Common problems in Time Domain Reflectometry attacked with the Ramer-Douglas-Peucker algorithm: from radiation effects on optical fibres to coaxial level monitoring

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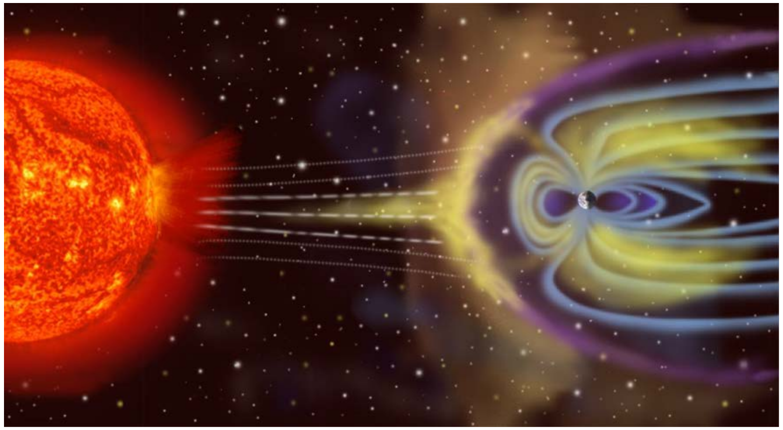
INTRODUCTION

Long term exposure to ionizing radiation induces transmission losses in optical fibers. When Time Domain Reflectometry (TDR) techniques are used to study these effects, some common problems may emerge. We propose here an application of the Ramer-Douglas-Peucker (RDP) algorithm for the analysis of the experimental results of a simple coaxial level monitoring sensor.

HARSH RADIATION ENVIRONMENTS



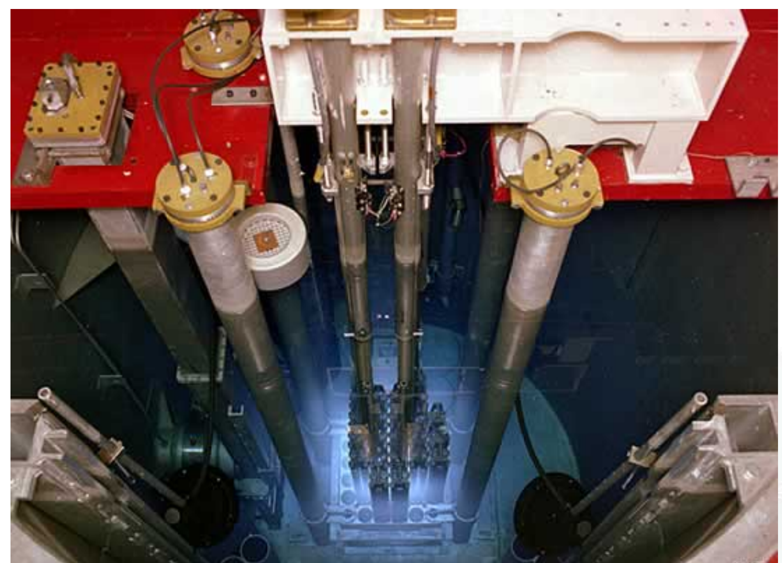
SPACE RADIATION ENVIRONMENTS (*)

Maximum Energies of Particles	
Particle Type	Maximum Energy
Trapped Electrons	10s of MeV
Trapped Protons & Heavy Ions	100s of MeV
Solar Protons	GeV
Solar Heavy Ions	GeV
Galactic Cosmic Rays	TeV

(*) from Barth et al., "Space, atmosphere, and terrestrial radiation environments", IEEE transaction on nuclear science, Vol. 50, No.3, 2003

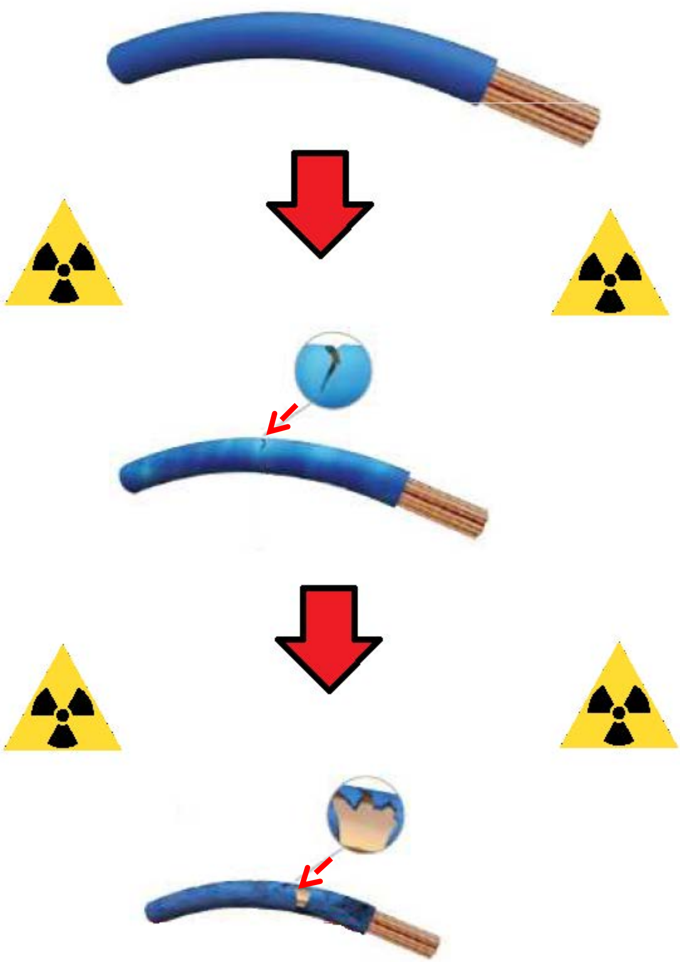
NUCLEAR POWER PLANTS (**)

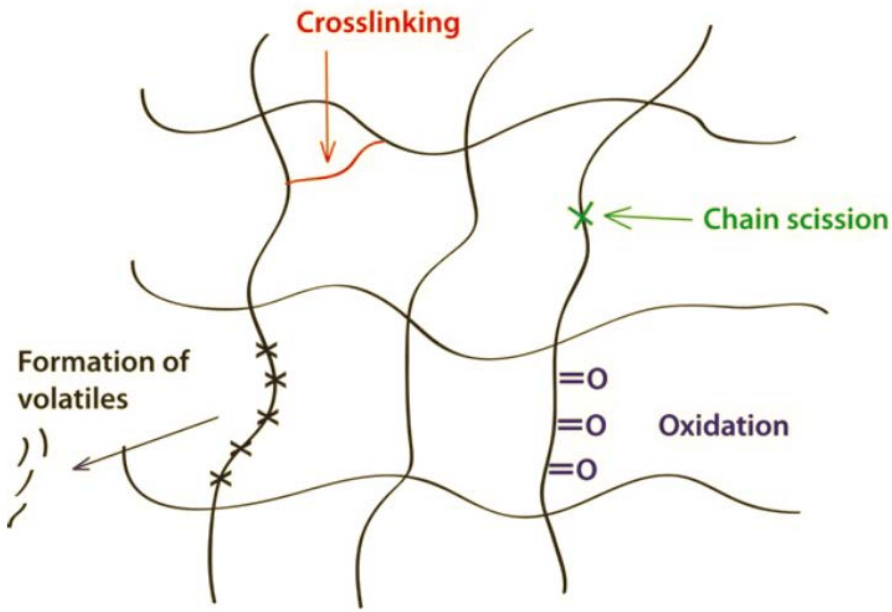
- **Normal operations:**
  - o Gamma ray: few keV to 8 MeV
  - o Neutrons: thermal (0.025 eV) to fission (> 10 Mev)
- **LOCA:**
  - o Gamma and beta from decay of fission products (max of 28 Gy/s in few seconds)

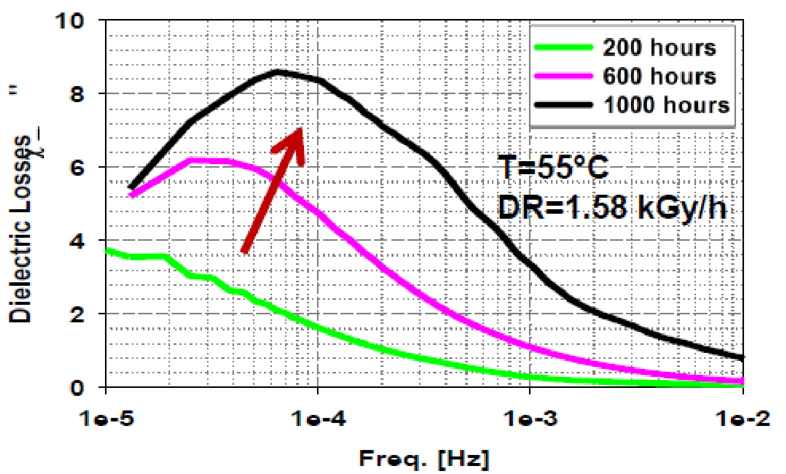


(**) from Eichhorn, "Engineering Dielectrics: Electrical Properties of Solid Insulating Materials" , Volume IIA, 1983

POSSIBLE RADIATION EFFECTS ON CROSSLINKED POLYMERS



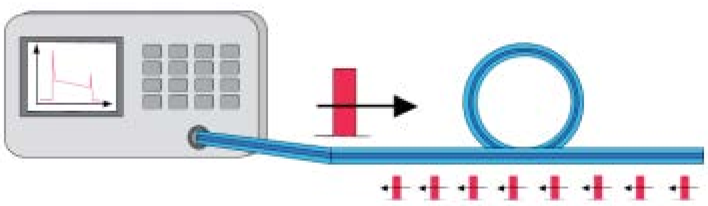




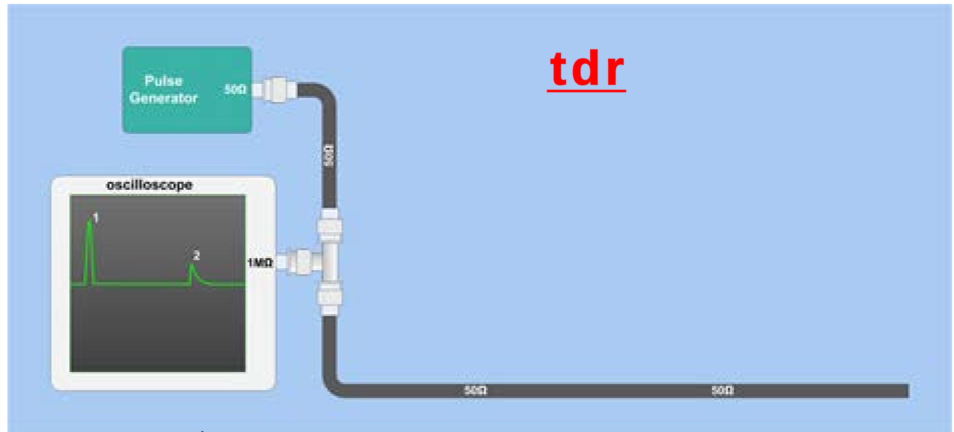
HOW TO STUDY RADIATION EFFECTS ?

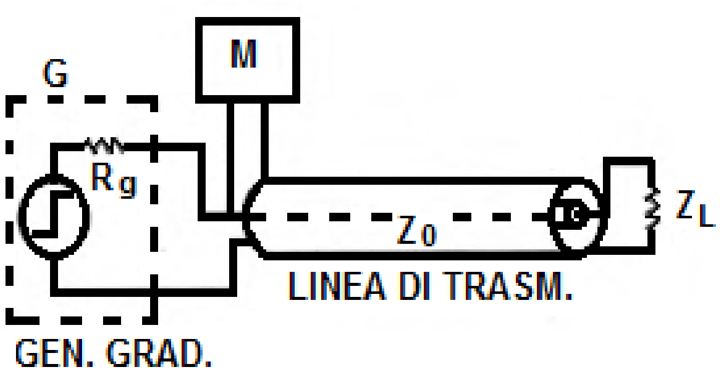
To study the radiation effects on a transmission line like an optical fiber a possible approach is to use the time or frequency response to an input signal using the reflectometry principle (like the RADAR).

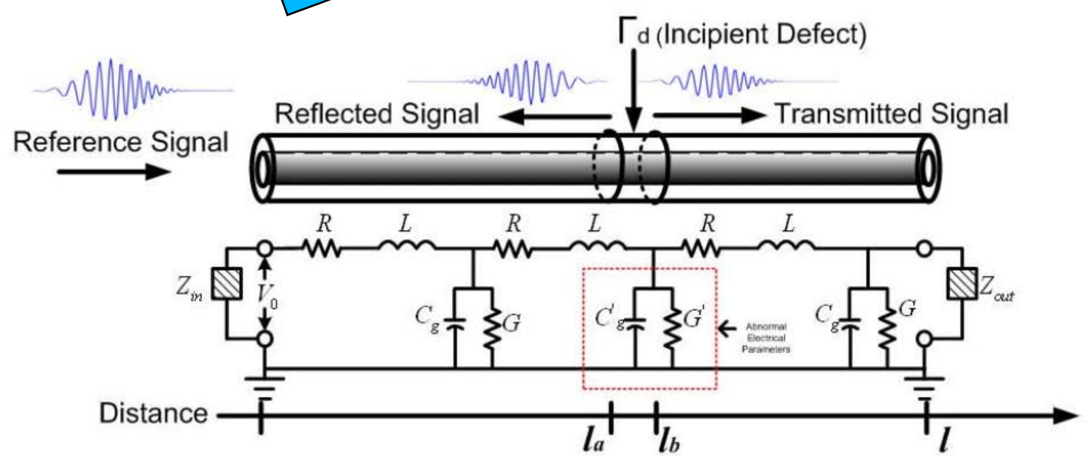
optical tdr



tdr

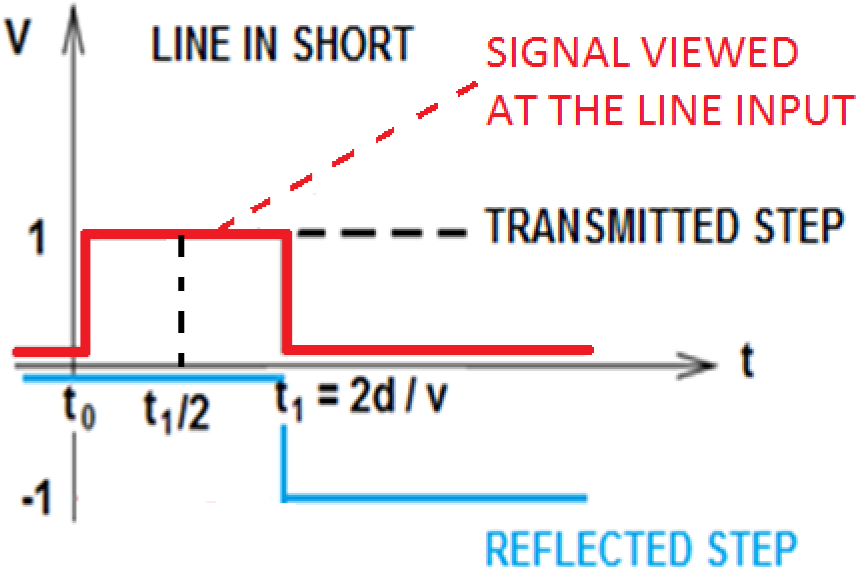


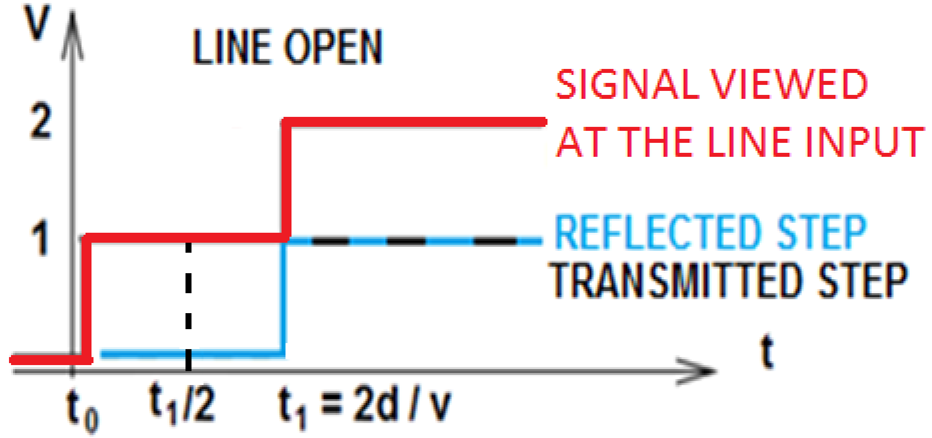




What is TDR ?

When the focus is on time measurements, the well-known technique is called Time Domain Reflectometry (TDR). If we inject a step signal into a lossless coaxial cable of length *d*:

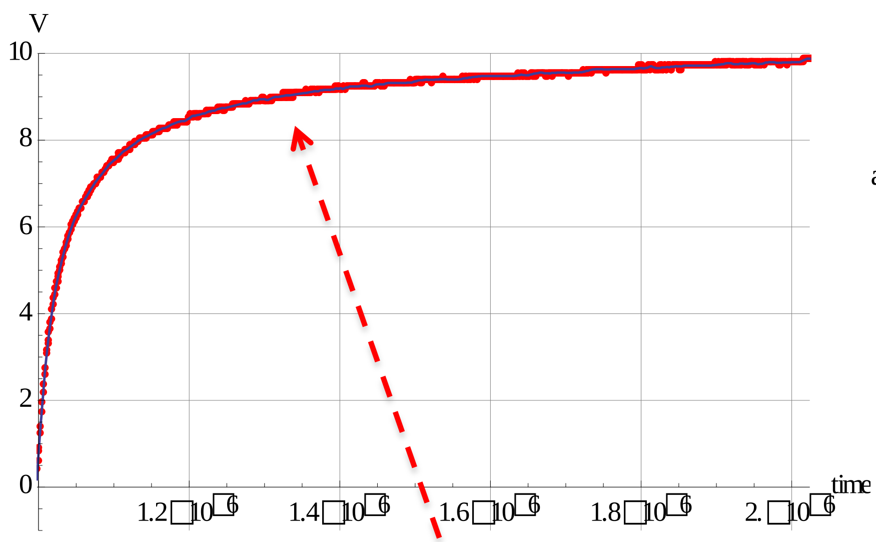




$t_1/2$ is the time needed
for the signal to travel the line

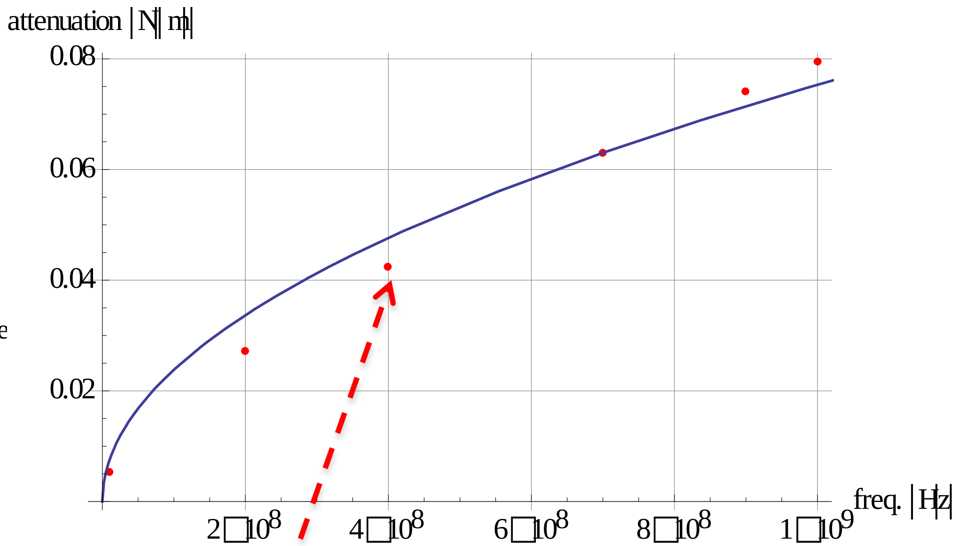
ATTENUATION MEASURE FROM STEP SIGNALS

The same step signal can be used also to estimate the attenuation since data fitting from the received signal allows the determination of the same coefficient:



$$V_0 \cdot erfc\left(\frac{\boxed{a}\, z}{2\sqrt{t - t_z}}\right)$$

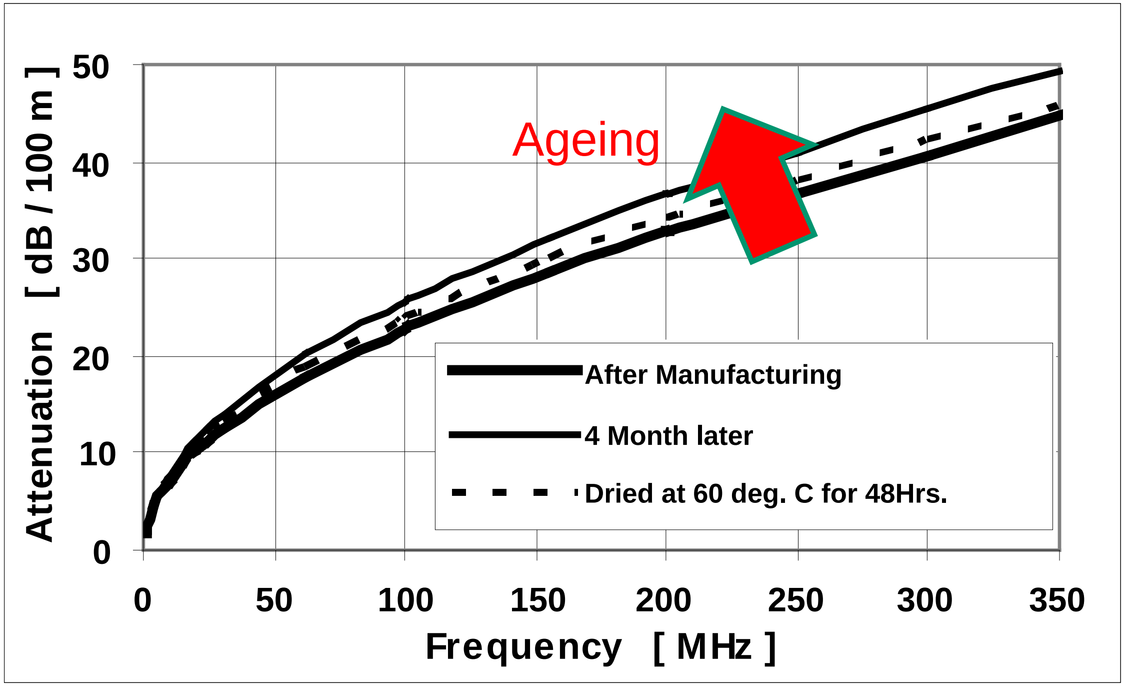
With OTDR it's possible to measure radiation-induced attenuation



$$\frac{\boxed{a}}{\sqrt{2}}\sqrt{\omega}$$

AGEING

Ageing / environmental conditions on attenuation measurement :

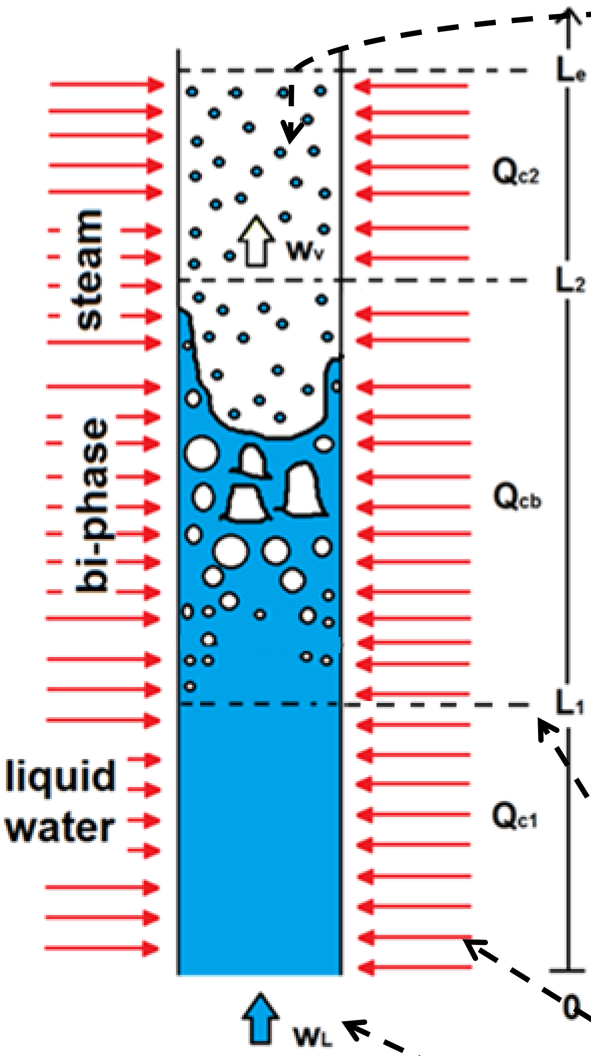


Attenuation and phase velocity* are depending on the cable ageing and they may be taken into account (with precautions) as global condition indicators:

$$\alpha(f) \simeq K\, f^{0.5\div1} \sqrt{\frac{C}{L}} \qquad v_p = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}} = \frac{1}{\sqrt{LC}}$$

* In TEM modes the phase velocity is the same as the velocity of light in the chosen medium

ENEA example: Once Through Steam Generator



OUTLET: single phase vapour

L2 height: liquid is totally evaporated

No distinct parts like economizers, evaporators, etc. Water enters into the heated tube and becomes steam along the flow path on the z-axis.

As is known, there's an extreme interdependency between the pre-heating, evaporation and superheating phase.

Hence, its I&C system is essential to keep the steam pressure and levels within narrow working limits

L1 height: where liquid reaches satur. temp.

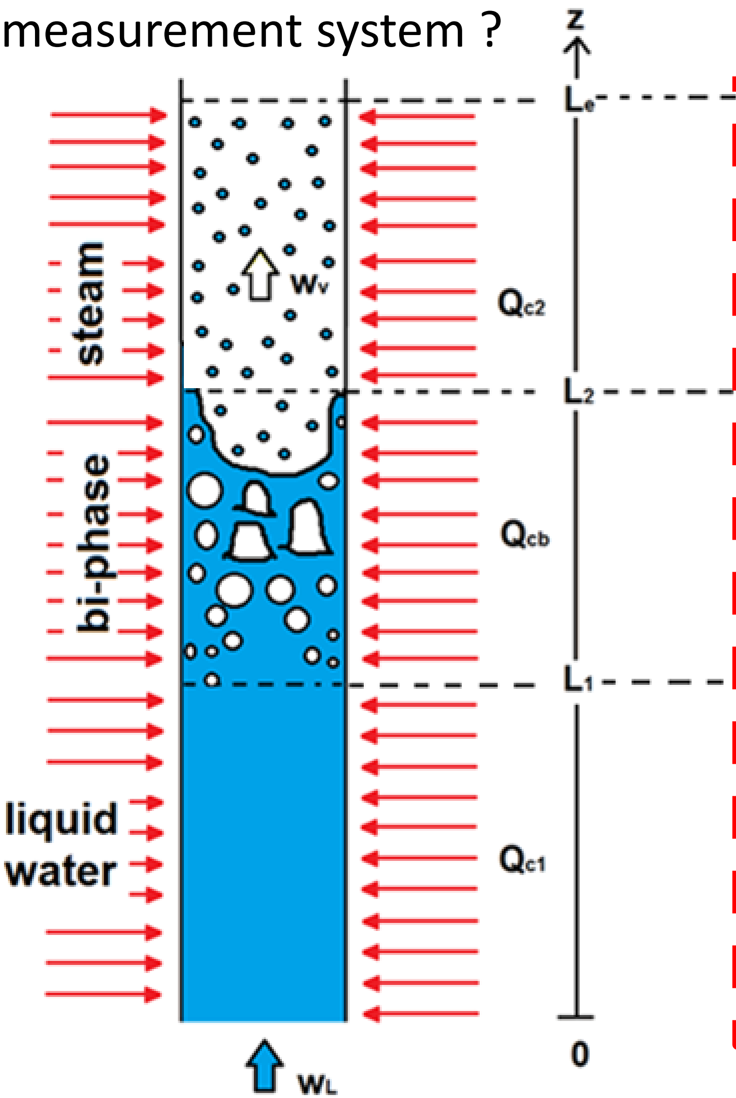
external heat flux

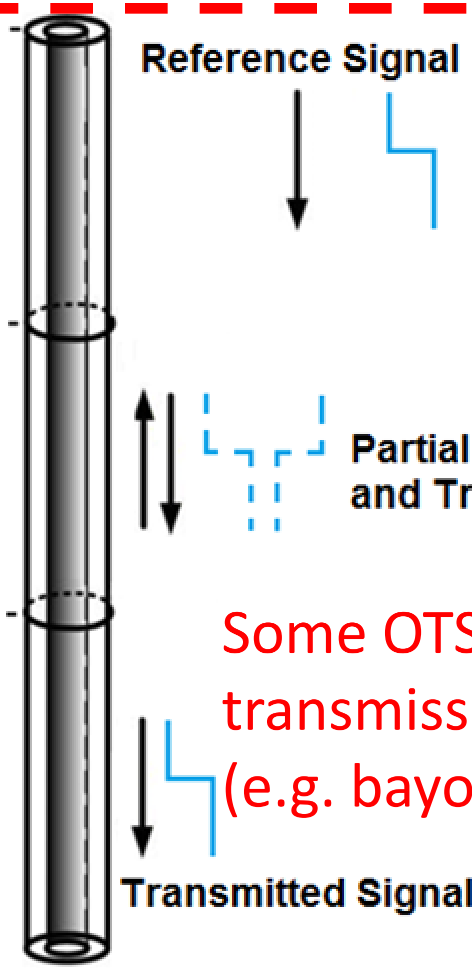
liquid flow rate

INLET: single phase liquid

OTSG theoretical model

Hence level monitoring in a OTSG is extremely important but what could be a non invasive, response quick and not steam/liquid interface dependent level measurement system ?

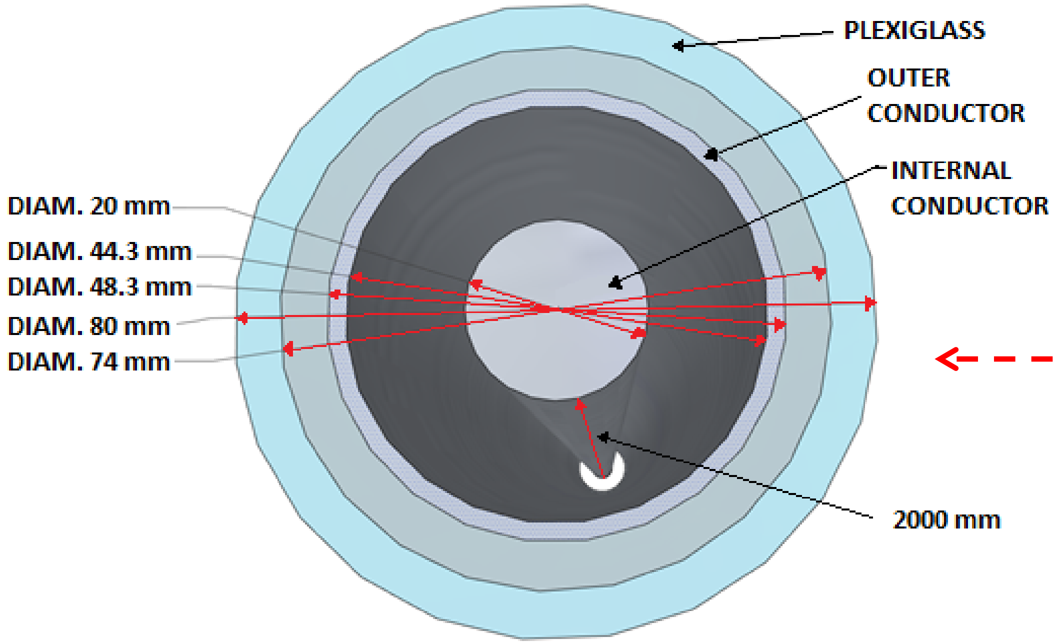


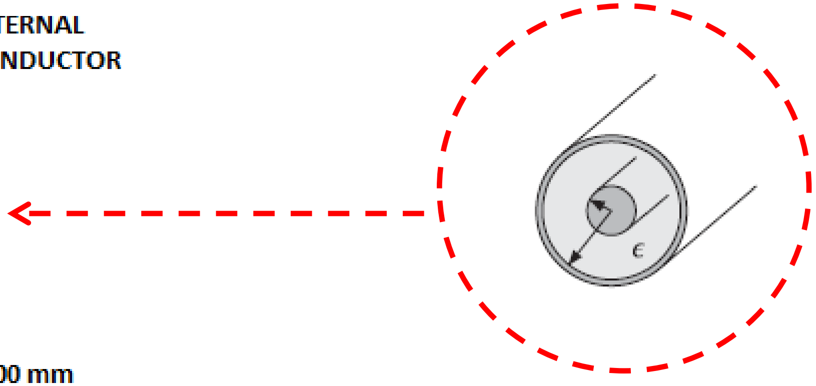


Electric signals used as level monitoring

Some OTSGs already have a transmission line geometry (e.g. bayonet type)

Transmission line basics





coaxial line

Since a OTSG bayonet type is very similar to a coaxial type of transmission line, we'll represent it with a:

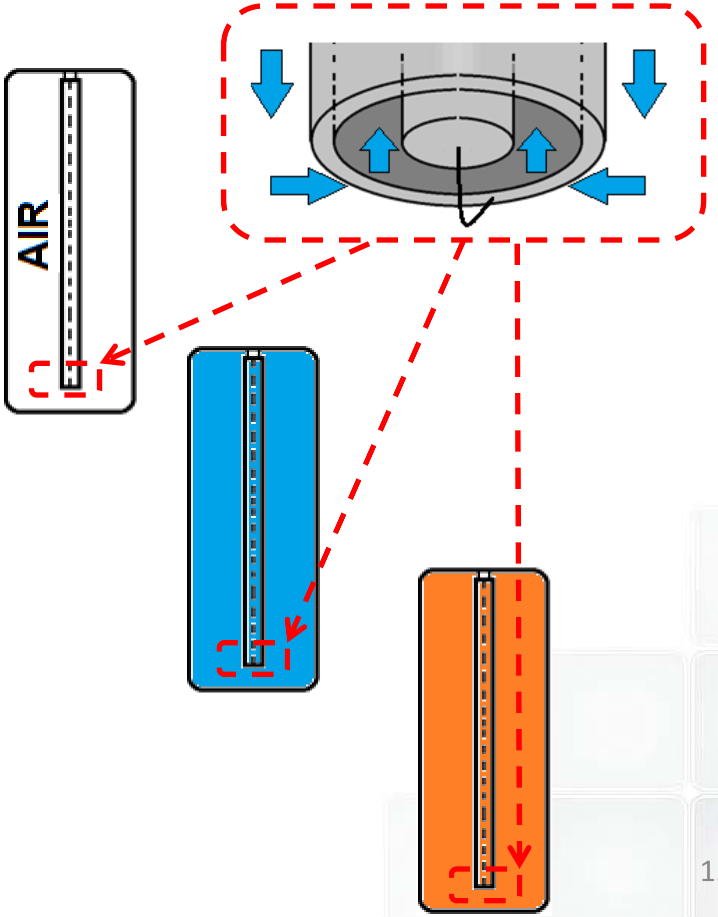
- solid internal conductor of radius r_a
- filling dielectric (liquid, gas, mixture)with permittivity ε
- hollow external conductor of internal radius r_b and external r_c

Along the transmission line, if there's a reflected signal, this is due only to the change in the dielectric found along the propagation path. That happens to the impedance when there's an air / water transition since:

$$Z_0^{air} \simeq 138 \cdot \log_{10}\left(\frac{r_b}{r_a}\right) \simeq 50\ \Omega$$

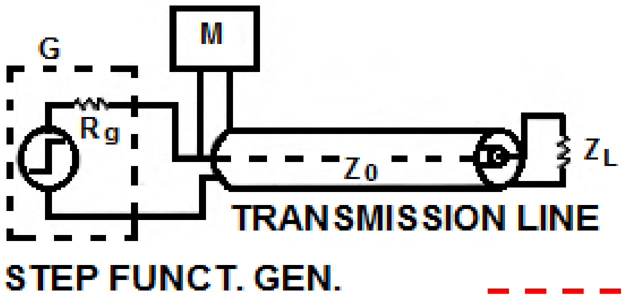
$$Z_0^{water\ 20°C} \simeq \frac{Z_0^{air}}{\sqrt{\varepsilon_r}} \simeq \frac{50}{\sqrt{80}} \simeq 5.6\ \Omega$$

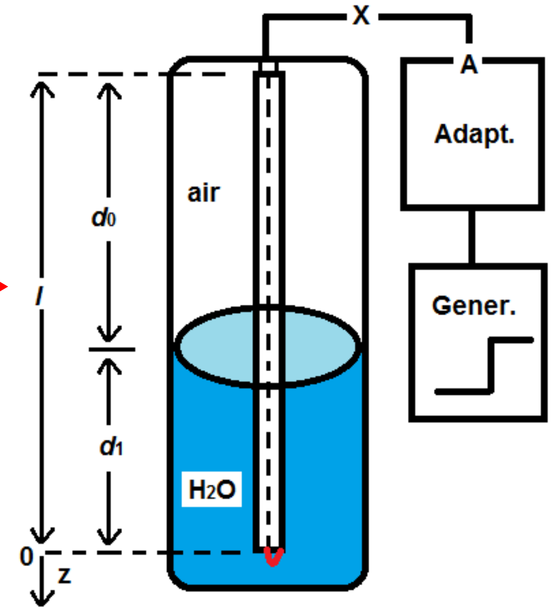
$$Z_0^{water\ 300°C} \simeq \frac{Z_0^{air}}{\sqrt{\varepsilon_r}} \simeq \frac{50}{\sqrt{20}} \simeq 11.1\ \Omega$$



Theoretical signal analysis

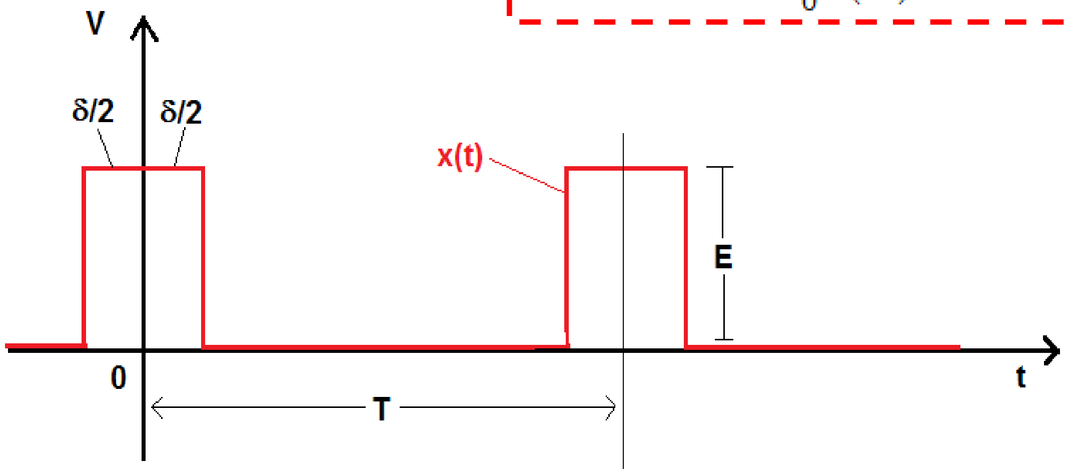
Hence measuring the reflection coefficient along the line means measuring the liquid level inside the line





Generalized Reflection Coefficient:

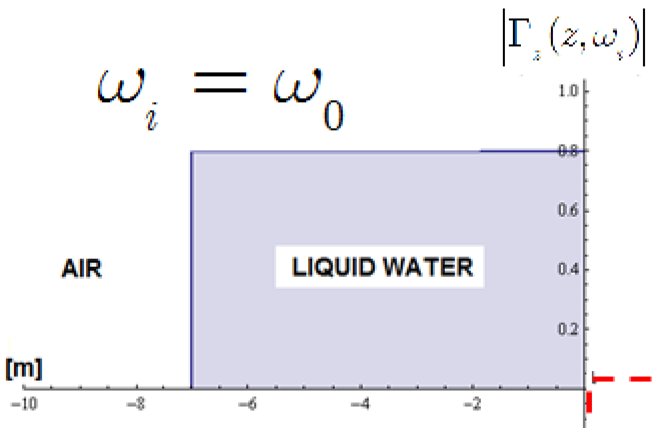
$$\Gamma_z(z,\omega) = \frac{V_0^-(\omega)}{V_0^+(\omega)} e^{+2\gamma(\omega)z}$$

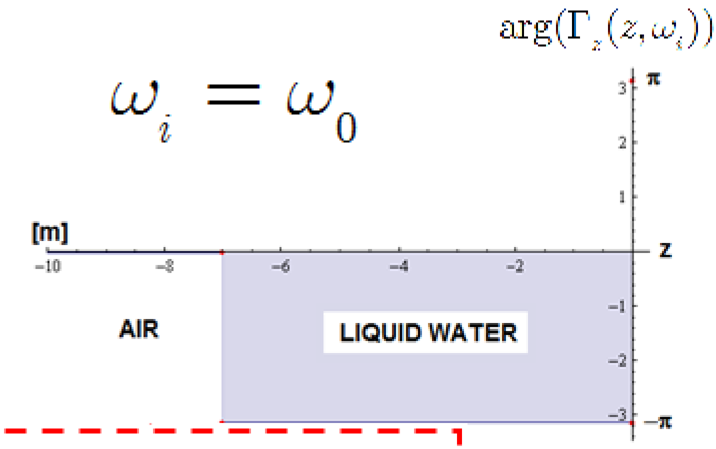


injected signals: rectangular impulsive with δ =100 ns and T=1/f0, f0 = 100 kHz)

Theoretical signal analysis

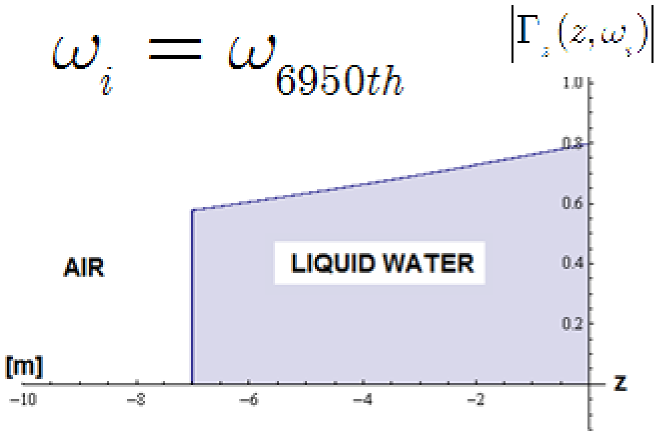
Sensor length 10 m, PTA conditions, water-air interface at 7 m from end, stainless steel AISI 316, rb ≅ 2.3 ra

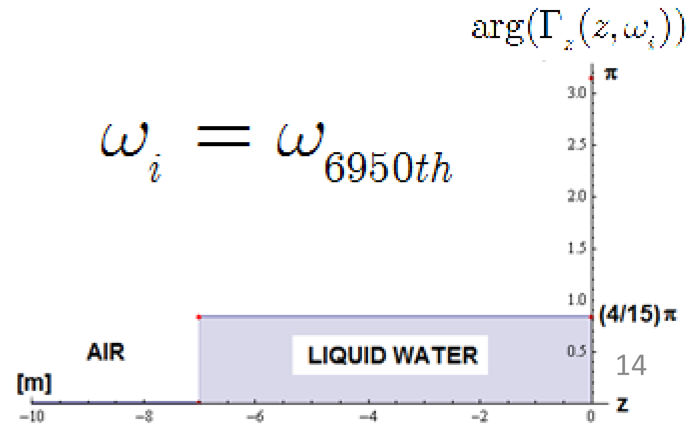




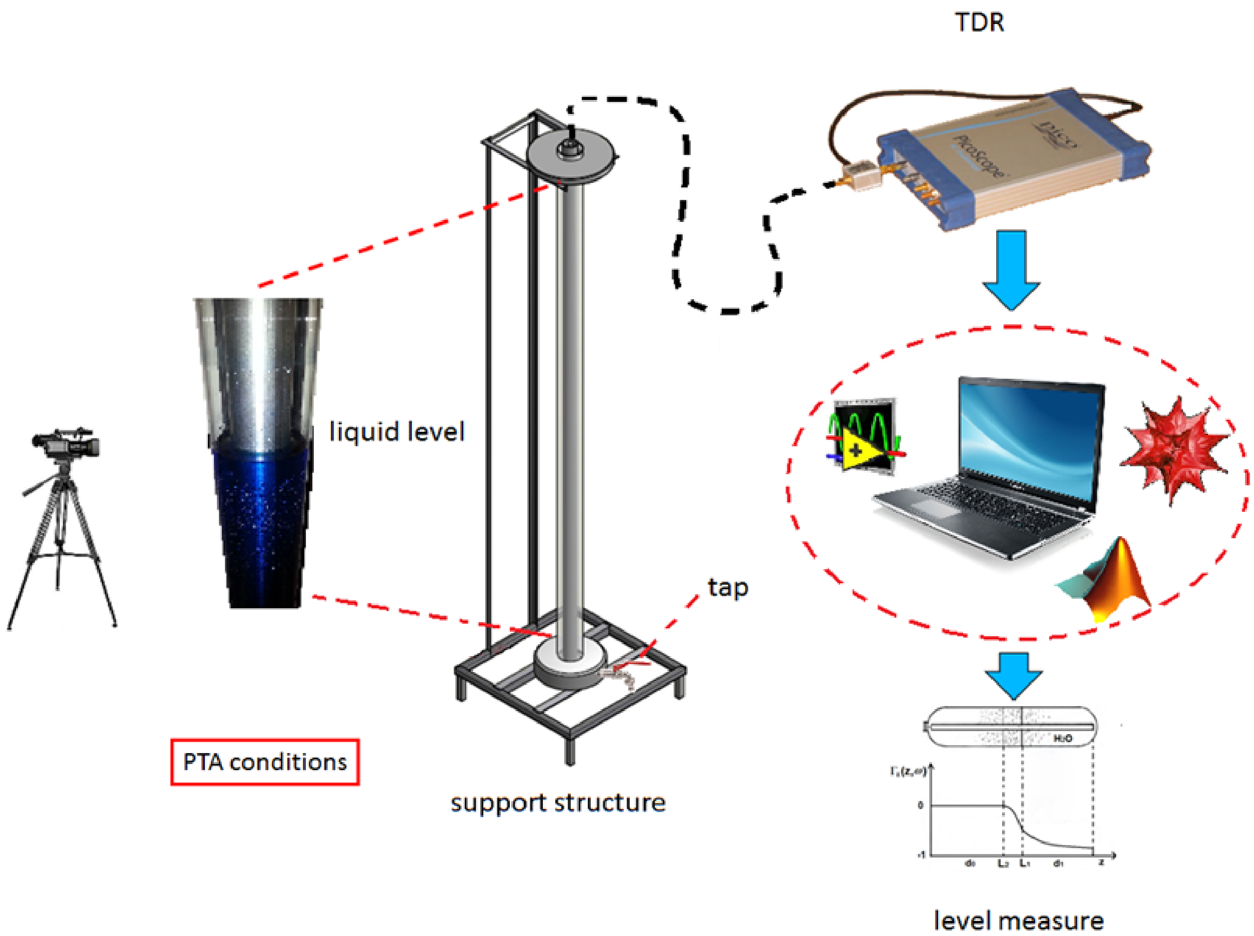
Generalized Reflection Coefficient:

$$\Gamma_z(z,\omega) = \frac{V_0^-(\omega)}{V_0^+(\omega)} e^{+2\gamma(\omega)z} = \frac{Z_L - Z_0}{Z_L + Z_0} e^{+2\gamma(\omega)z}$$





Experimental test at PTA



No hydraulic loop, the sensor is loaded at PTA conditions (standard ambient temperature and pressure conditions) with water until a fixed level (optically measurable).

Experimental test at PTA

overlapped part of the 4 different static experiments

Different "static" level measurements (from right to left:

- baseline in air
- 10.5 cm
- 20.5 cm
- 40 cm of water at PTA)

Calibration procedure:
velocity ratio **k** determination

$$v_p = \frac{c_0}{\sqrt{\varepsilon_r \mu_r}} \Rightarrow k = \frac{v_p}{c_0}$$

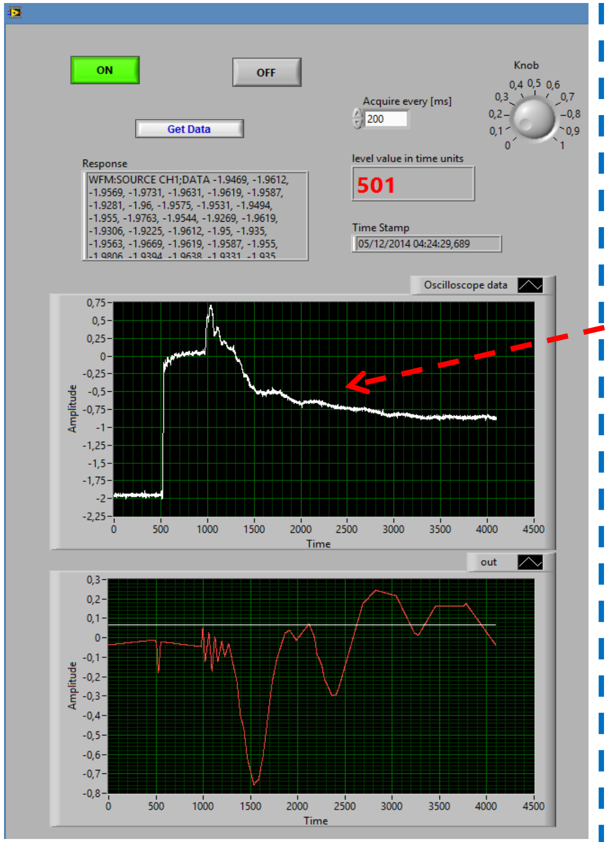
$$L = v_p \frac{\Delta t}{2} = \frac{1}{2} \boxed{k} c_0 \Delta t$$

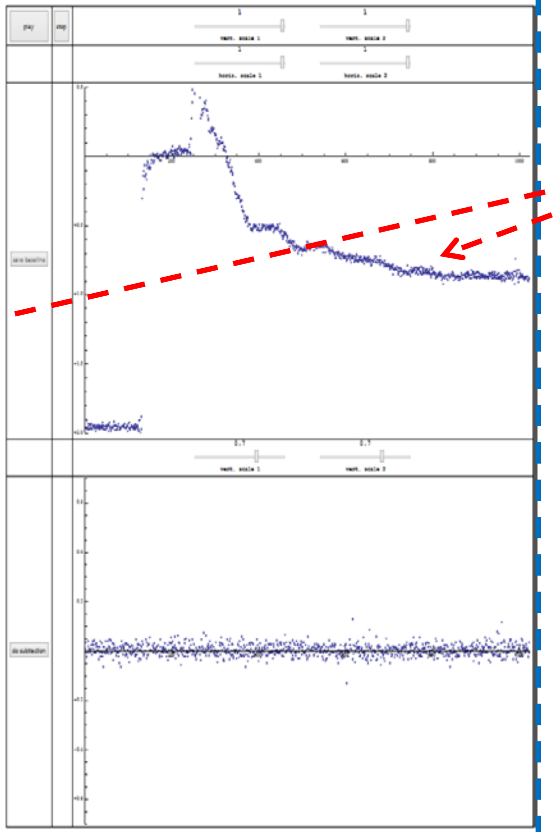
level measure equation

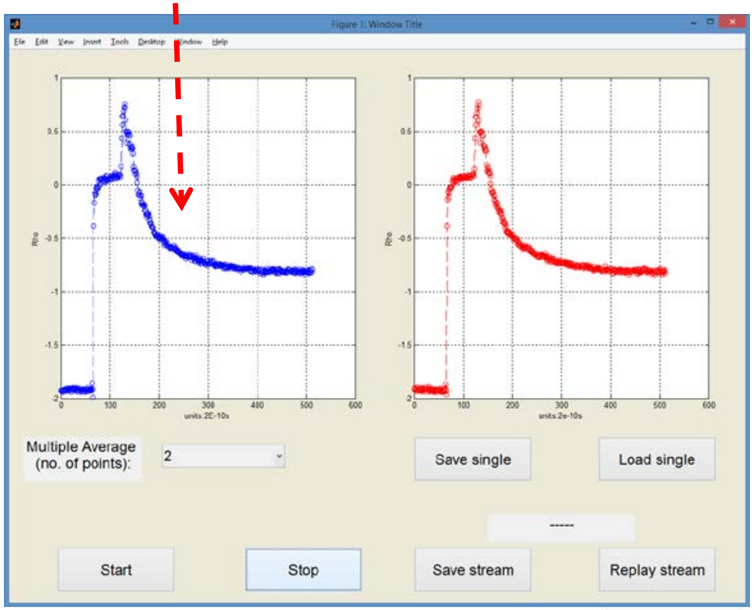
measure no. n	optical measure [mm]	delay time between measure n and n-1 [ns]	velocity ratio k
1	0	--	--
2	105	(2-1): 0.798	0.501
3	255	(3-2): 1.020	0.490
4	400	(4-3): 0.915	0.528
5	550	(5-4): 1.072	0.466
6	700	(6-5): 0.955	0.524
7	845	(7-6): 0.968	0.500
8	990	(8-7): 0.968	0.499
9	1140	(9-8): 0.955	0.524
10	1290	(10-9): 0.994	0.503

Experimental test at PTA

Experimental reflection coefficient:







LabVIEW + Matlab

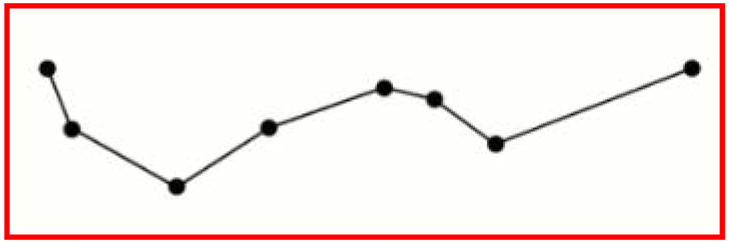
Wolfram Mathematica

Matlab

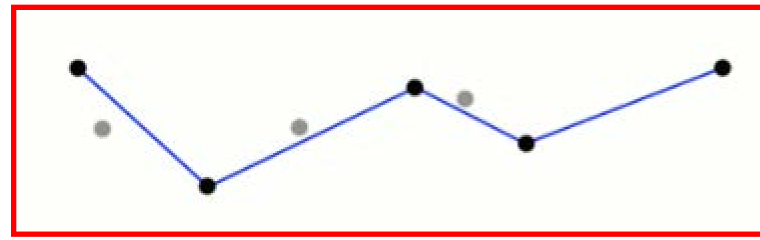
TDR level measurement algorithm implementation on multiple software platforms

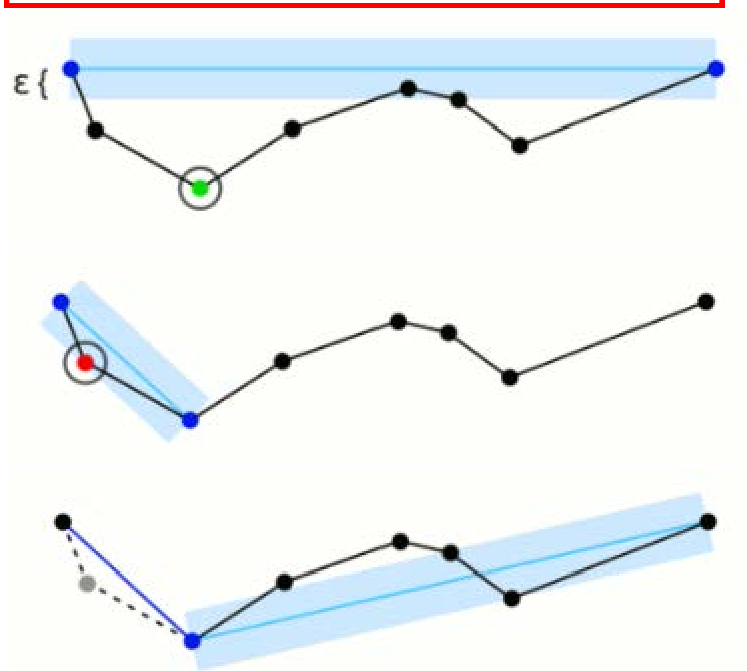
Ramer Douglas Peucker algorithm

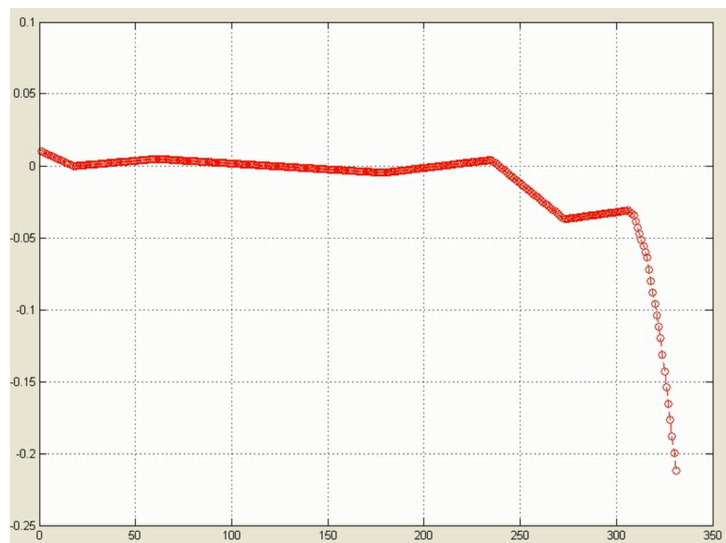
After having obtained the signal difference between the signal and the baseline in air, filtered it and normalized it, the Ramer Douglas Peucker (RDP) algorithm is applied for reducing the number of points still maintaining the basic features of its shape:



... recursive ...

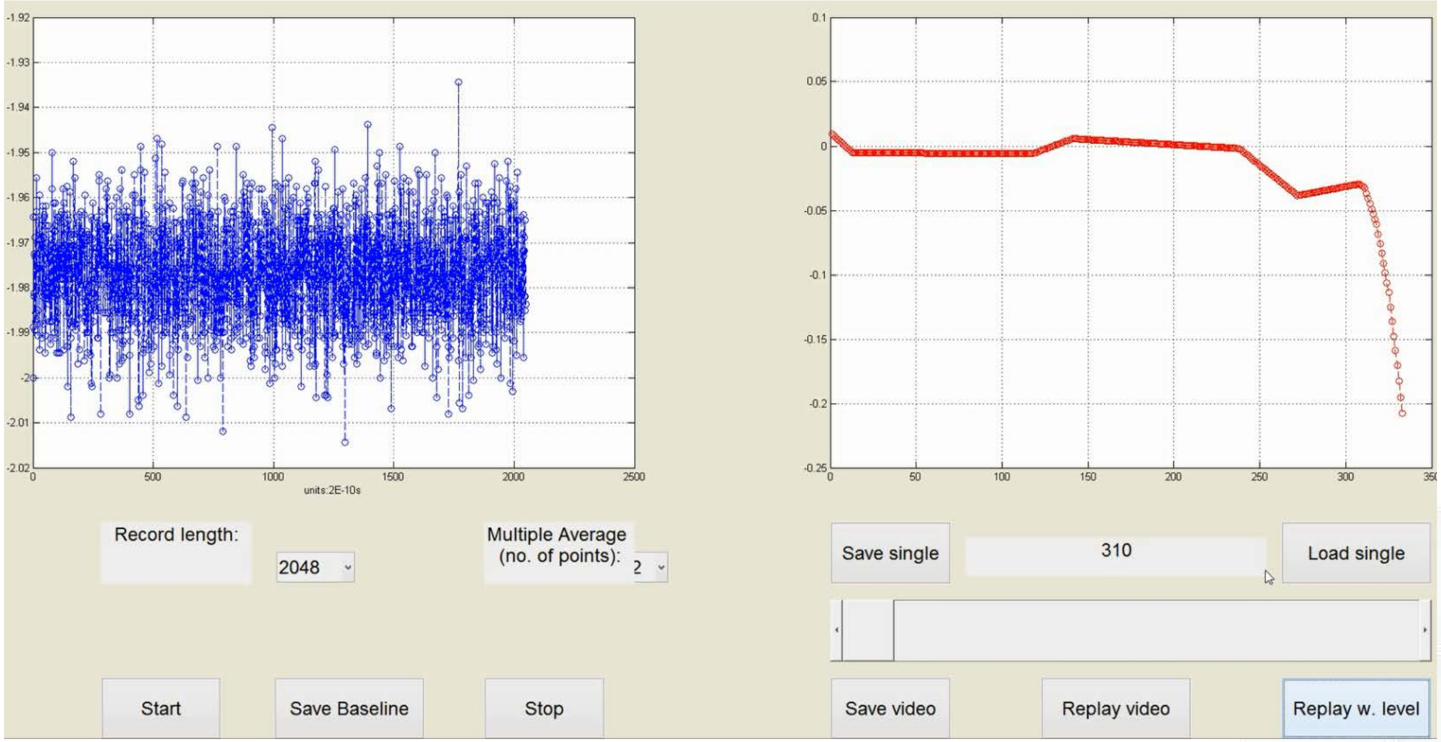






Serializing / deserializing data with MATLAB

Since the RDP algorithm takes time to be executed, in order to save each experimental data set in the fastest way it's possible, it's possible to use two undocumented functions of MATLAB applied to the raw data.
Two undocumented built-in functions **getByteStreamFromArray** and **getArrayFromByteStream**, used internally by the save and load functions may be used to save and replay the experimental data:



Conclusions

- The OTDR for the radiation effects study on optical fibers has several common points with the TDR technique
- TDR applied to OTSG (e.g. bayonet type) shows that it's a <u>feasible</u> approach, quick in response and non invasive
- The preliminary experimental phase at PTA both in static and dynamic conditions fits well with the proposed theoretical model
- The Ramer Douglas Peucker algorithm together with two undocumented MATLAB functions was used to analyse the experimental data
- The experimental phase test at PTE is still to be conducted

Questions & Answers