FROM RESEARCH TO INDUSTRY

cea tech

Utilisation de la réflectométrie pour fiabiliser les câbles d'un système

Contact :

CEA LIST

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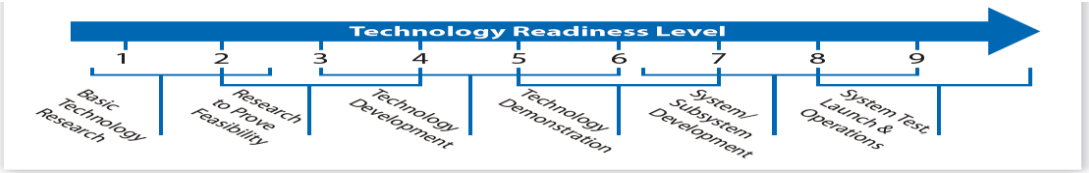
CEA experience in cable diagnosis

- Our Laboratory :

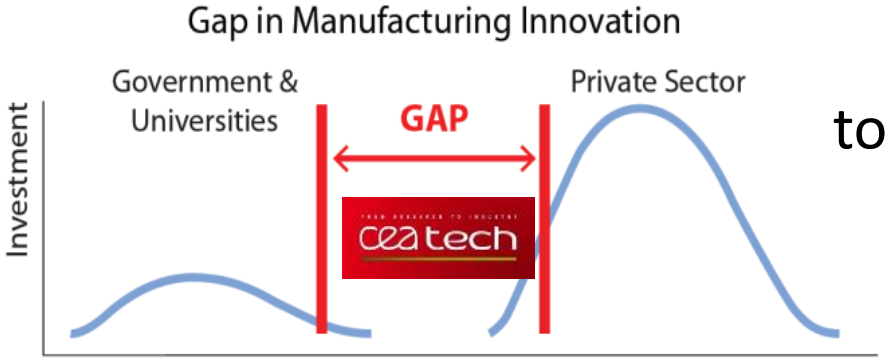
LFIC : Laboratoire Fiabilité et Capteurs Intégrés

More than 10 years experience and knowledge in network cable diagnosis

- CEA policy :



Source: AMP Steering Committee



To create breakthrought
to take advantage and to create new jobs
by industrial transfer
for French companies

Ubiquitous wired network

Modern Car

Civil plane

Naval

Fighter

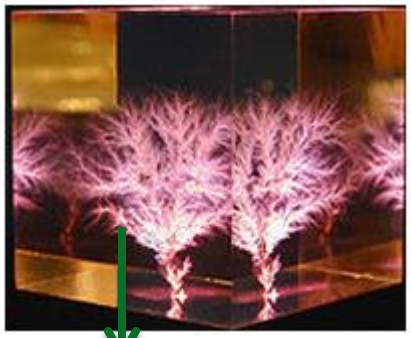
Railway

FPSO

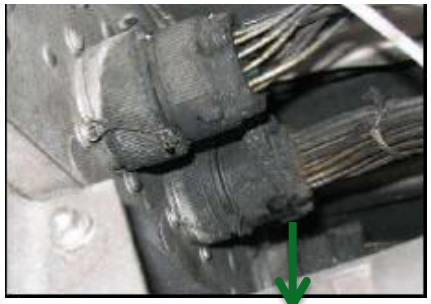
(Floating Production, Storage and Offloading unit)

Some wire defects : NPP

Humidité



Isolation : Electrical Tree

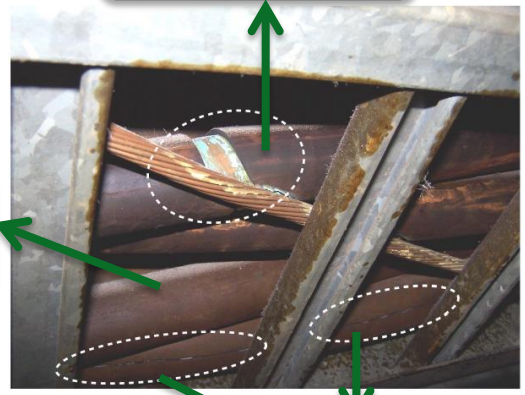


Conducteur et Contacts: Corrosion

Température

Exposition des couches intérieures

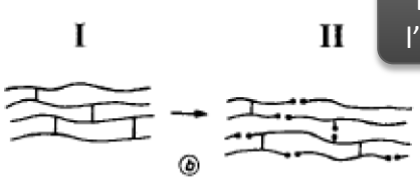
Changement de couleur et durcissement



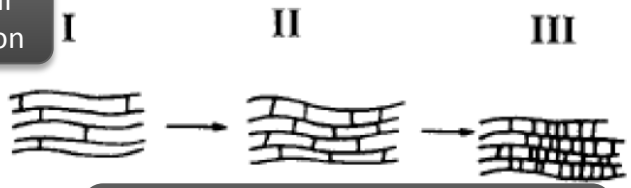
Fentes dans l'isolation

Radiation

Effet sur l'isolation



Rupture de Liaisons
➔ Radicaux Libres

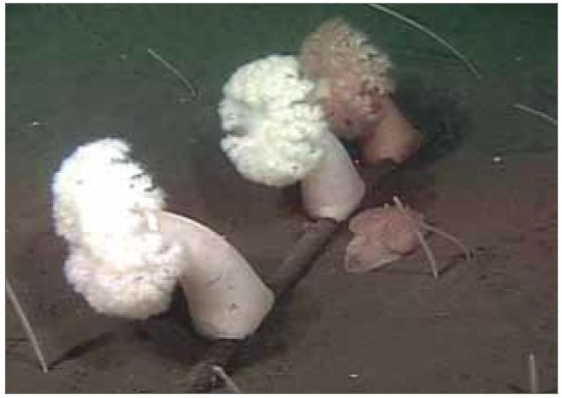


Liaison des radicaux libre
➔ Changement des propriétés du matériel

Some wire defects : Underwater

Développement d'organismes vivants

Développement d'anèmones



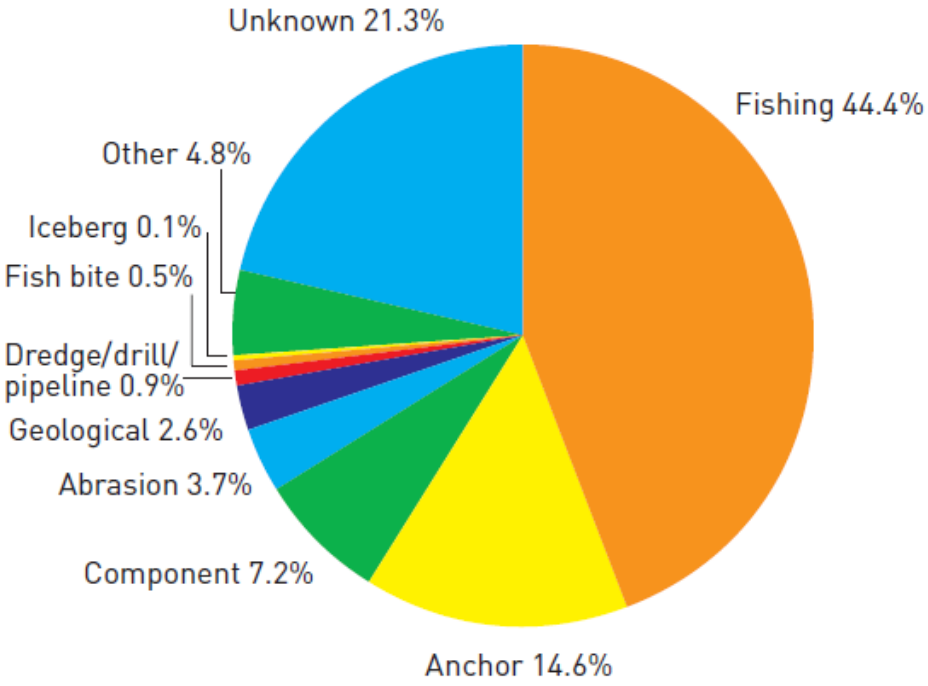
Grappin de bateau de pèche

Frottement contre des roches

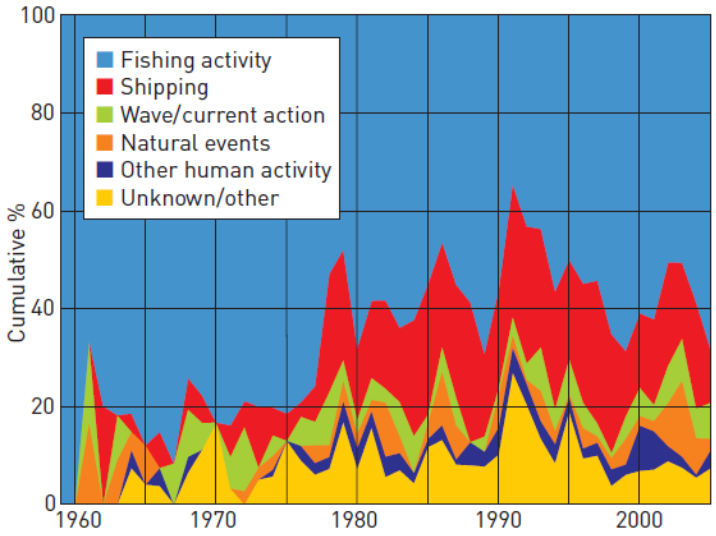
Ancres

Main causes of degradation on electrical wire : Submarine

- Around more than 100 detected failure for the submarine wire



Proportion des causes de défaut entre 1959 et 2006 sur 2162 entrées (Tyco Telecommunications Inc)

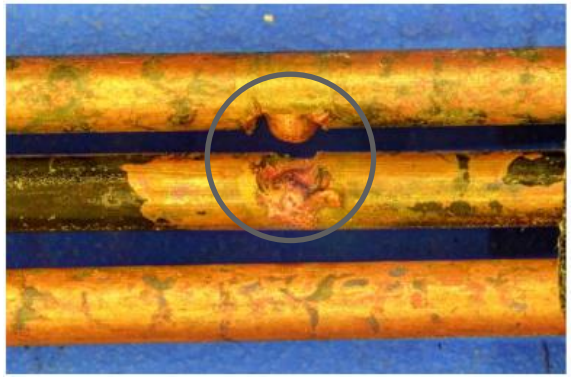


Causes des défauts jusqu'à 200m de profondeur par an (Wood and Carter - IEEE 2008)

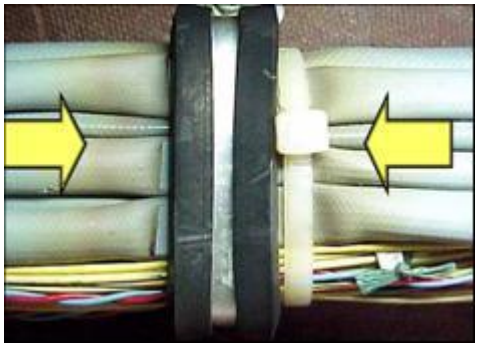
Some wire defects : aeronautic

Frottement

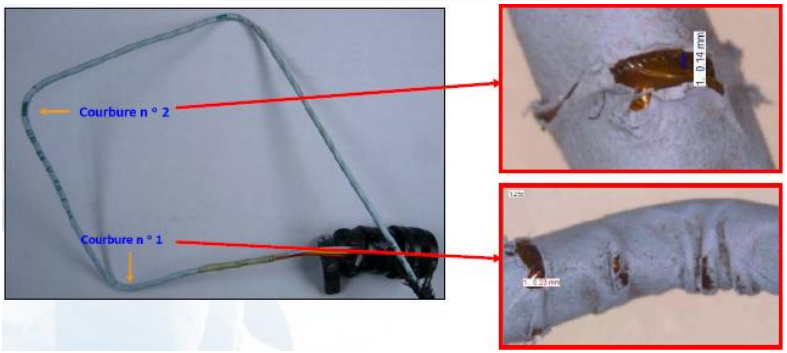
Arc Electrique



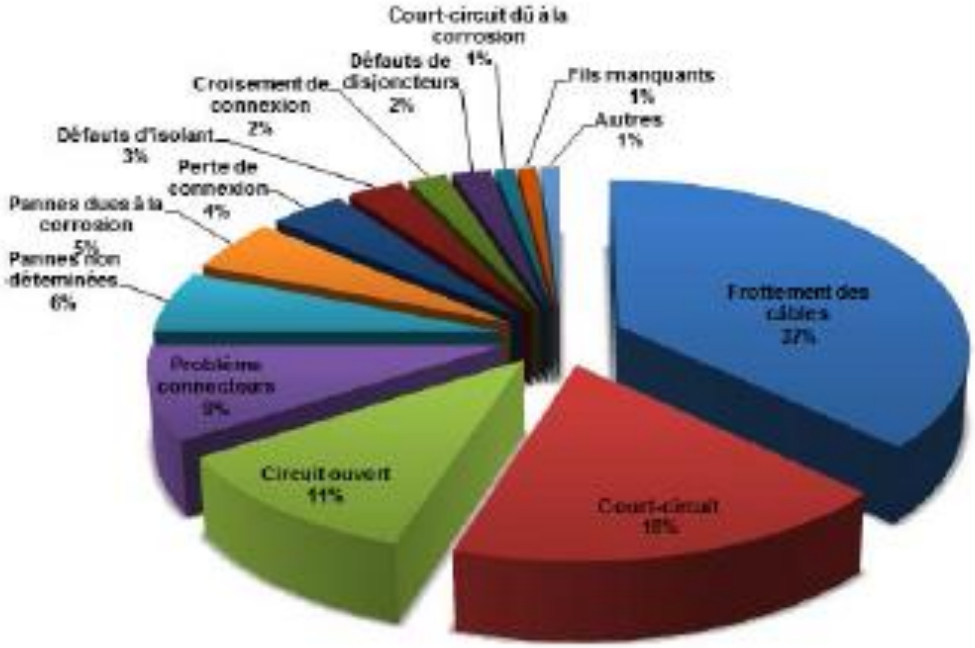
Ecrasement



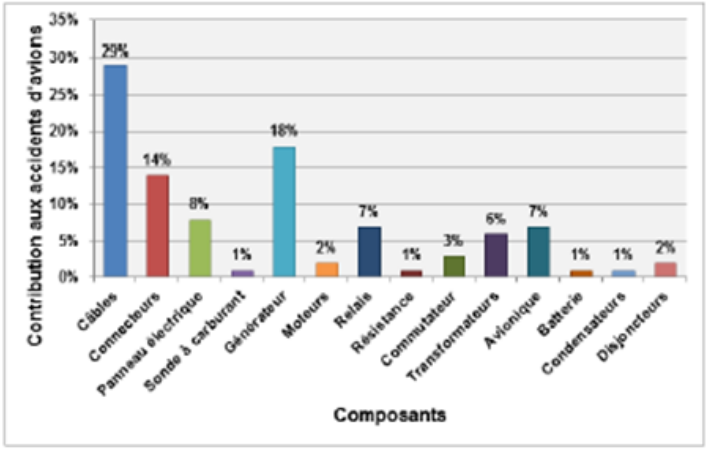
Rayon de courbure



Main causes of degradation on electrical wire : Aeronautics



K. R. Wheeler, D. A. Timucin, I. X. Twombly, K. F. Goebel, and P. F. Wysocki. Aging Aircraft Wiring Fault Detection Survey. Technical Report V.1.0, NASA Ames Research Center, Moffett Field CA 94035, June 2007.



G. Slensky. Aircraft Wiring System Integrity Initiatives. Technical report, Air Force Research Laboratory, AFRL/MLSA WPAFB, OH 45433.

⇒ With open circuit or short circuit, the system are out of order

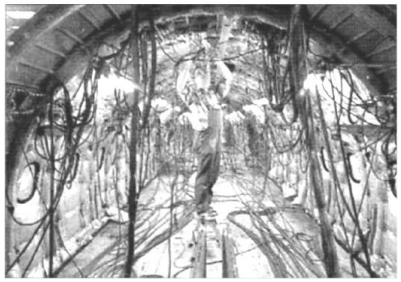
⇒ Chafing defect more important than open or short circuit in ratio.

⇒ With time, Chafing transforms the defect in open or short circuit

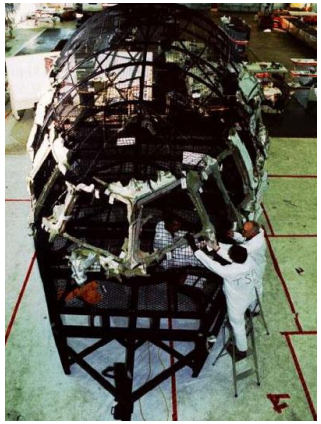
⇒ Wires with its connectors are the main cause of accident

Some consequences about wire failures

- A plane staying on the ground cost $150.000 by hour (Boeing)



- TGV delay cost around 750€ by minute (SNCF)



- Swissair flight 111

  Fire on board made by short-circuit in electrical wires

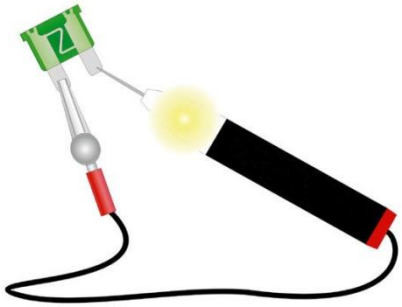
- TWA fligth 800

  Explosion made by short-circuit near fuel tank

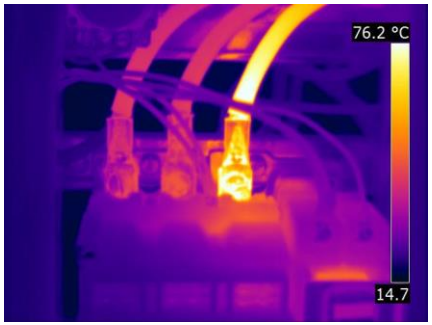
How to ?

- Visual control
  - Long, tedious
  - Human error

- Continuity test
  - Straightforward tool
  - No localization



- Thermography
  - Too slow
  - Open circuit not cover



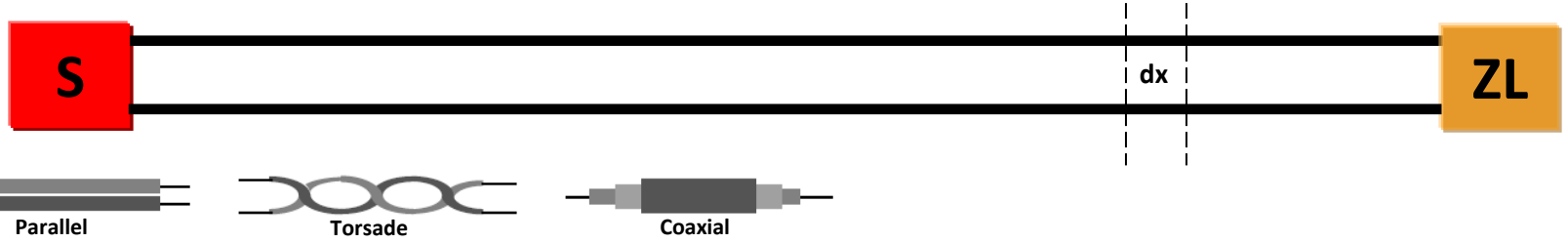
- Reflectometry
  - Cost
  - Real time
  - Easy to operate and to integrate

Reflectometry : Principle

- Like a radar!
- Injection of a probe signal in a wire
  - Probe signal propagation
  - Each wire strangeness leads a reflection of a part of the probe signal energy
- … the reflected signal is analyzed
  - An echo occurs for each wire strangeness
  - Possible defect information is given by the echo shape
- A defect “flight time” could be obtain
  - Corresponding to the defect localization (distance)
  - The propagation speed estimation is a key parameter

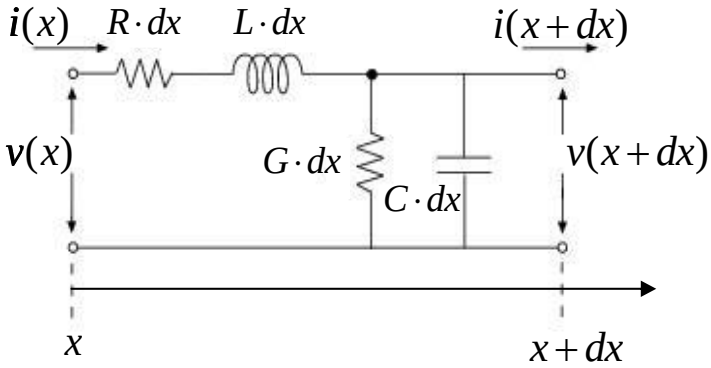
Reflectometry : Principle

- The reflectometry principle is related to the signal propagation mechanism into a transmission line (TL)



➢ **Modeling and characterization of a TL**

- ➢ R, L, C, G Model
- ➢ based on Telegrapher's equations
- ➢ to figure out how a signal is propagated into a TL
- ➢ we have to look signal distortion phenomenon
  - ➢ Attenuation and dispersion

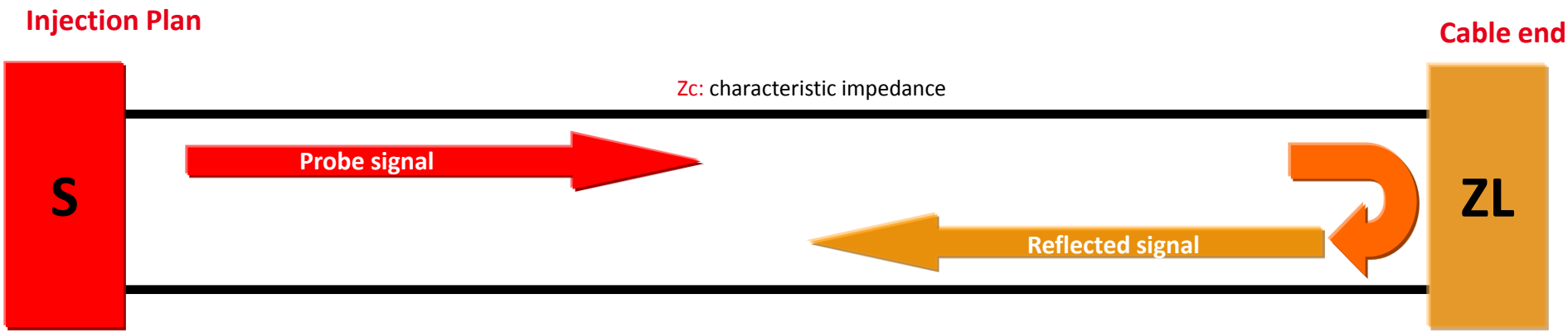


Telegrapher's equations

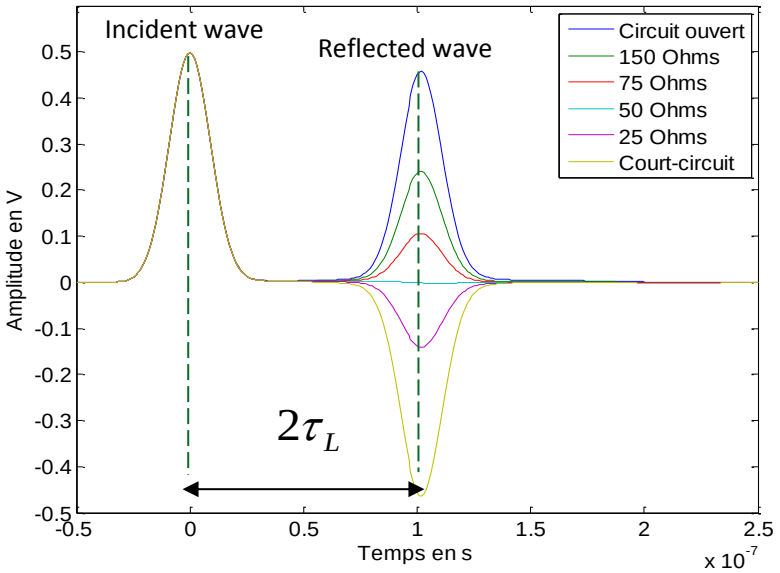
$$\frac{\partial^2 v(x,t)}{\partial x^2} = LC \cdot \frac{\partial^2 v(x,t)}{\partial t^2} + (LG + RC) \cdot \frac{\partial v(x,t)}{\partial t} + RG \cdot v(x,t)$$

$$Z_c = \sqrt{\frac{R + jL\omega}{G + jC\omega}} \qquad V_g = \frac{1}{\sqrt{LC}}$$

Reflectometry : Principle



TDR Reflectograms



→ **Probe signal travelling along a line and returning with a delay equivalent to two times the defect distance**

$$d = \frac{2\tau_L \cdot v_g}{2}$$

→ **Defect (ZL) localization and characterization are obtained directly from the reflectograms analysis in the time domain**

Reflectometry : Principle

Particular cases:

- ZL = ∞ : ΓL =+1, open circuit – The amplitude of the reflected signal is similar to the probe signal one
- ZL = 0 : ΓL = -1, short circuit – The amplitude of the reflected signal is the opposite of the probe signal
- ZL = Zc : ΓL = 0, no reflexion – The line is suitable

$$\Gamma_L = \frac{Z_L - Z_c}{Z_L + Z_c}$$

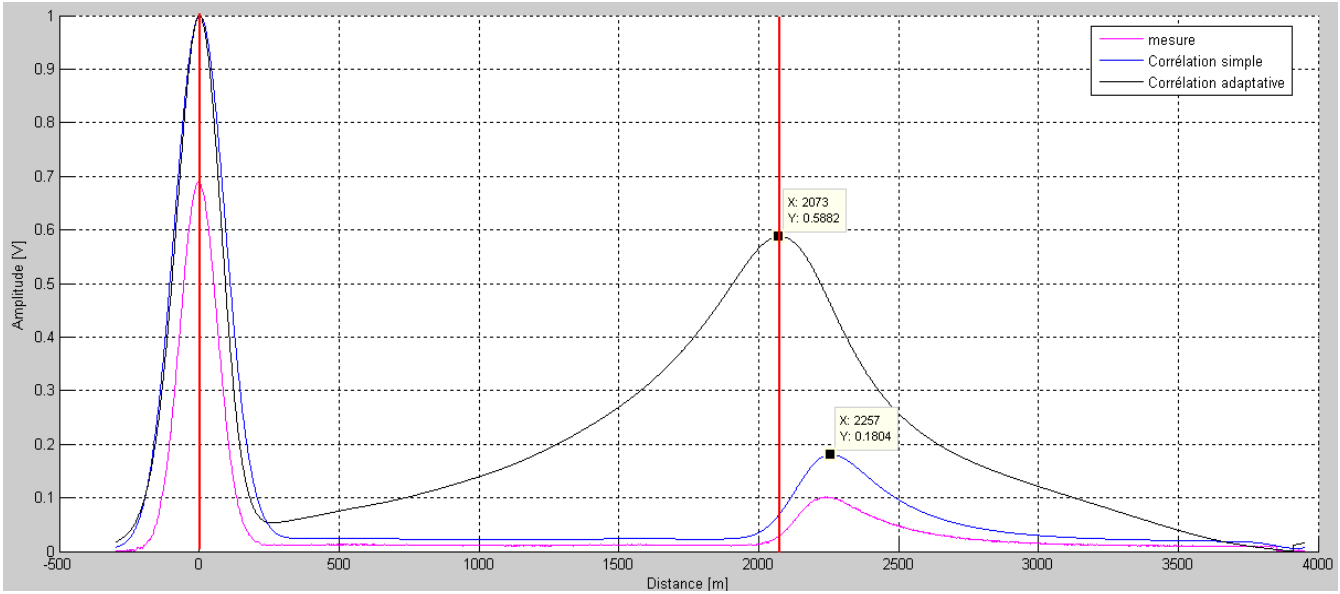
CEA Breakthrought

Some new technologies developed

Long distance

- Adaptive correlation for performance enhancement :
  - Sensitivity

Railway signalization cable , reel length : 2km



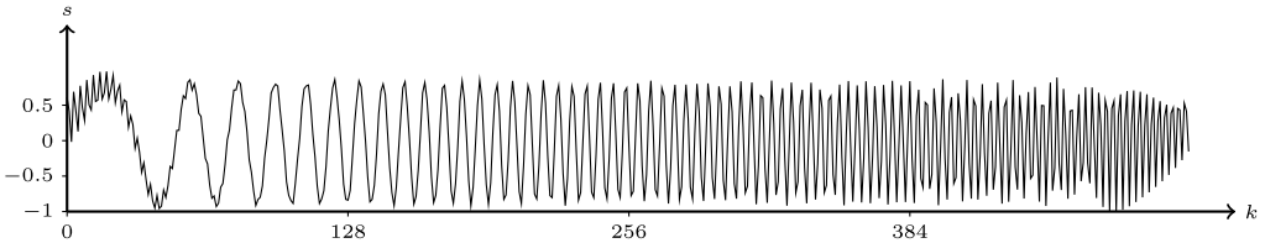
	Measure	Standard correlation	**Adaptive correlation**
Amplitude (V)	0.1	0.18	**0.59**
Localization (m)	2260	2257	2073
Relative error	13%	13 %	**3.7 %**

On line Diagnosis

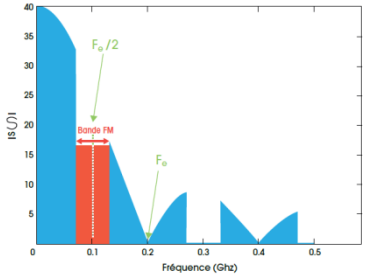
MCTDR (Multicarrier Time Domain Reflectometry)

- Probe signal corresponds to a sum of sine curves

$$s_n = \sum_{k=1}^{N/2} c_k \cos\left(\frac{2\pi k}{N} n + \theta_k\right)$$



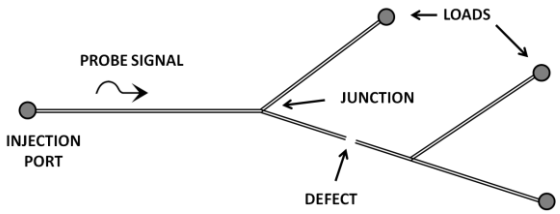
- The probe signal spectrum is controllable by cancelling the desired carried signal

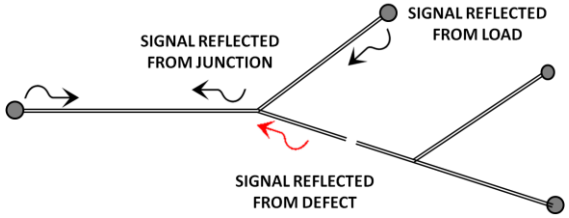


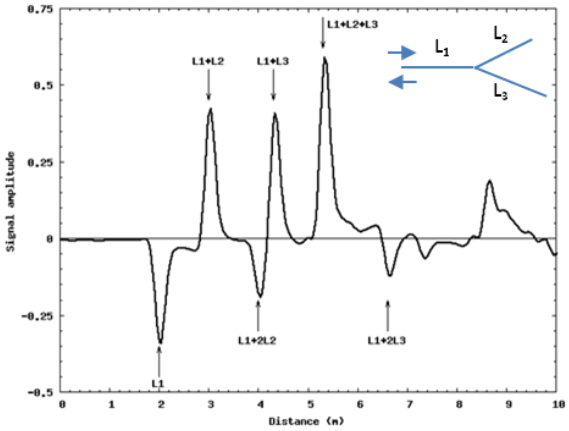
- Safe diagnosis : Harmless ness
- EMC Compliance
- Low sensitivity to SNR
- **MCTDR in TRL > 5**

AIRBUS GROUP
AIRBUS HELICOPTERS
DASSAULT AVIATION

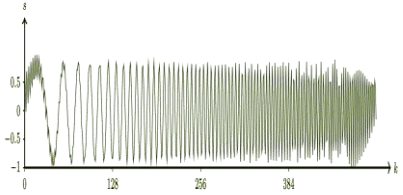
Complex network

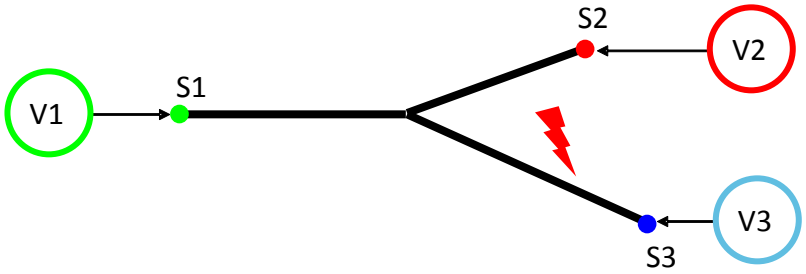


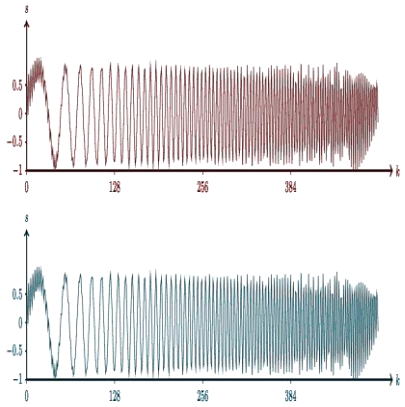




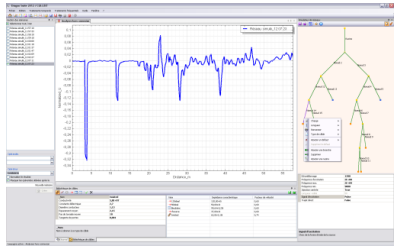
Distributed-MCTDR



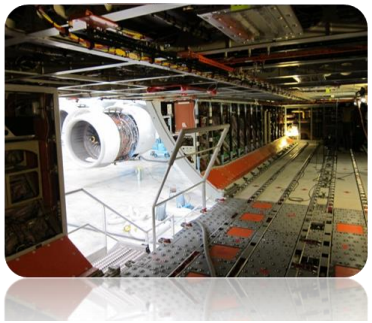


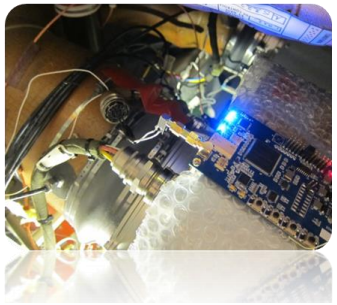


- The reflectometry distribution is obtained with a weighted mean process allowing a cross-correlation between reflectometers.
- Multi-sensing strategy allowing to avoid the ambiguity.
- A specific tool is proposed to facilitate the reflectometer deployment and to simulate the diagnosis strategy



Technology integration



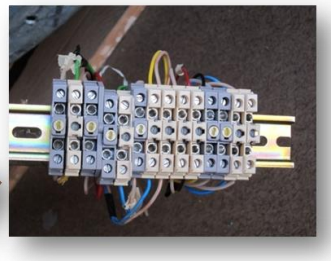


Avionic

DIAGNOCHIP, a 3 mm2 130nm integrated reflectometer

- A mixed Analog/Digital IP for real time processing
- 5cm resolution (4GHz guided wavelength)

Railway



Solar power

CEA Breakthrought

Some new technologies in progress

Reflectometry for soft defect

- **External source of failure**
  - Mechanical stress
  - Assembly errors
  - Corrosion, oxidation
  - Effect of environment s
- **Internal source of failure**
  - Manufacturing errors
  - Wear-out defect
  - Local hot-spot

Wear type	Primary signs	Detection method
Overheating of the wire	Wear zone	Visual inspection **Reflectometry**
Bad contact	Change in impedance Local hot spot	Thermal, Point by point test **Reflectometry**
Intermittent short circuit faults	Electromagnetic Magnetic Interference Electric arc	Visual inspection **Reflectometry**
Short circuit faults	Circuit-breaker system	**Reflectometry**
Broken insulation	Crack, damaged area	Visual inspection **Reflectometry**
Exposed conductor	Loss of the function Fire	Visual inspection **Reflectometry**
Corrosion	Loss of signal or data	Visual inspection **Reflectrometry**
Humidity	Loss of signal or data	**Reflectometry**

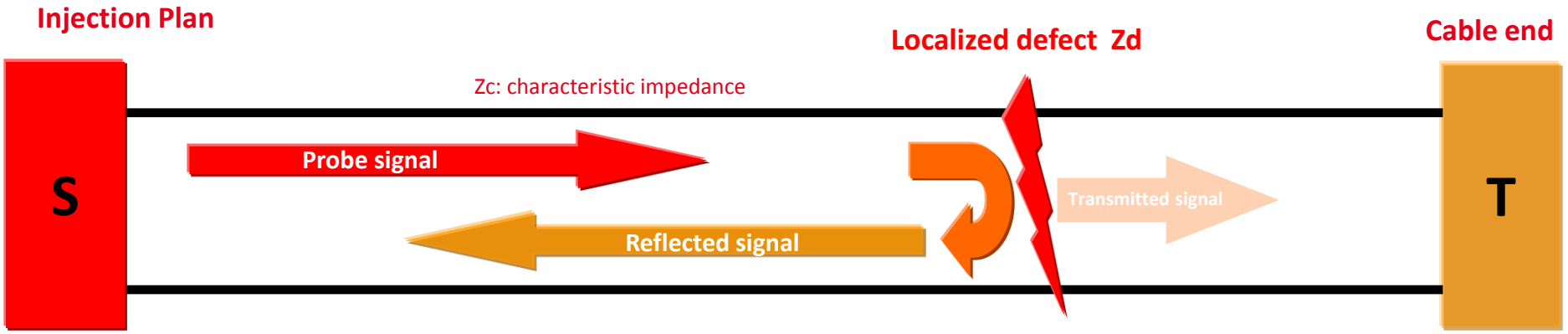
Wear out and/or Loss of the function

Local alteration of R, L, C, G parameters
Local alteration of the characteristic impedance Zc
Local alteration of the propagation speed

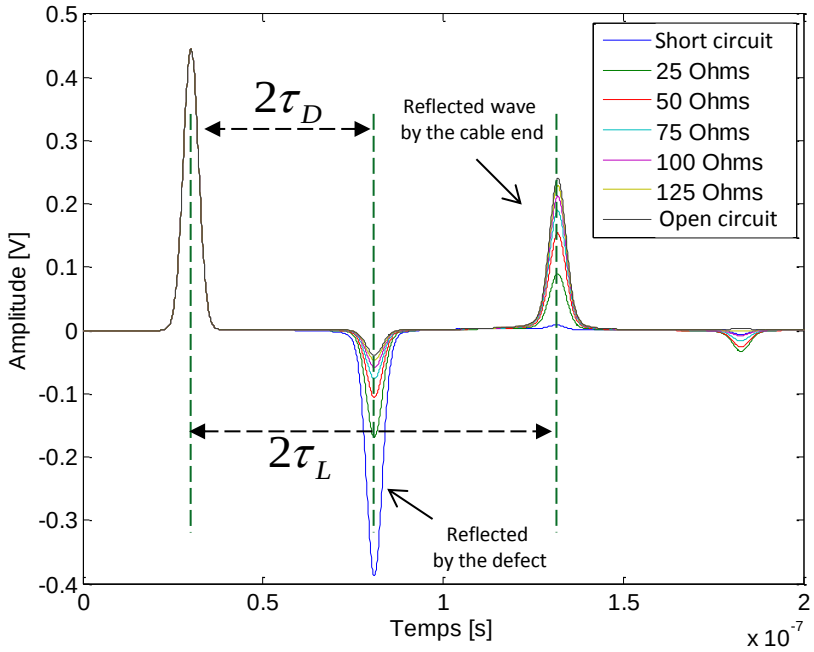
$\Gamma L \neq 0$

- Open defect
- Soft defect

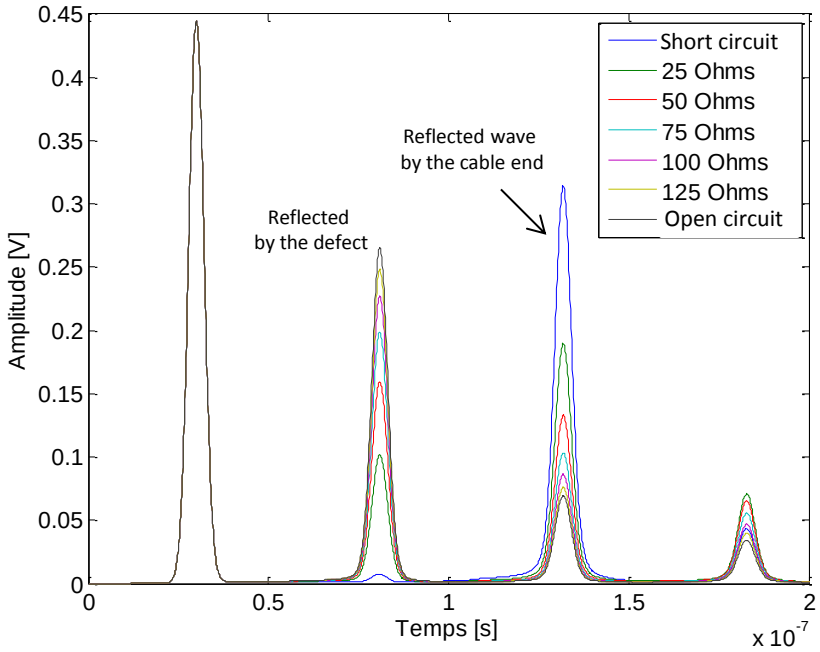
Reflectometry for soft defect



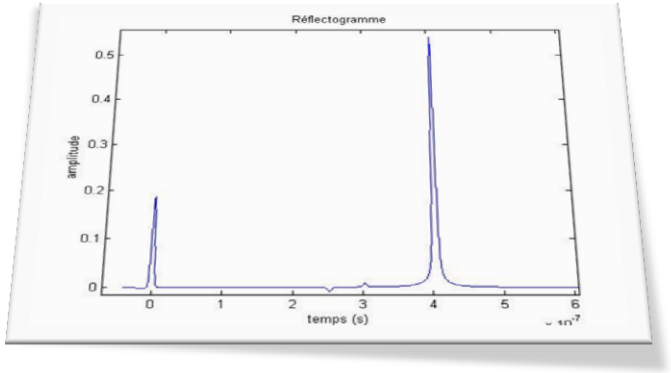
Parallel defect



Serial defect

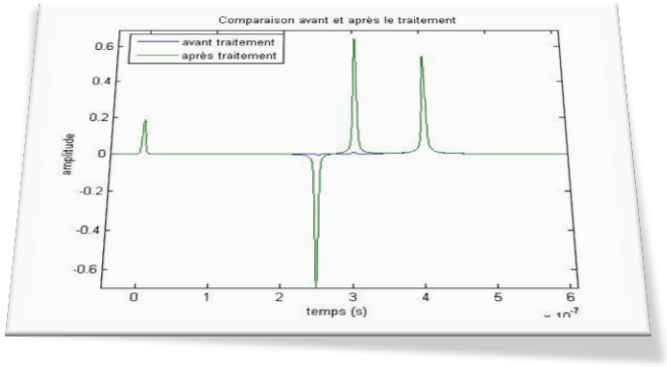


Soft defect methods



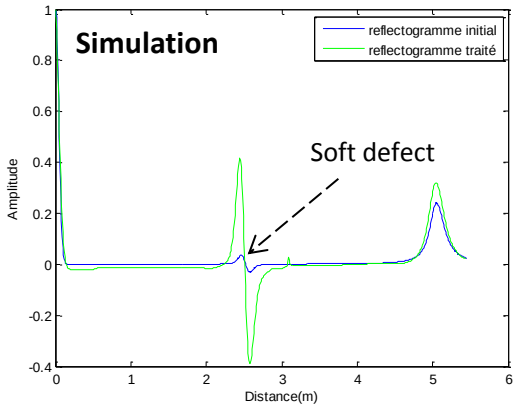
TDR/FDR measure

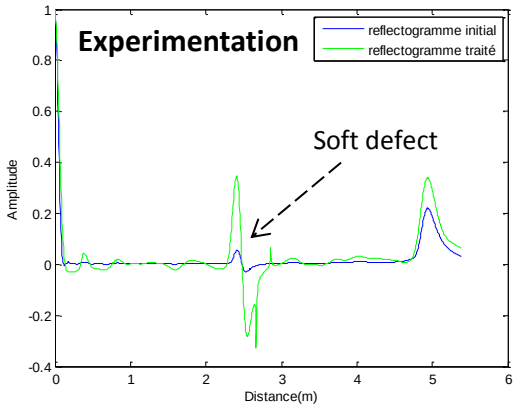
Soft defect Localization



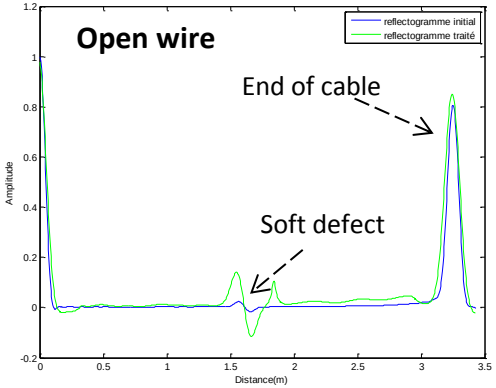
Soft defect detection (chafing)

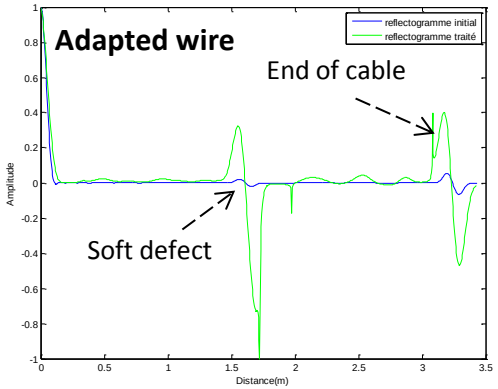
- One of our advance post processing for soft defect signature amplification





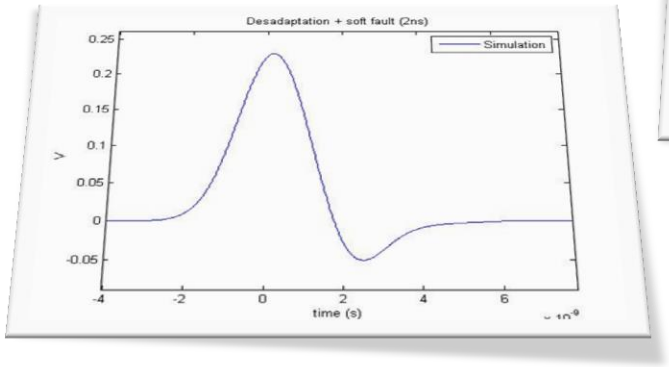
Cab_224b
Twisted pair (5 m) - Shielded - AWG24 0.25mm²
Soft defect = sheath + shield (pulled out) 2cm

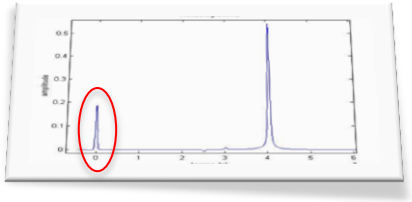




Coaxial cable RG58CU (3.20 mètres)
Soft defect = sheath + shield (pull out) 2cm

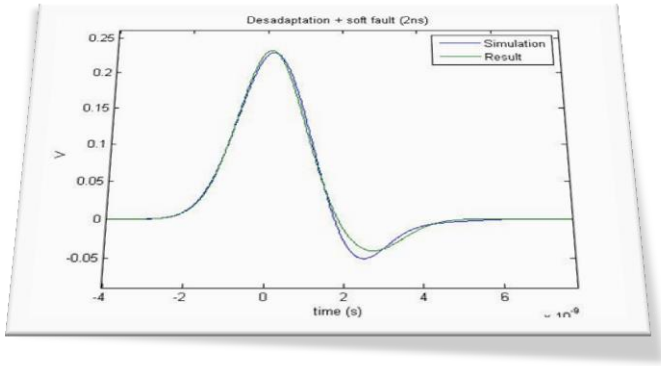
Blind zone method



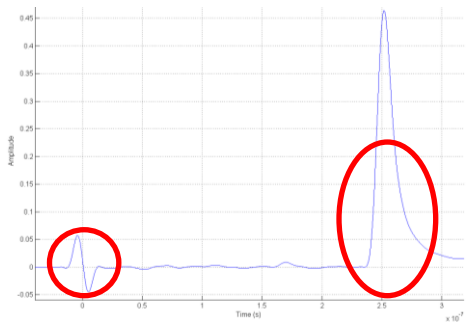


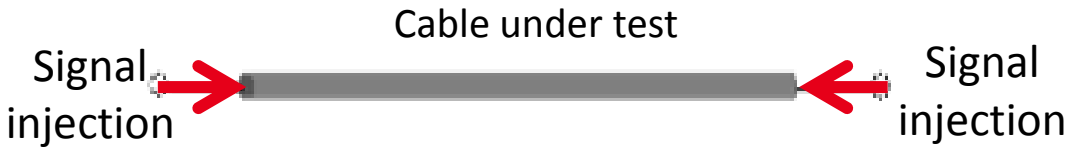
TDR/FDR measure

Impedance characterization in injection blind zone

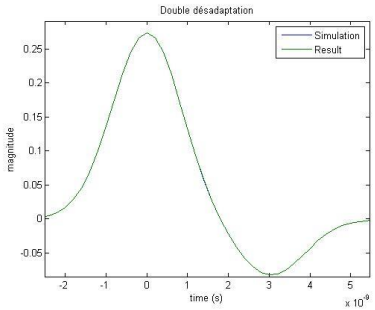


Interconnection characterization

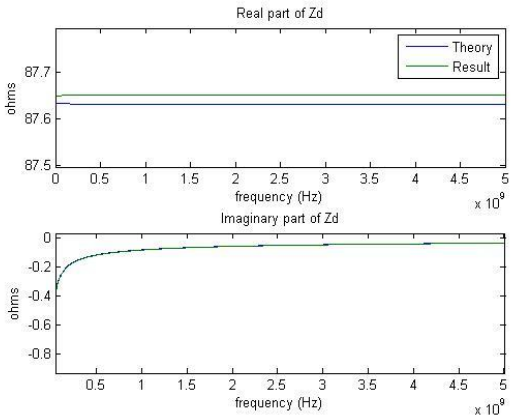




Cable connection and junction characterization



$V^2 = 4,65$
Likelihood ratio

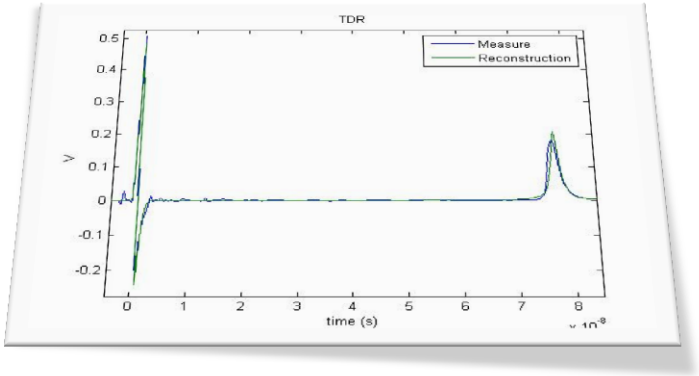


0,1% real part
1-2% imaginary part
ld = 30 cm

⇒ To characterize interconnection or connector (database)

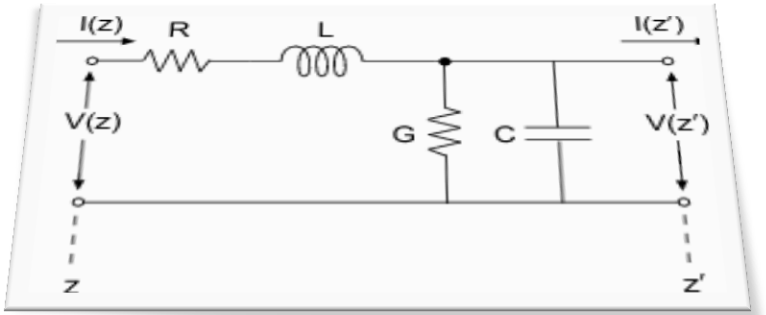
⇒ To diagnosis soft defect in the interconnection

RLCG extract method



TDR/FDR measure

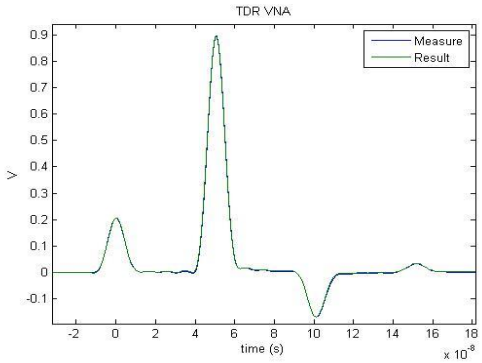
RLCG model



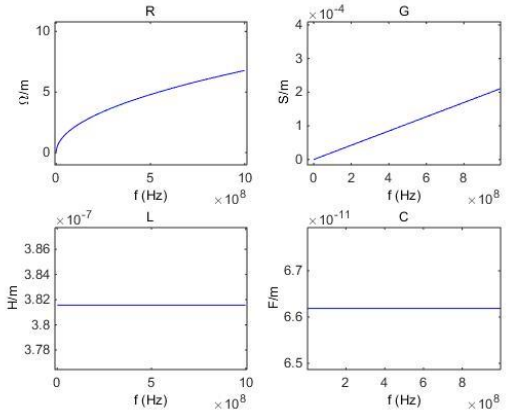
Cable and aging characterization

Cable characterization by RLCG parameters extraction

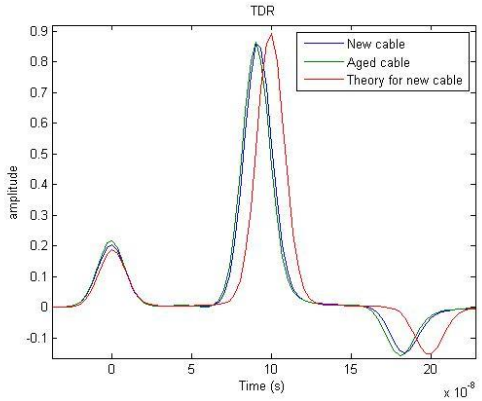
Coaxial (5 m) Zc = 75 Ω

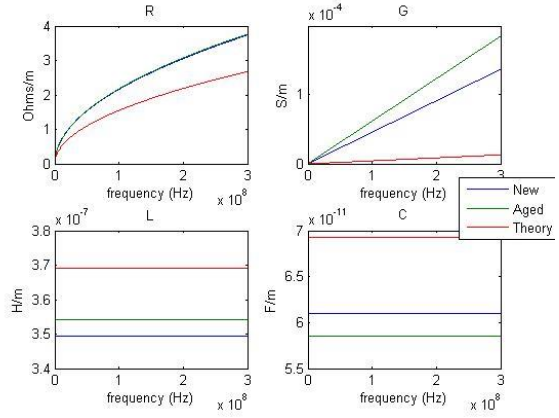


$V^2 = 3,7$
Likelihood ratio



Aging characterization





New

Aged

Coaxial (9,8 m) Zc = 75 Ω

CEA Breakthrought

And for the next future

CEA Breakthrought

All these new technologies and know how in LFIC

What are the new technologies for the future ?

Which new application domain ?

⇒ Use a cable like environement sensor (temperature, humidity, …)

⇒ New application domain : SHM

CEA is aware about industrials needs

Merci pour votre attention

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