The use of pulse shape in PD testing of cable systems using VLF

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Introduction

Hipot VLF testing of power cable systems is widely used for condition assessment of Medium Voltage networks:

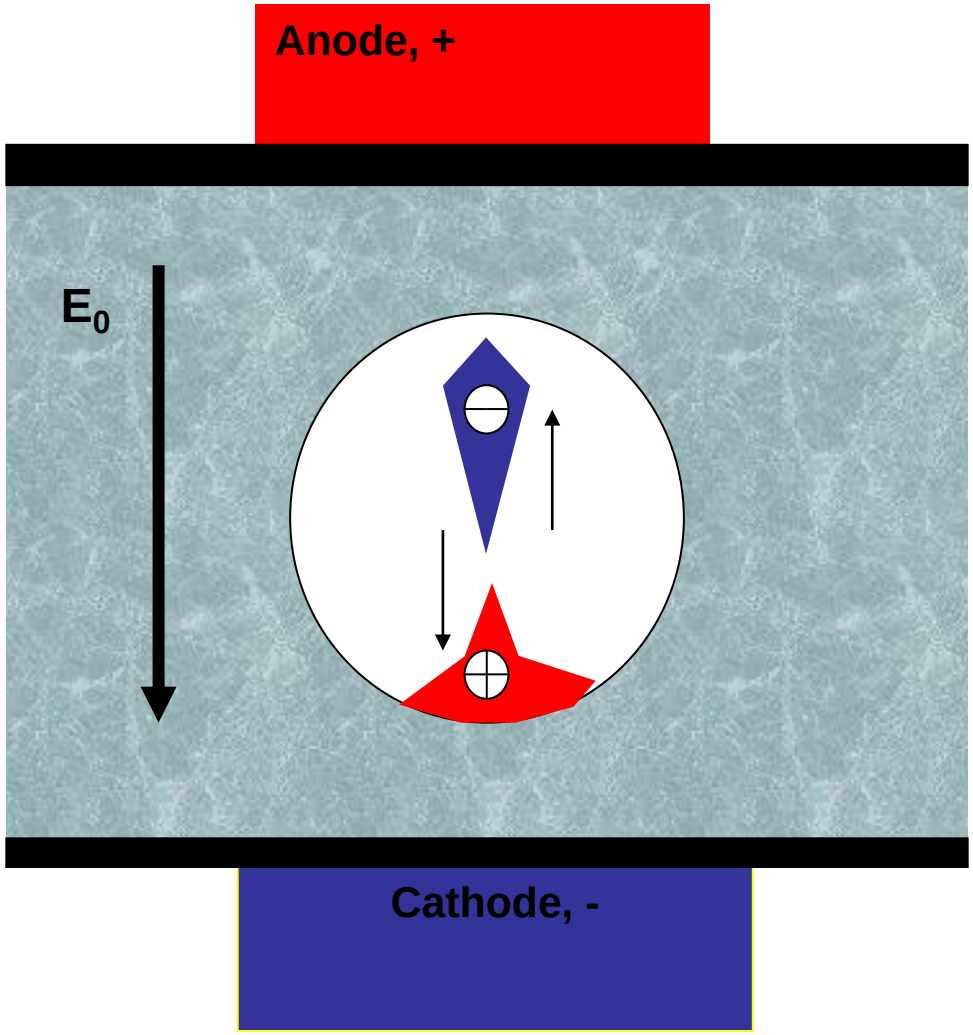
- **Compact generators are able to test several km of distribution feeder**
- **VLF does not lead to significant space charge accumulation in polymer-insulated cables (space charge accumulation time is longer than VLF half-cycle)**
- **Combined PD and VLF test detects and localizes the presence of local defects which may not break down the insulation during the VLF test**

What happens during a PD? (1)

The PD transfers:

- Electrons to the cavity surface acting as anode

- Positive ions to the cavity surface acting as cathode



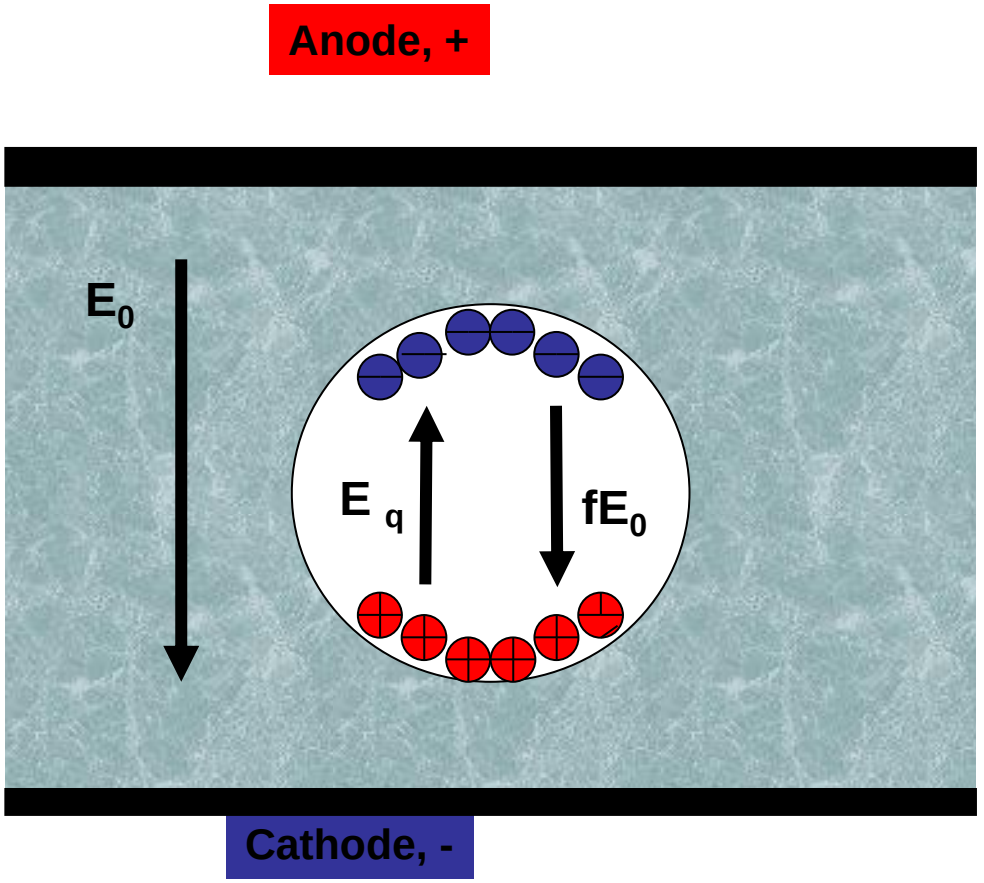
What happens during a PD? (2)

This charge distribution generates a local field E_q

The local field has opposite sign to the external field (i.e., due to the external source), fE_0.

Thus, the local field reduces the internal field (i.e., the field inside the cavity).

$$E_i = fE_0 - E_q$$



I.e. **deployed charge prevents other PD to occur**, until

1) Charge relaxes, or
2) Polarity is reverted (which increases the internal field)

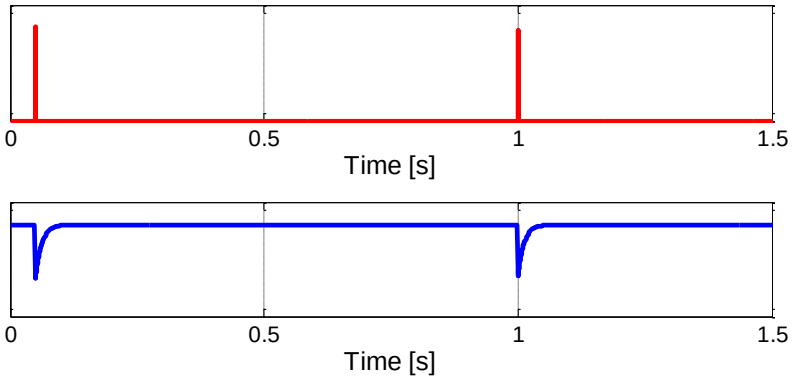
Main differences between PD under DC and AC

DC:

Voltage constant → Low repetition rate (typically one discharge per second or less)

- **Charge from previous PD reduces the internal field;**
- **No polarity inversions;**

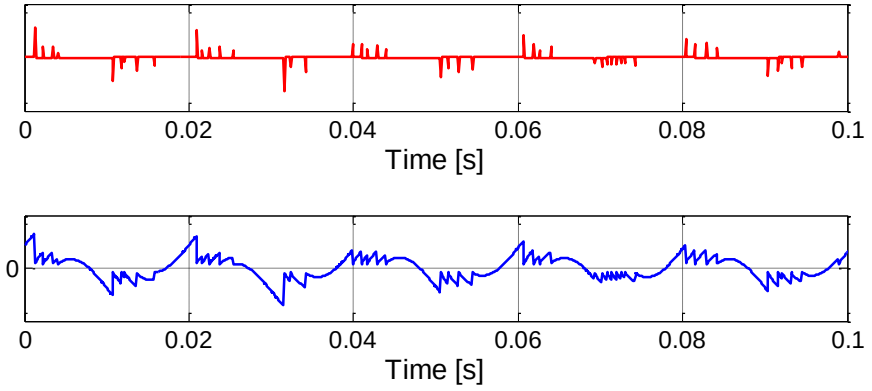
I_{PD}= PD current pulses E_i = Field inside the cavity



AC or varying voltage:

Sinusoidal voltage at industrial frequency → Repetition rate is generally higher than under DC (up to hundreds of pulses per second), due to:

- **Time varying background field;**
- **Polarity inversions;**



What about VLF ?

- **Internal PD have much smaller repetition rate at VLF than at 60 Hz (intermediate behavior between DC and AC)**
- **Electromagnetic noise and external disturbances are also present**
- **PD testing at VLF requires advanced noise rejection techniques**

Case Study: MV feeder, on-line and VLF off-line PD test

Apparatus: Medium voltage cable feeder
Voltage level: 25kV
Location: USA

Application of PD phenomena separation by T-F mapping, on-line and at sinusoidal VLF PD. Localization through TDR method

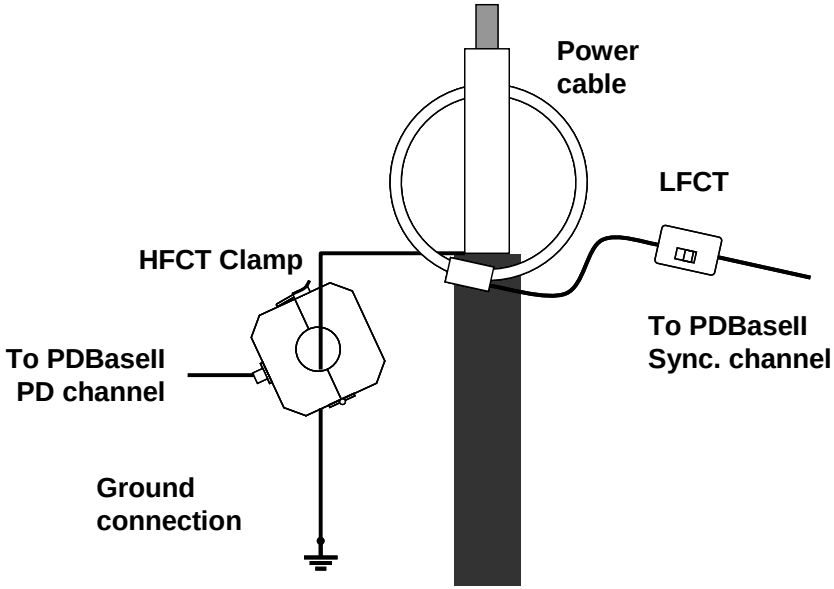
1. Measurement Setup

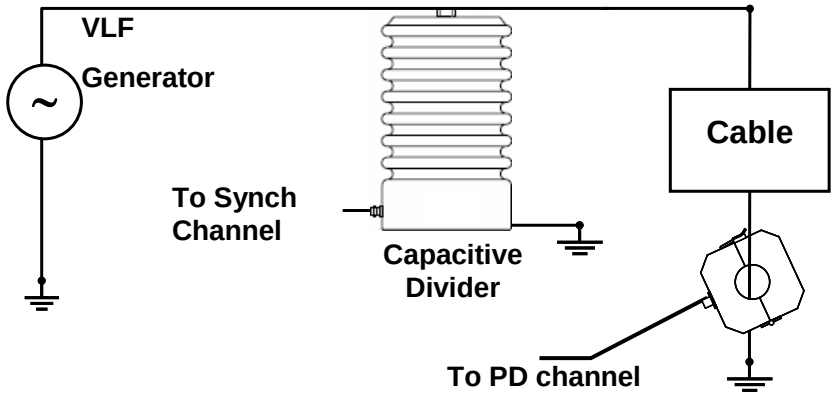
PD signals:

HFCT (High Frequency Current Transformer) clamped around the ground lead of the cable termination

Synchronization signal:

- ❑ through a Low Frequency Current Transformer clamped around the cable termination for on-line measurement
- ❑ through a capacitive divider for the off-line VLF test (VLF scope output can be used as well if available)



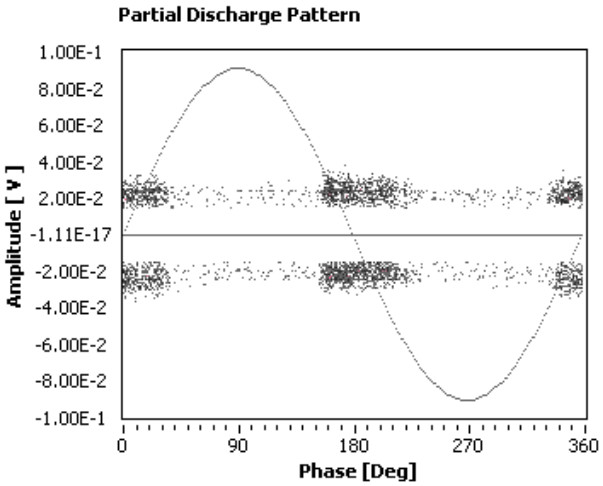


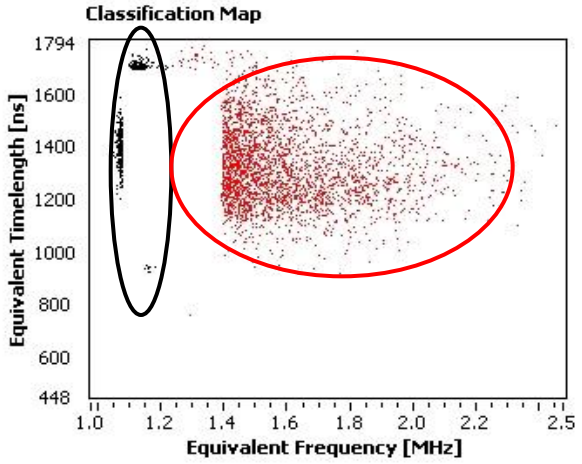
2. On-line test

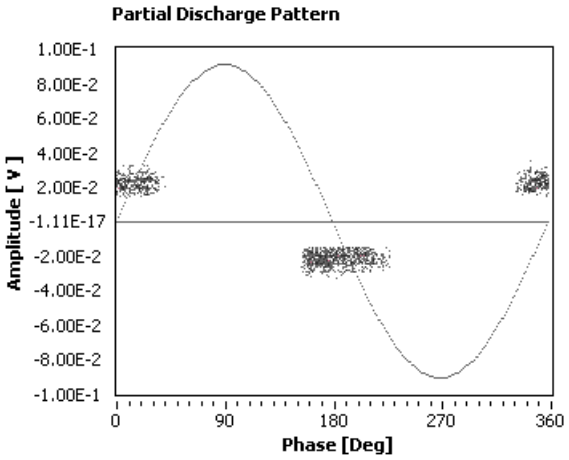
Step 1: On-line 14kV (phase to ground) @ 60 Hz;

Power supplied by the grid (no loads connected)

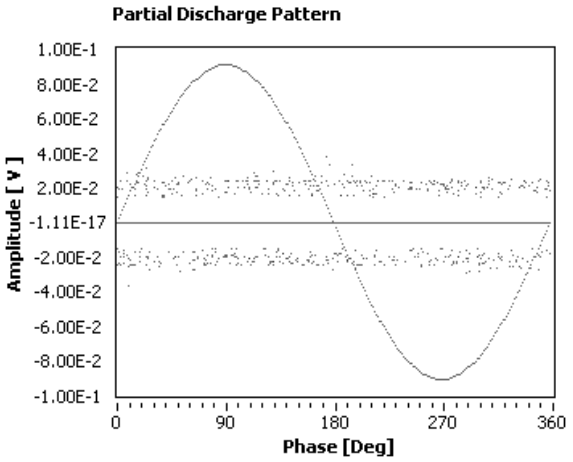
Noise level is high (SNR ≈ 1), TF map allows to separate patterns







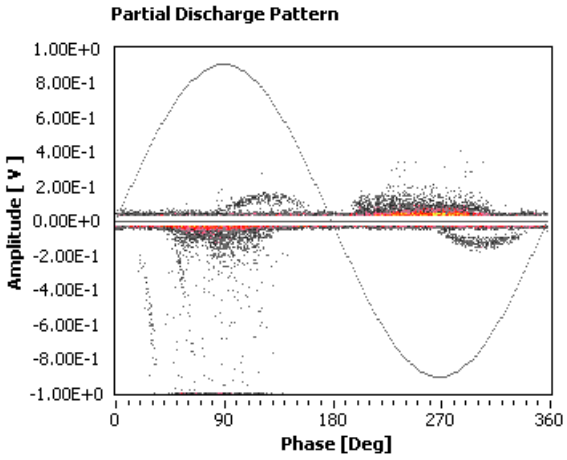
Red Cluster (Internal PD)

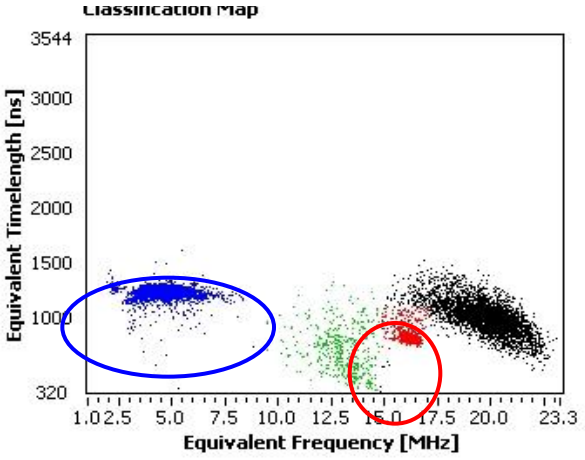


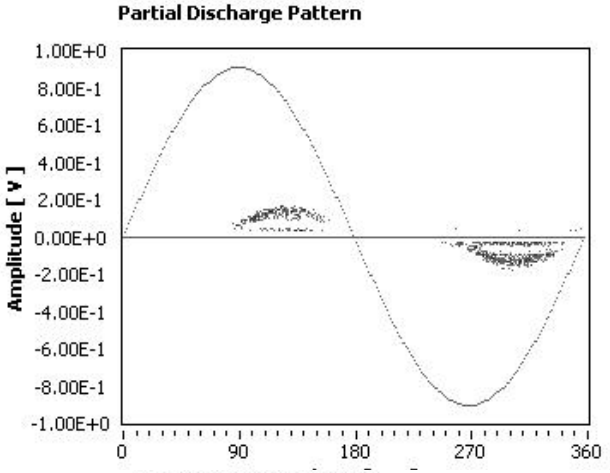
Black Cluster (Background noise)

3. Off-line VLF test

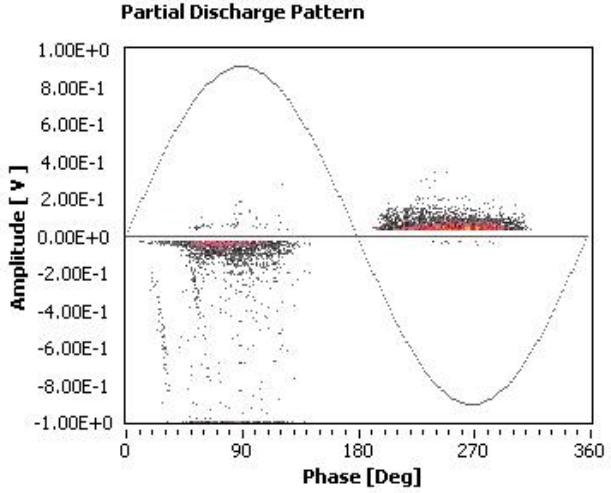
Step 2: Off-line 23kV (phase to ground) @ 0.1 Hz (sine-wave compact VLF unit);
During off-line test the background noise is much lower than on-line (cable disconnected from the grid), but disturbances from VLF arise.
PD activity is detected off-line as well, together with other phenomena.







Internal PD
(Red cluster)

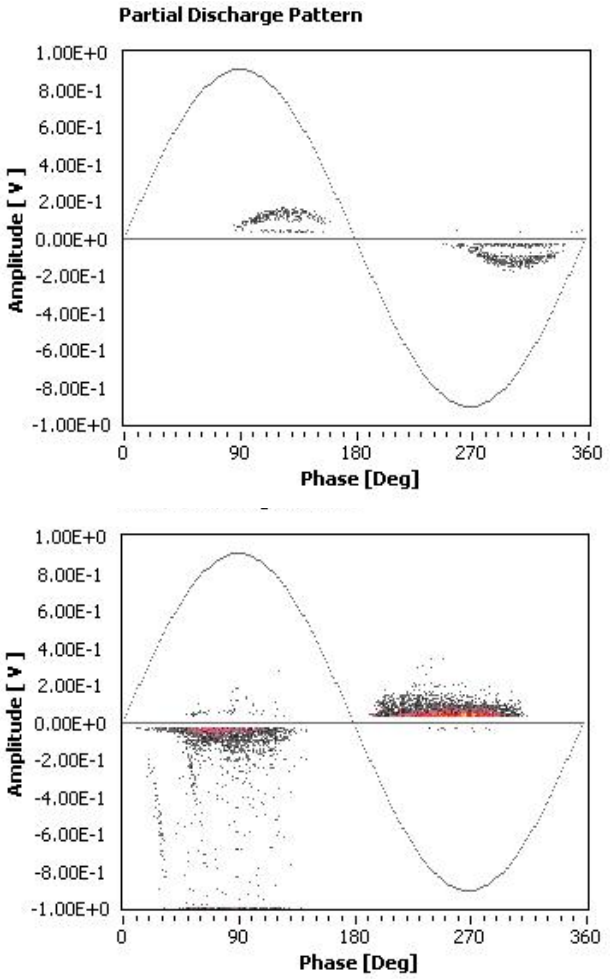


Disturbance
from VLF Unit
(blue cluster)

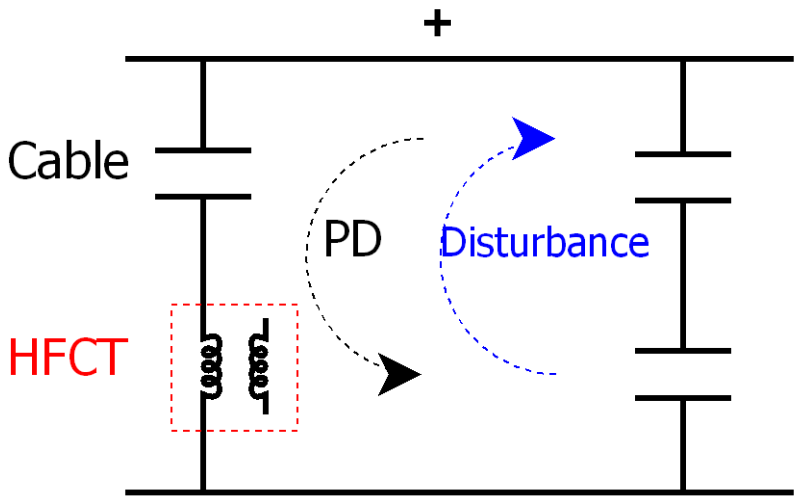
2. Off-line test

Comment:

Using HFCT (around the ground lead) as sensor and UWB detector allows the information provided by the PD pulse polarity to be used to understand if detected pulses are generated inside or outside the EUT



Internal PD (Direct Polarity)

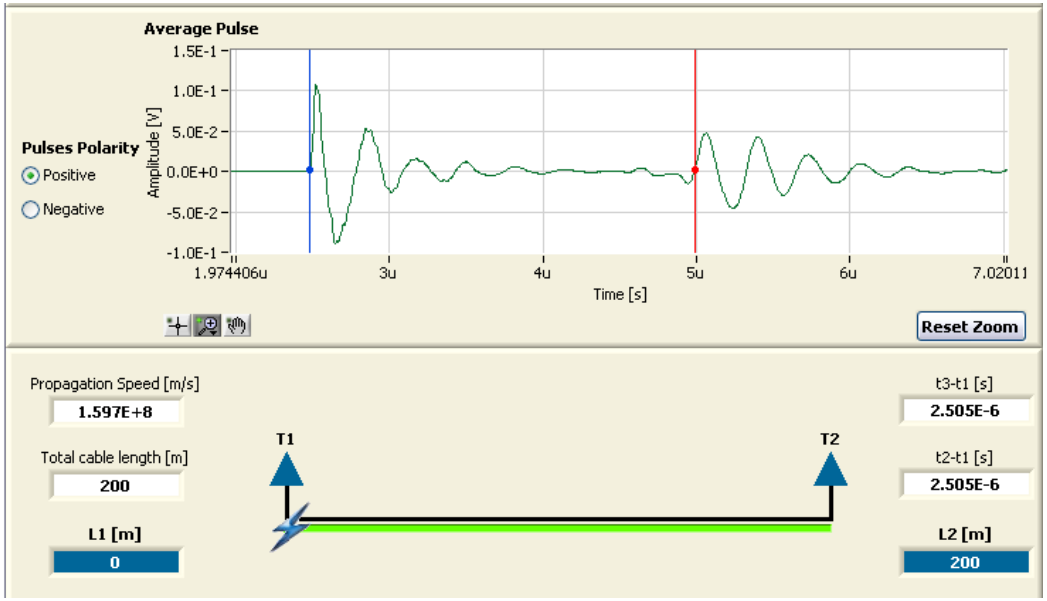


Disturbance (Opposite polarity)

3. Off-line VLF test

TDR Location: 1) Evaluation of cable length

- Thanks to the separation capability it is possible to apply the TDR location tool to homogeneous clusters of pulses (i.e. groups of pulses all coming from the same source).
- In a first step the TDR tool is applied to disturbance pulses coming from the VLF generator in order to evaluate cable length and / or to check the cable propagation speed.

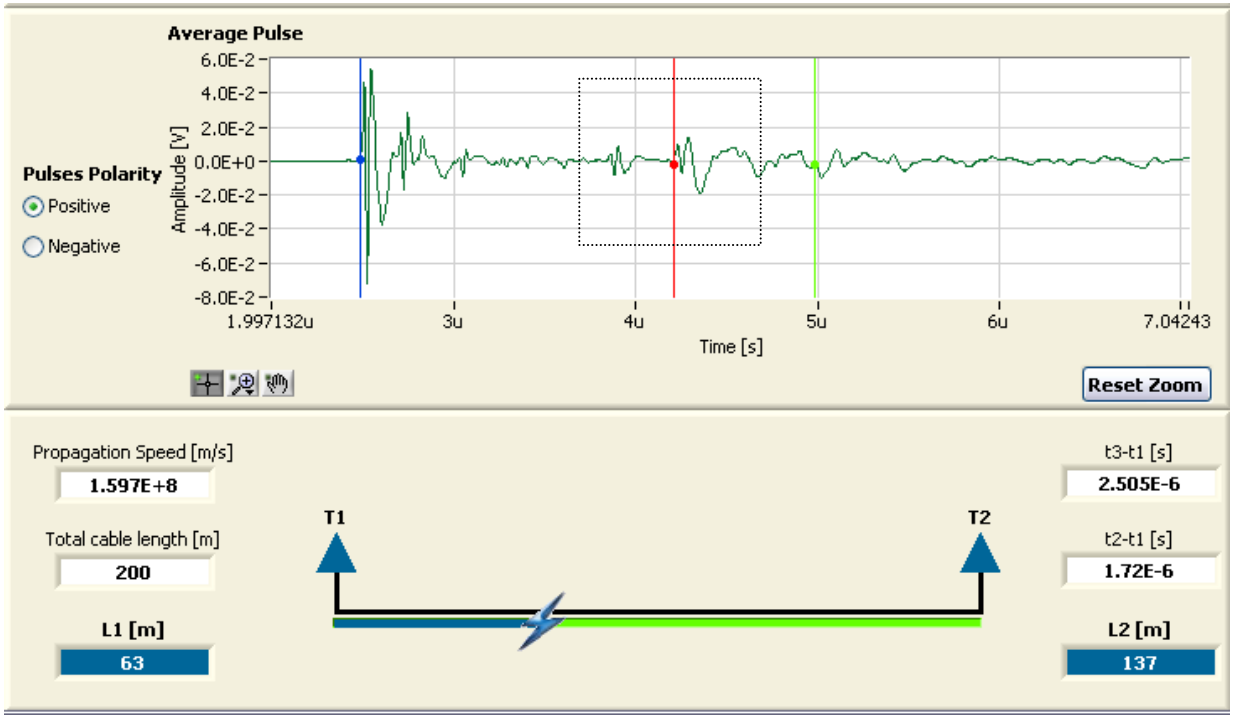


The length of the cable under test found to be longer than given by the customer (650 ft, instead of 500 ft)

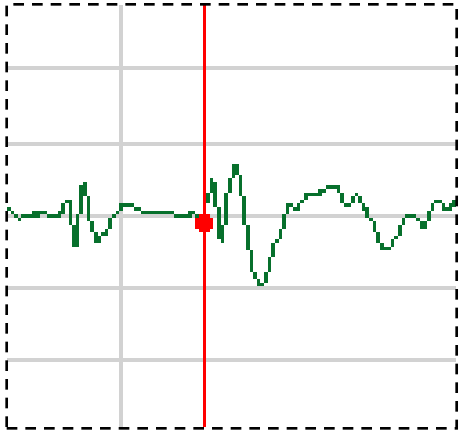
3. Off-line VLF test

TDR Location: 2) PD Source

After checking cable length it is possible to apply the TDR localization tool to the PD source. Just need to place a third cursor on the biggest intermediate reflection



PD was located at 63 m from the measurement point



Conclusions

- Combining PD testing with VLF withstand allows for PD source localization
- Combining PD testing with VLF allows for testing at lower voltages, minimizing any risk of damage during the VLF test
- Using PD with a VLF source, compared with a 60 Hz power source, provides the same PD information with a smaller, more compact, test system
- The use of information provided by the PD pulse shape (only possible through UWB PD analyzers) is very important in order to perform:
  - Enhanced **noise rejection**
  - **Separation** of PD signals from disturbances
  - **PD source location** through TDR technique

Thank you !