

Diagnostic de Défauts de Câbles Electriques par l'Estimation de l'Impédance Caractéristique Distribuée

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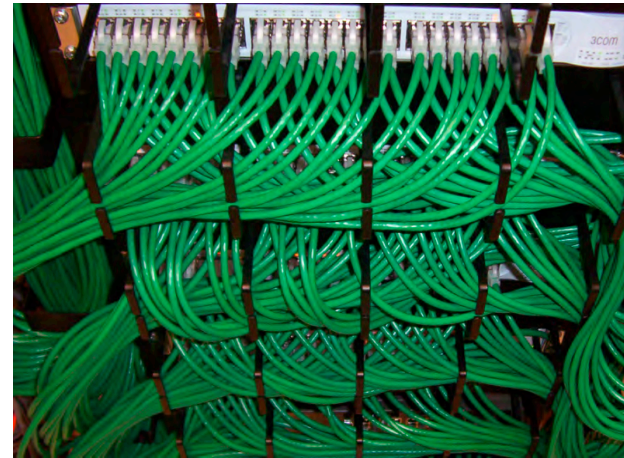
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Electrical cables are everywhere

Power lines



Data lines



In fixed infrastructures or
in vehicles



Cables are usually solid, but...

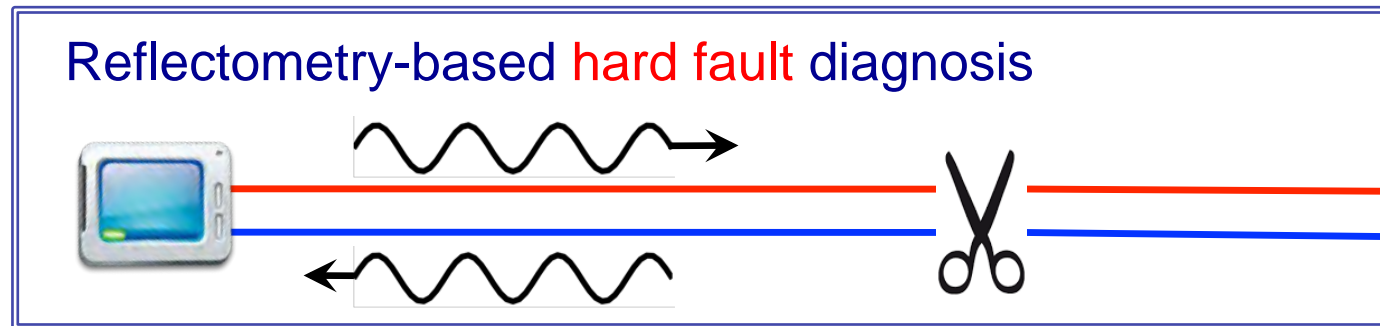
they are often installed
for decades,



and there are more
and more cables.

It is easy to notice that a cable is cut off

Reflectometry-based methods can also tell the **distance** of the cutoff point.



It remains relatively easy to deal with such **hard faults**, but how about **soft faults** (défauts non francs) ?

Reflectometry for **soft** faults?

Mechanical accidents



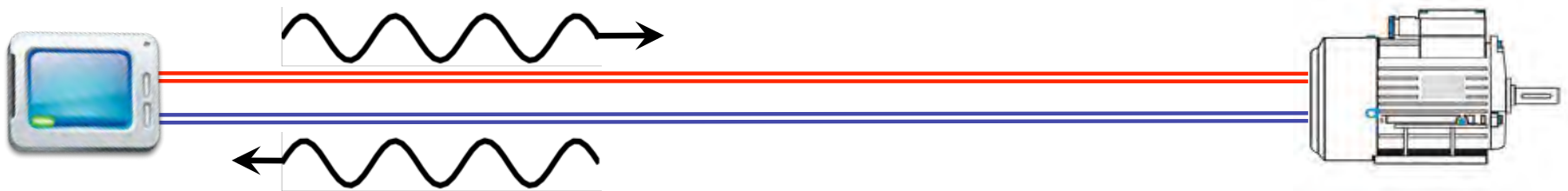
Chemical attack



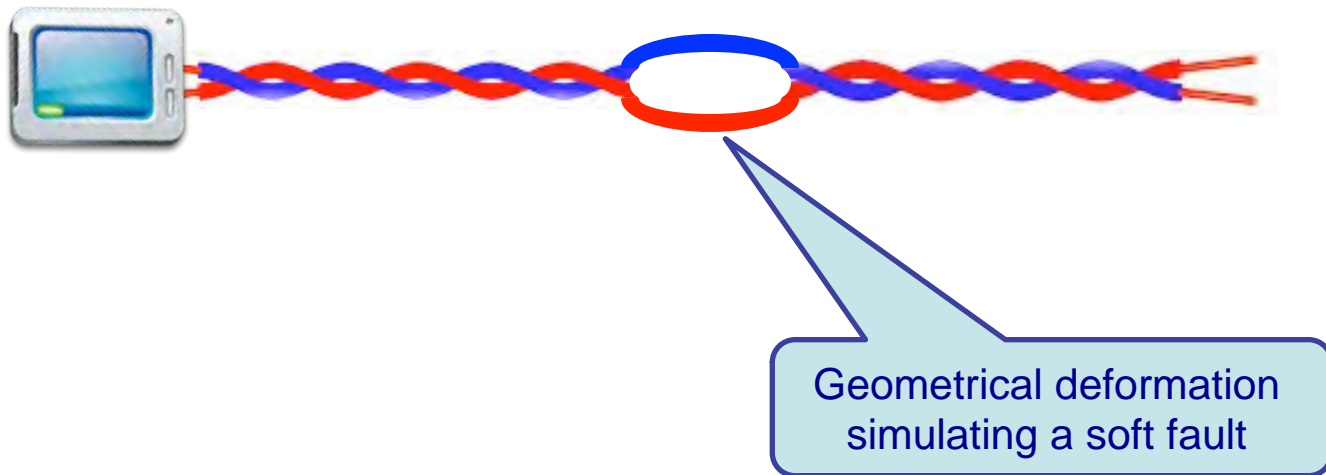
Over heating



Difficulty: single point observation for fault detection-location-characterization.



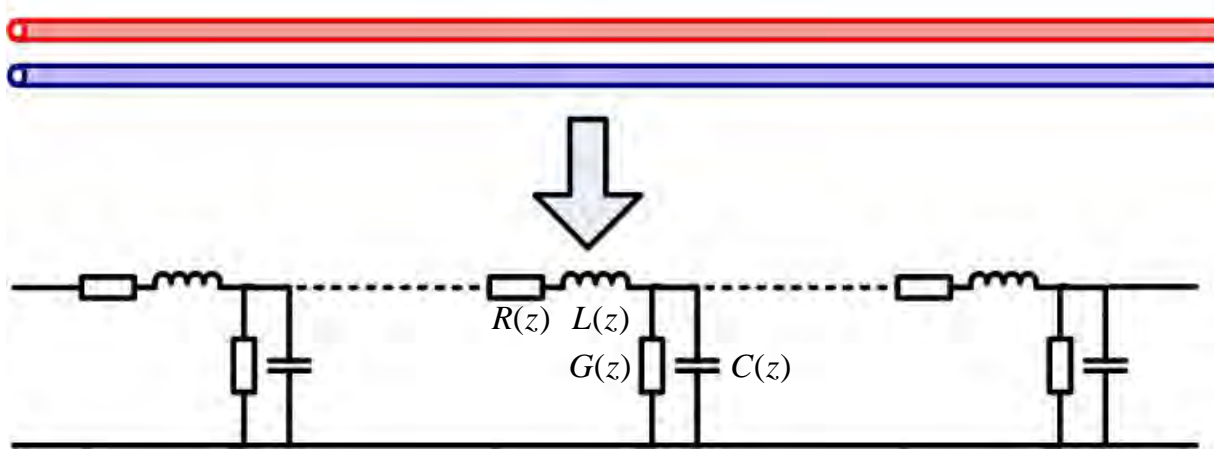
Demo: real time soft fault diagnosis



Difficulty: multiple reflections

(video illustration)

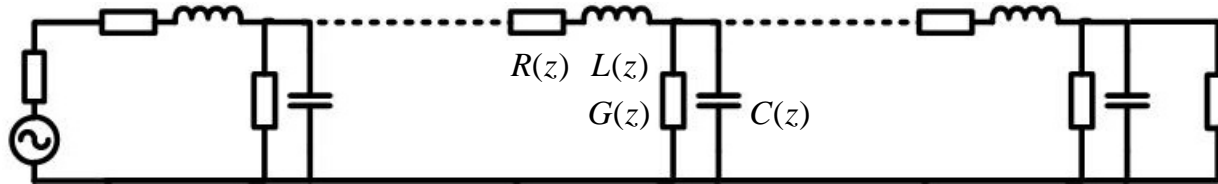
Advanced reflectometry: model-based analysis



$$\frac{\partial V(t,z)}{\partial z} + L(z) \frac{\partial I(t,z)}{\partial t} + R(z)I(k,z) = 0$$
$$\frac{\partial I(t,z)}{\partial z} + C(z) \frac{\partial V(t,z)}{\partial t} + G(z)V(k,z) = 0$$

Telegrapher's equations + inverse algorithm \Rightarrow diagnosis

From time domain to frequency domain



$$\frac{\partial V(t,z)}{\partial z} + L(z) \frac{\partial I(t,z)}{\partial t} + R(z)I(k,z) = 0$$

$$\frac{\partial I(t,z)}{\partial z} + C(z) \frac{\partial V(t,z)}{\partial t} + G(z)V(k,z) = 0$$

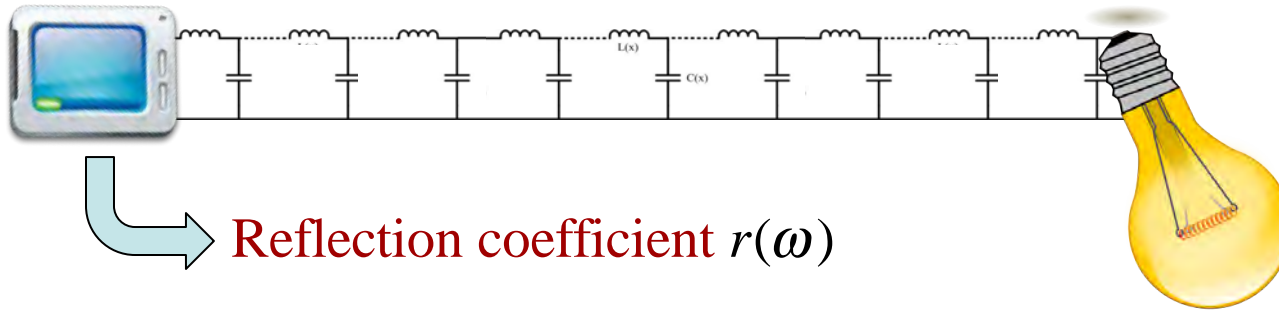
Fourier transform

$$\frac{dV(\omega,z)}{dz} + R(z)I(\omega,z) + i\omega L(z)I(\omega,z) = 0$$

$$\frac{dI(\omega,z)}{dz} + G(z)V(\omega,z) + i\omega C(z)V(\omega,z) = 0$$

$$\text{Characteristic impedance: } Z_0(z) = \sqrt{\frac{L(z)}{C(z)}}$$

The reflection coefficient

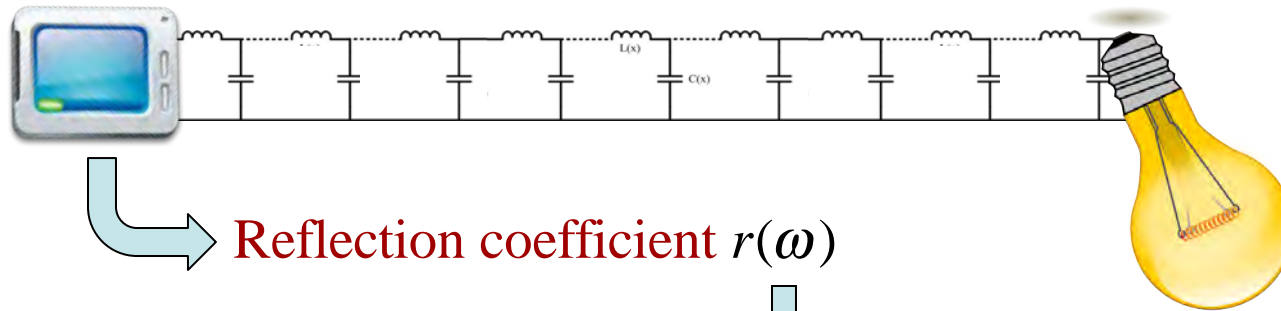


Reflected wave

$$r(\omega) = \frac{V(\omega, x_S) - Z_S I(\omega, x_S)}{V(\omega, x_S) + Z_S I(\omega, x_S)} = \frac{Z(\omega, x_S) - Z_S}{Z(\omega, x_S) + Z_S}$$

Incident wave

The transmission line inverse problem



$$Z_0(x) = \sqrt{\frac{L(x)}{C(x)}}$$

The inverse algorithm based on the **inverse scattering** theory

The inverse scattering theory about Zakharov–Shabat equations

$$\begin{aligned}\frac{dv_1(\omega, x)}{dx} + i\omega v_1(\omega, x) &= q(x)v_2(\omega, x) \\ \frac{dv_2(\omega, x)}{dx} - i\omega v_2(\omega, x) &= q(x)v_1(\omega, x)\end{aligned}$$

was studied during the 1970s-1980s for the analysis of nonlinear wave equations. It turns out to be useful for the cable inverse problem!

Historical reference: [Jaulent 1982, J. Math. Phys.]

The inverse scattering algorithm

Fourier transform:
$$\rho(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} r(\omega) \exp(-i\omega x) dk$$

Solution of Gel'fand-Levitan-Marchenko (GLM) integral equations:

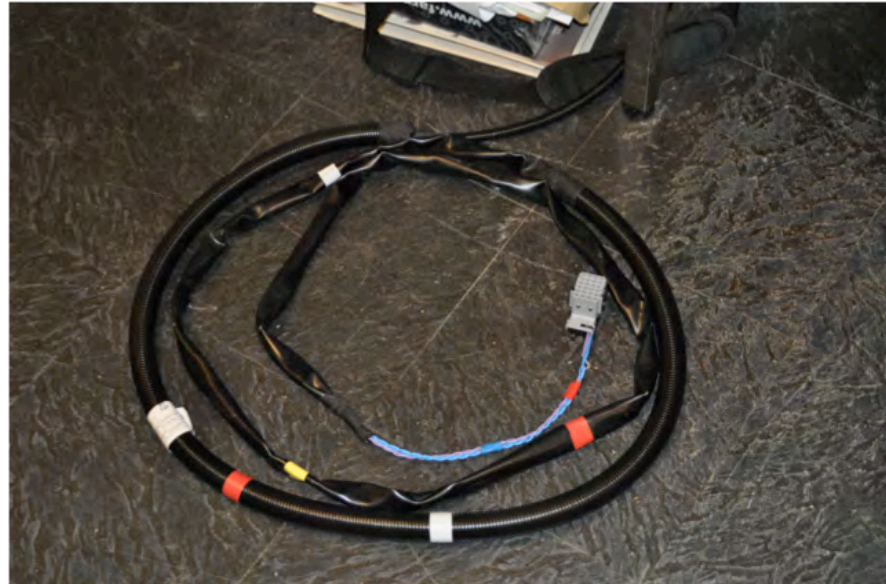
$$A_1(x, y) + \int_{-y}^x A_2(x, s) \rho(y + s) ds = 0$$

$$A_2(x, y) + \rho(x + y) + \int_{-y}^x A_1(x, s) \rho(y + s) ds = 0$$

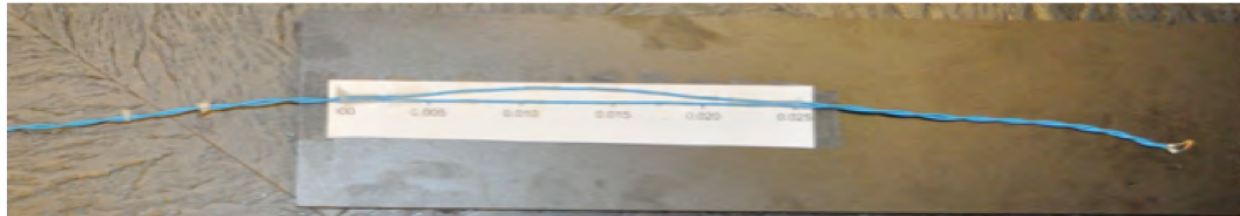
$$q(x) = 2A_2(x, x)$$

$$Z_0(x) = Z_0(x_s) \exp\left(-2 \int_{x_s}^x q(\tau) d\tau\right)$$

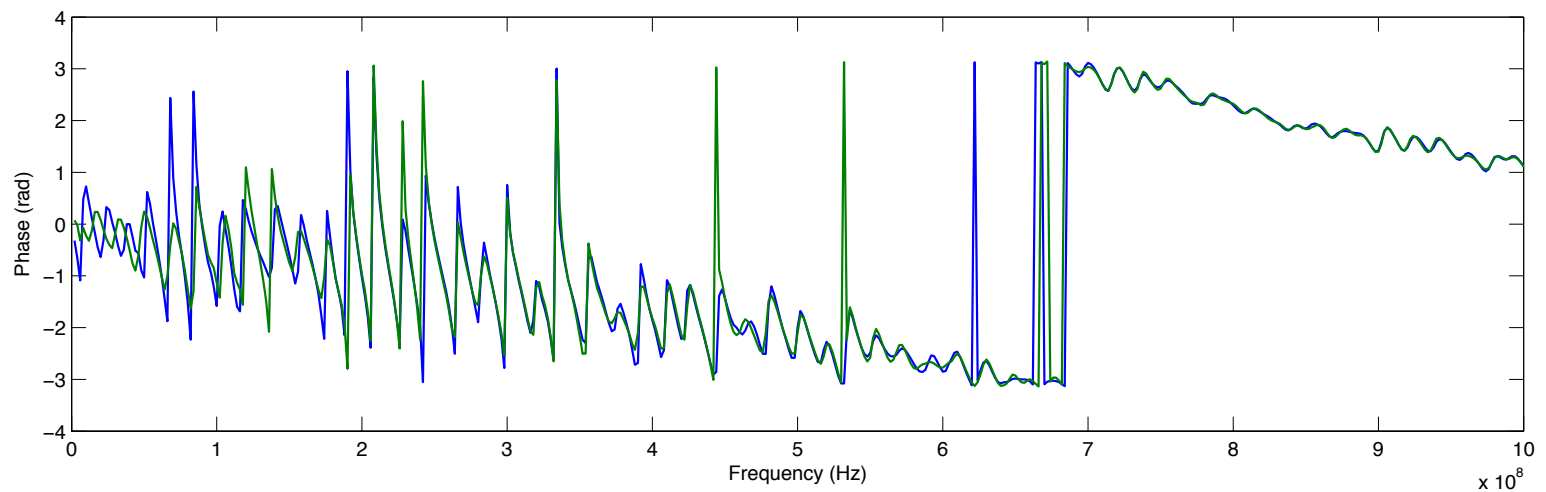
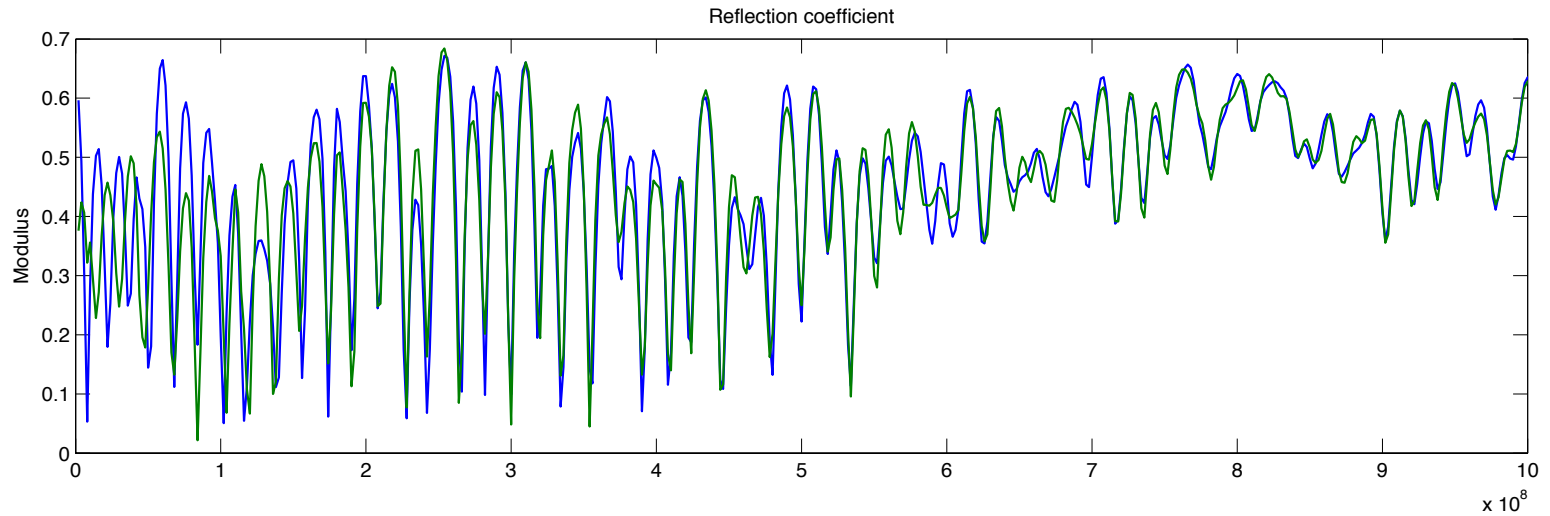
Laboratory instruments



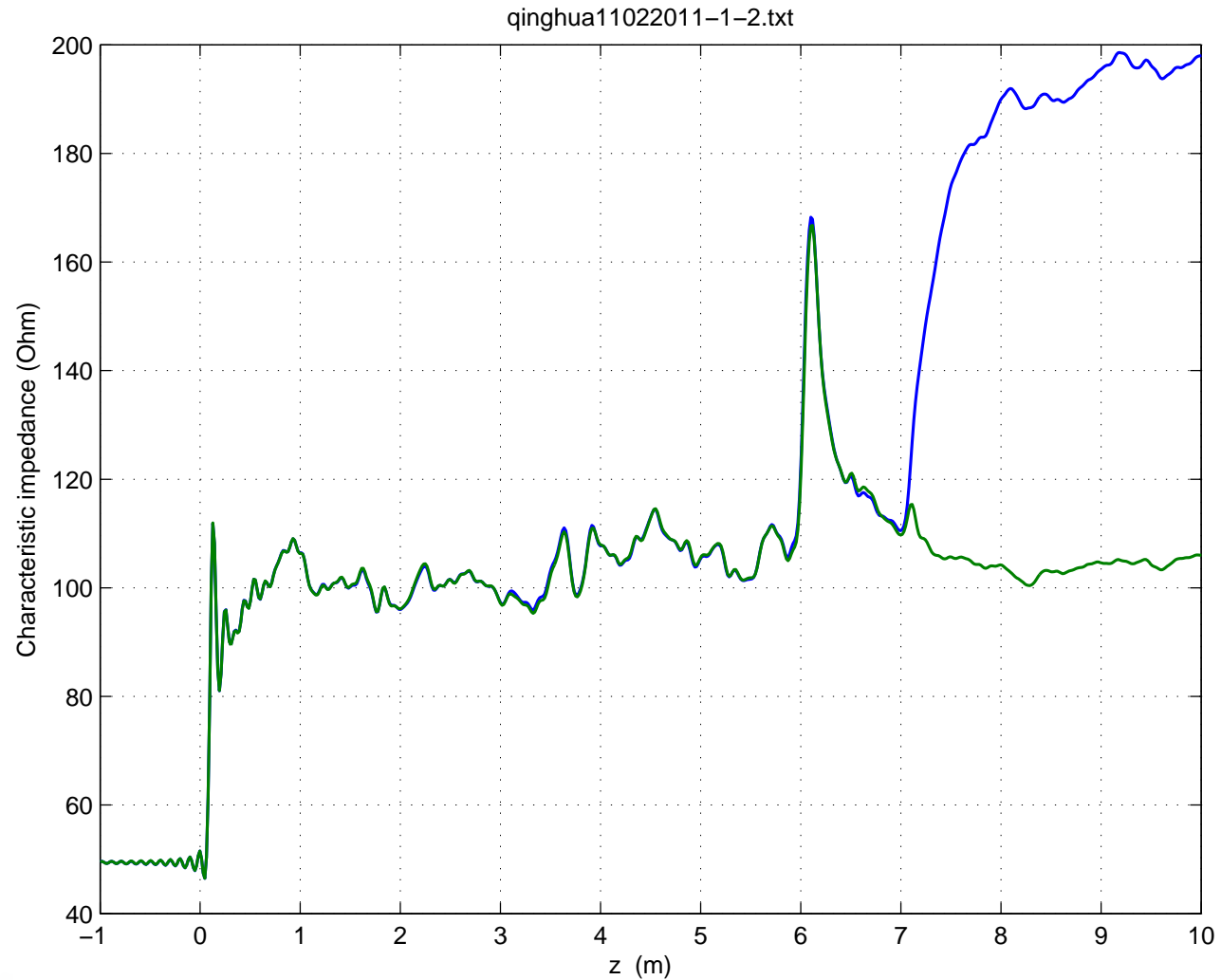
Pictures by LGEP



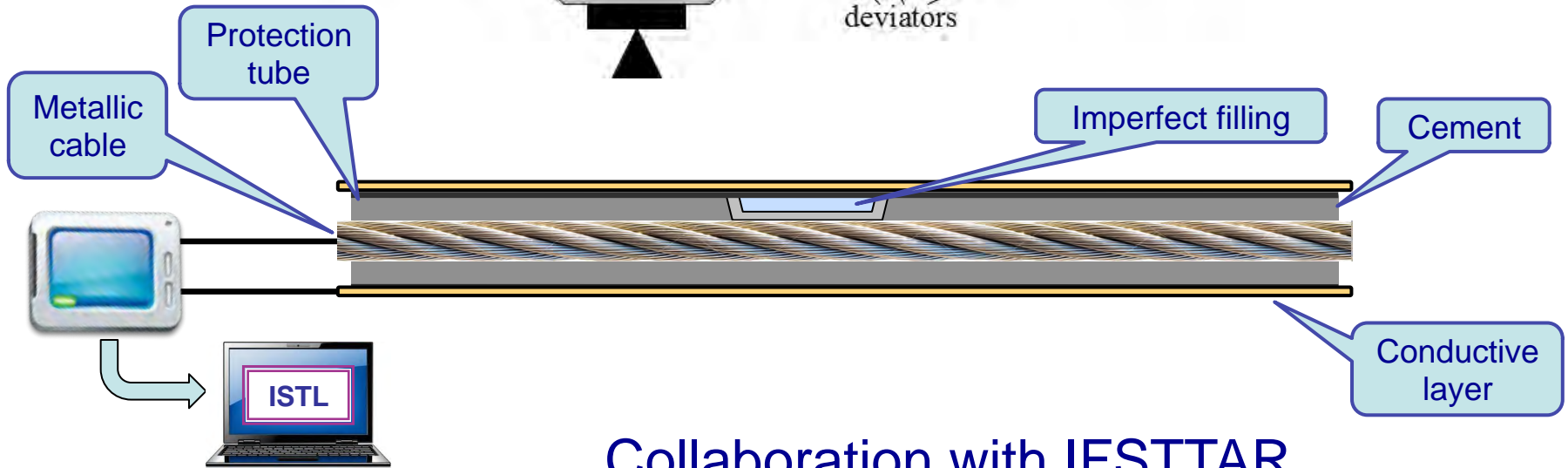
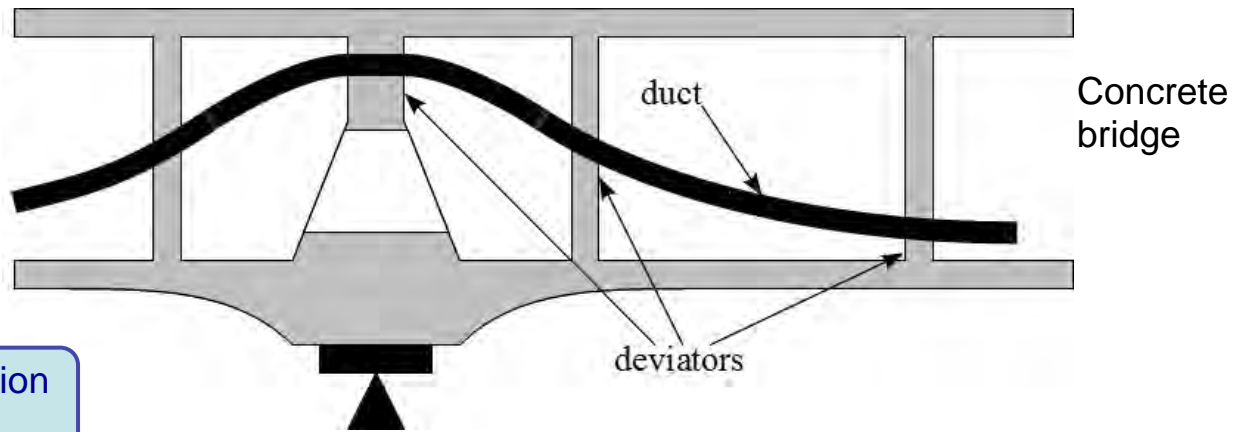
Laboratory experimentation



Laboratory experimentation



Application in civil engineering: non destructive post-tensioned cable monitoring



Collaboration with IFSTTAR

Conclusion

Inverse scattering applied to reflectometry is a powerful tool for soft fault diagnosis of electrical cables.

Fast algorithm for real time applications.

Applications in electrical engineering and in civil engineering.

Ongoing research: electrical network monitoring.