Introduction to Cable Fault Location on MV cables

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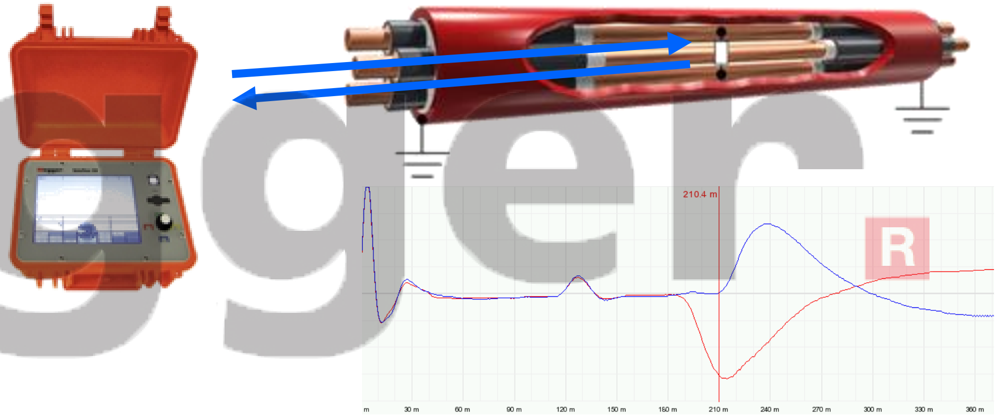
Cable Fault Locating
TDR Prelocation

(Time Domain Reflectometry)

Megger

Principles of the Time Domain Reflectometry (TDR Technology)

- The TDR works on the same principle as a radar unit
- The pulse travels down the cable. The pulse is reflected on each changing of the impedance and travels back to the TDR
- The TDR then converts this time to the distance



Propagation Velocity and Distance

$$l_x = \left(\frac{v}{2}\right) \cdot t_x$$

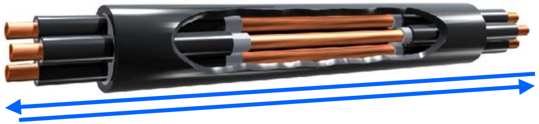
$\left(\frac{v}{2}\right)$ Half of propagation velocity

v Propagation velocity of the electric impulse

t_x Propagation time of the impulse to the end of the conductor and back

l_x Length of the conductor

Propagation Velocity and Distance



Cursor Position at different Propagation Velocities :

212 m at v/2 = 80.0 m/µs

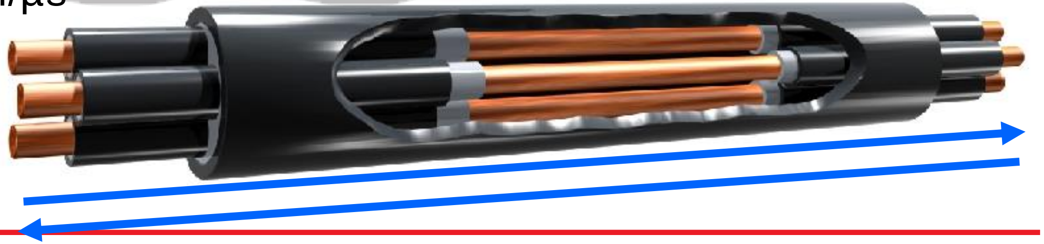
199 m at v/2 = 75.0 m/µs

238 m at v/2 = 90.0 m/µs

Propagation Velocity of an Electrical Pulse

Propagation velocity v/2 (m/µs):

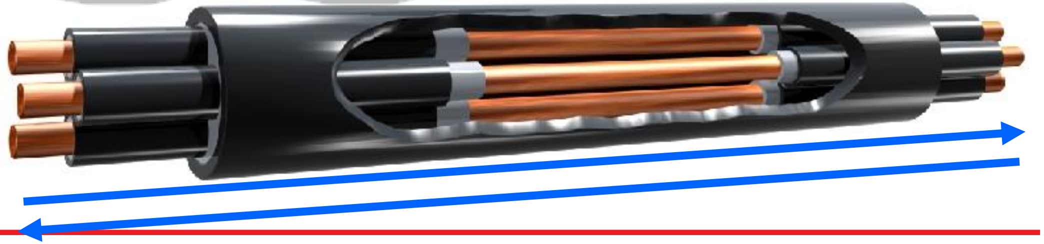
PILC	80 m/µs (77-82 m/µs)
PVC	78 m/µs (70-80 m/µs)
XLPE	85 m/µs (82-86 m/µs)
mixed line	83 m/µs
Telecom cable	95 – 120 m/µs
Overhead line	147.5 m/µs



Propagation Velocity Influences

Factors that affect Propagation Velocity:

- Impedance
- Dielectric (colour, type of insulation)
- Age of the cable
- Temperature
- Water   v/2 = approx. 65 m/µs
- Position of the cores inside the cable

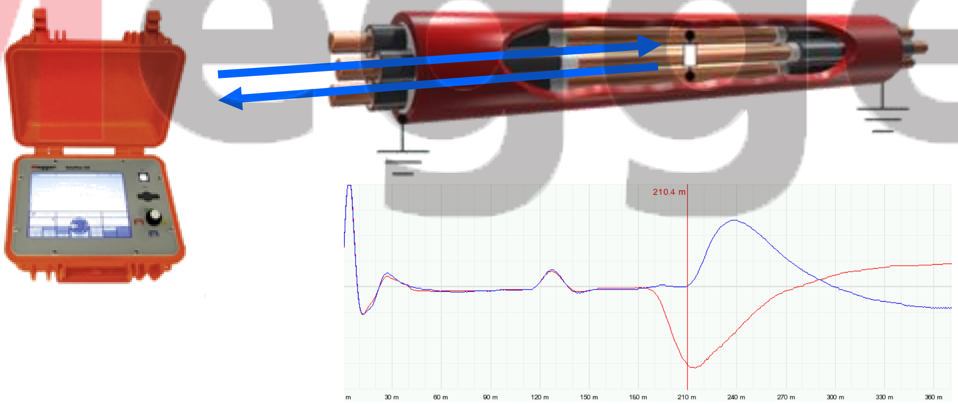


Propagation Velocity v/2 in m/µs or ft/µs

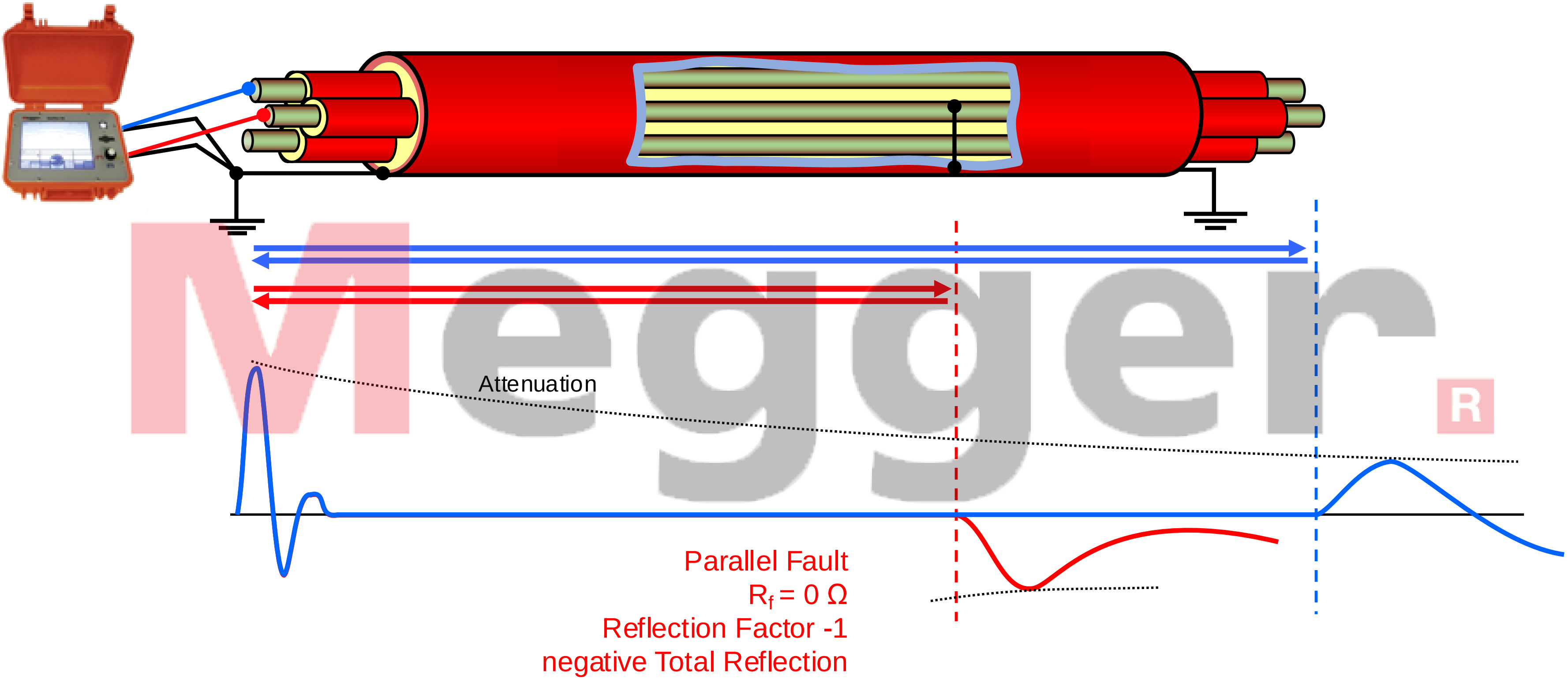
Cable type (based on VDE)	Insulation	Diel. const. ε • *rel*	V/2	Deviation m/µs
A-2YF(L)2Y	PE	2.3	94	small
A-2Y(St)2Y	PE	2.3	100	small
A-02Y(LCo)2Y	Foam-Pe	1.7	116	small
A-PMbc	Paper	1.6	112(118)	110-126
A-PWE2Y	Paper	1.6	118	110-126
NAEKBA	Paper/Pulp	3.5	80	77-83
NAKBA	Paper/Pulp	3.5	80	77-85
NAKLEY	Paper/Pulp	3.5	80	77-83
NAHEKB	Paper/Pulp	3.5	80	77-83
NAKEBA	Paper/Pulp	3.5	80	77-83
NKBA	Paper/Pulp	3.5	80	77-85
NKLEY	Paper/Pulp	3.5	80	77-83
NAYY	PVC	5.0	78	70-82
NAYCWY	PVC	5.0	75	69-78
NYY	PVC	5.0	78	70-82
NYCWY	PVC	5.0	75	69-78
NA2XY	XLPE	2.3	85	small
NA2XSY	XLPE	2.3	85	82-86
NA2XSYV	XLPE	2.3	85	82-86
NA2XS(F)2Y	XLPE	2.3	85	82-86
N2XSY	XLPE	2.3	85	82-86

Reflection Factor

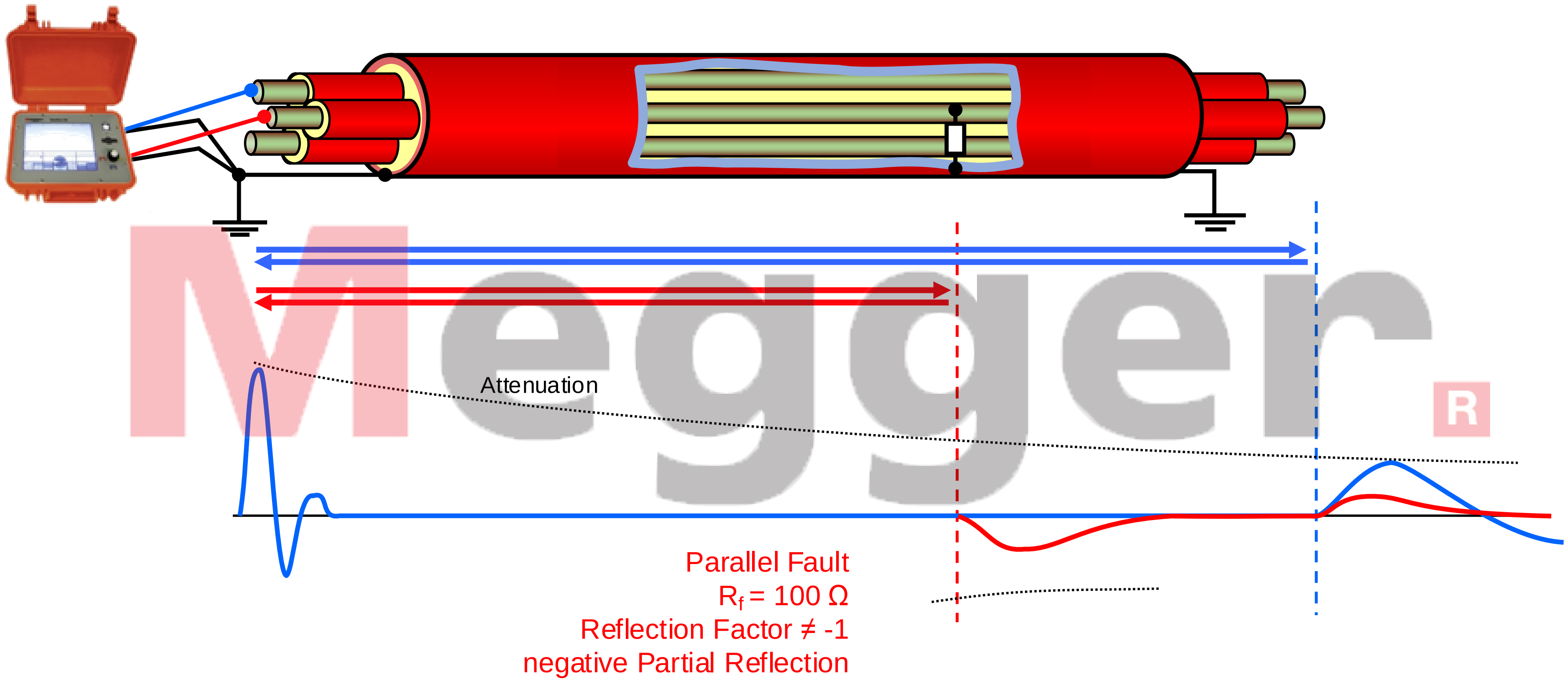
- No changing of the impedance - no reflection
- Change of the impedance - good reflection
- Short and break - total reflection



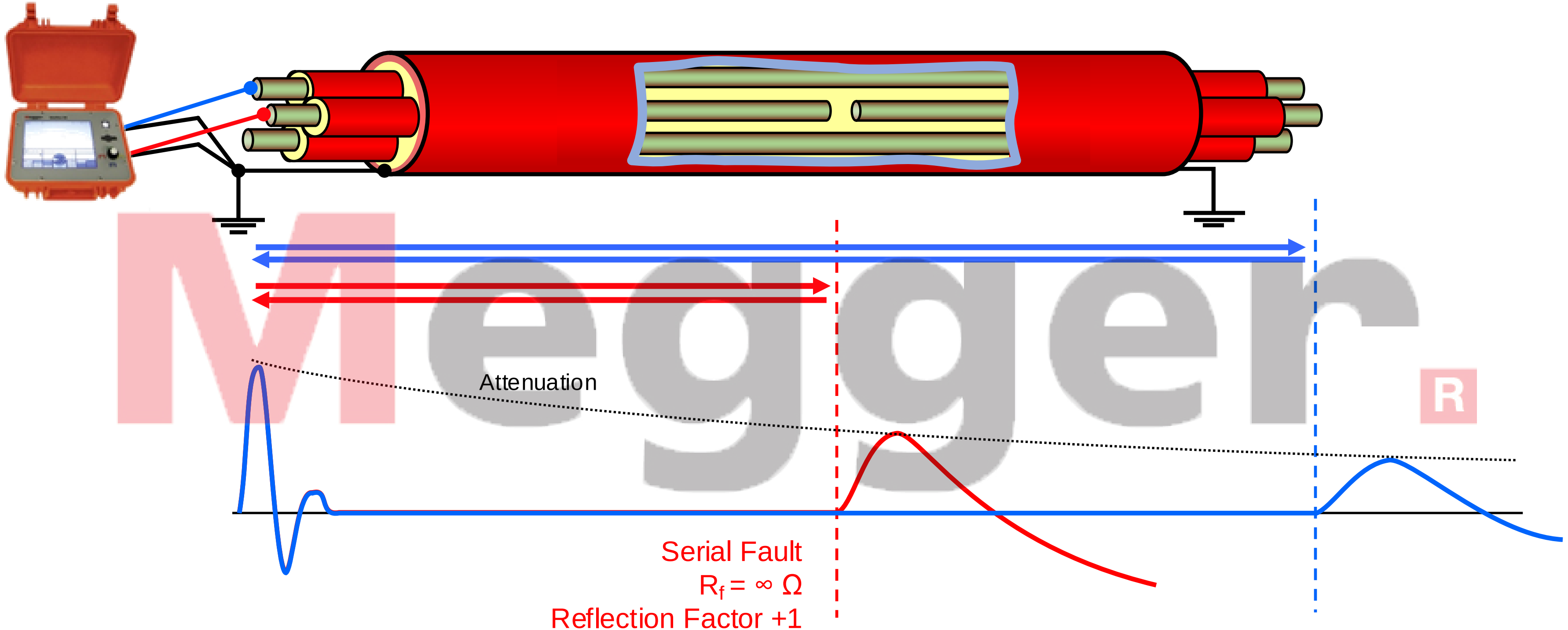
Reflection Factor Short Circuit 0 Ω



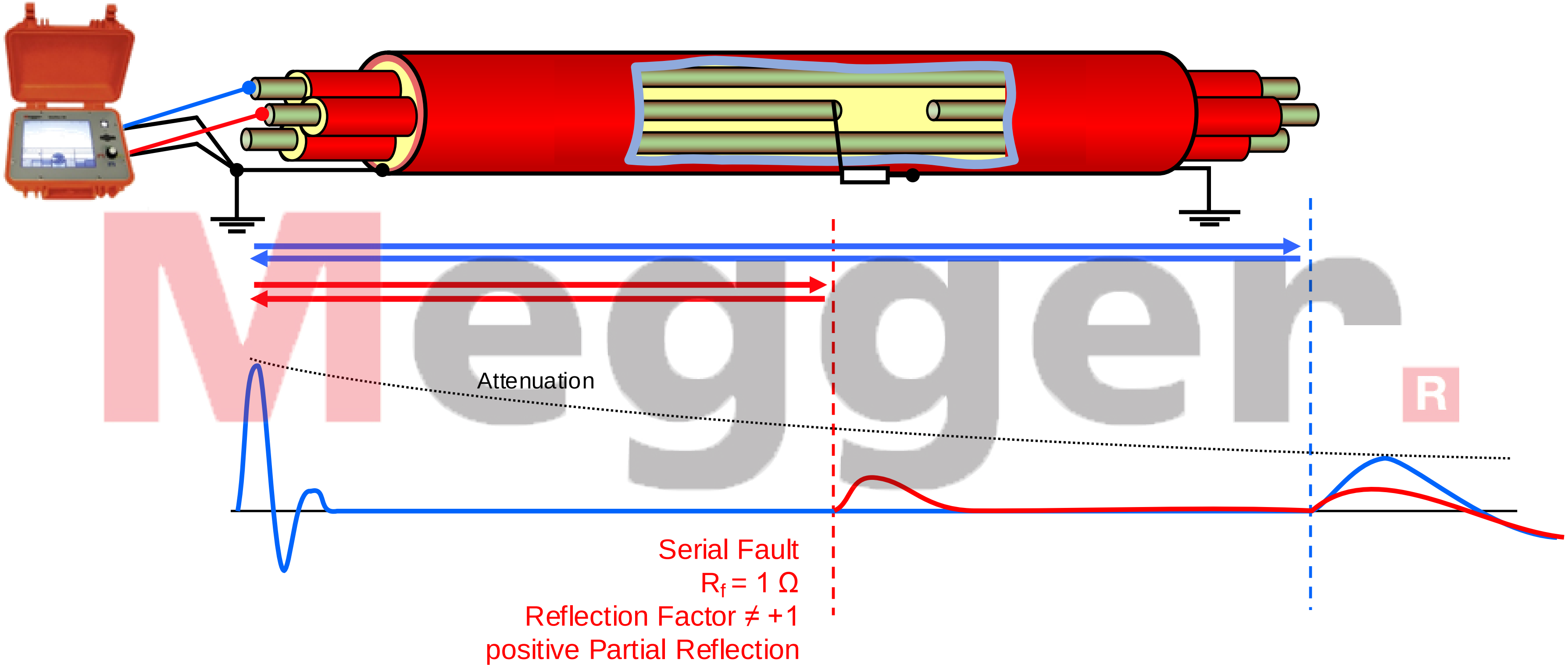
Reflection Factor Parallel Fault 100 Ω



Reflection Factor Interuption, Break, Open Circuit



Reflection Factor Serial Fault > 0 Ω



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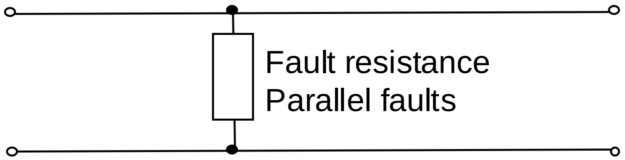
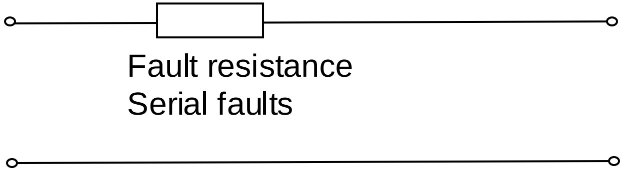
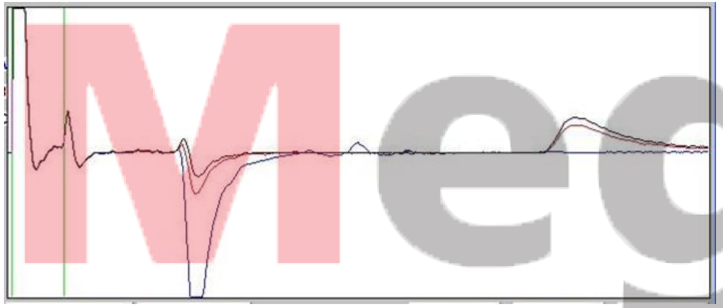
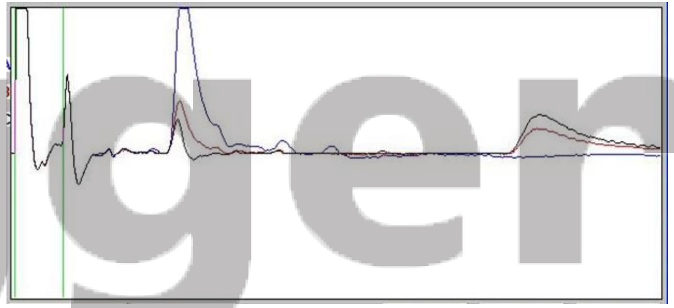
Reflection Factor Parallel and Serial Fault Resistance









$R_{parallel} = 0\ \Omega$
$R_{parallel} = 100\ \Omega$
$R_{parallel} = 250\ \Omega$

$R_{serial} = \infty$
$R_{serial} = 100\ \Omega$
$R_{serial} = 10\ \Omega$

Typical Reflections

Reflection Factor Examples

Cables with different impedance
(e.g. cable type change)

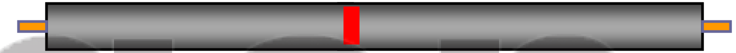
Z_1 = 50 Ω Z_2 = 5 Ω

Negative Reflection
(tramway cable)

Z_1 = 50 Ω Z_1 = 300 Ω

Lines with ohmic fault resistance
(e.g. insulation damage)

Z_1 = 50 Ω Z_1 = 50 Ω

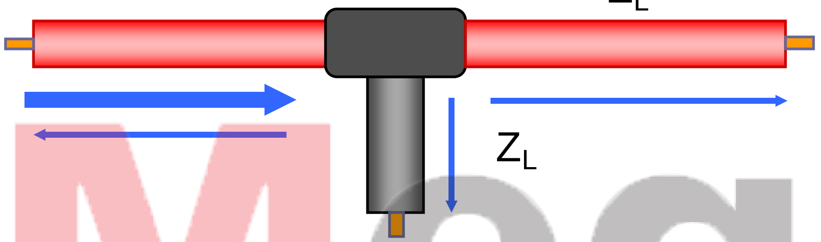


R_F = 25 Ω

Negative Reflection
(parallel fault)

Positive Reflection
(overhead line)

Reflection Factor Branched Network



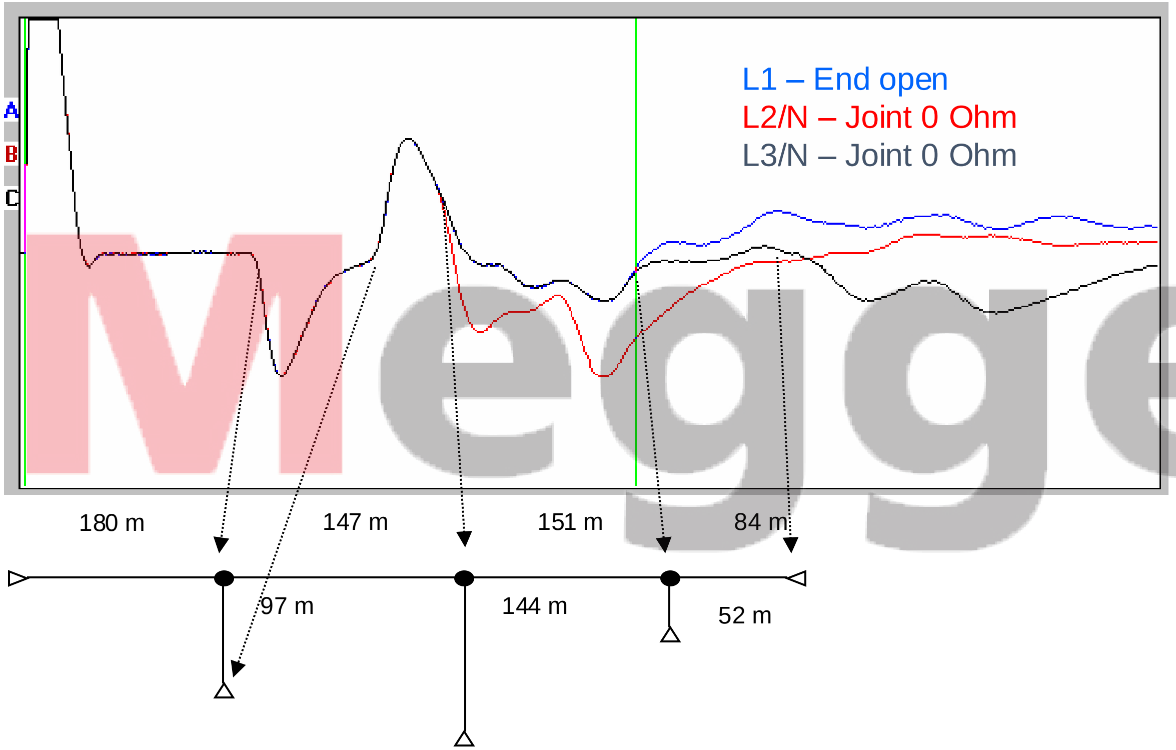
Cable behind the T-joint

Cable behind the T-joint

$$r = -\frac{1}{3}$$

Negative Reflection
(T-joint, cables with equal impedance)

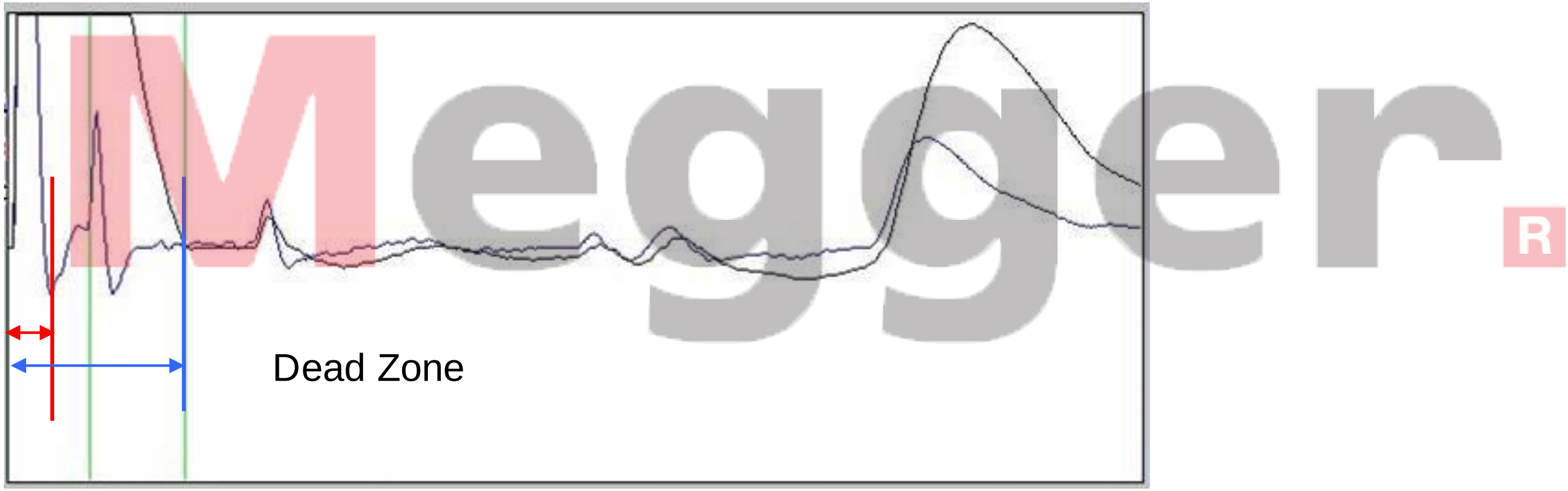
Reflection Factor Fault in the Joints



- Attenuation in each T-joint
- Reflection from each end

Pulse Width / Dead Zone

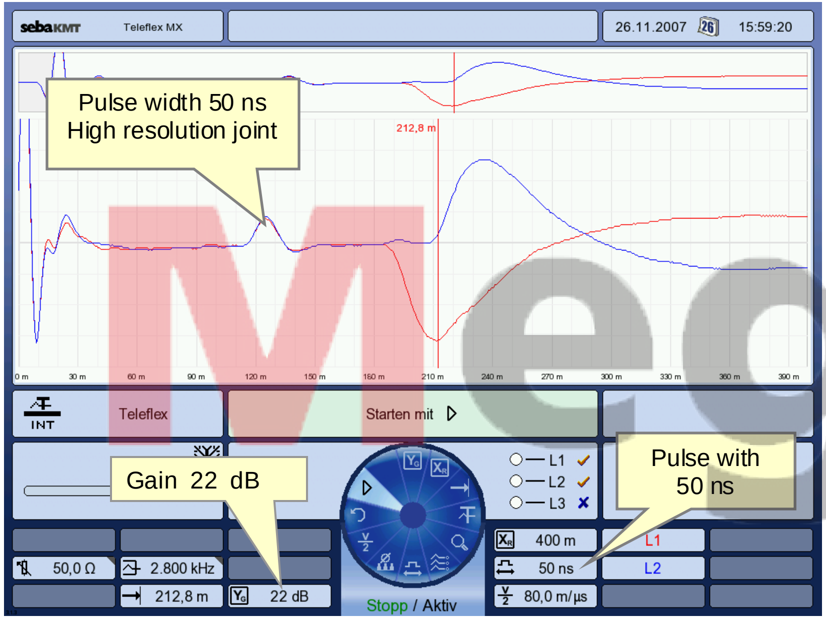
Narrow pulse	short distance high resolution short dead zone	Wide pulse	long distance low resolution long dead zone



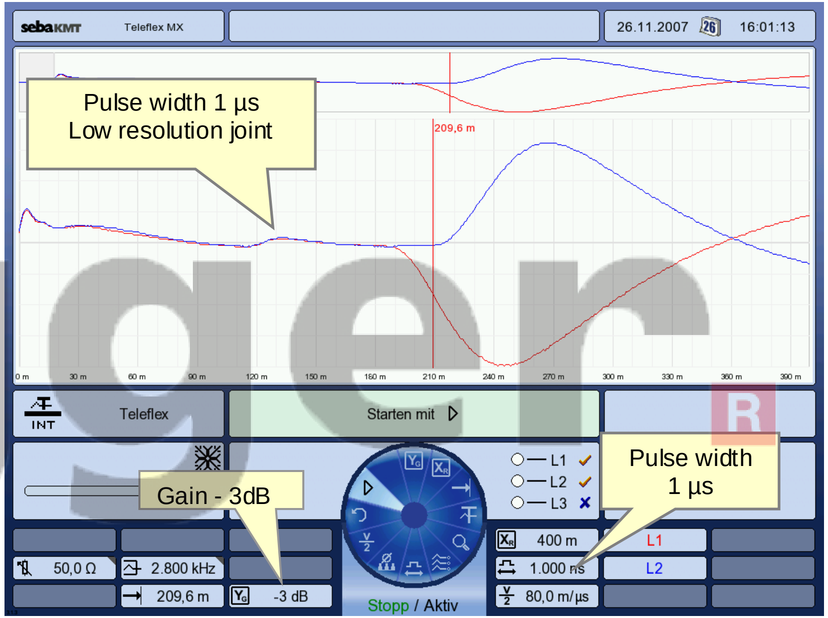
Pulse Width

Pulse Width	Range [time]	Range [distance] ($^V/_2$ = 80 m/µs oder NVP = 0.533)	Dead-Zone
100 ns	Bis zu 6.25 µs	Bis zu 500 m	8 m
200 ns	6.25 µs … 31.25 µs	500 m … 2,5 km	16 m
500 ns	31.25 µs … 93,75 µs	2,5 km … 7,5 km	40 m
1 µs	93,75 µs … 375 µs	7,5 km … 30 km	80 m
2 µs	375 µs … 750 µs	30 km … 60 km	160 m
5 µs	750 µs … 2 ms	60 km … 160 km	400 m

Pulse Width

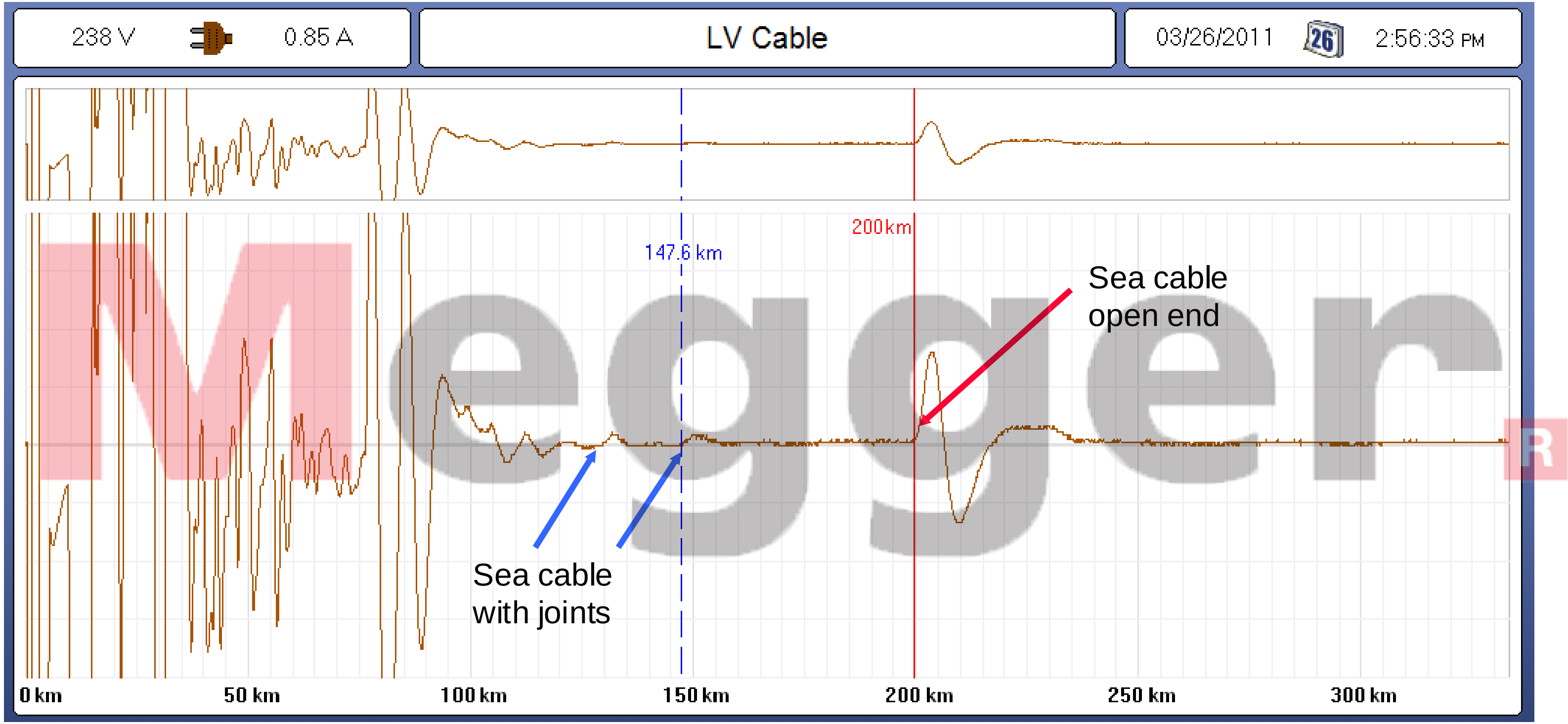


sebaKMT Teleflex MX
26.11.2007 15:59:20
Pulse width 50 ns
High resolution joint
212,8 m
Teleflex
Starten mit
Gain 22 dB
Pulse with
50 ns
L1
L2
L3
50,0 Ω
2.800 kHz
212,8 m
22 dB
400 m
50 ns
80,0 m/µs
Stopp / Aktiv

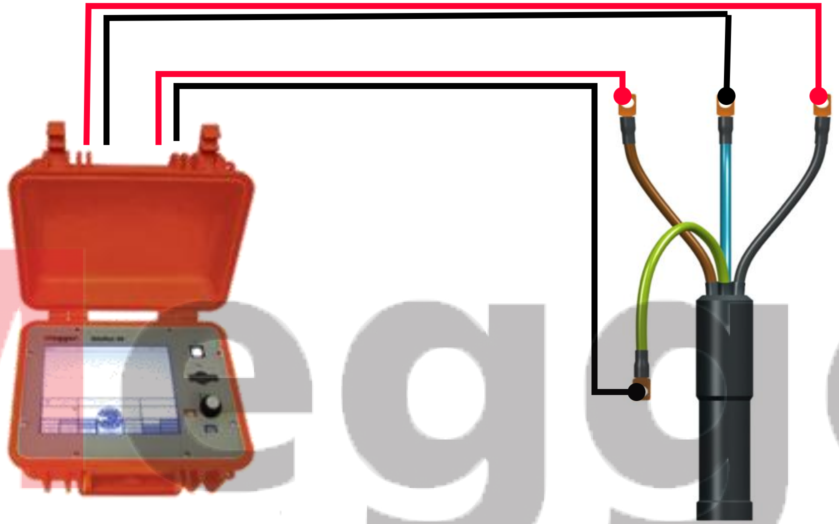


sebaKMT Teleflex MX
26.11.2007 16:01:13
Pulse width 1 µs
Low resolution joint
209,6 m
Teleflex
Starten mit
Gain - 3dB
Pulse width
1 µs
L1
L2
L3
50,0 Ω
2.800 kHz
209,6 m
-3 dB
400 m
1.000 ns
80,0 m/µs
Stopp / Aktiv

HV DC Link – 200 km

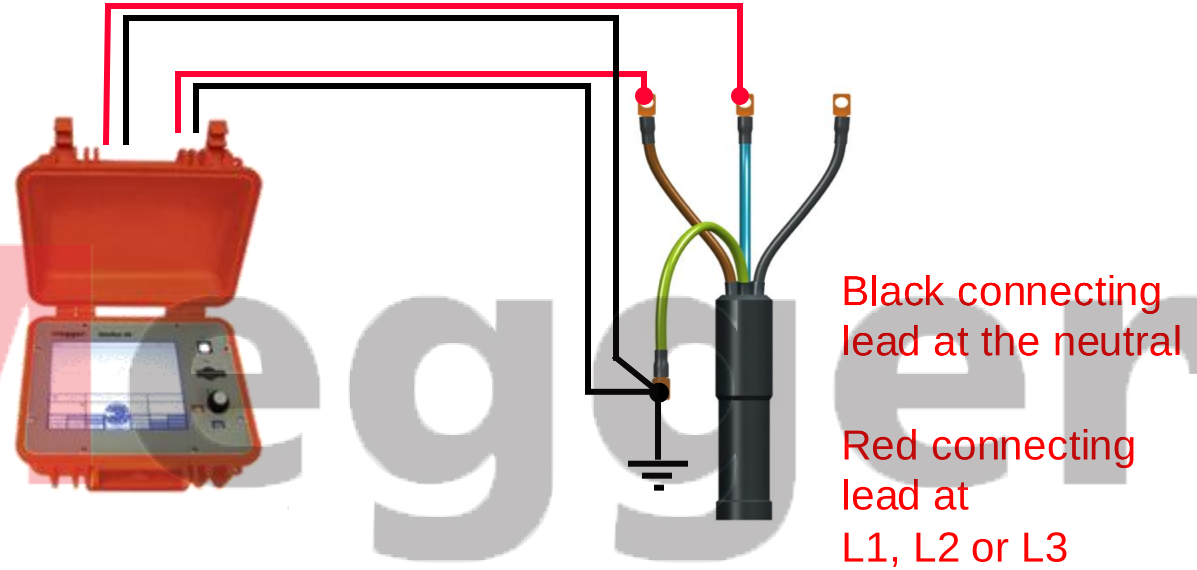


Symmetric coupling of TDR´s



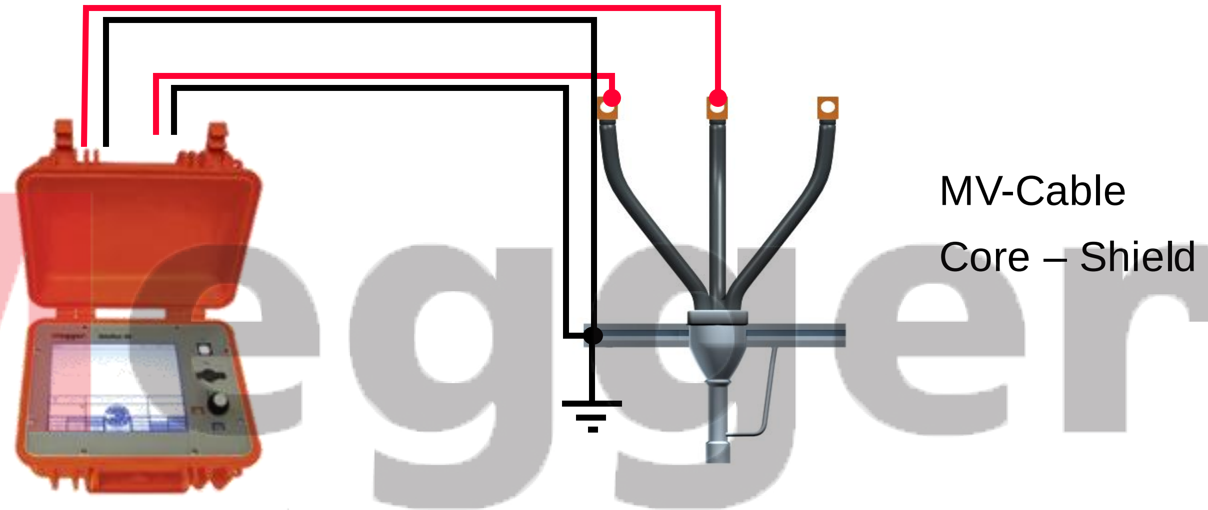
- Telecom cable Pair – Pair
- LV-cable without shield Core – Core
  Core – Neutral (Neutral disconnected from the ground)

Asymmetric coupling of TDR´s



- Telecom cable — Core – Shield
- LV-cable without shield — Core – Neutral
- LVC-cable with shield — Core - Shield

Asymmetric coupling of TDR´s



Black connecting lead at the shield
Red connecting lead at L1, L2 or L3

Cable Fault Locating
Prelocating High Resistive Faults with HV-Methods

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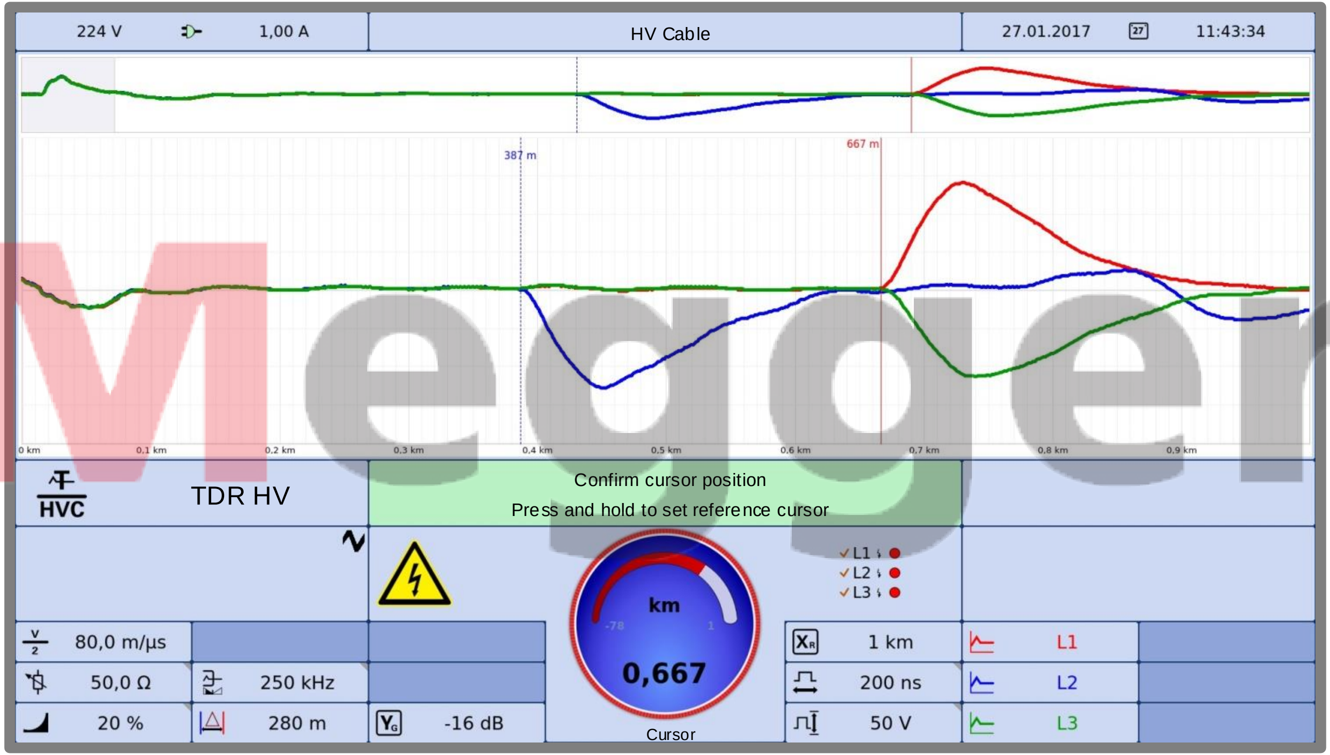
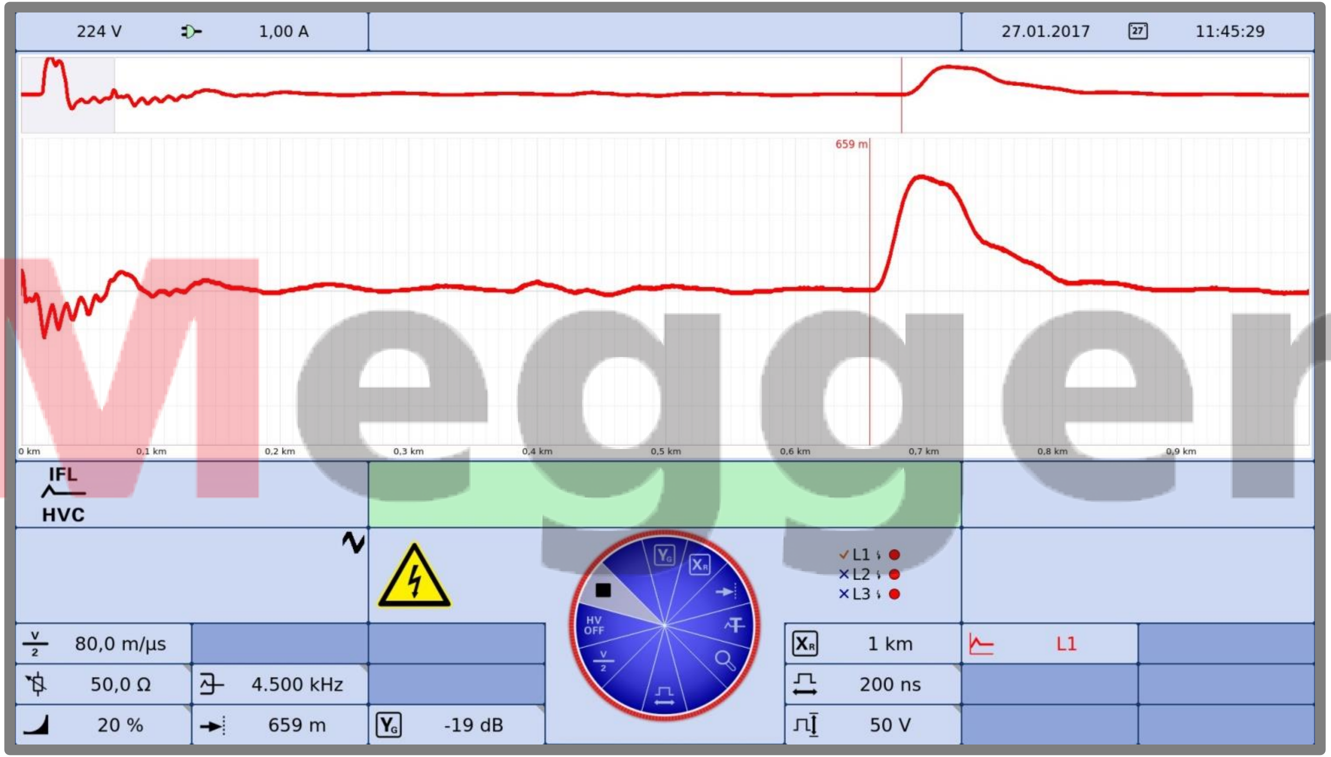
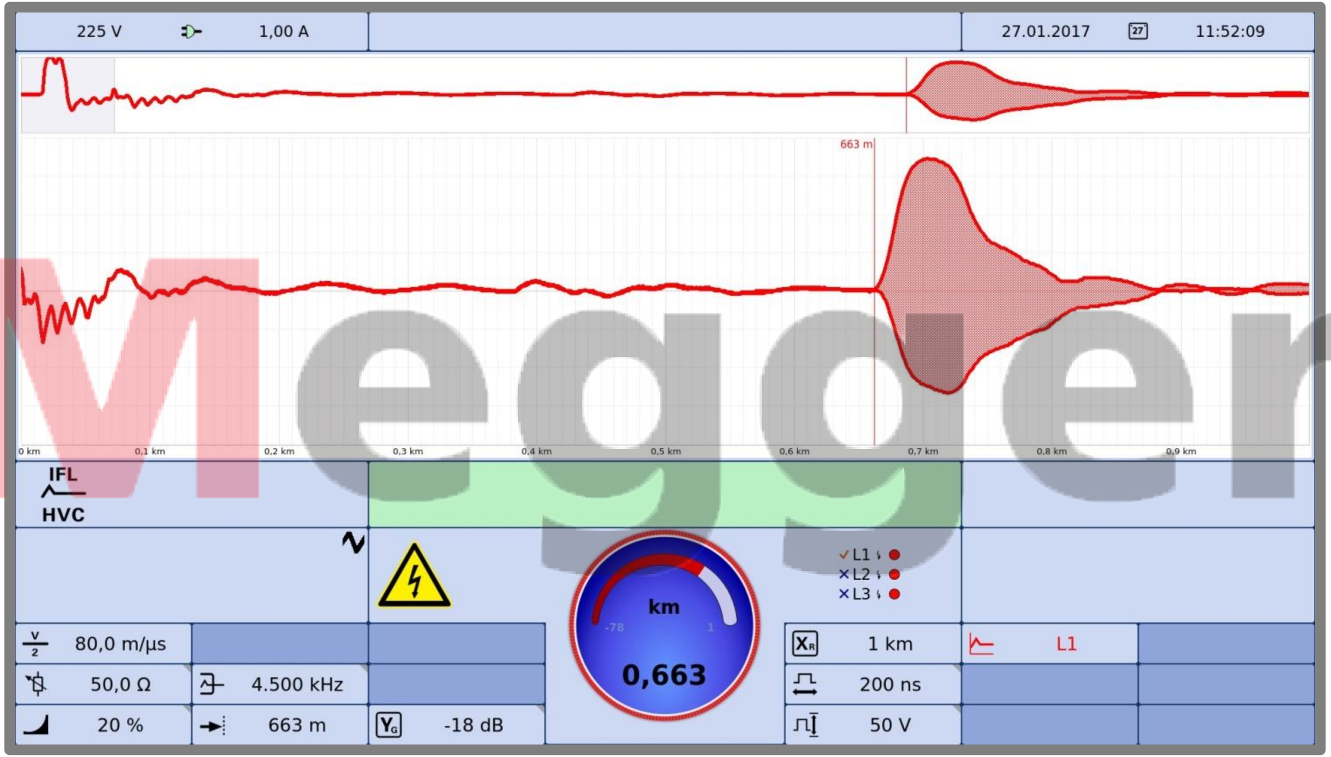
Prelocation TDR Time Domain Reflectometer (“cable radar“)



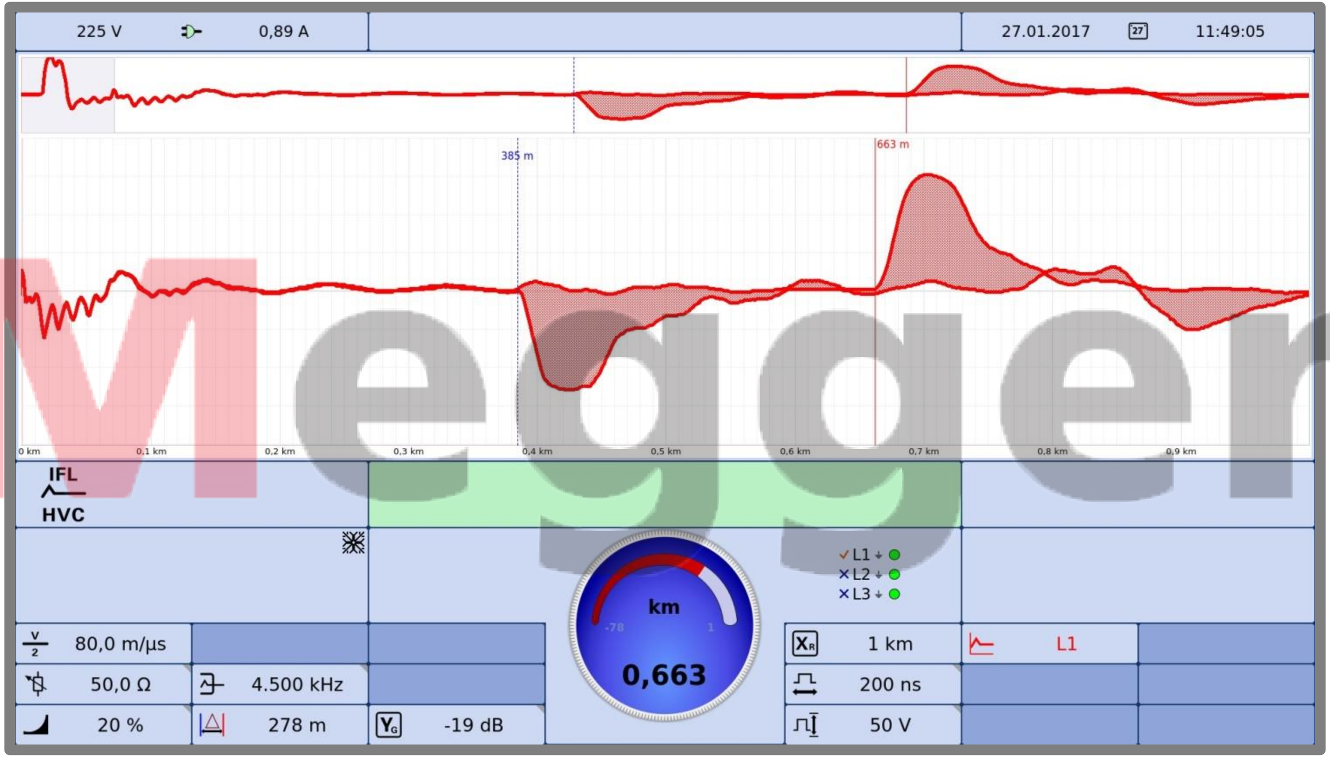
Prelocation IFL Intermittant Fault Locating (finding cable end)



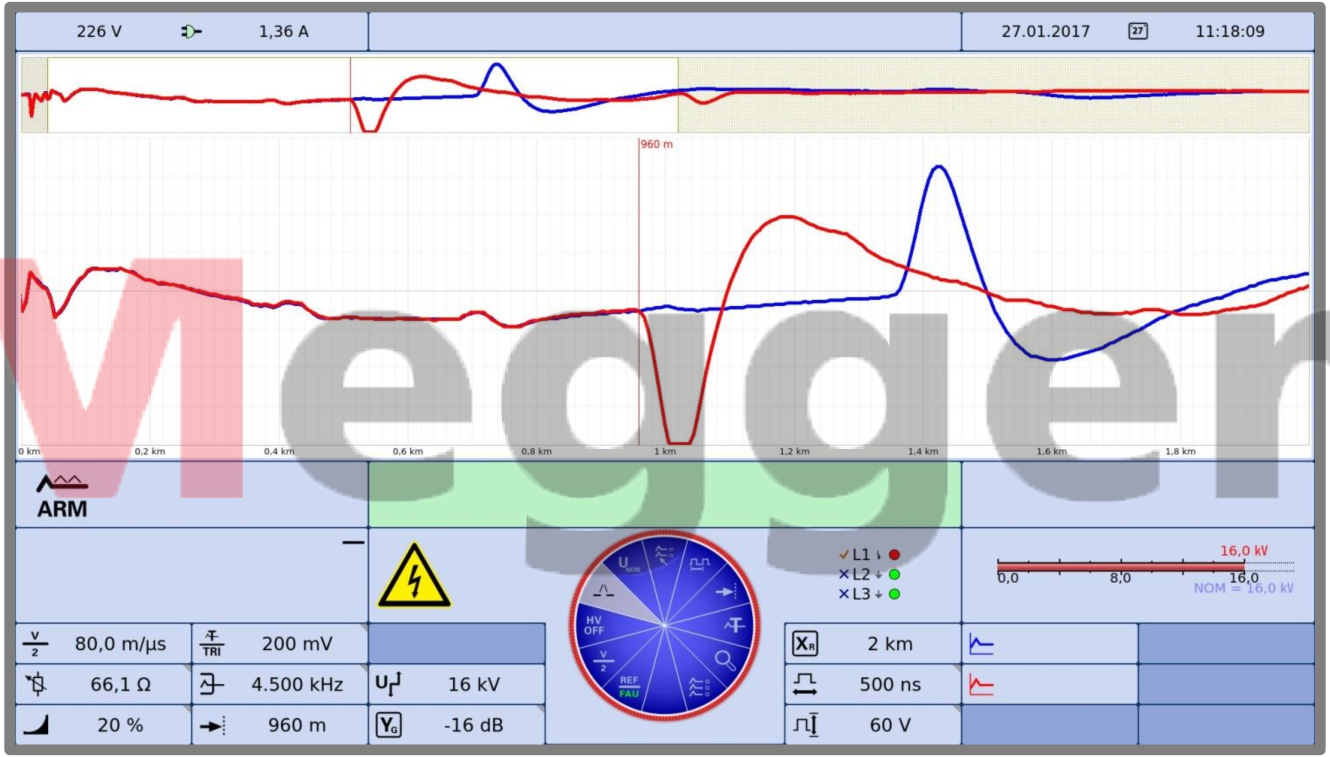
Prelocation IFL Intermittant Fault Locating (finding cable end)



Prelocation IFL Intermittant Fault Locating



Prelocation IFL Arc Reflection Method



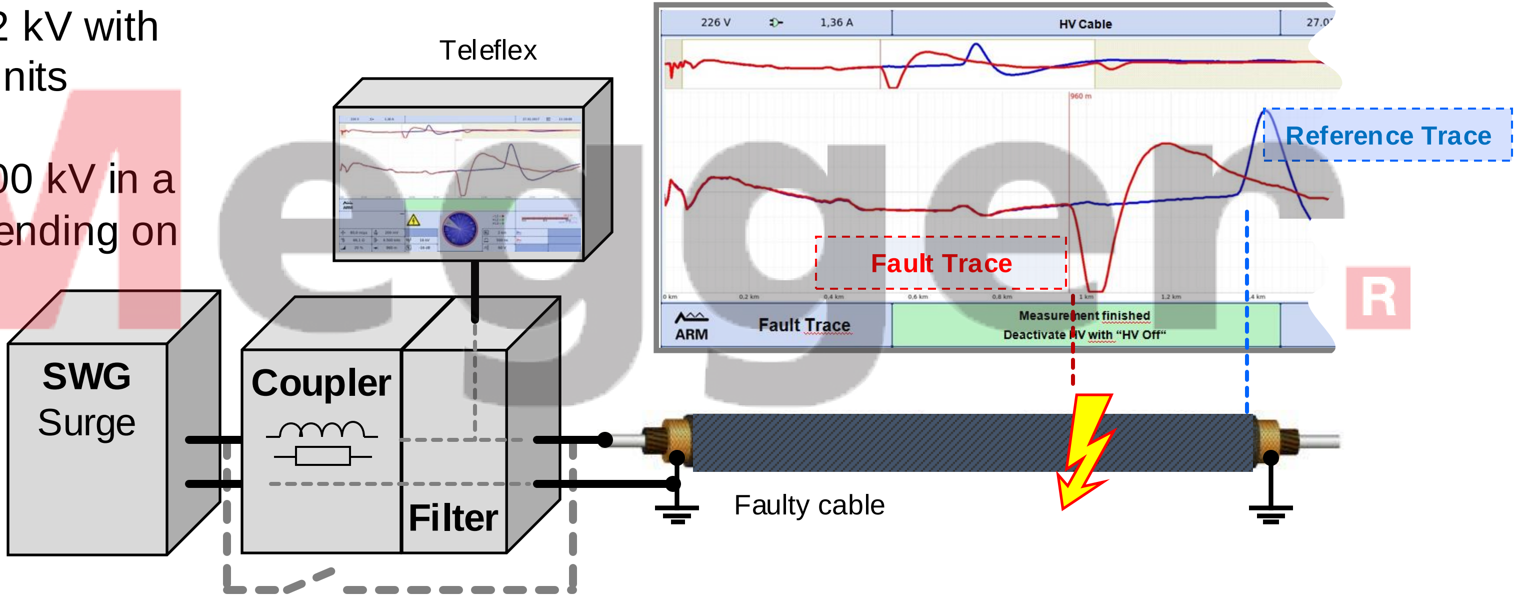
Arc Reflection Measurement (ARM)

Passive coupling

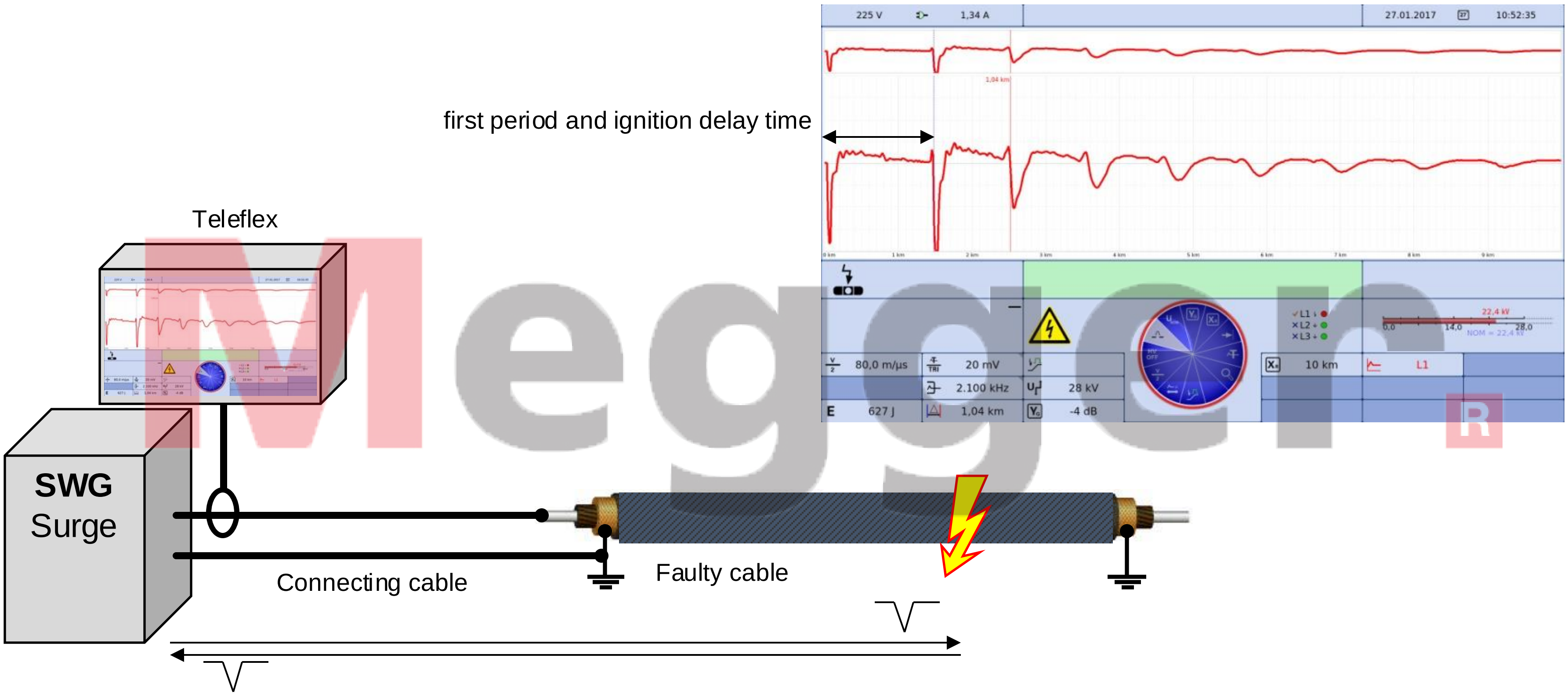
Voltage level with ARM:

Up to max. 32 kV with stand-alone units

Up to max. 100 kV in a test van (depending on equipment)

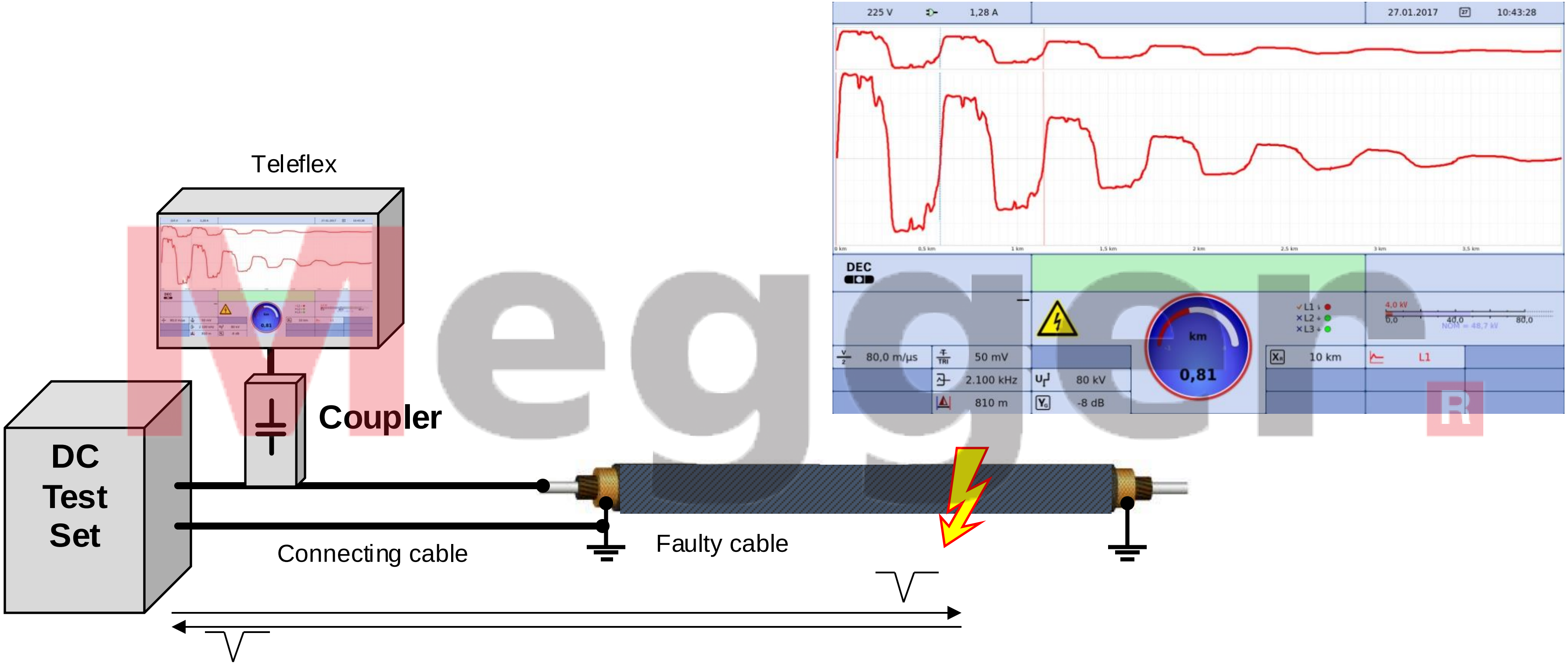


Test Setup ICE (Impulse Current Equipment)



ICE Prelocation - Field Test

Test Setup Decay Method



Prelocation Decay

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Comparison of basic HV-Prelocating Methods

ARM

- most common HV-fault locating method
- most details visible (joints, cable end, ...)
- up to SWG-voltage (typically 32 kV)
- connecting cable automatically subtracted
- set TDR range to cable length

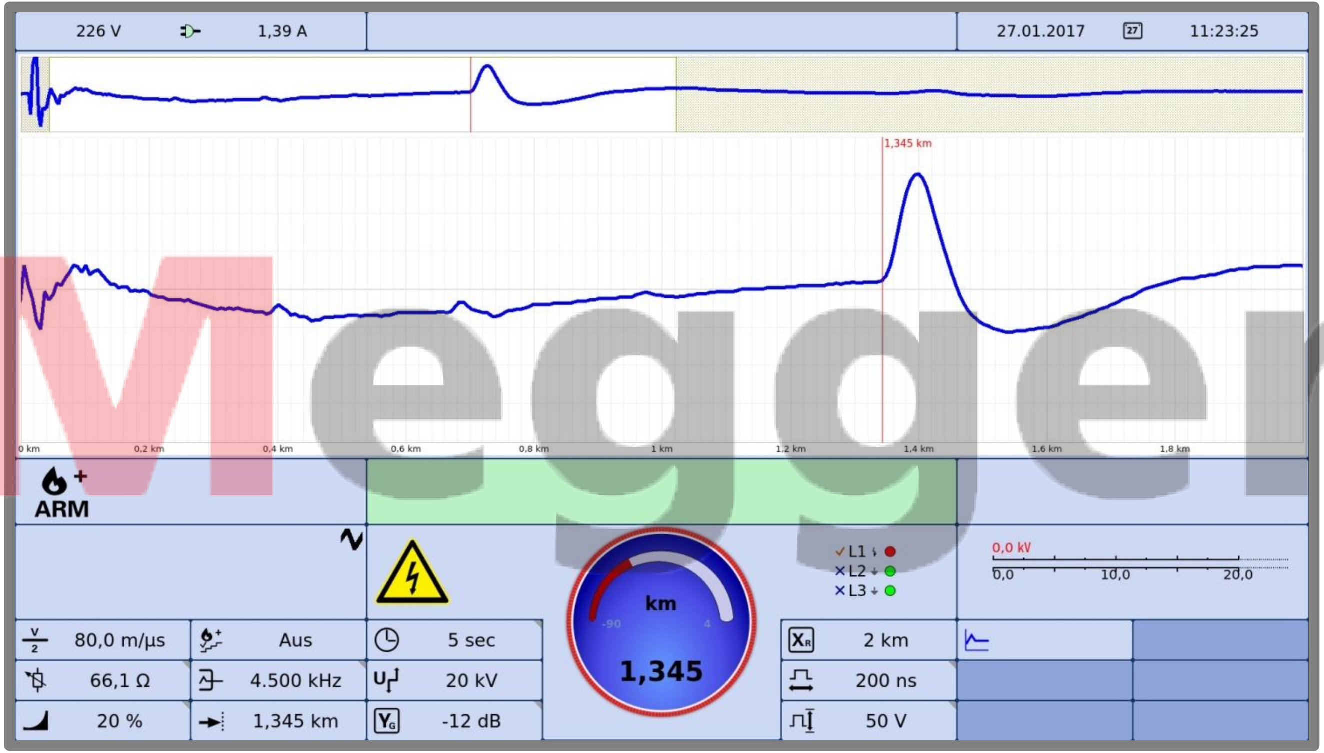
ICE Impulse Current

- good for long lead cables and faults in wet joints
- up to SWG-voltage (typically 32 kV)
- set TDR range to 5 or 10 times cable length
- measure length of one period
- don't consider first period (includes ignition delay time)
- measured length may be 7 to 15 % too long due to varying v/2, depending on pulse ignition and shape
- subtract connecting cable

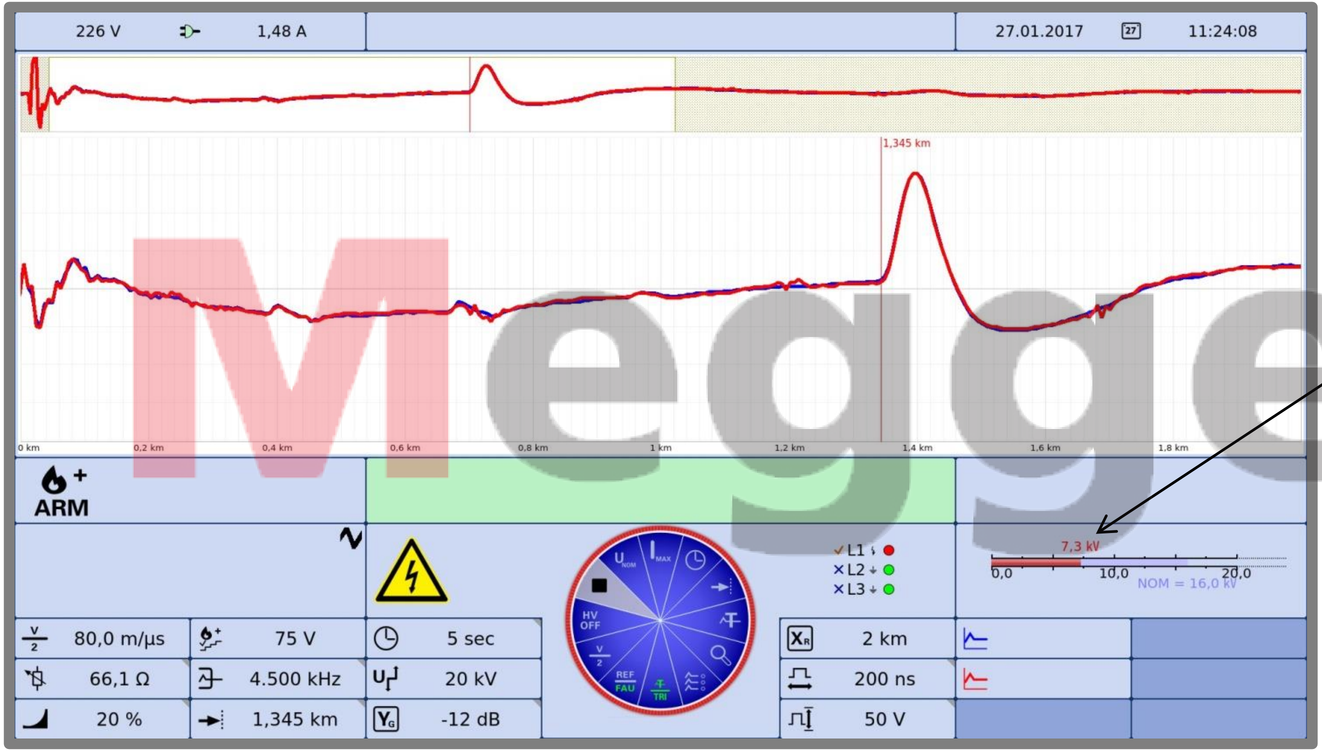
Decay

- good for HV-fault locating at higher voltages (Centrix up to 80 kV, R30 up to 400 kV)
- faulty cable has to be "chargeable", failing with a flash-over. Leakage current faults cannot be located
- set TDR range to 5 or 10 times cable length
- measure length of one period
- subtract connecting cable

ARM Power Burning acquire reference trace (normal TDR measurement)



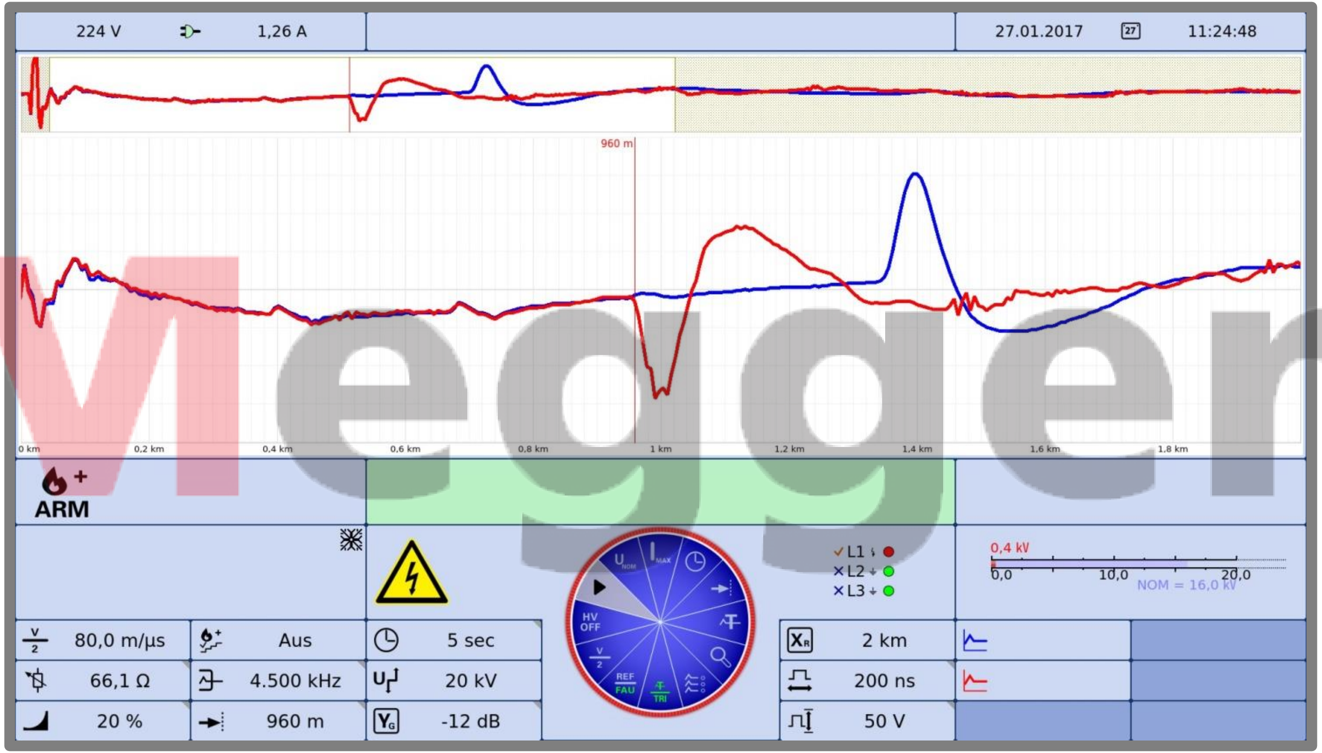
ARM Power Burning waiting for trigger while voltage rises



Observe:

- Measuring Range 20 kV
- Voltage Setting 16 kV (gray)
- Actual output (increasing) 7,3 kV (red)

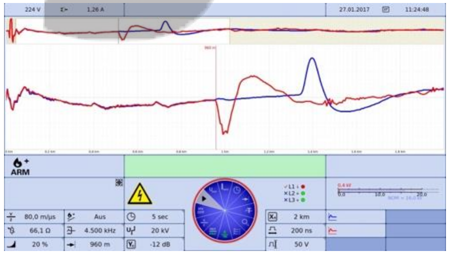
ARM Power Burning fault trace was triggered



Prelocation ARM Power Burning Why ARM Burning and not old-fashioned burning?

- **Burning is bad for XLPE cables**
  High frequency HV transients are unhealthy for aged plastic insulation.
- **Burning makes pinpointing difficult**
  Burning too much will create a solid short circuit and acoustic pinpointing is not possible. Twist or Turbidity methods apply.
- **Burning takes time and power**
  It can take between 5 min. to 1 hour … at high power consumption.
- **Prelocation takes many separate steps**
  TDR, burning, TDR again … with all necessary switching between modes.

ARM Burning takes 5 seconds
and is easy and clear as ARM



Cable Fault Location

Acoustic Pinpointing Method

MV and LV Cable Systems

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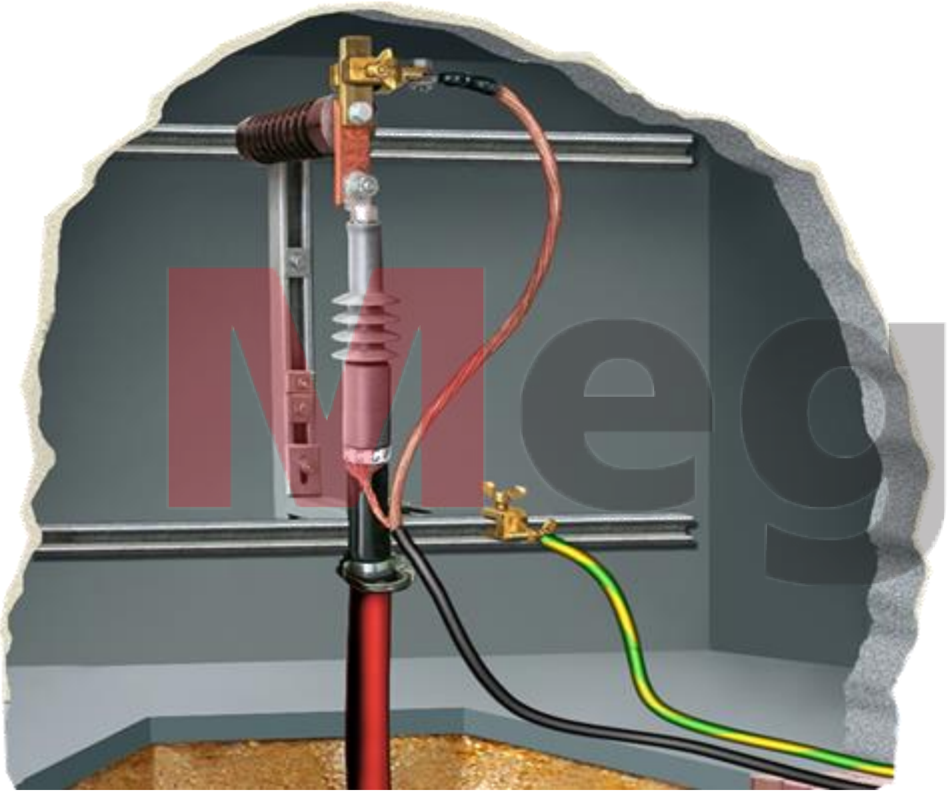
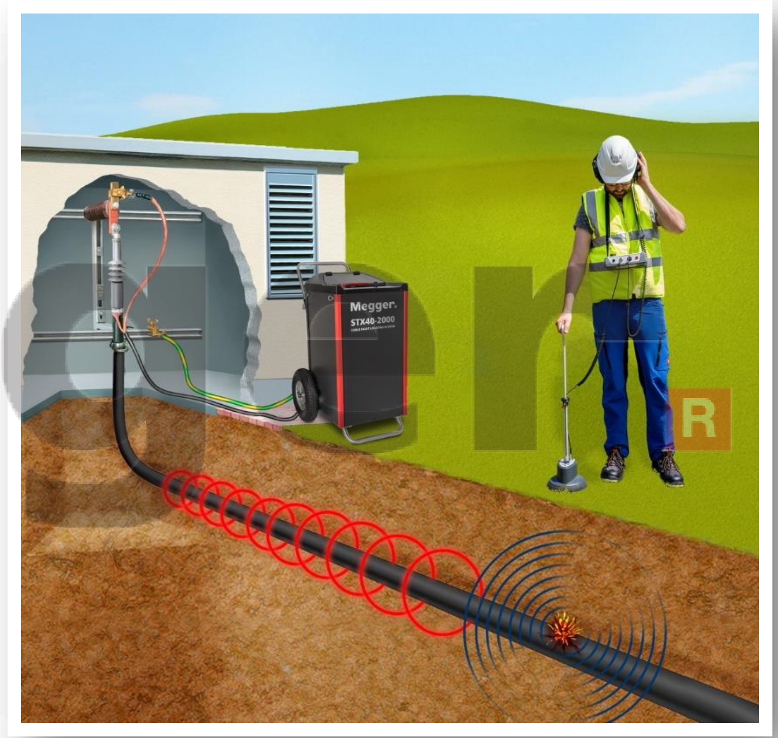
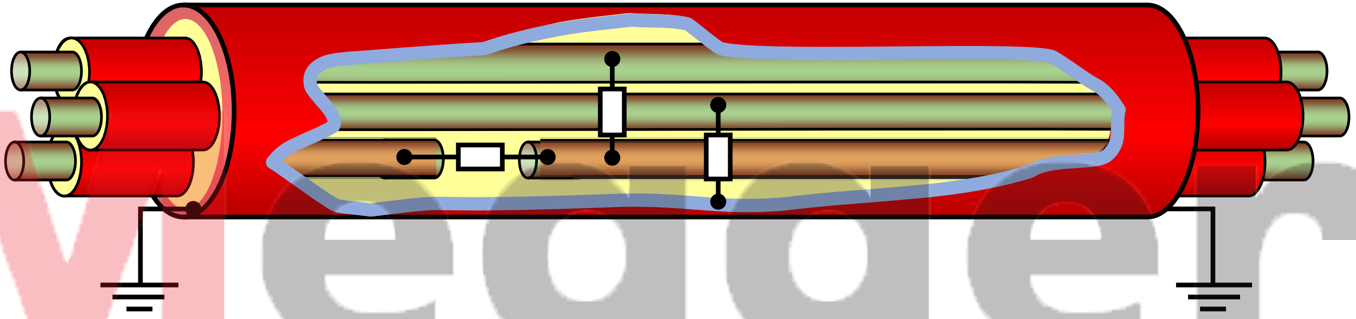
Pinpointing – Acoustic Method Using a Surge Wave Generator SWG





Pinpointing – Acoustic Method Which faults can be pinpointed?



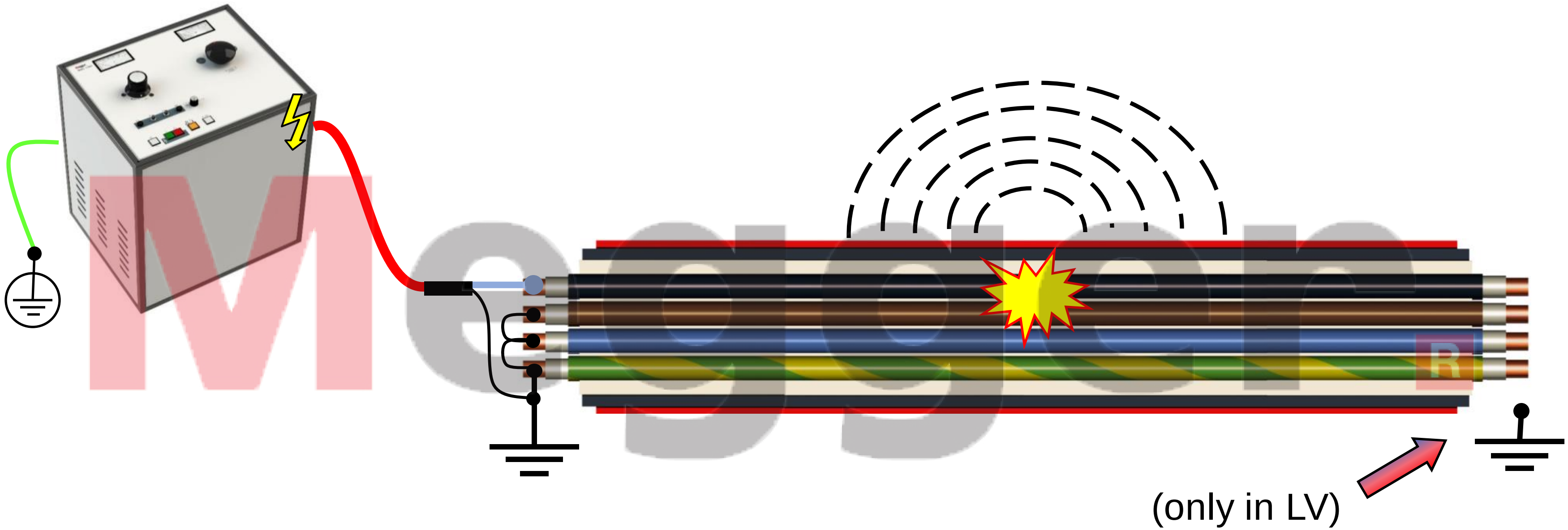
High resistance series faults
Conductor or joint

High resistance parallel faults
Conductor – Conductor
Conductor – Shield

Connection of portable HV Instruments Connection Core - Sheath

Attention: low resistance protective ground < 2 Ω

Connection of portable HV Instruments Connection Core - Core



Attention: low resistance protective ground < 2 Ω

Pinpointing – Acoustic Method Dependence on volume intensity

Energy of surge generator
- 500 J is sufficient at portable surge generator
- min. 1.000 J in KMW (damping in 50 m connection cable)
- min. 1.000 J in branched cable system

Type of fault (low-resistance, high-resistance)

Ground conditions
- loose ground, e.g. sand, root area → damped sound
- short distance 1-3 m: high frequencies are good to hear
- long distance 3-5 m: low frequencies are better to hear

Contact sensor to earth
- sheet, tripod, peak

Pinpointing – Acoustic Method Switching Voltage Ranges/Capacitors

Surge Energy

$$E = \frac{1}{2} C \cdot U^2$$

8 kV – position, 31.2 µF

$$C_{total} = 4 \cdot C_{single}$$

8 kV

16 kV – position, 7.8 µF

$$C_{total} = C_{single}$$

8 kV

8 kV

32 kV – position, 1.95 µF

$$C_{total} = \frac{C_{single}}{4}$$

8 kV

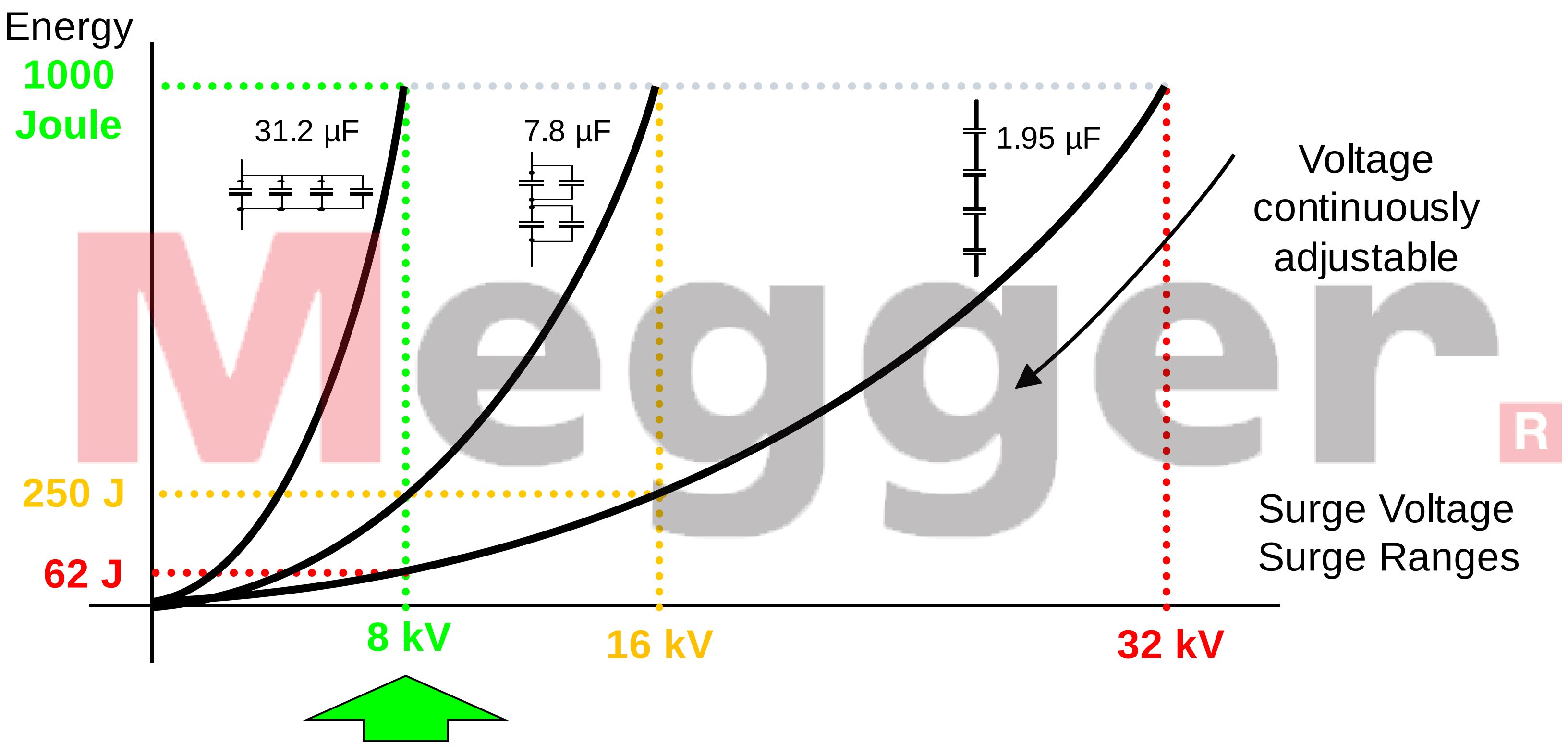
7.8 µF

8 kV

8 kV

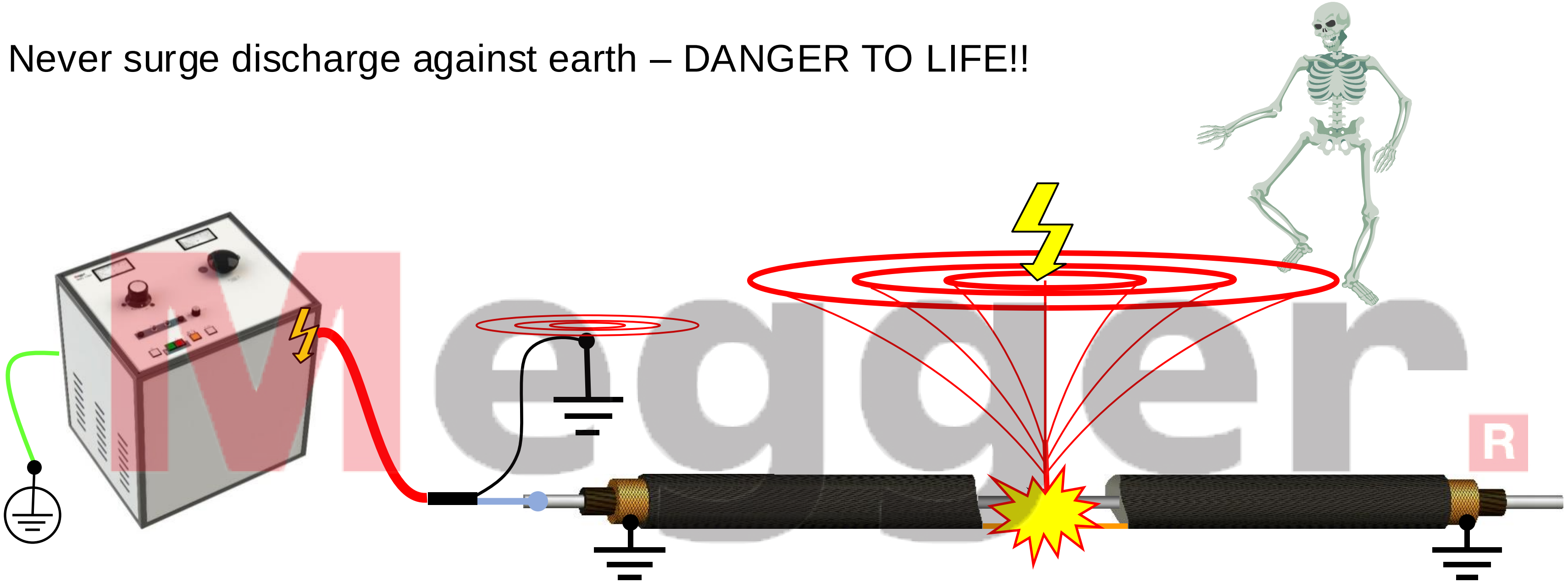
8 kV

Pinpointing – Acoustic Method Influence of Voltage Square to the Energy Formula



Connection of portable HV Instruments

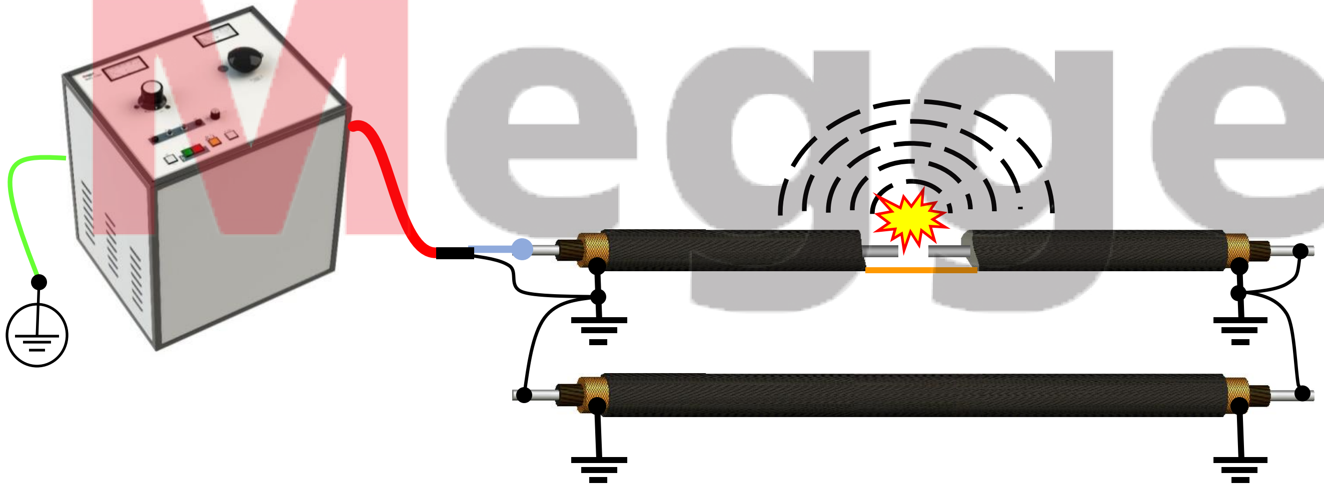
Never surge discharge against earth – DANGER TO LIFE!!



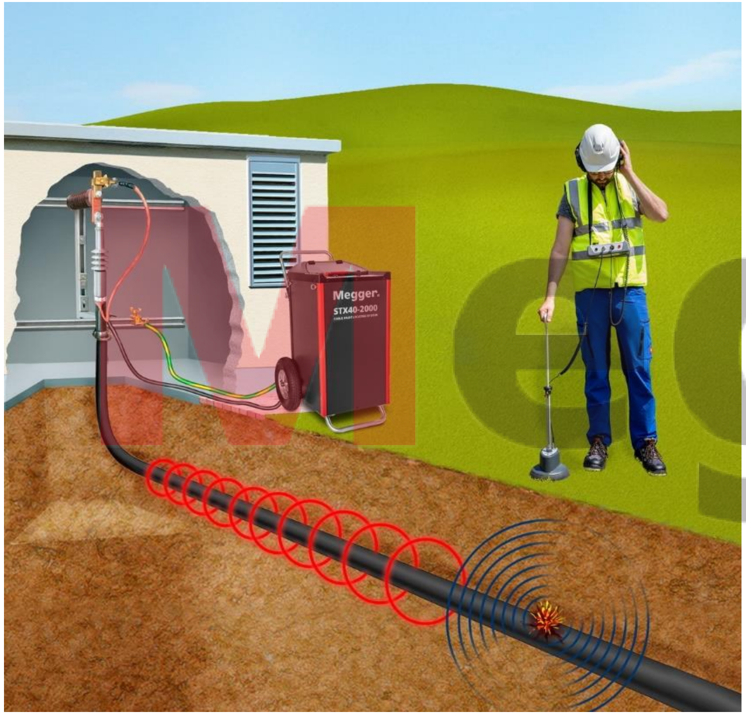
This danger consists for all cables without sheath or metal jacket!
Keep an eye on the discharge conditions of the surge generator!
Alternative DC - or AF – step voltage method

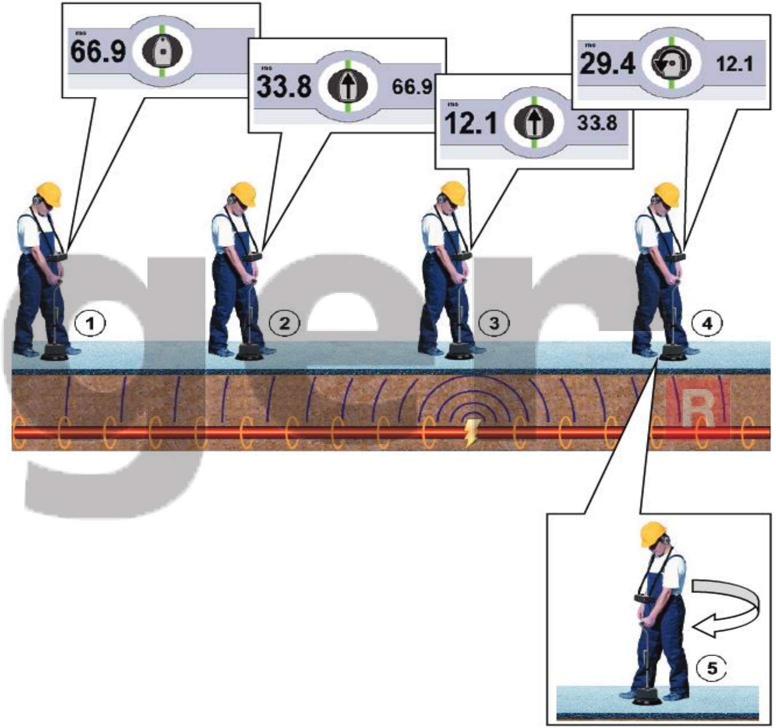
Pinpointing – Acoustic Method

- Works only if flash-over distance is very small
- Use a Return Conductor as Phase Conductor !
- The Sheath or the Metal Jacket or the Cable is not always a good Return Conductor (Corrosion!)



Pinpointing – Acoustic Method Distance Method digiPHONE+

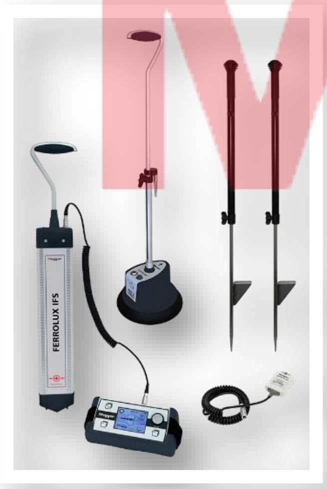




digiPHONE^{+}

The **digiPHONE^{+}** System consists of:

- the Receiver
- the Sensor
- and the Headset



available as

combined unit with:

- Cable locator
- Sheath Fault Pinpointer

Display Elements

Head Set Status
Active, OFF, 84 dbA

Cable Position below Sensor

Bluetooth on

Filter

Background Noise Reduction
Grey - Active, but not effective
Black - Effective

Last (reference) Difference Value

Actual Difference Value
Grey – first, not confirmed
Black - confirmed

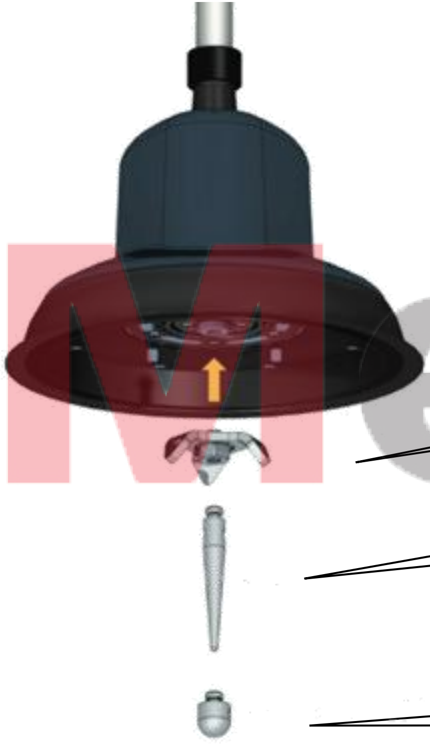
Peak Hold Magnetic Channel

Bargraph Autoscale

Level Magnetic Channel

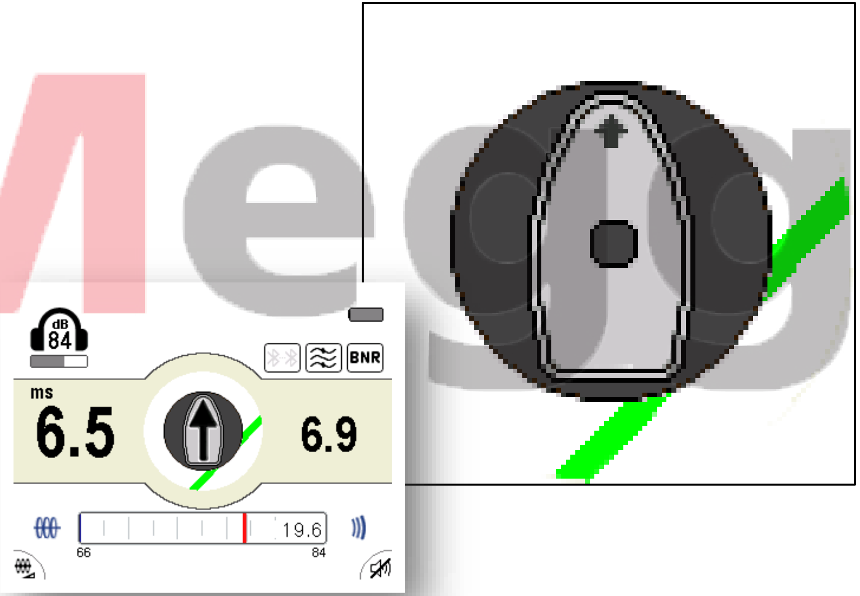
Function keys (selectable)

Sensor connection to the ground



digiPHONE+ Tracing

A green cable symbol beneath the sensor symbol in the centre of the **digiPHONE+** display shows the side position of the sensor in relation to the cable trace.



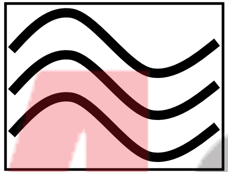
digiPHONE+ Muting

coming close
to the handle:

mute

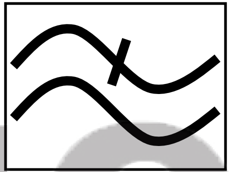
digiPHONE+ Filter

OFF 100 … 1500Hz



This filter setting provides the maximum bandwidth so that the flashover noise can be heard with as little distortion as possible.

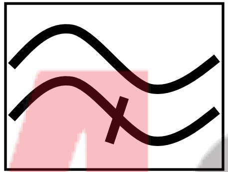
Low pass 100 … 400Hz



The distance to the fault is large and the ground is soft. The time measurement is more difficult.
However, reducing high frequencies can have a detrimental effect on precisely the sound characteristics of high-pitched flashover noise (hard ground, close to the fault).

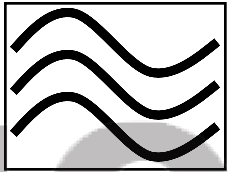
digiPHONE+ Filter

High pass 700 … 1500Hz



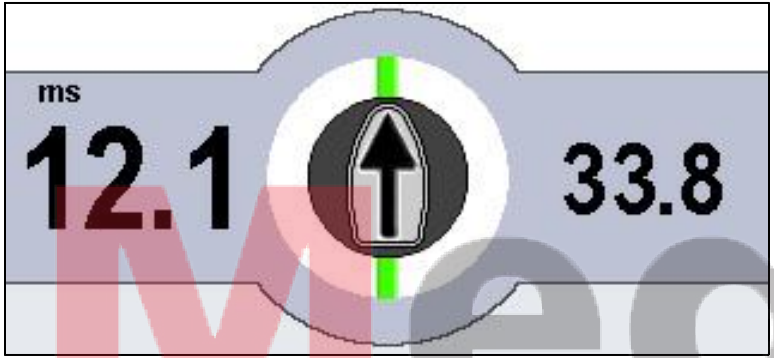
High-pitched flashover noise in particular (hard ground, close to the fault) are not changed very much by this.

Band pass 300 … 500Hz



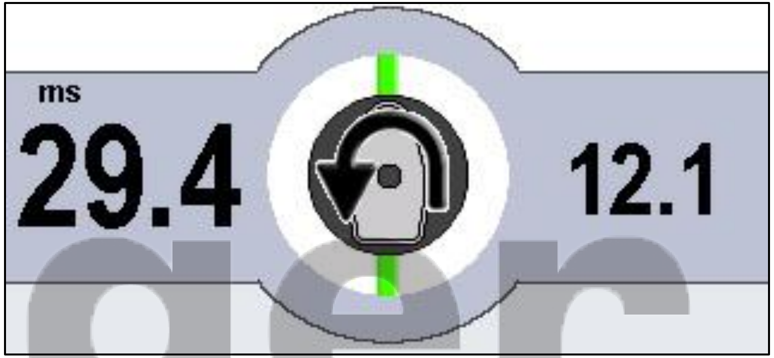
A balanced filter setting which suppresses both low and high frequencies.
However, reducing high frequencies can have a detrimental effect on precisely the sound characteristics of high-pitched flashover noise (hard ground, close to the fault).

digiPHONE+ “Compass”



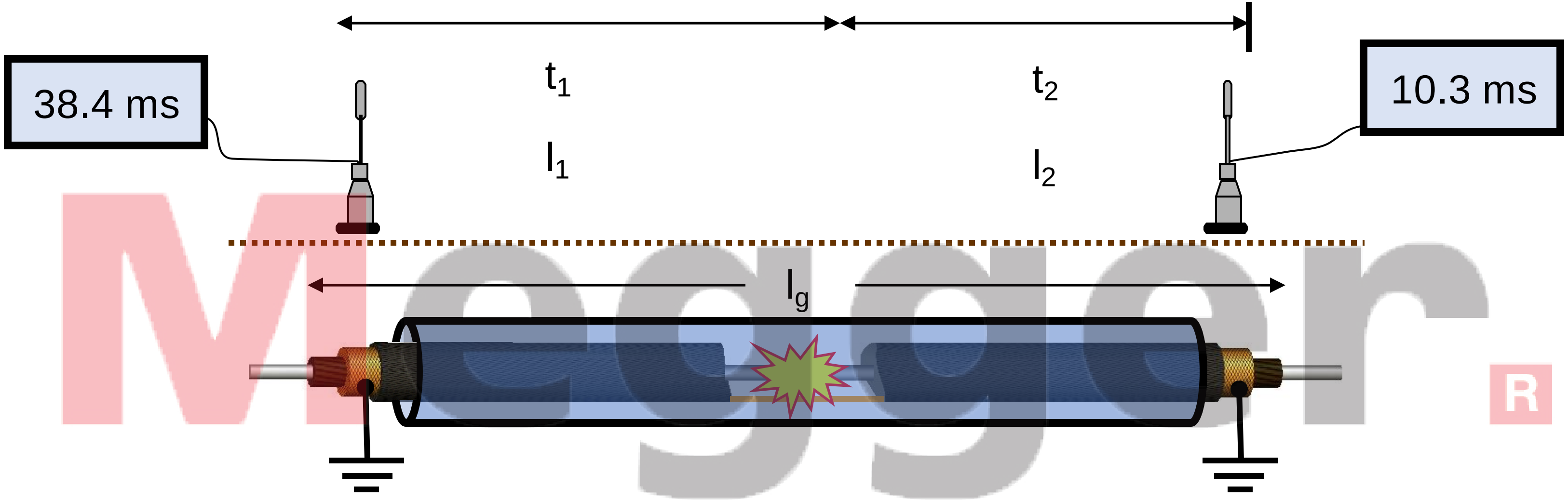
Before the fault:

The new value is lower than the old difference value



After the fault:

The new value is higher than the old difference value



Example: $t_1 = 38.4$, $t_2 = 10.3$, $l_g = 50$ m

$$l_x = l_g \frac{t_1}{t_1 + t_2}$$

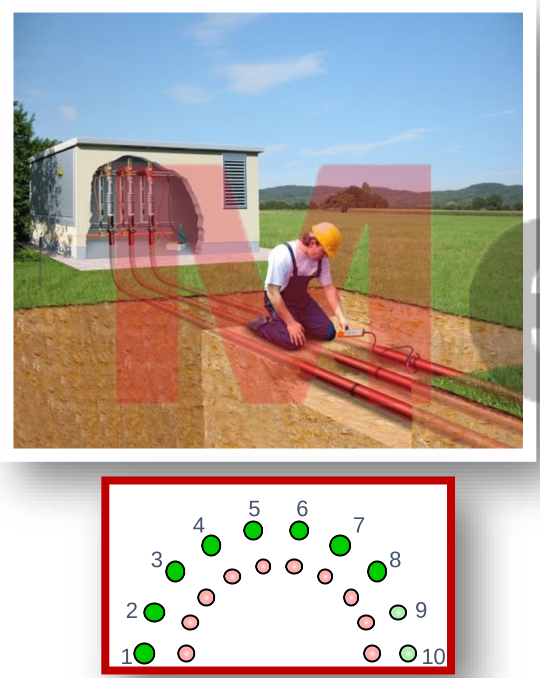
$$l_x = 50 \cdot \frac{38.4}{38.4 + 10.3} = 39.4 \text{ m}$$

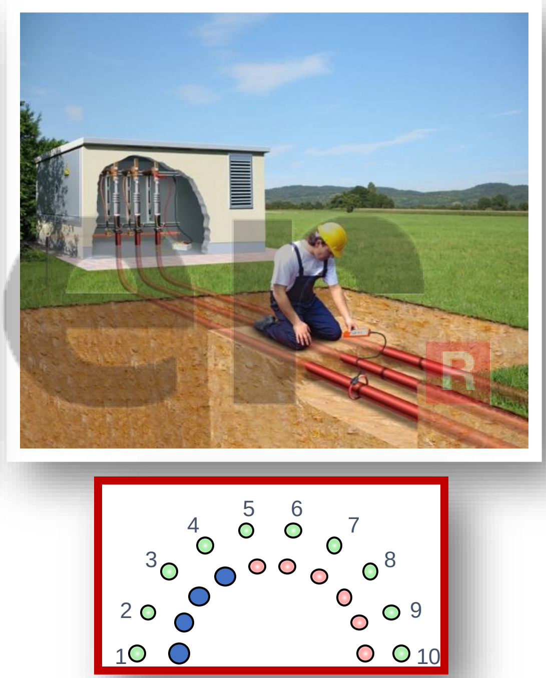
Cable Identification

Megger

Cable Identification Hardware

Pulse Method in de-energised Cables Mode of Operation

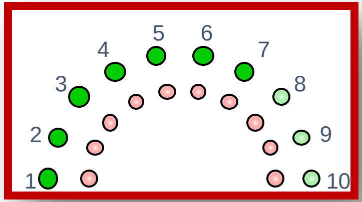




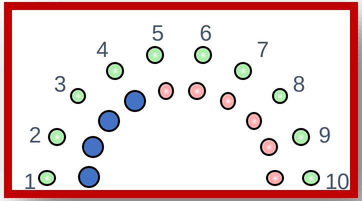
Pulse Method in de-energised Cables Evaluation

Polarity

Intensity



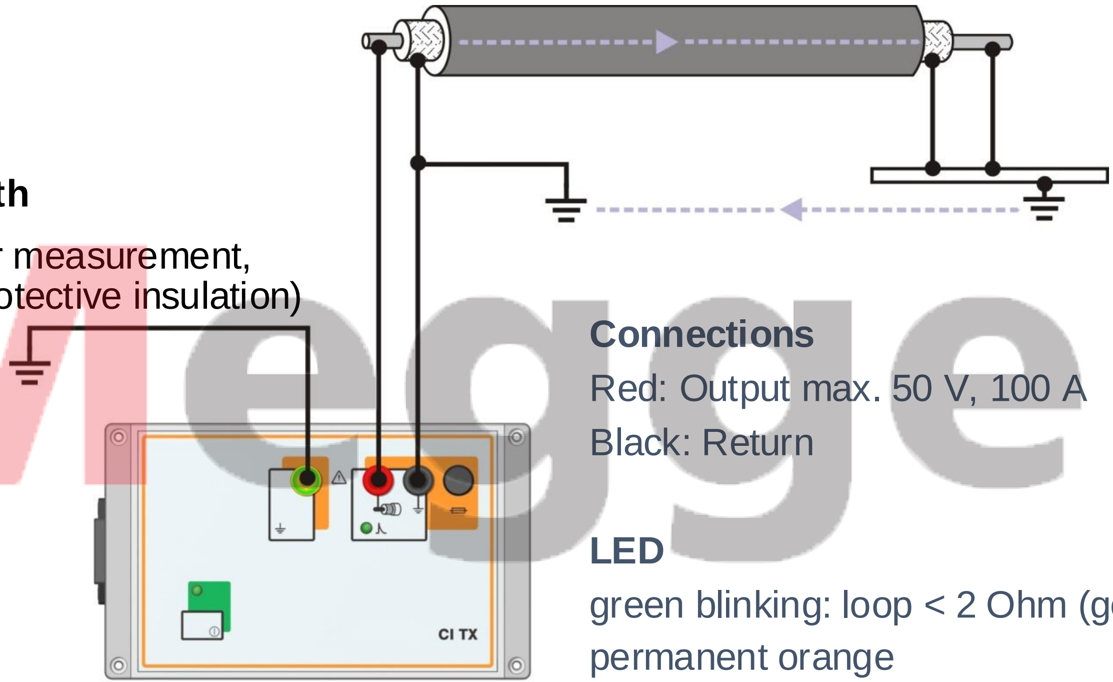
Comparing polarity and intensity of various cables



Cable Identification CI Generator TX

Protective Earth

(not relevant for measurement, housing with protective insulation)



Connections

Red: Output max. 50 V, 100 A

Black: Return

LED

green blinking: loop < 2 Ohm (good)

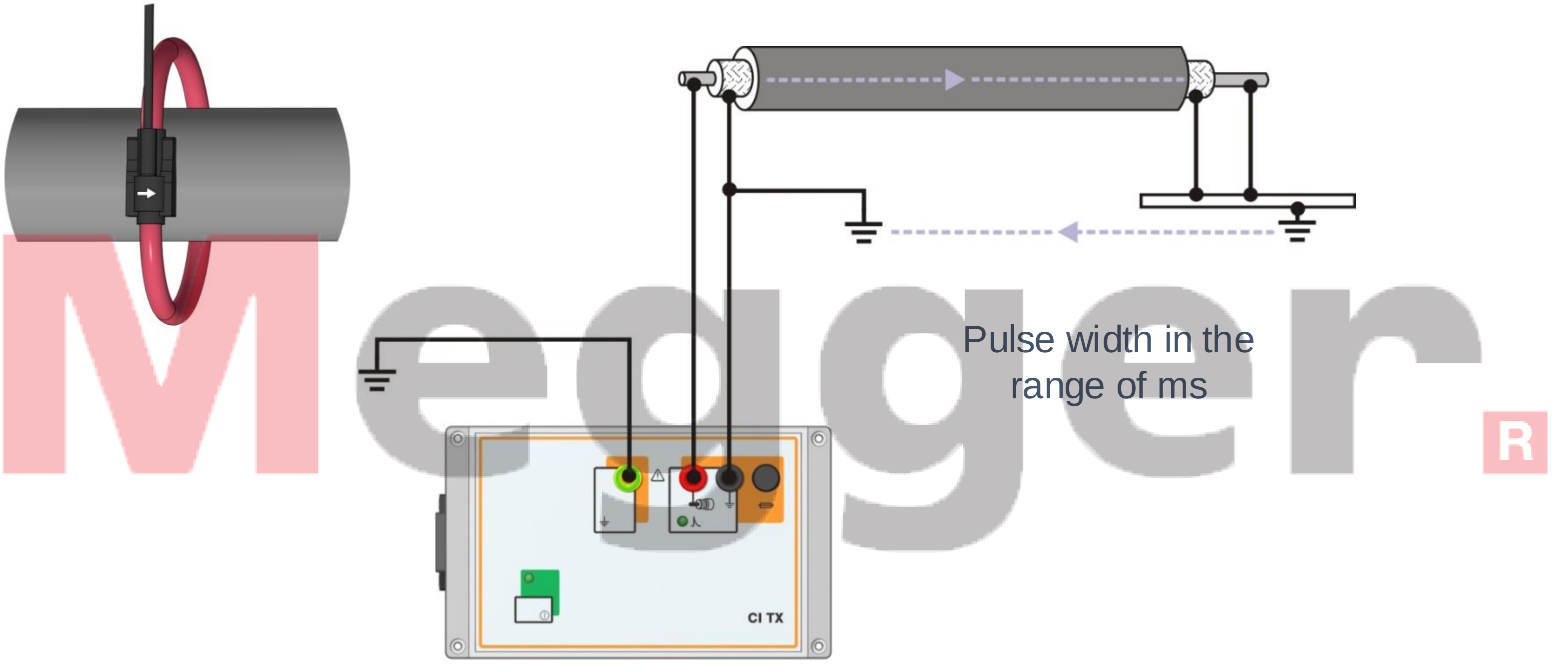
permanent orange

permanent red: loop > 6 Ohm (bad)

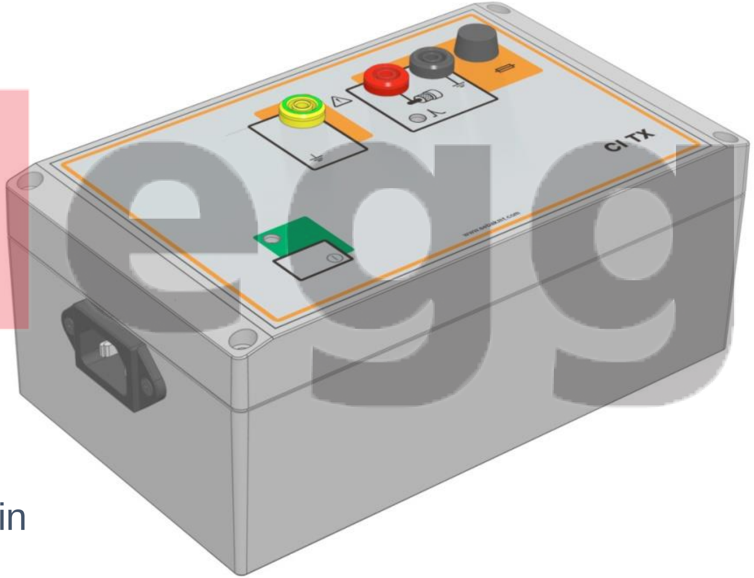
ON Button

LED green: Battery full

Cable Identification CI Generator TX ”directional Pulses“



Cable Identification CI Generator TX



for testing:

bridge outputs red and black.
Green pulse LED must be on and blinking.

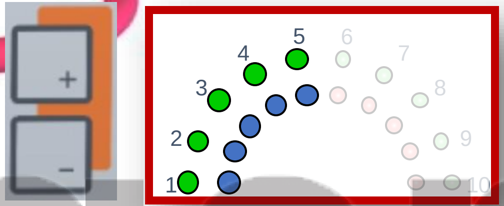
This can also check the receiver CI RX.

Power Supply:

rechargeable battery
or mains power.

Battery will be charged in mains operation.

Cable Identification CI Receiver RX



Amplification

should never be higher than 5,
else, something is not right in the current loop (leakeage current, loop too long, …).

ON Button

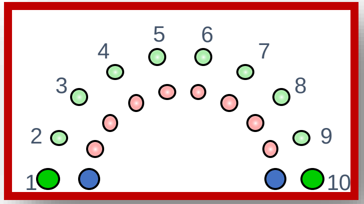
will autom. switch off after 2 min.,
keeps the gain setting.

Cable Identification CI Receiver RX

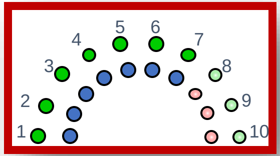
- a logic will check the plausibility of each pulse for pulse rate, shape, etc.. It might take 1 … 3 pulses before a display will appear.

- Amplification (gain) should never be necessary to be higher than position 5,
else, also distortions will be amplified too high.

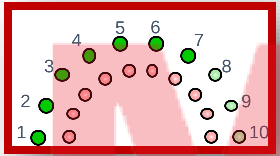
- 50 Hz current measurement by simultaneously pressing Plus/Minus. LEDs 1 and 10 show this mode.
Measurement shows only current flow,
it does NOT show that this cable is de-energised !



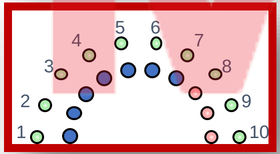
Cable Identification CI Receiver RX



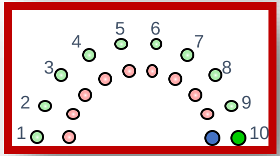
after turning on or when adjusting gain, the red and green LEDs will show the gain level for 3 seconds (von 1 bis 10).



correct direction of current flow.

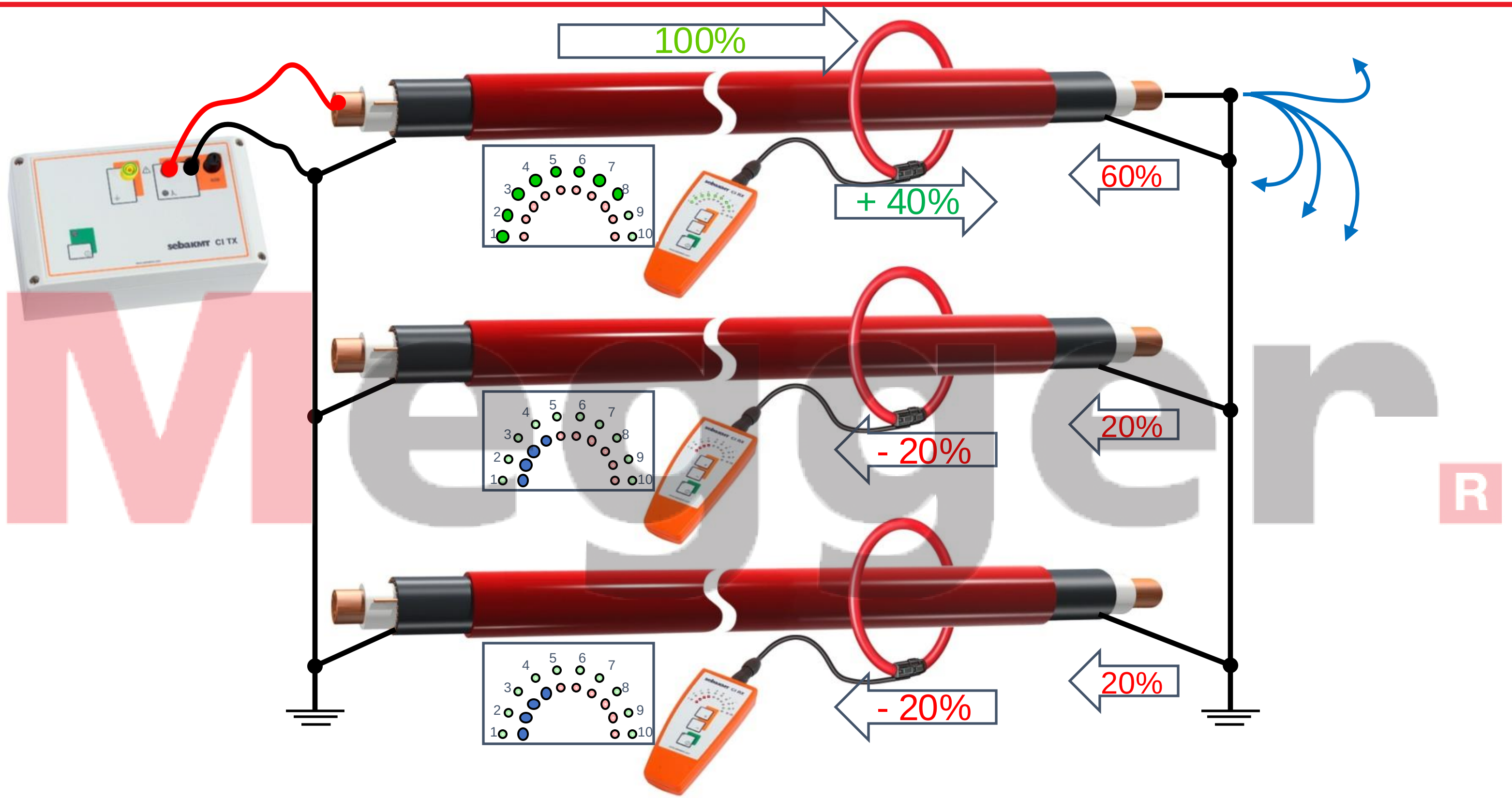


wrong direction of current flow.

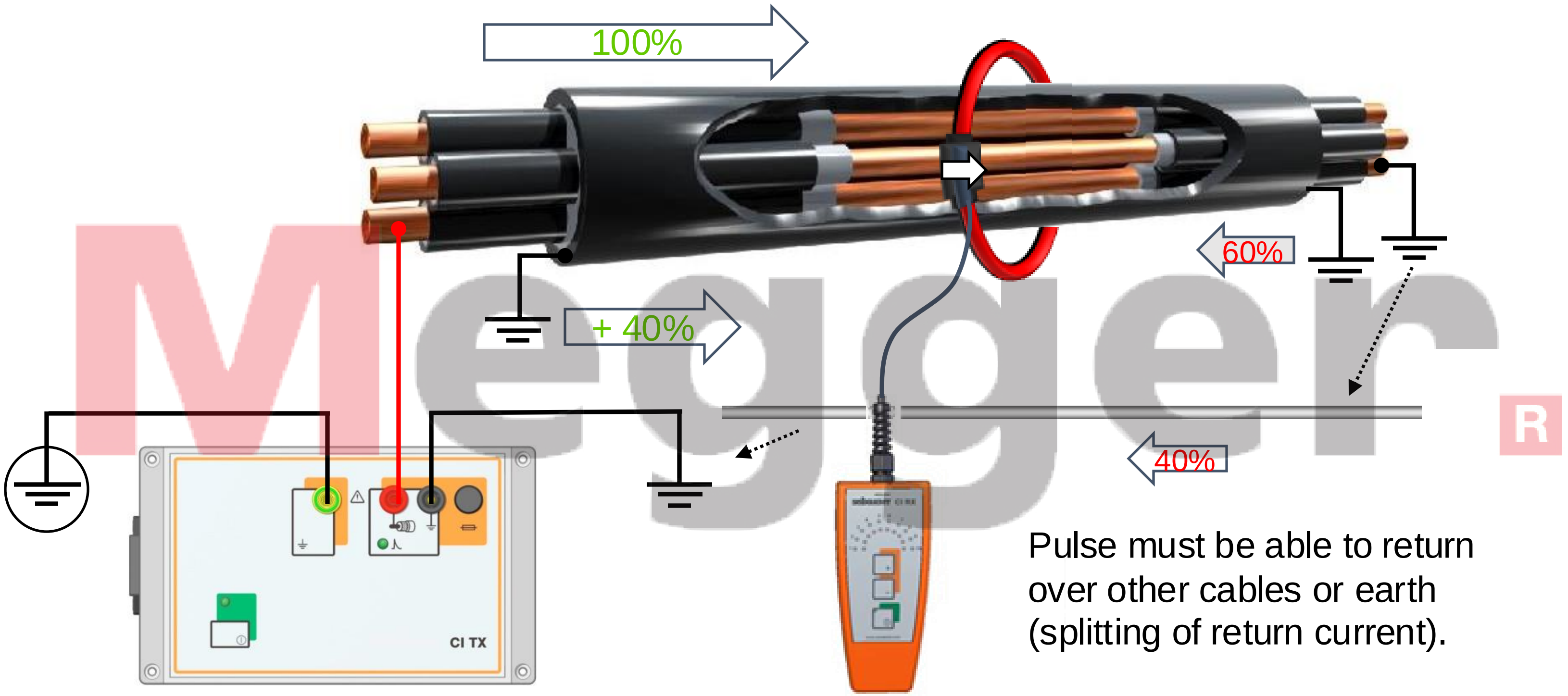


Gain too high, saturation of sensor.
Red and green LEDs 1 and 10 will show. Reduce gain.

Pulse Method in de-energised Cables Mode of Operation

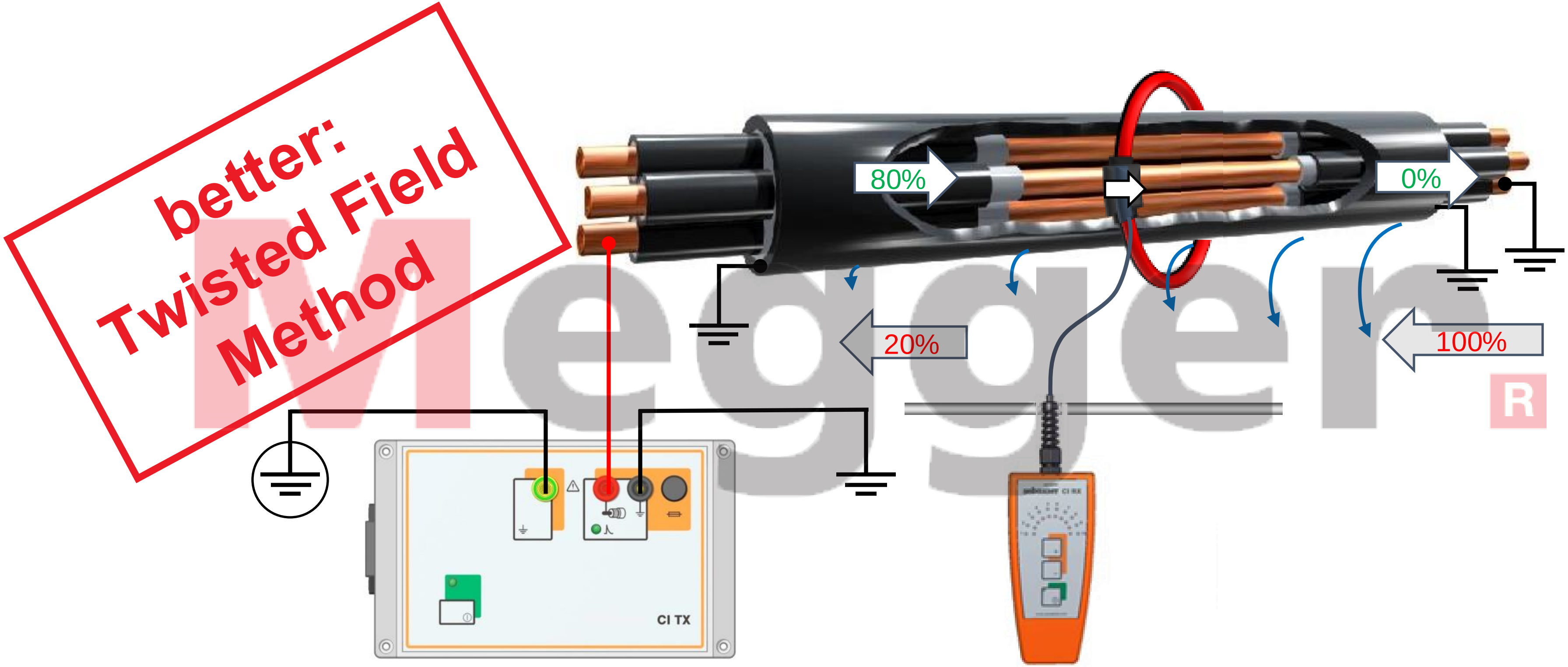


Pulse Method in de-energised Cables PILC Paper insulated Cable

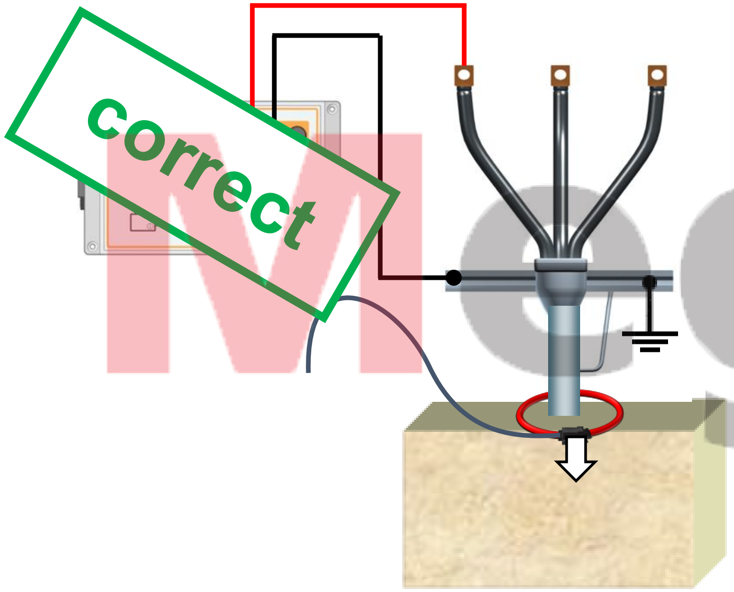


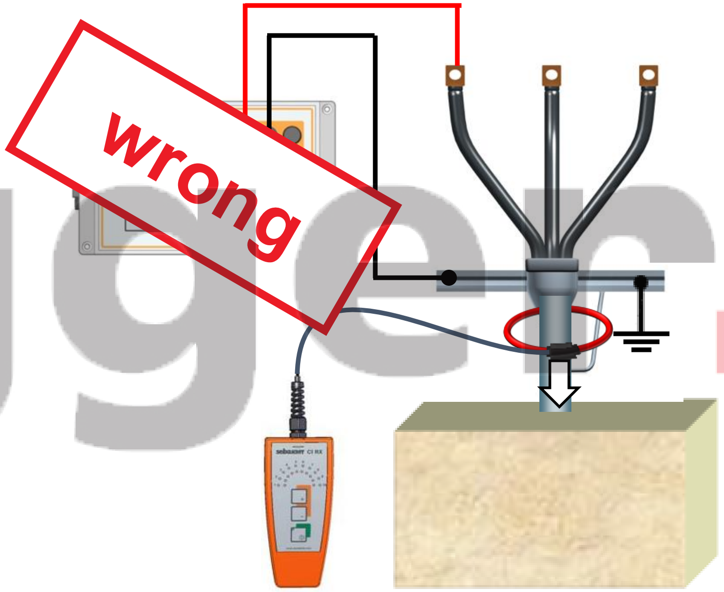
Pulse must be able to return over other cables or earth (splitting of return current).

Pulse Method in de-energised Cables PILC Paper Insulated Cable

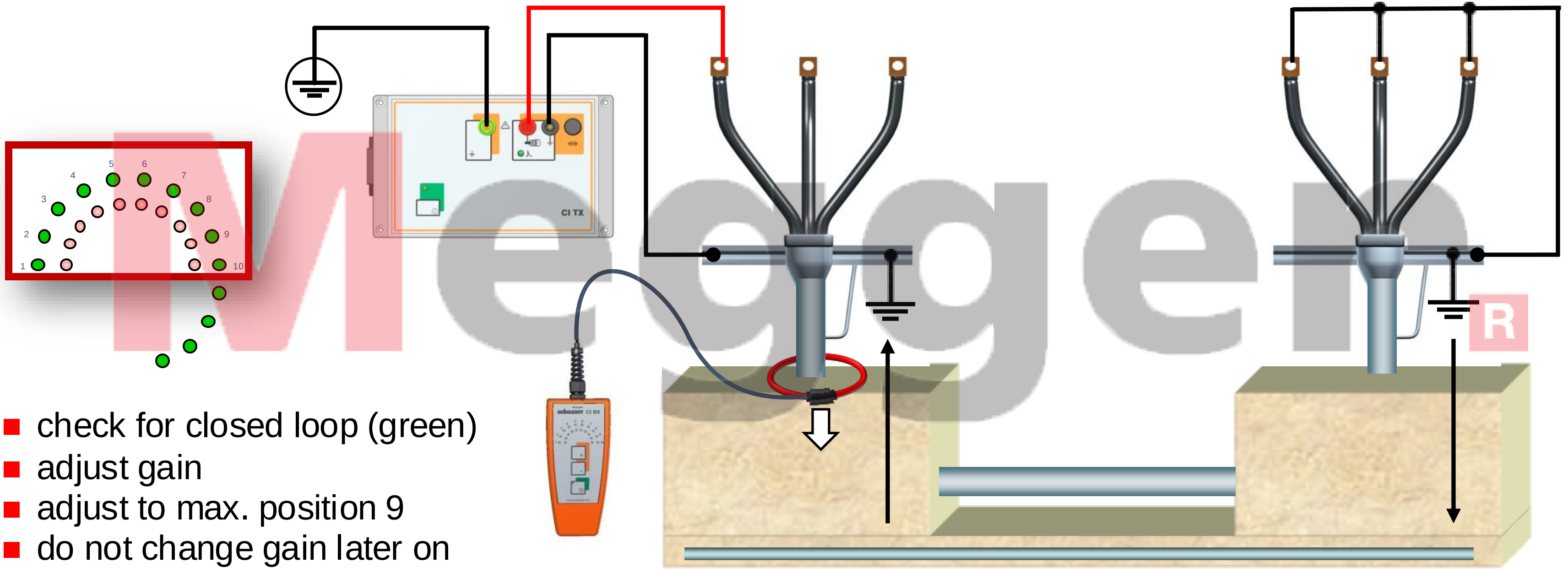


Pulse Method in de-energised Cables "calibration"





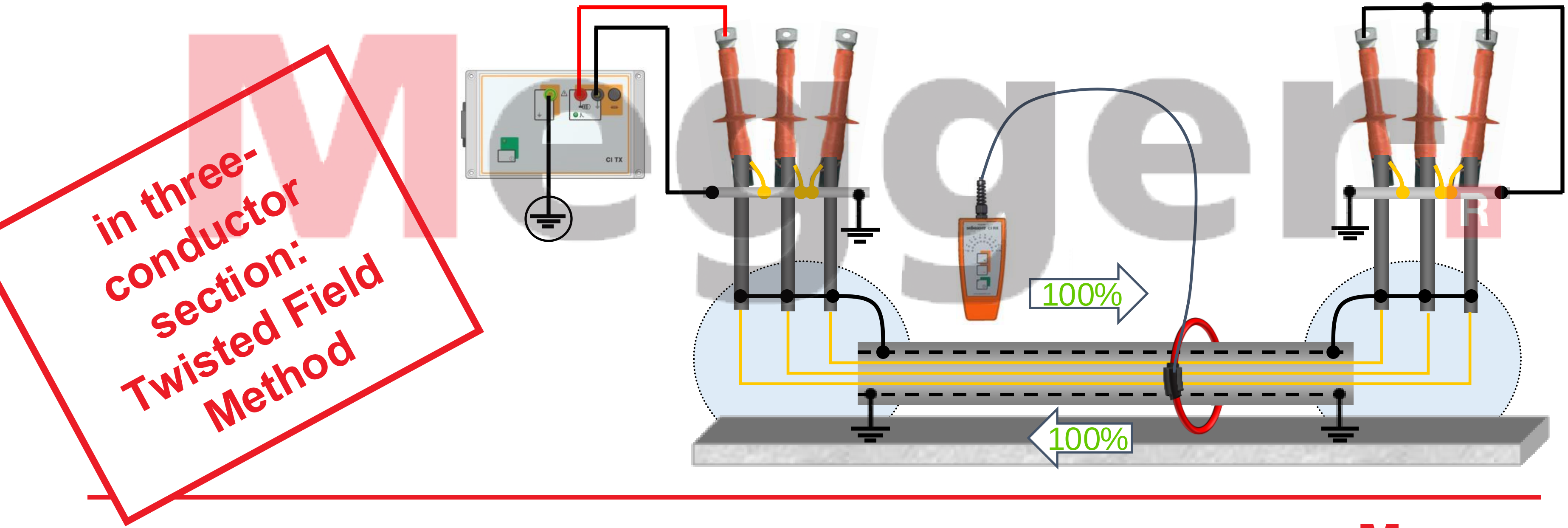
Pulse Method in de-energised Cables "calibration"



- check for closed loop (green)
- adjust gain
- adjust to max. position 9
- do not change gain later on

Pulse Method in de-energised Cables Problem with mixed Cables

Going and returning current can cancel out
→ No safe identification



Cable Identification

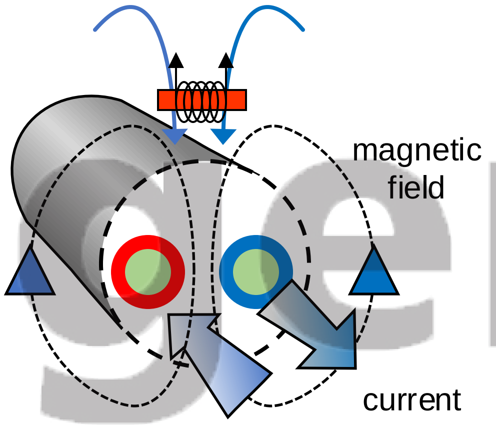
Twisted Field Method
(multi-conductor cables only)

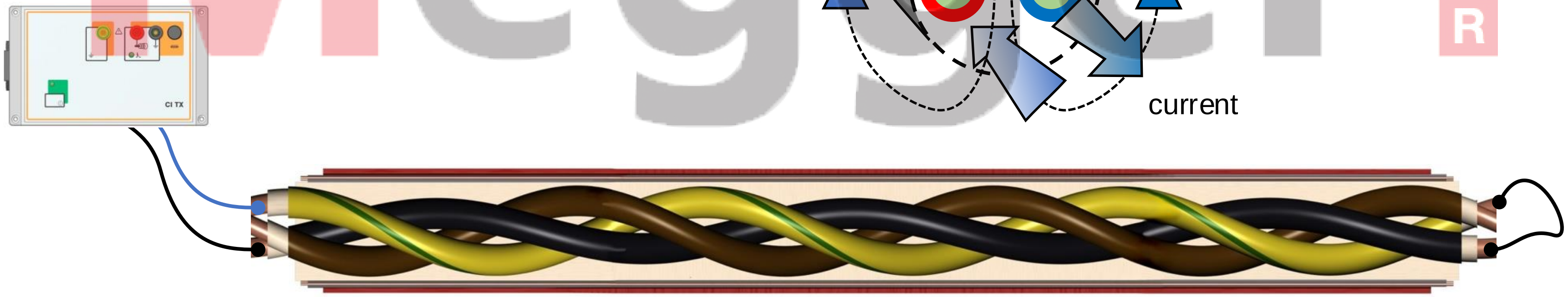
1. in de-energised Cables
2. in energised cables (LV)

Megger.

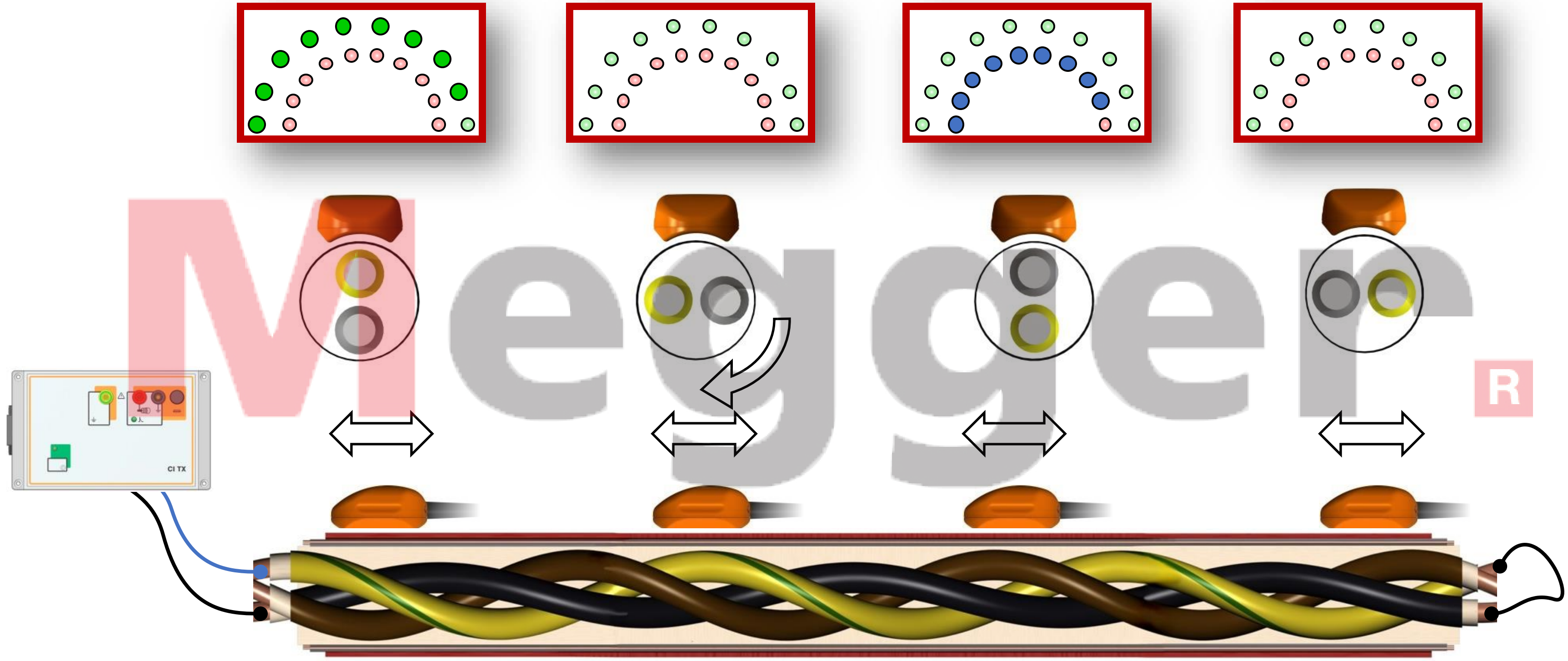
Twisted Field Method (multi-conductor cables only) Connection

Going and returning current are NOT concentric and thus will not cancel out. Two magnetic fields will appear in opposite direction.

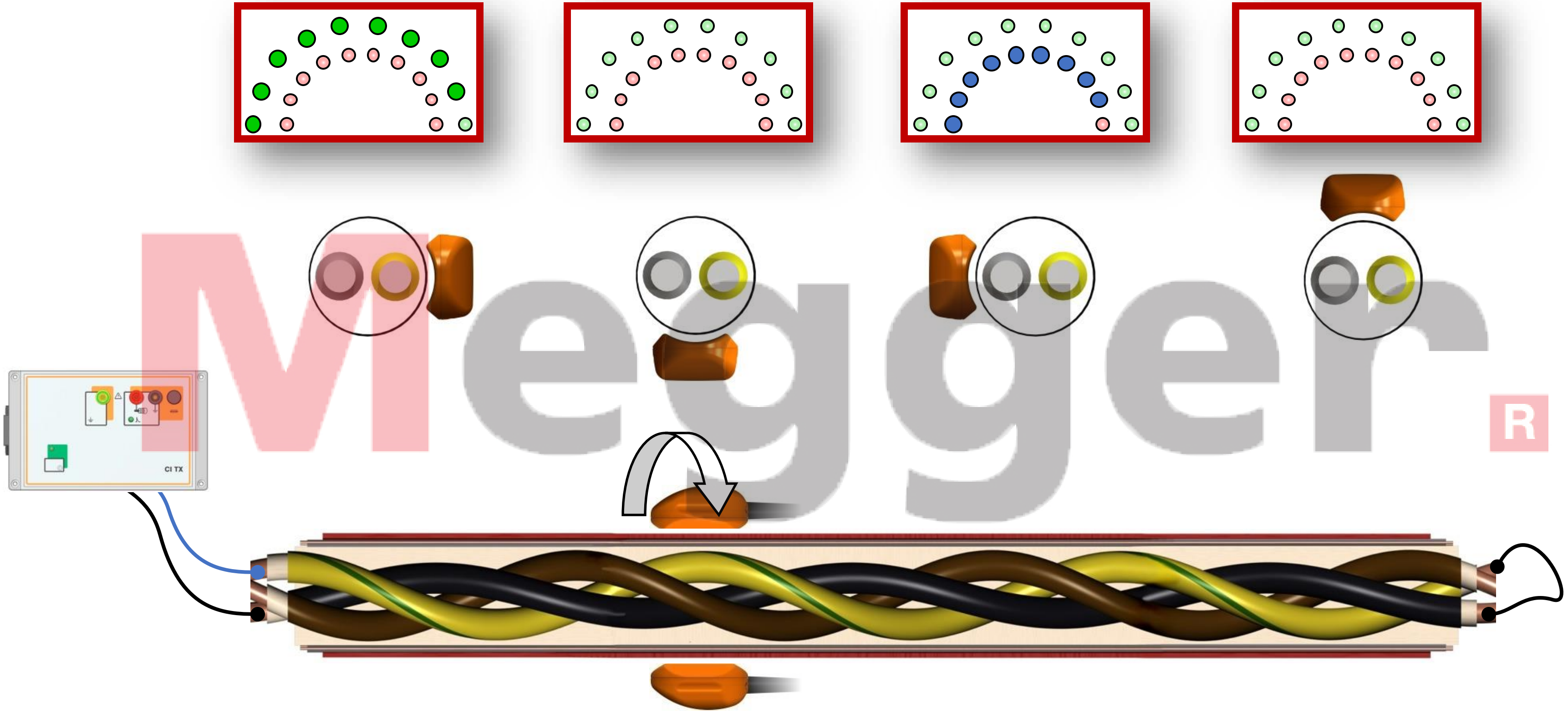




Twisted Field Method (Longitudinal Twist)



Twisted Field Method (Transversal Twist)

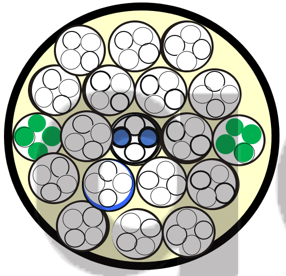


Twisted Field Method Connection

Note:

better **THIS WAY**

than **THIS WAY**

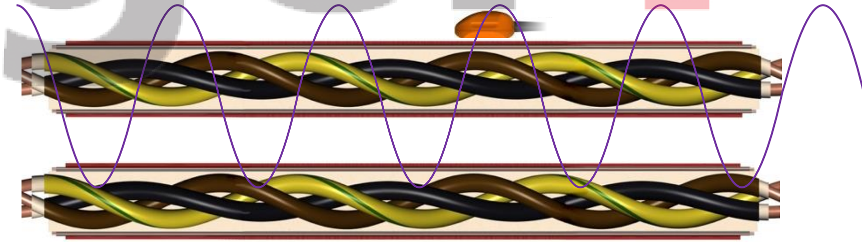


Twisted Field Method

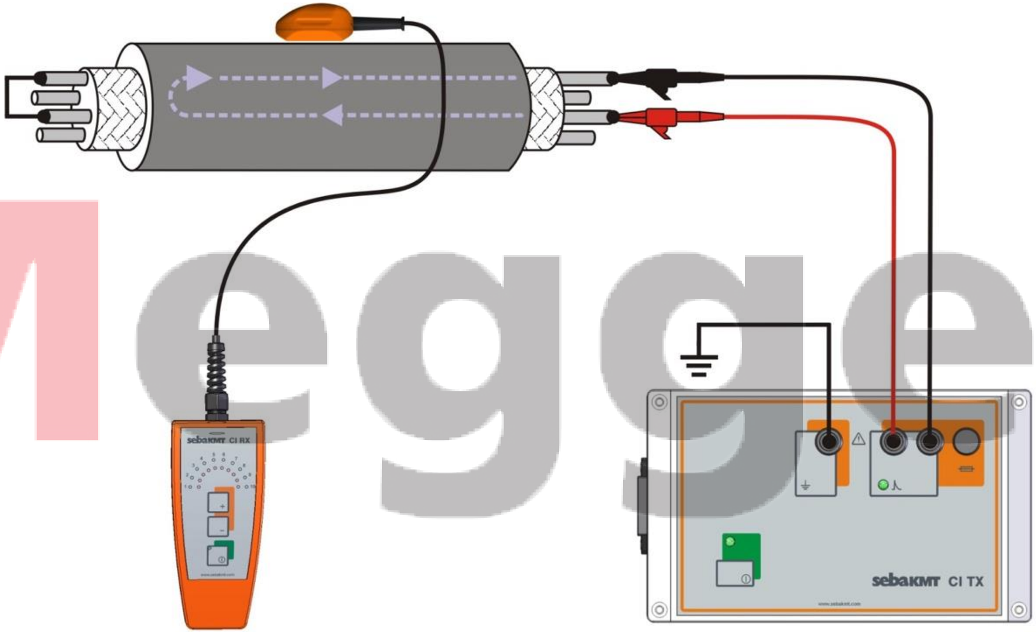
Important also here:

Keep amplification low.

- Confirm by using longitudinal and transversal twist.
- Longitudinal twist might also be seen at a small distance to the target cable.
  Danger of wrong identification
- Power cables have quite long twist.
  Confirm by using longitudinal, transversal twist or pulse method.

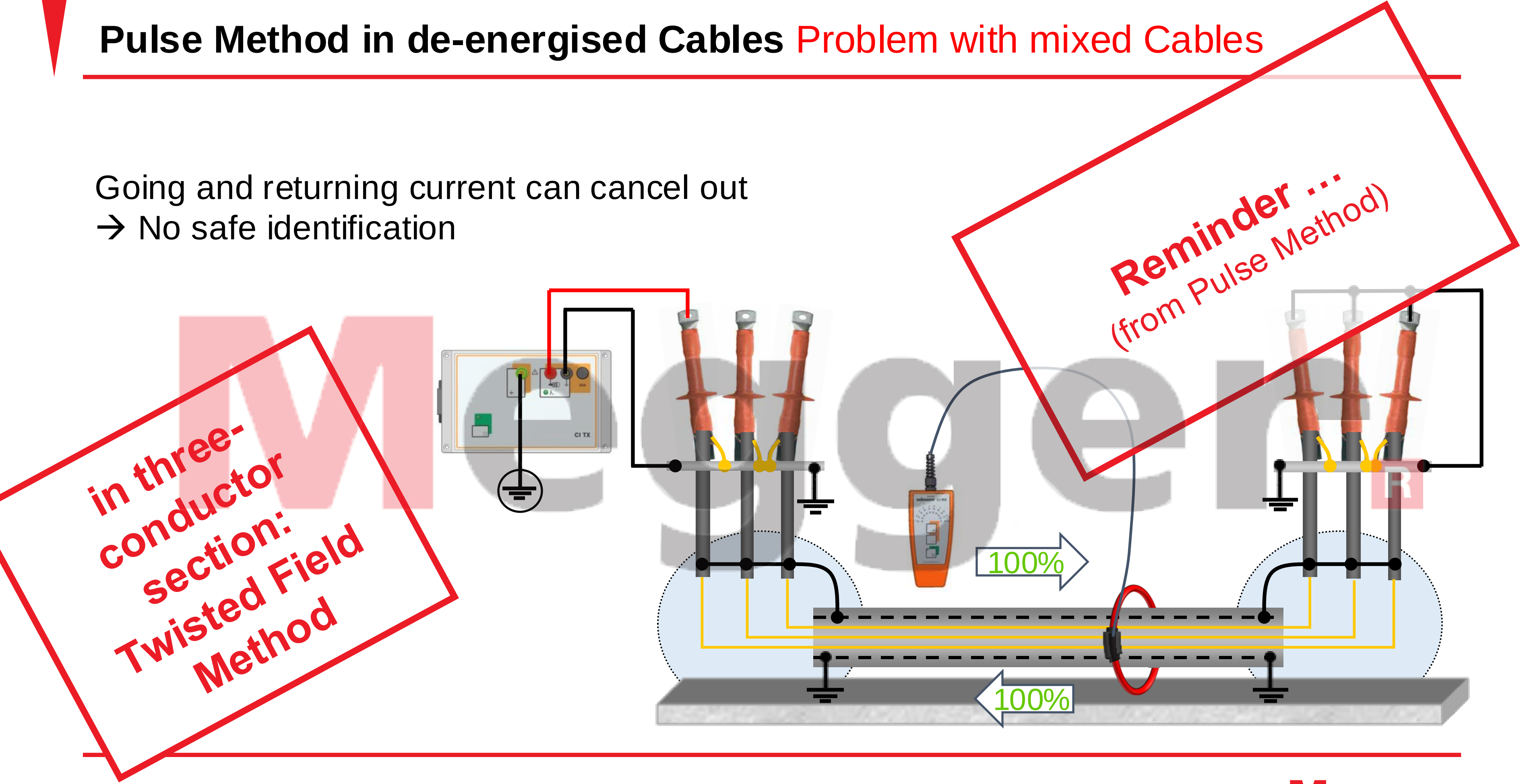


Twisted Field Method De-energised Connection CI TX

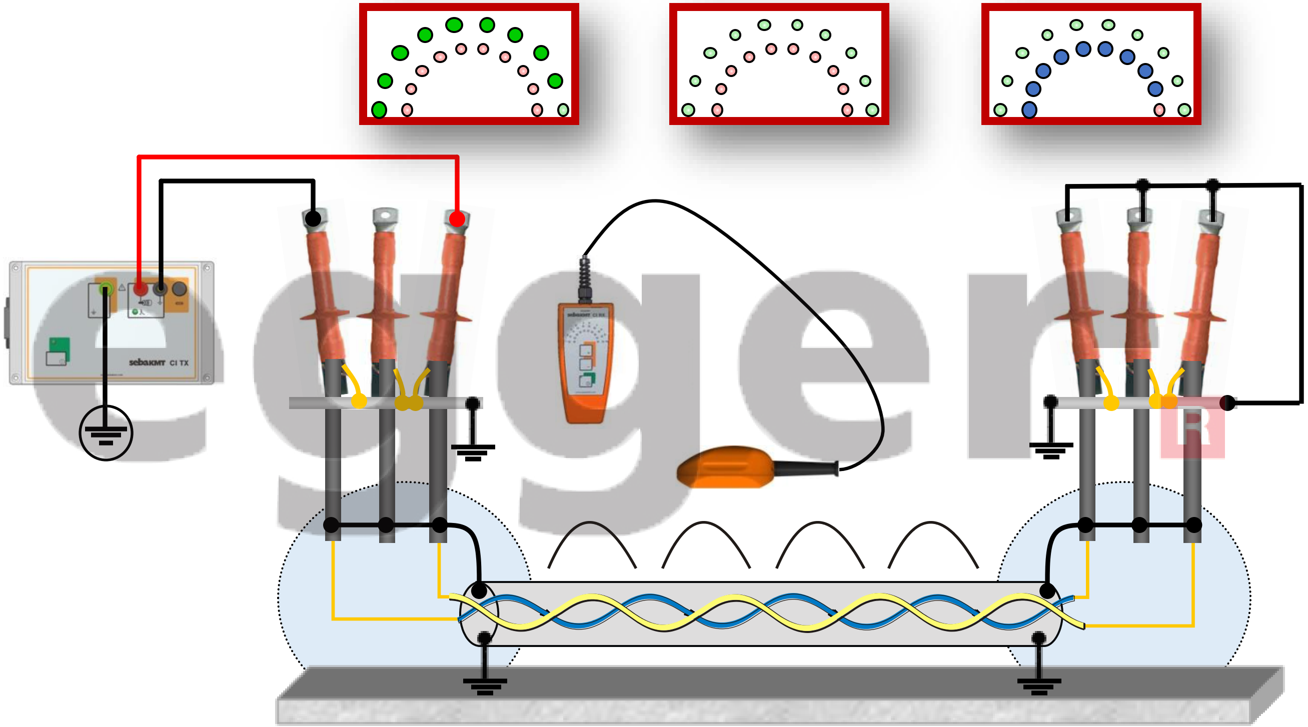


Pulse Method in de-energised Cables Problem with mixed Cables

Going and returning current can cancel out
→ No safe identification



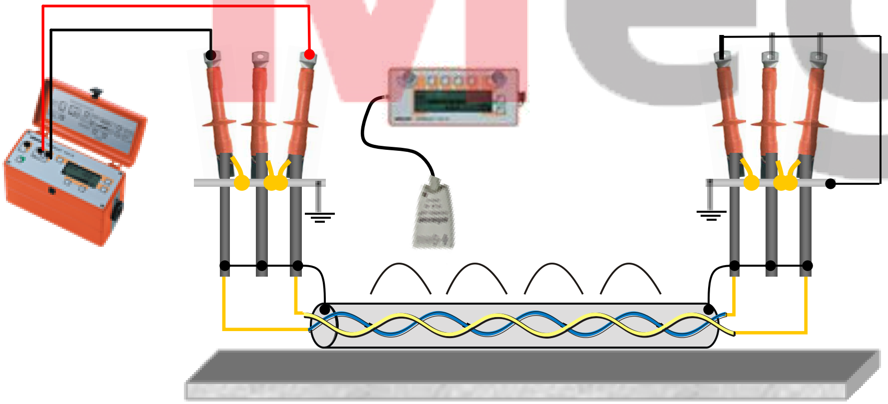
Twisted Field Method Solution with mixed cables

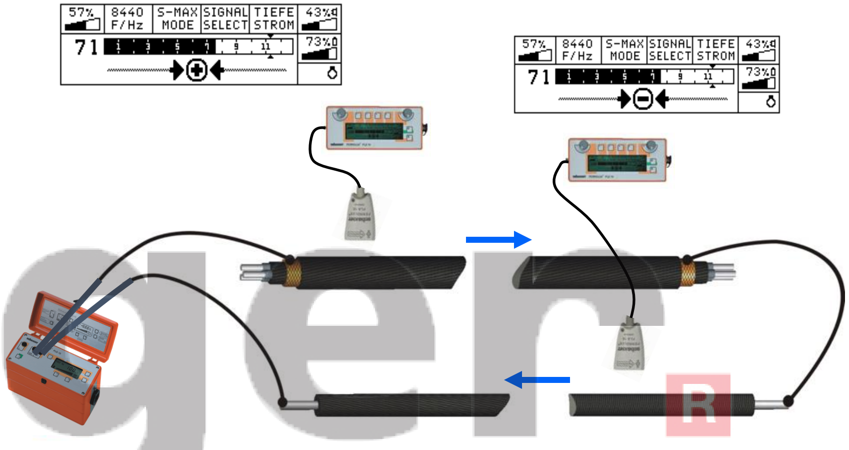


Megger

Cable Identification with Audio Frequency “cable tracers“

Twisted Field Method
with accessory
identification coil





Safe identification only
possible with defined
return path.
Not recommendable.

Questions

Megger