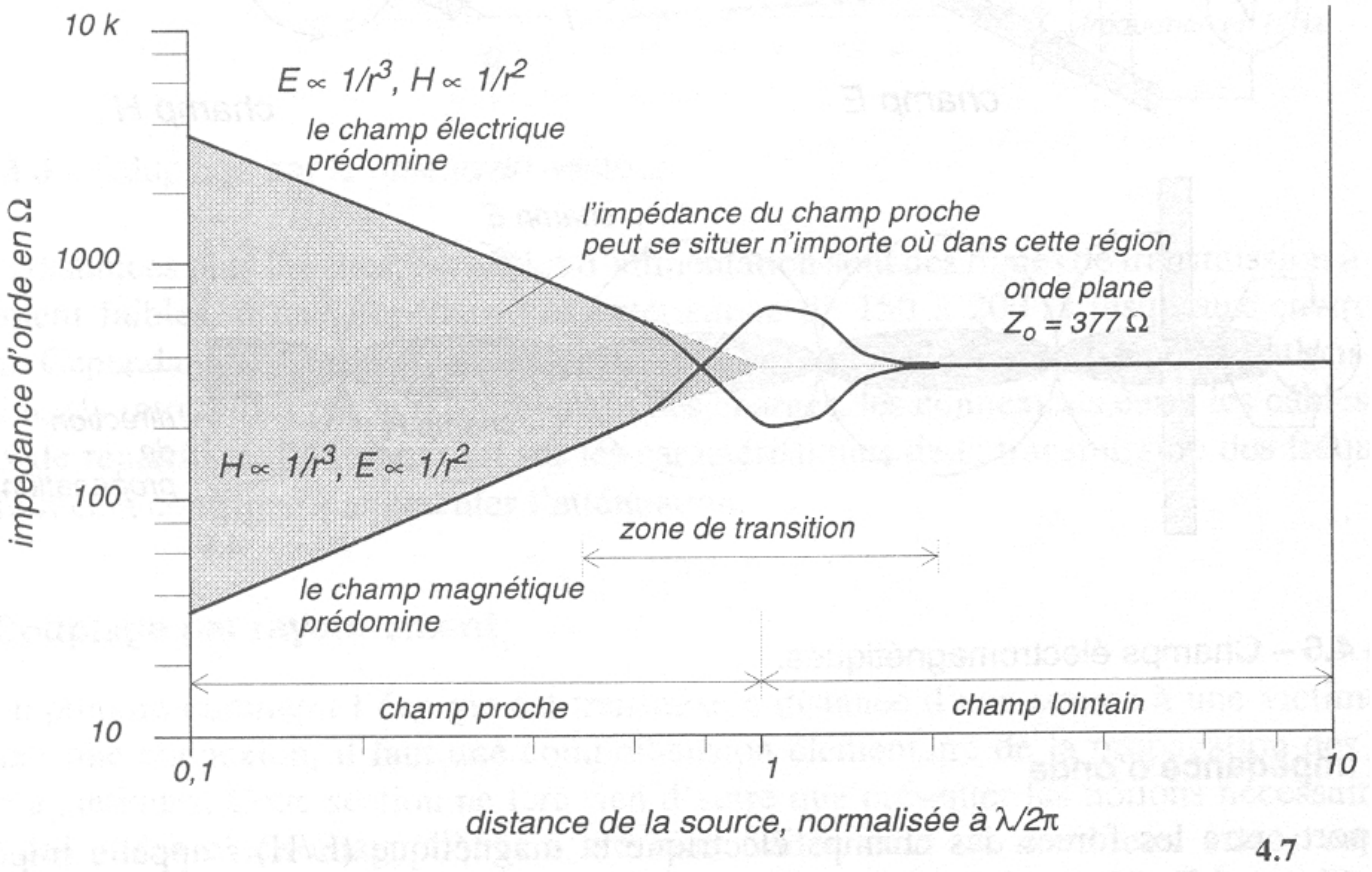
D. Radiated Coupling
Wave impedance of electromagnetic field

E/H is called wave impedance. It is an important parameter as it determines the couplign efficiency ot this wave with a structure, and the efficiency of a shielding structure.

In far-field ($r \gg \lambda/2\pi$), plane wave, E and H are decreasing in the same proportion with distance.
Z is a constant and in air 377Ω.

In near-field ($r \ll \lambda/2\pi$), Z is determined by the characteristics of the source.

D. Radiated Coupling



D. Radiated Coupling
Far-field – near-field

Rayleigh criterion

This criterion is related to the radiating diagram of an antenna, too large to be considered as a ponctual source.
To consider a far-field condition as acceptable, it is needed that the phase shift of the components of the radiated field from the 2 ends of the antenna is small, regarding λ.
We have a criterion related to λ and maximum dimension D of antenna:

$$d > 2D^2/\lambda$$

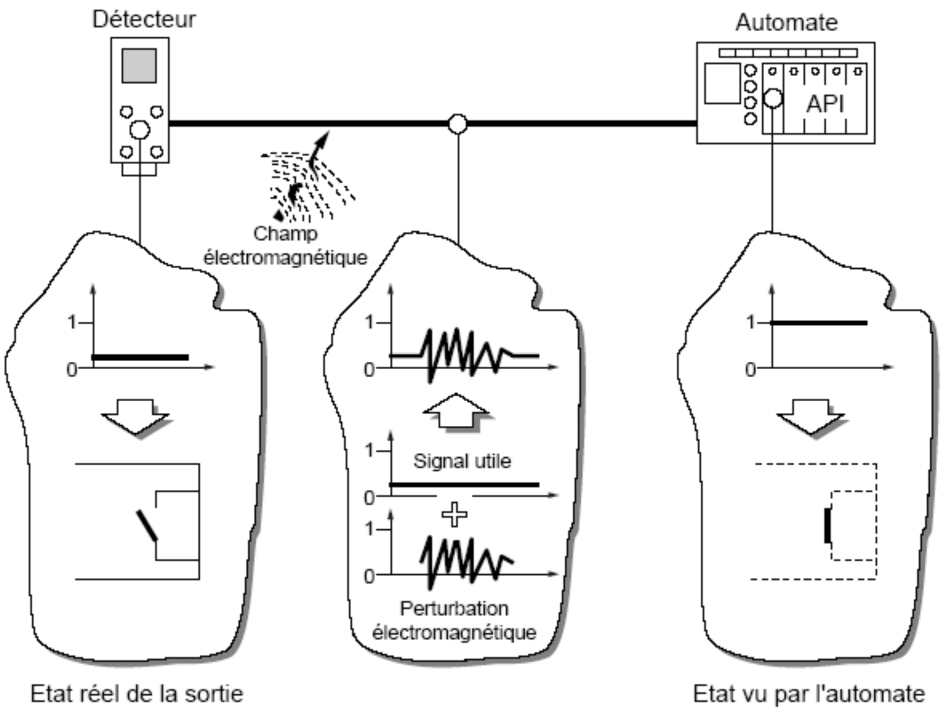
Disturbances and Power Quality

Véronique Beauvois, Ir.

2015-2016

Definition of a disturbance

An electromagnetic phenomenon susceptible to degrade the performances of an apparatus or system.



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Types of disturbances - Classification

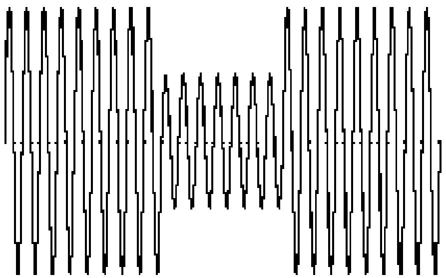
- frequency: L.F. / H.F.
- conducted / radiated
- narrowband / broadband
- duration (t): permanent, repetitive, transient, random
- common mode/differential mode

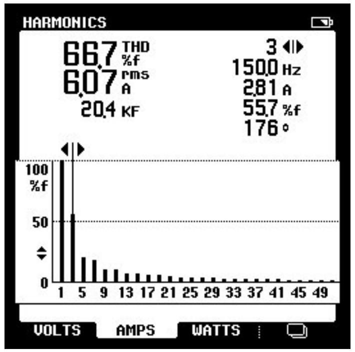
Types of disturbances - Classification

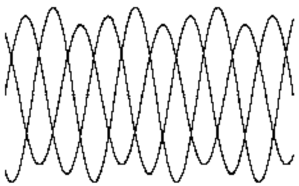
Frequency: L.F. / H.F.

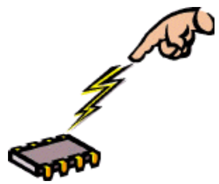
- 0≤f ≤…1 MHz
- conducted

- f > 30MHz
- radiated





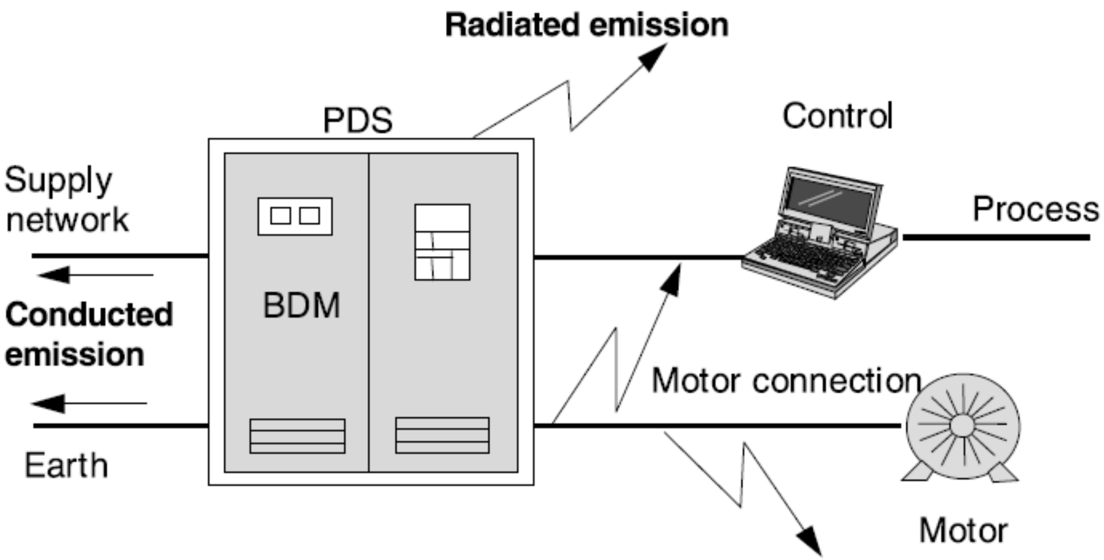




Types of disturbances - Classification

Conducted
Voltage/current

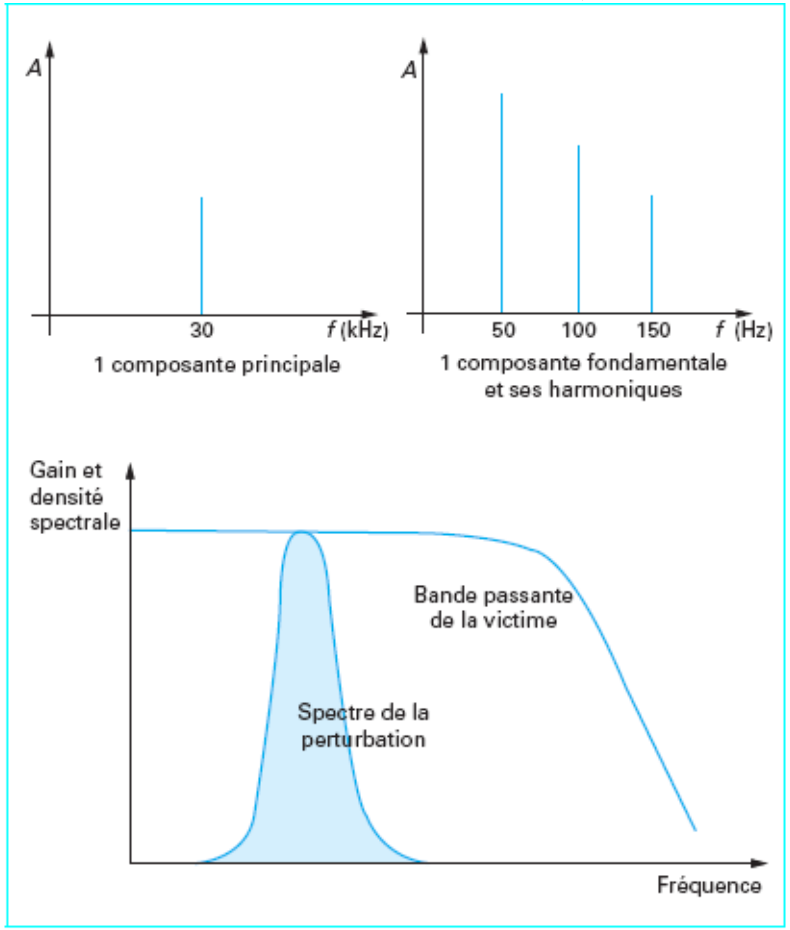
Radiated
Electric/Magnetic fields

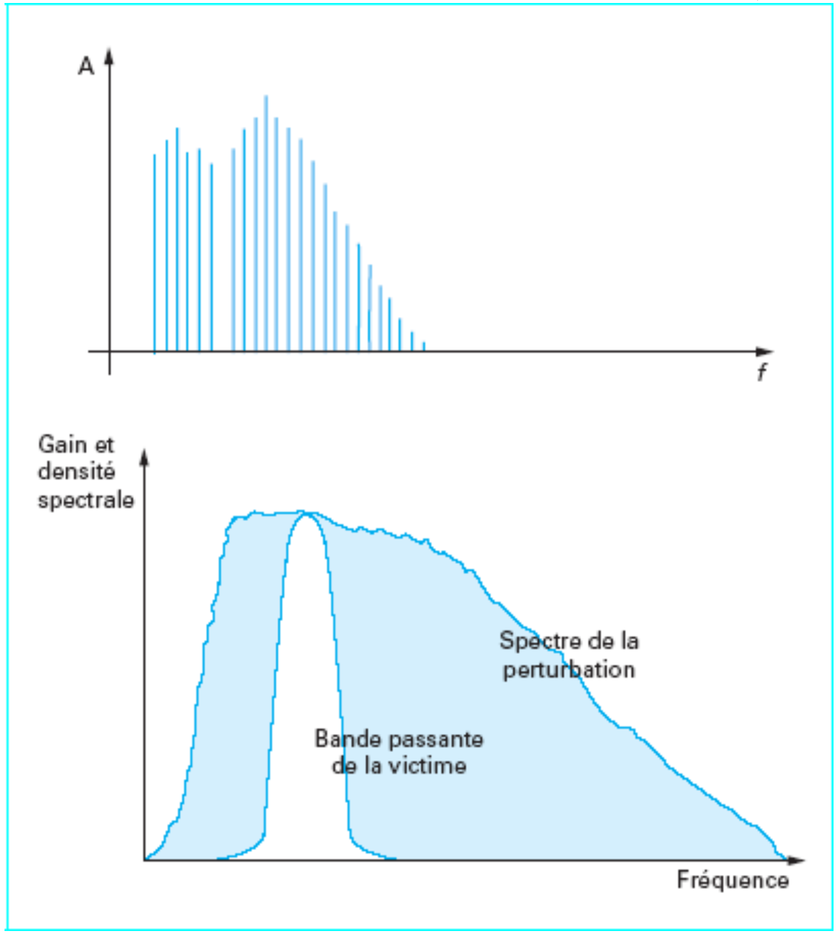


Types of disturbances - Classification

Narrowband (disturbance bandwidth < receiver’s one)

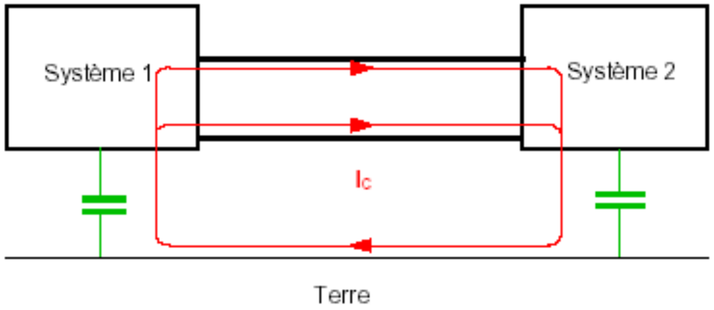
Broadband (disturbance bandwidth > receiver’s one)

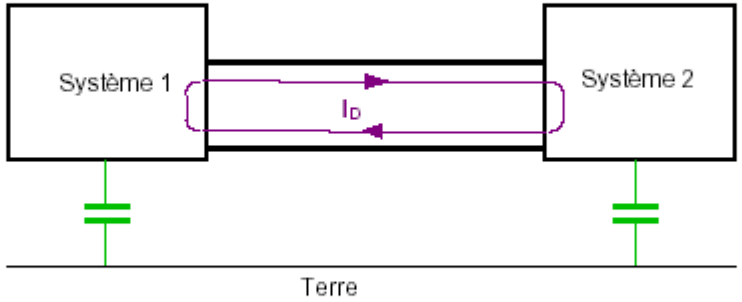




Types of disturbances - Classification

Common Mode – Differential Mode





L.F. & conducted >> Power Quality

3-phase systems

$$v_a(t) = \sqrt{2}V \cos(\omega t + \phi_u)$$

$$v_b(t) = \sqrt{2}V \cos(\omega t + \phi_u - \frac{2\pi}{3})$$

$$= \sqrt{2}V \cos(\omega(t - \frac{T}{3}) + \phi_u)$$

$$v_c(t) = \sqrt{2}V \cos(\omega t + \phi_u - \frac{4\pi}{3})$$

$$= \sqrt{2}V \cos(\omega(t - \frac{2T}{3}) + \phi_u)$$

Parameters?

- frequency (50 Hz)
- amplitude (V)
- waveshape (sinusoidal)
- symetry (phase shift 120°)

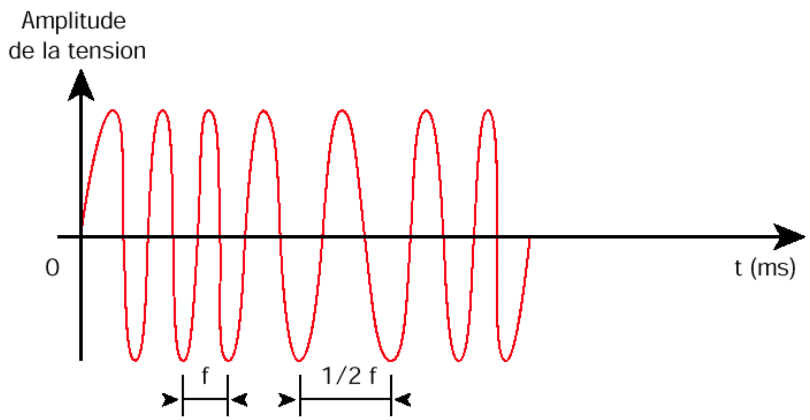
Types of disturbances

1. Frequency – Deviation

Frequency variations are very small (less than 1 %) in the European network (mesh).

Consequently, very few problems for electronic equipement.

In a small isolated network (e.g. island or emergency power system) , the situation is different. Some process need a very precise control of speed and frequency variation could disturb.



2. Amplitude

2.1 Voltage dips and short interruptions

Voltage dips could be related to short-circuit in the network or at the customer premises (defaults, atmospheric problems, …).

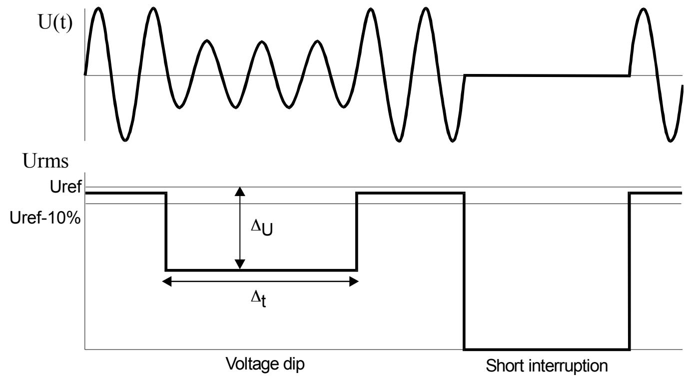
In this case only drop of voltages more than 10 % are considered (otherwise they are voltage fluctuations).

Definition of voltage dip [EN 50160] : quick reduction of power supply at a value between 90 and 1 % of the nominal voltage, followed by a recovering very soon. Duration from 10 ms to 1 min., by definition.

Short interruptions [EN 50160] : reduction of power supply under 1 % of the nominal voltage.

Short : less than 3 minutes.

Consequences : some equipment could stop, if the depth and duration are over certain limits (according to the sensitivity of the load).



2. Amplitude

2.1 Voltage fluctuations / Flicker

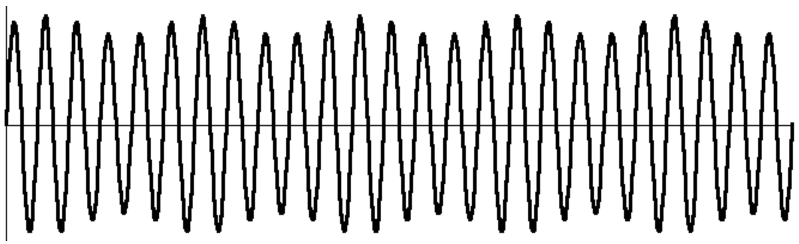
In some installations, quick variations of power (produced or consumed) could be observed (welding, wind turbines, arc furnaces, air conditioning, …). This could lead to voltage variations. Flicker [EN 50160] : visible change in brightness of a lamp due to rapid fluctuations in the voltage of the power supply. The voltage drop is generated over the source impedance of the grid by the changing load current of an equipment (frequent starting of an elevator motor, air conditioning systems, arc furnaces, welding machines, …).

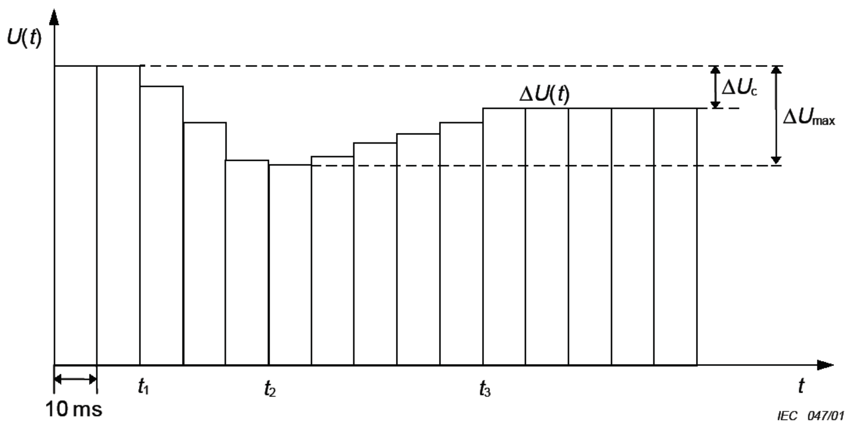
Effects in the band 0.5-25Hz. Major consequences on lamps.

Standards

EN 61000-3-3 (I < 16A)

EN 61000-3-11 (16A < I < 75A)

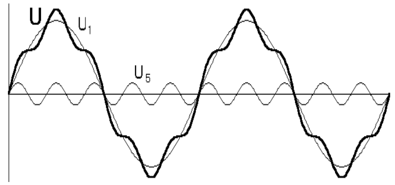




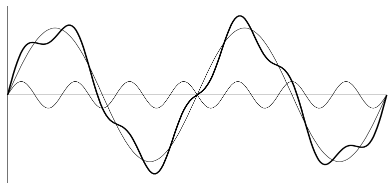
3. Waveshape

3.1 Harmonics / Interharmonics

Harmonics: components of frequencies which are multiple of fundamental (50Hz) and create a distortion of the sinusoidal waveshape.

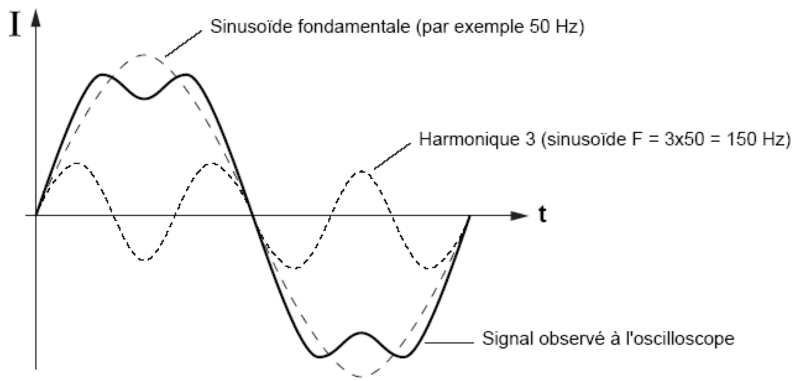


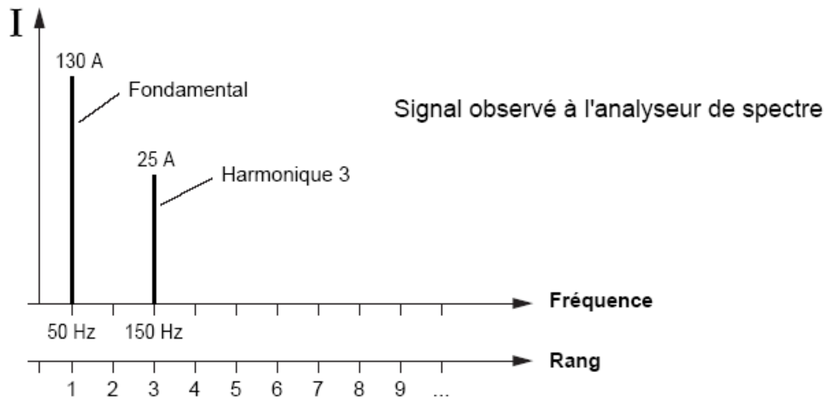
Interharmonics: components which are non integer multiples of fundamentals (very rare, arc furnaces, static frequency converters for low speed applications and cycloconverters, e.g. cement crushers). $K.f_m$ +/- $k.f_o$ (f_m is mains frequency and f_o for output frequency).



Harmonics

We have seen that a periodic signal could be represented by a sum of sinus with different amplitudes and phases, with frequency multiple integer of fundamental (frequency f).
Harmonics.





$$\boxed{f(t) = a_0 + \sum_{n=1}^{N} a_n \sin(n\omega t) + \sum_{n=1}^{N} b_n \cos(n\omega t)}$$

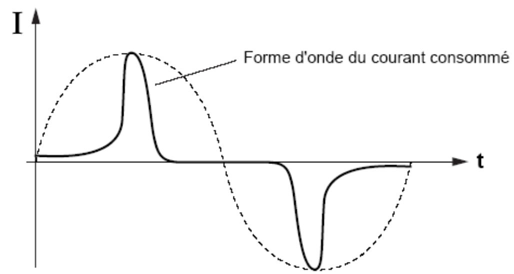
Harmonics

Origin?

All non linear loads are associated with a non sinusoidal current and generates harmonics

Sources?

inverters, choppers, dc-dc converters
• rectifiers
• speed controllers
• frequency converters
• dimmers
• lighting
• Induction heating systems
• Saturated magnetic circuits



Courant consommé par un tube fluorescent

Consequences?

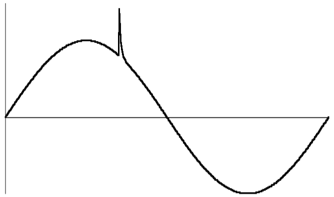
Heating (motors, transformers, cables, …)
Losses (transformers)
Saturation (transformers)
Additional torque components (motors)
Resonance (Q compensation capacitors)
Homopolar compenents (H3)
Defaults (power electronics, IT, relays, controlers, …)
…

Types of disturbances

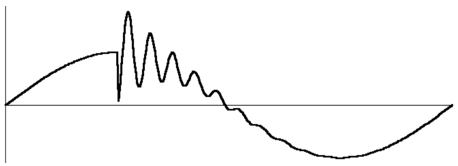
3. Waveshape

3.2 Transient

Overvoltages: related to the release of low voltage apparatus, inductive loads, capacitor banks start (Q compensation) and fuse fusion.



Sinusoidal damped overvoltages: some actions on the medium voltage network as a breaker opening or closing, switches disconnection, … may cause a voltage variation which excites the line with a very short pulse with a short rise time. The consequence is a damped sinus.

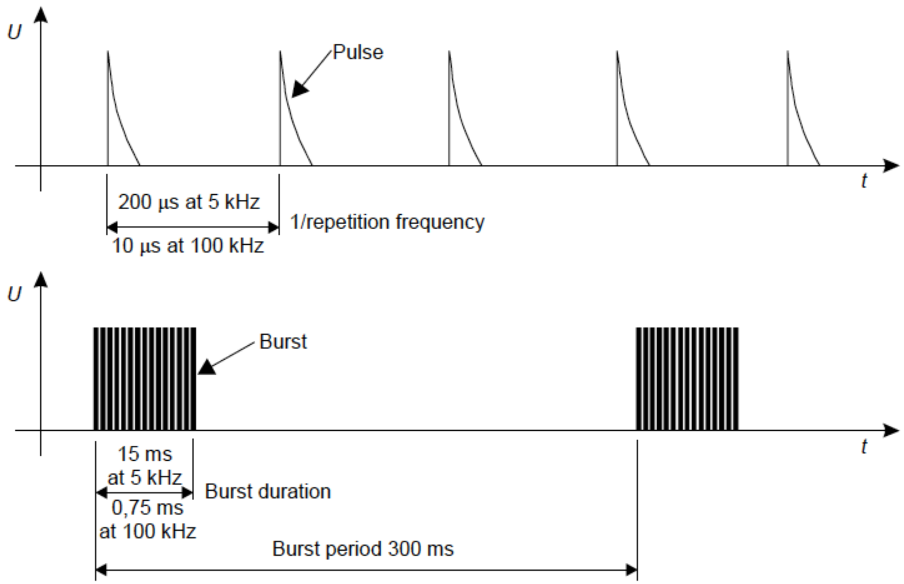


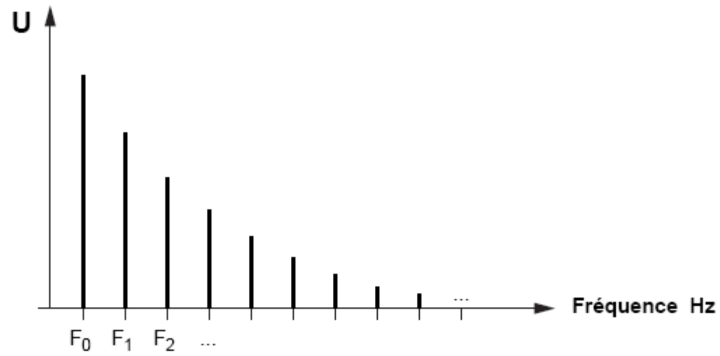
Types of disturbances

3. Waveshape

3.2 Transient

Burst



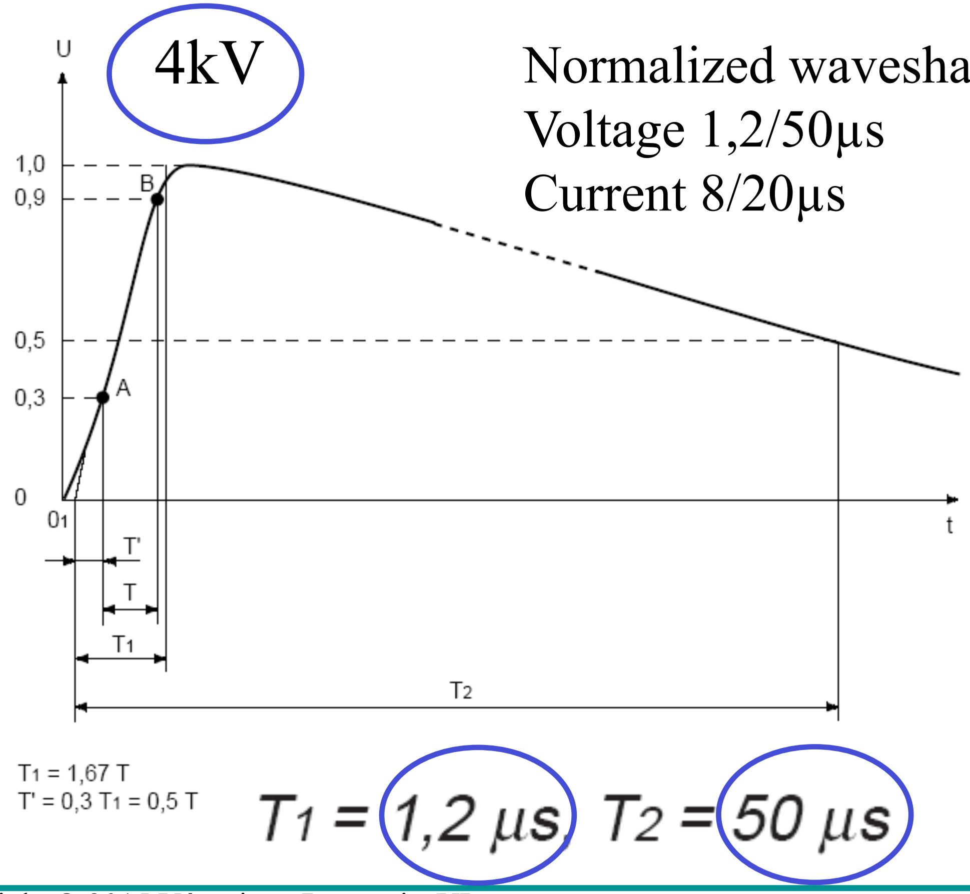


0…200MHz…

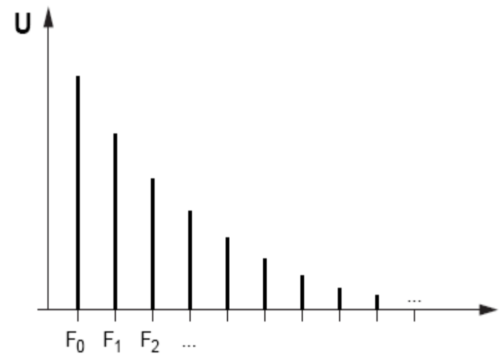
3. Waveshape

3.2 Transient

Surge



Normalized waveshape
Voltage 1,2/50µs
Current 8/20µs



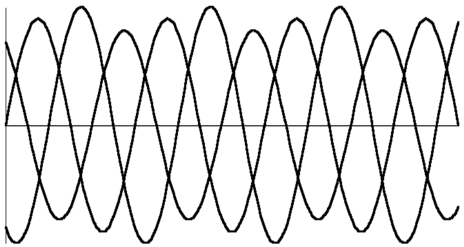
0…100MHz…

4. Symmetry / Unbalance

Dissymmetry in the network are very small.

The main problem is the one-phase loading in a 3-phase network, and the repartition of those loads.

Consequences: additional heating and flickering problems.



Types of disturbances

DEFINITION OF POWER QUALITY (PQ)

Power Quality = Voltage Continuity + Voltage Quality

Voltage Continuity
(Reliability of Supply)
- long interruptions

Voltage Quality

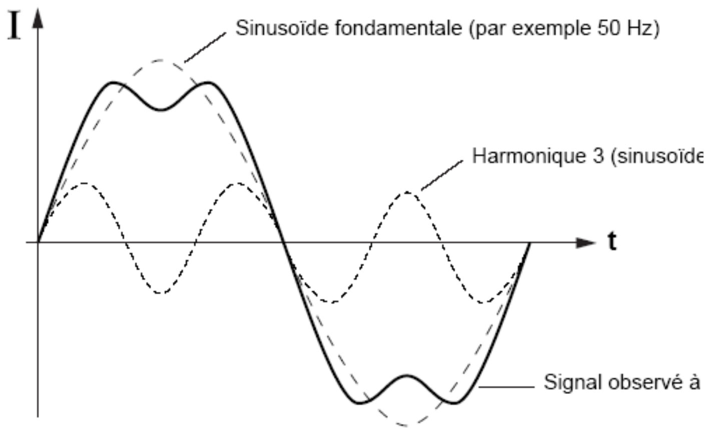
• frequency	- deviations
• magnitude	- deviations
	- dips & short interruptions
	- flicker
• waveform	- (inter)harmonics
• symmetry	- unbalance

Power Quality - Examples

Véronique Beauvois, Ir.
2015-2016

A. Harmonics – Neutral and cables diameter

One of the major effects due to harmonics is the increasing of RMS currents in the mains.



Harmonic 3 in phase

- Sum is not zero
- Sum in neutral : 3 x Iphase
- Heating
- Destruction risk
- Diameter of cabling should be adapted

(same for 3k multiples)

Université de Liège ULg

A. Harmonics – Neutral and cables diameter

	Distorsion rate
I1 225A	
I3 183A	81.3 %
I5 152A	67.6 %
I7 118A	52.4 %

Iph = 348A (1.55 x I1) (RMS of harmonics)

In = 3 x 183A = 549A (2.44 x I1)

Phases: 225A > 70mm² with Hn 150mm² (385A)

Neutral > 35mm² with Hn 300mm² (615A)

Based on R.G.I.E.

B. Eco light

Maximum RMS current and corresponding values in timewindow 1:

Voltage:	230.46 Vrms		THD=0.00 %	THV=0.010 V	POHV=0.007 V	PWHD=0.02 %
Current:	0.053 Arms	0.196 Apk	THD=122.00 %	THC=0.042 A	POHC=0.012 A	PWHD=228.02 %
Power:	6.7 W	P1=6.7 W	12.2 VA			
Powerfactor:	0.551	CosPhi1: 0.925				

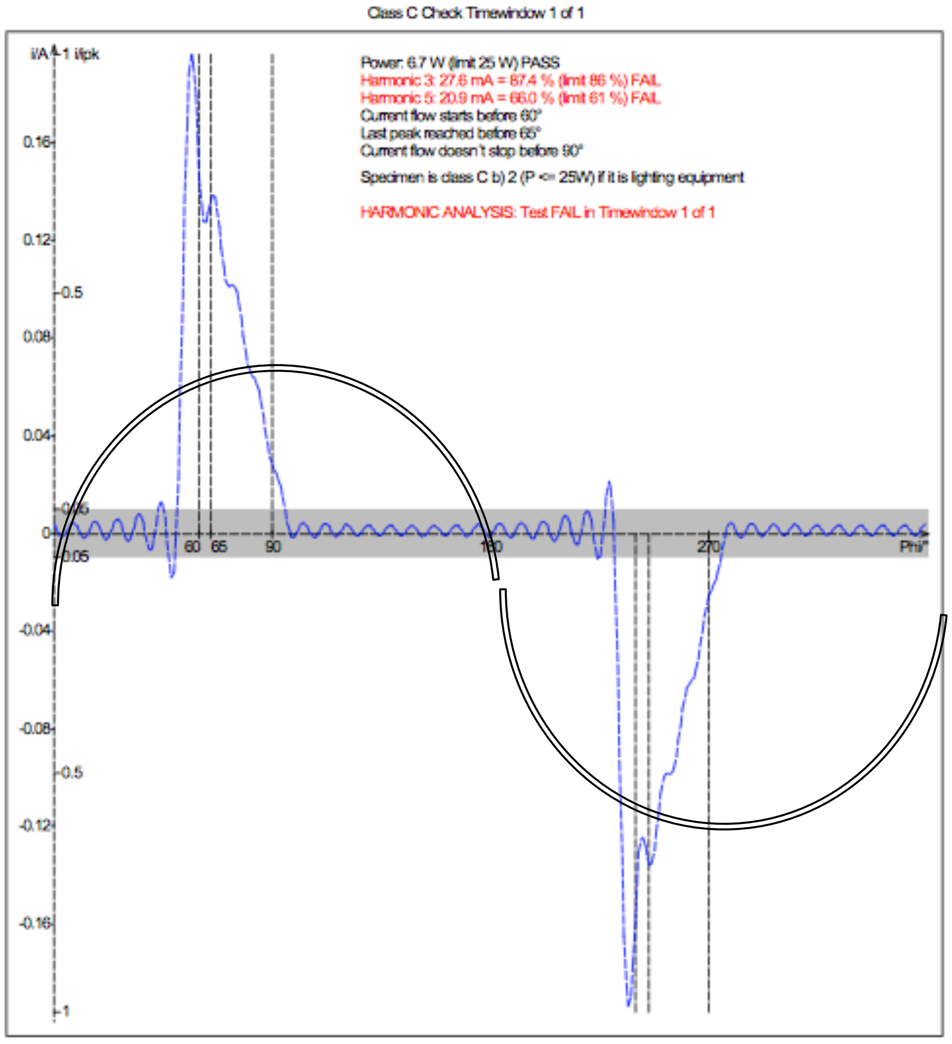
Testconditions: EN 61000-3-2:2006, f=50 Hz, Phase=L1, Range=0.80 A, Rated power: 100 W
Time window cycles=16, Grouping of harmonics=off

HARMONIC ANALYSIS: Test FAIL

Tobs = entire measurement; POHC: avg=0.01 A, limits=0.00 A; Rated power exceeded, changed to 6.73 W

Hn	Entire measurement (0.320 s = 1 time window(s))							Worst 2.5 min		Average		PASS	FAIL
	Maximum	Window	EN61000-3-2 Class C b) 1	Margin in MaxWin	100 to 150%	150 to 200%	Ex-ceeded	100 to 150%	Ex-ceeded	Value	Ex-ceeded		
DC	0.0013 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0013 A	0	X	
1	0.0316 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0316 A	0	X	
2	0.0001 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0001 A	0	X	
3	0.0276 A	1	0.0229 A	20.6 %	1	0	0	n.e.	n.e.	0.0276 A	1		X
4	0.0001 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0001 A	0	X	
5	0.0209 A	1	0.0128 A	63.0 %	0	1	1	n.e.	n.e.	0.0209 A	1		X
6	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	
7	0.0135 A	1	0.0067 A	100.5 %	0	0	1	n.e.	n.e.	0.0135 A	1		X
8	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	
9	0.0082 A	1	0.0034 A	144.1 %	0	0	1	n.e.	n.e.	0.0082 A	1		X
10	0.0001 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0001 A	0	X	
11	0.0068 A	1	0.0024 A	189.8 %	0	0	1	n.e.	n.e.	0.0068 A	1		X
12	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	
13	0.0069 A	1	0.0020 A	244.3 %	0	0	1	n.e.	n.e.	0.0069 A	1		X
14	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	
15	0.0061 A	1	0.0017 A	252.7 %	0	0	1	n.e.	n.e.	0.0061 A	1		X
16	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	
17	0.0050 A	1	0.0015 A	226.0 %	0	0	0	n.e.	n.e.	0.0050 A	0	X	
18	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	
19	0.0045 A	1	0.0014 A	231.6 %	0	0	0	n.e.	n.e.	0.0045 A	0	X	
20	0.0000 A	1	-.----	---.-	0	0	0	n.e.	n.e.	0.0000 A	0	X	

B. Eco light


Class C Check Timewindow 1 of 1
Power: 6.7 W (limit 25 W) PASS
Harmonic 3: 27.6 mA = 87.4 % (limit 86 %) FAIL
Harmonic 5: 20.9 mA = 66.0 % (limit 61 %) FAIL
Current flow starts before 60°
Last peak reached before 65°
Current flow doesn't stop before 90°
Specimen is class C b) 2 (P <= 25W) if it is lighting equipment
HARMONIC ANALYSIS: Test FAIL in Timewindow 1 of 1
i/A
1 i/ipk
0.16
0.12
0.08
0.04
0
-0.04
-0.08
-0.12
-0.16
0.5
0.05
-0.05
-0.5
-1
60
65
90
180
270
Phi°

C. LED

Name:	*PBE	Serial no:	
Department:	Laboratoire CEM	Operating modes:	EUT ON
Company:	Université de Liège - ACE	Comment1:	dimming
Test report no:	07	Comment2:	
Device:	0055	Comment3:	--
Specimen:	B	Comment4:	--
Manufacturer:	AAAN	Date:	05.03.2010
Type:		Test date:	05.03.2010

Maximum RMS current and corresponding values in timewindow 1:

Voltage:	230.44 Vrms		THD=0.01 %	THV=0.012 V	POHV=0.003 V	PWHD=0.01 %
Current:	0.066 Arms	0.121 Apk	THD=28.43 %	THC=0.018 A	POHC=0.002 A	PWHD=28.37 %
Power:	5.4 W	P1=5.4 W	15.2 VA			
Powerfactor:	0.354	CosPhi1: 0.371				

Testconditions: EN 61000-3-2:2006, f=50 Hz, Phase=L1, Range=0.80 A, Rated fundamental / pf: 3.0 A, 1.0
Time window cycles=16, Grouping of harmonics=off

HARMONIC ANALYSIS: Test FAIL

Tobs = entire measurement; POHC: avg=0.00 A, limits=0.01 A; Rated I1/Pf exceeded, changed to 0.06 A/0.354

Ha	Entire measurement (0.320 s = 1 time window(s))							Worst 2.5 min		Average		PASS	FAIL
	Maximum	Window	EN61000-3-2 Class C a)	Margin in MaxWin	100 to 150%	150 to 200%	Ex-ceeded	100 to 150%	Ex-ceeded	Value	Ex-ceeded		
DC	0.0071 A	1	-,- - - -	- - - , -	0	0	0	n.e.	n.e.	0.0071 A	0	X	
1	0.0631 A	1	-,- - - -	- - - , -	0	0	0	n.e.	n.e.	0.0631 A	0	X	
2	0.0113 A	1	0.0013 A	796.2 %	0	0	1	n.e.	n.e.	0.0113 A	1		X
3	0.0102 A	1	0.0067 A	51.4 %	0	1	1	n.e.	n.e.	0.0102 A	1		X
4	0.0060 A	1	-,- - - -	- - - , -	0	0	0	n.e.	n.e.	0.0060 A	0	X	
5	0.0031 A	1	0.0063 A	-51.0 %	0	0	0	n.e.	n.e.	0.0031 A	0	X	
6	0.0024 A	1	-,- - - -	- - - , -	0	0	0	n.e.	n.e.	0.0024 A	0	X	
7	0.0025 A	1	0.0044 A	-43.3 %	0	0	0	n.e.	n.e.	0.0025 A	0	X	

D. Generators – Renewable Energy

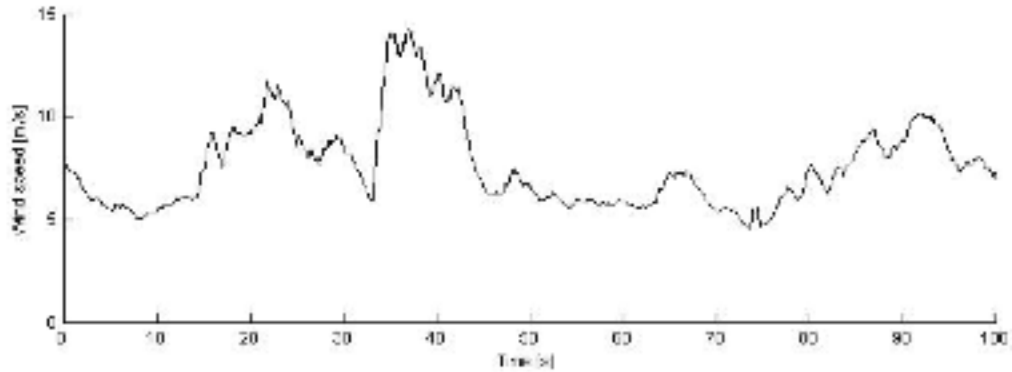


Figure 4. Wind speed series

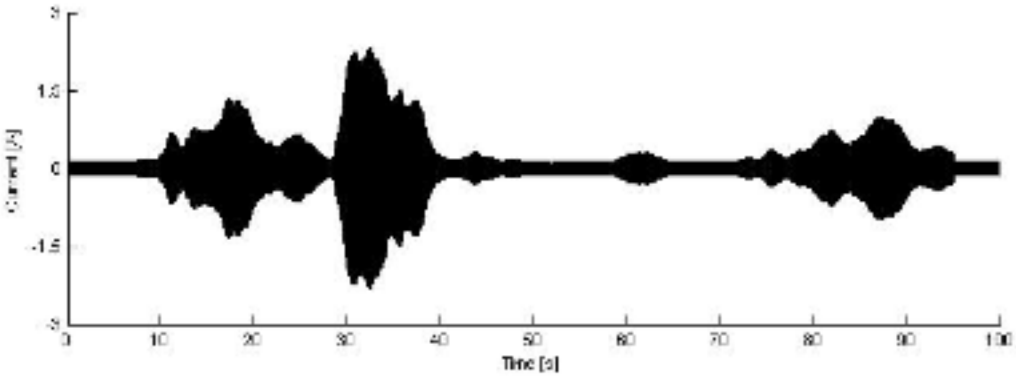


Figure 5. Disturbing current