Matched Pulses to Improve Fault Detection in Wire Networks

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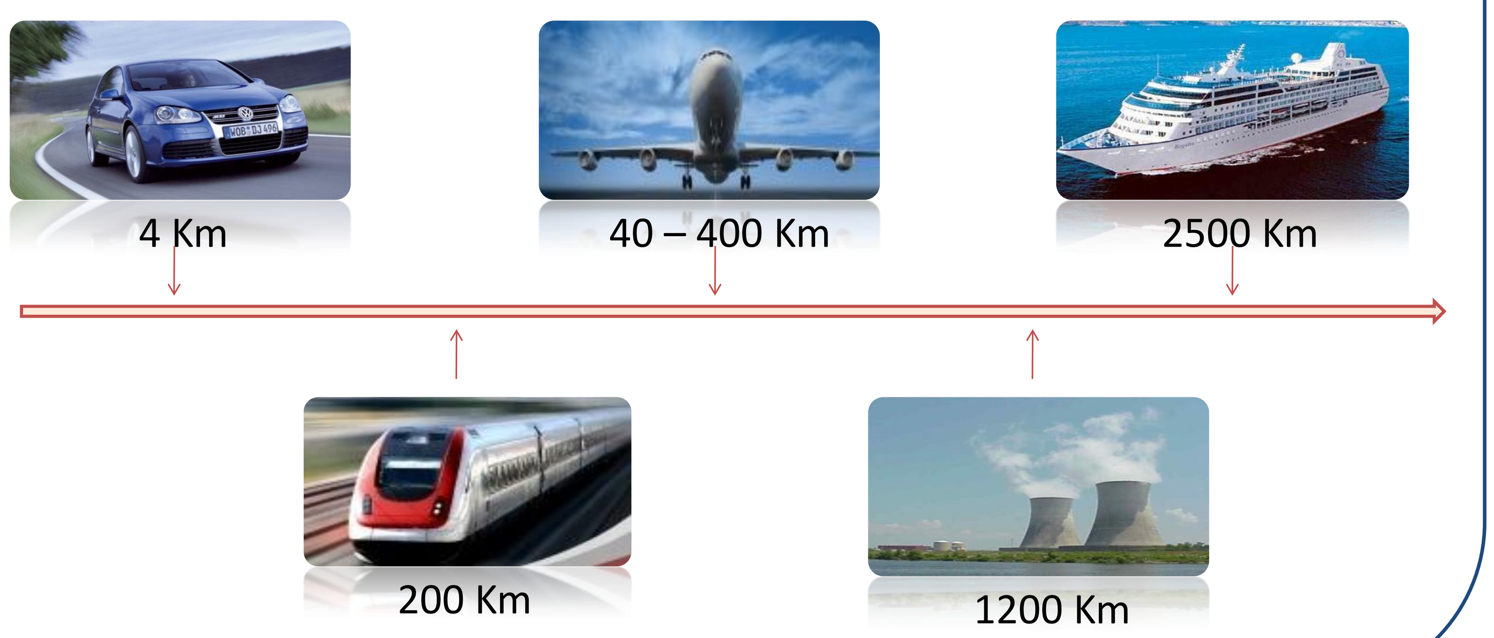
1 - Introduction

Wired systems are everywhere ➡ Problems of security and maintenance cost related to faulty electrical wiring

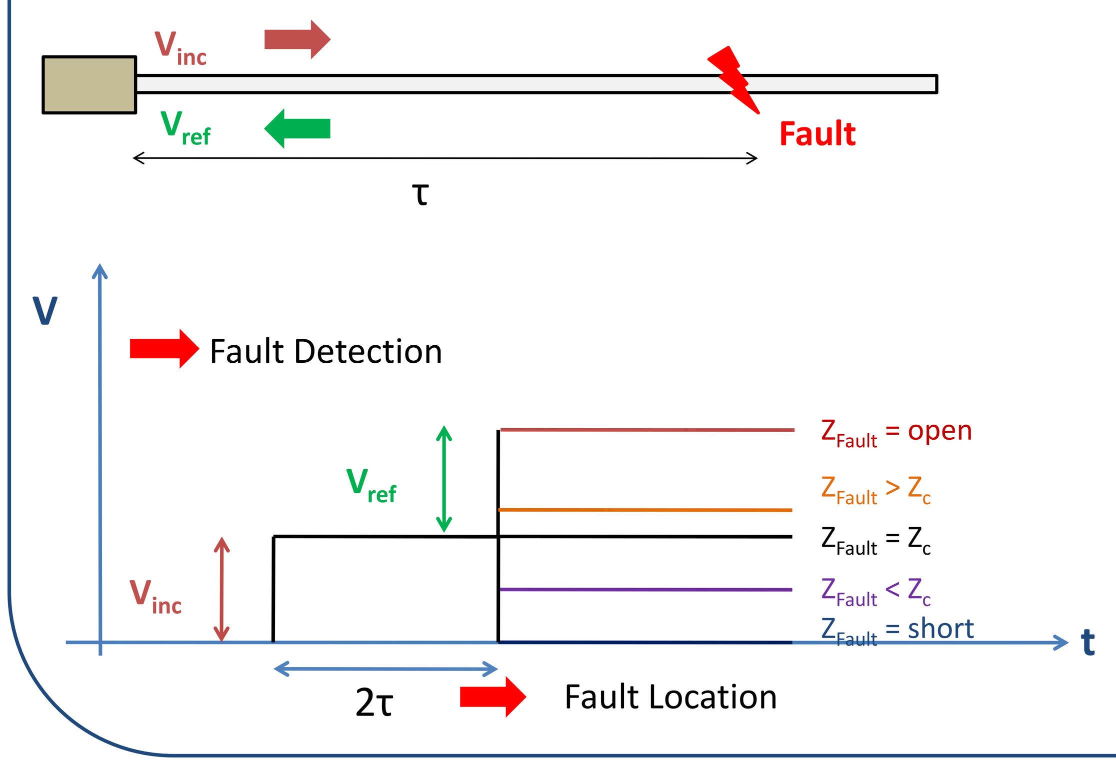


2 – Existing Reflectometry methods

Principle :

1 – Inject a predefined testing signal in the system under test

2 – Analyze the reflected signal to determine the fault's value and position



Limitations:

Faults → Hard (generally detectable)
→ Soft (difficult to detect)

Wire networks

Faults can be masked by discontinuities

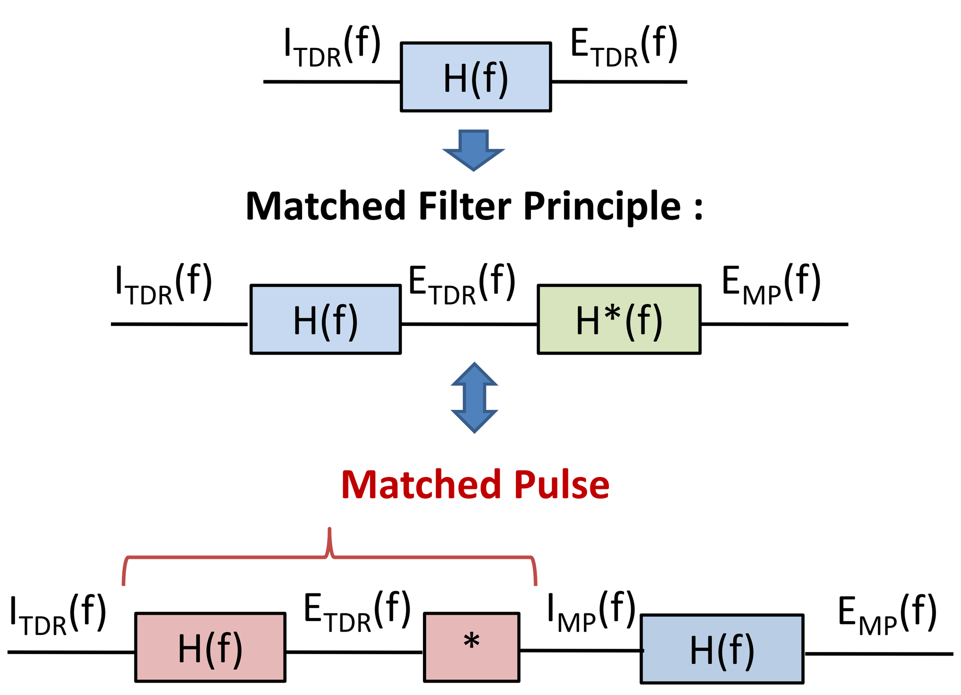
Reflections disperse the energy of the fault's echo

3 – The Matched Pulse approach (MP)

Purpose : increase the detection probability of an eventual fault

Idea : adapt the testing signal to the network under test

The Matched Pulse approach (MP) based on the properties of Time Reversal



$I_{TDR}(f)$: testing signal in the frequency domain

$E_{TDR}(f)$: received signal (echo) in the TDR case

$E_{MP}(f)$: echo in the MP case

H(f) : transfer function of the difference system (with and without the fault)

4 – Mathematical analysis

The normalized energy of the TDR echo:

$$\mathcal{E}_{\mathrm{TDR}}(f)=\frac{\int|E_{TDR}|^2\mathrm{d}f}{\int|I_{TDR}|^2\mathrm{d}f}=\frac{\int|H(f)|^2|I_{TDR}(f)|^2\mathrm{d}f}{\int|I_{TDR}|^2\mathrm{d}f}$$

The normalized energy of the MP echo:

$$\mathcal{E}_{\mathrm{MP}}(f)=\frac{\int|E_{MP}|^2\mathrm{d}f}{\int|I_{MP}|^2\mathrm{d}f}=\frac{\int|H(f)|^4|I_{TDR}|^2\mathrm{d}f}{\int|H(f)|^2|I_{TDR}|^2\mathrm{d}f}$$

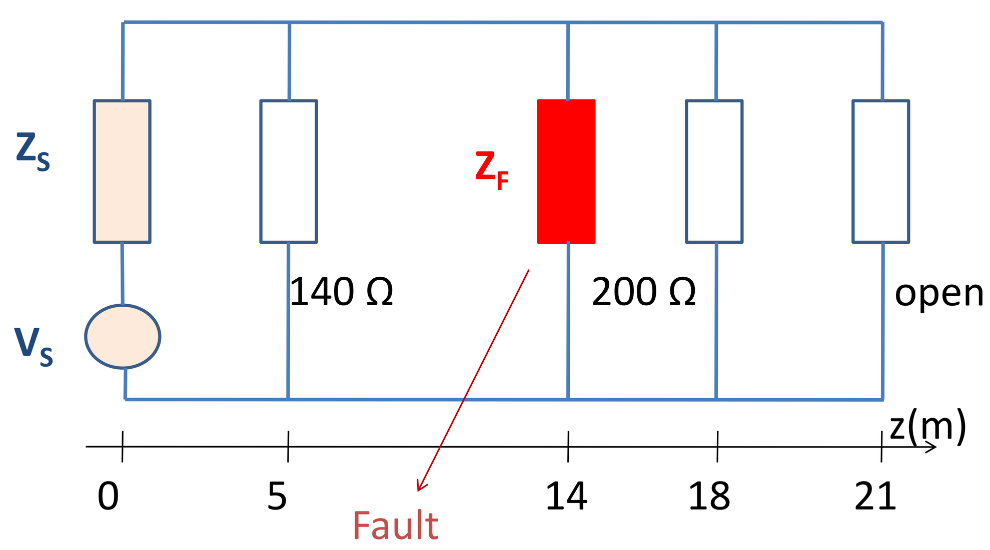
Gain of the normalized echo energies of the TDR and MP:

$$G=\frac{\mathcal{E}_{\mathrm{MP}}(f)}{\mathcal{E}_{\mathrm{TDR}}(f)}$$

➡ **G ≥ 1**

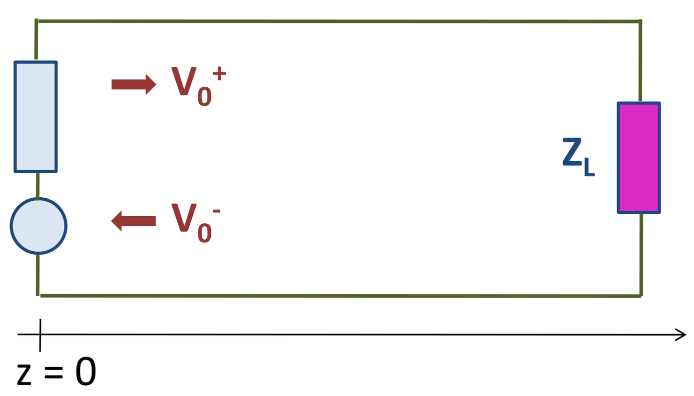
5 – Parametric study

Analyzed configuration



- Uniform Lossless Transmission Line
- Characteristic impedance of the Line Z_C =75 Ω
- Adapted source ($Z_S = Z_C$)
- Bandwidth = 300 MHz

Simulation method



$$V(z)=V_0^+\exp(-j\gamma z)+V_0^-\exp(j\gamma z)$$
$$I(z)=I_0^+\exp(-j\gamma z)-I_0^-\exp(j\gamma z)$$

V_0^+ and V_0^- : modal voltages

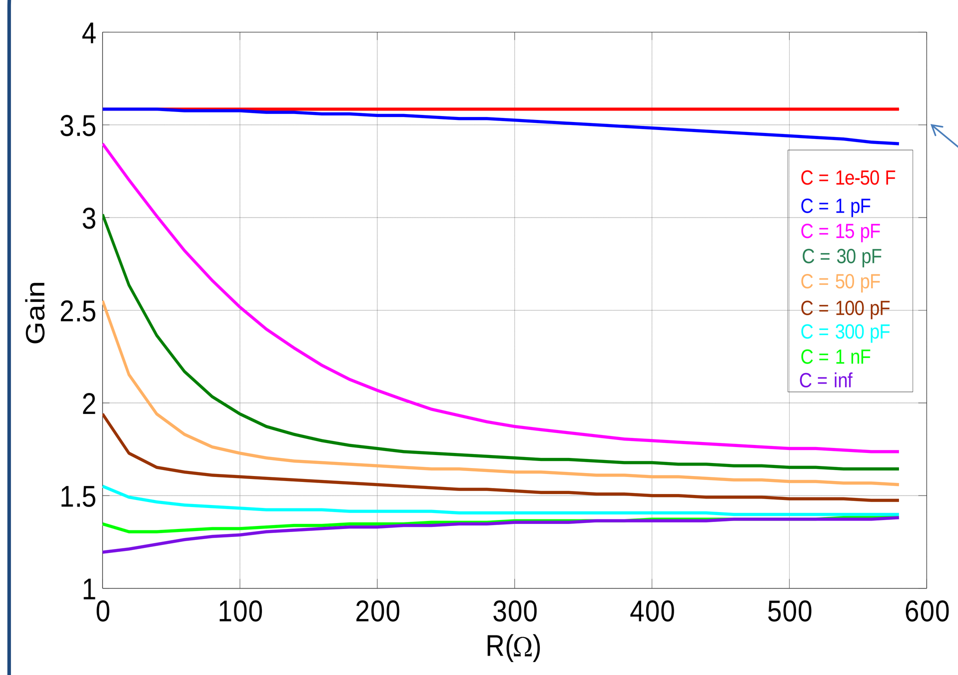
I_0^+ and I_0^- : modal currents

γ : propagation constant

6 – Numerical results

The values of **G** in terms of the fault's impedance values :

$$Z_F=R+\frac{1}{j\omega C}$$



For small values of C, the value of R does not influence $G(Z_F)$

Dispersion introduced by the capacitance C

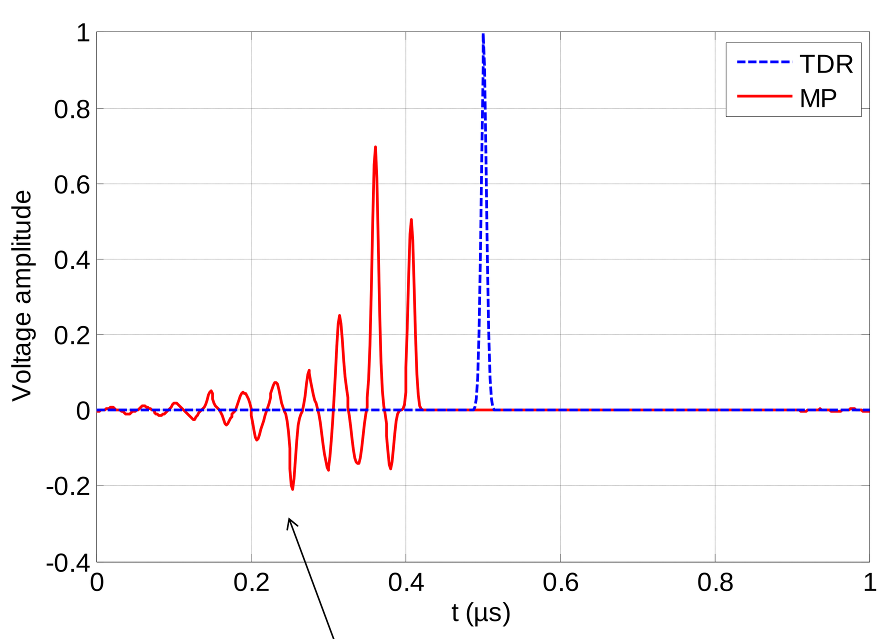
1/τ = 1/RC = cutoff frequency of Z_F

When 1/τ starts to reduce the bandwidth of the injected signal, the gain starts to decrease.

7 – Physical Interpretation

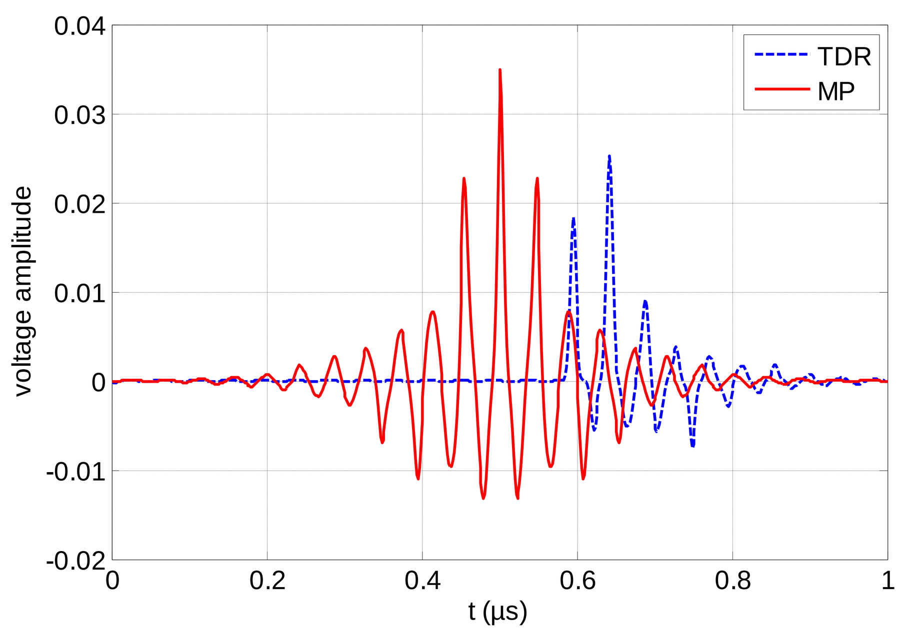
Soft fault R = 600 Ω ➡ | Γ_F | = 0.059

Injected signals in the TDR and MP cases :



Its shape will contribute to maximize the energy of the echo from the fault to be detected

Echoes :



Primary peak / secondary peak :

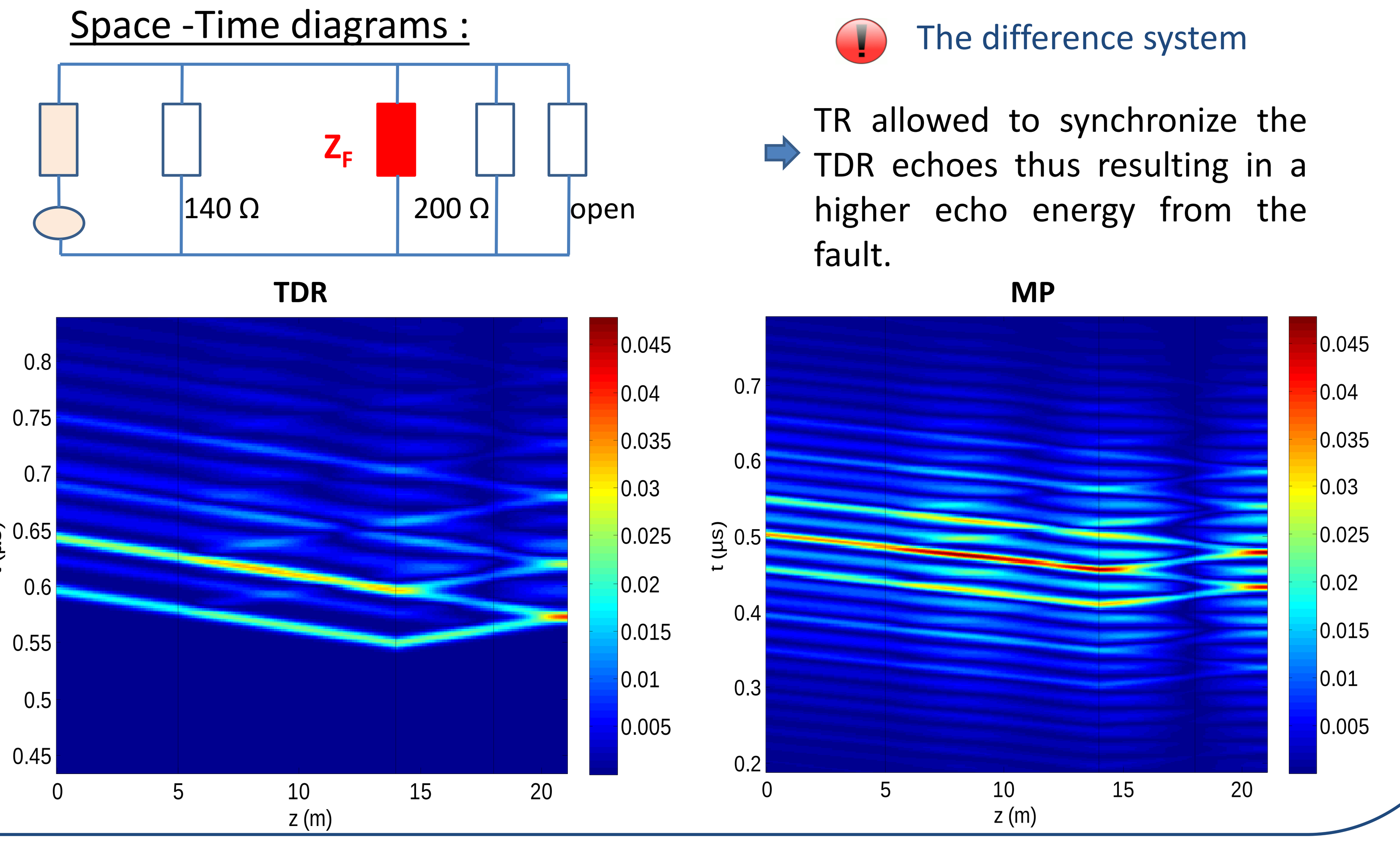
MP : 1.53

TDR : 1.38

MP peak / TDR peak = 1.39

MP correlation peak / TDR correlation peak = 2.21

Space -Time diagrams :



The difference system

➡ TR allowed to synchronize the TDR echoes thus resulting in a higher echo energy from the fault.

8 – Conclusion

➢A new approach to fault detection in wire networks was presented

➢ It results in a higher echo energy when compared to TDR

➢ A physical interpretation was proposed

9 - Perspectives

➢Study the impact of the network topology on the MP performance

➢ Experimental measurements

➢ Apply the MP approach to fault location

10 - References

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