APPLICATION NOTE

Pre-location pulse reflection process

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1. Introduction

The exact determination (pinpointing) of a cable fault should be as a result of pre- location so that the various pinpointing processes only have to be used on short cable lengths. This results in a significantly shorter complete location time, whilst cables are protected at the same time. Due to pulse reflection laws, the fault in question must exhibit certain values in order to be located. Borderline cases can also be pre-located through conversion, either on a long-term (burning) or short- term (high-voltage measurement procedure) basis.

The pre-location methods are split into the following two areas:

- Processes based on pulse reflection (TDR)
- Transient methods (HV methods)

2. Basics

A pulse is fed through the beginning of the cable, which runs up to the fault position at the typical cable diffusion speed (v/2) and is then reflected back to the beginning (fig. 1). The time required by the pulse for forward and reverse travel is then calculated and multiplied by the v/2 speed. This value corresponds to the calculated distance to the fault position.

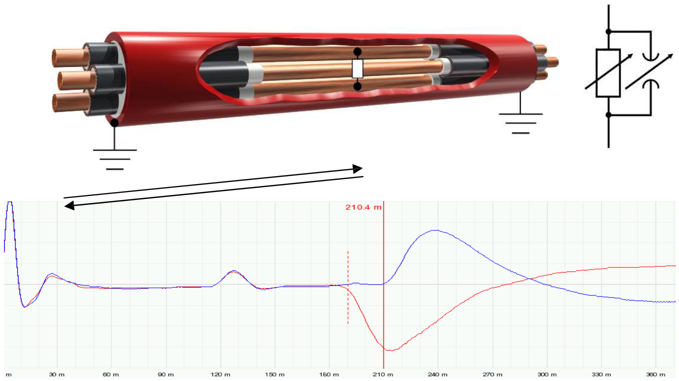


Fig. 1: Reflection at fault (negative) and cable ed (positive)

Reflection at sleeve (positive / negative or negative / positive)

Diffusion speed of the pulse (v/2)

$$l_x = t\frac{v}{2}$$

$$\frac{v}{2} = \frac{l_g}{t}$$

l_x = Distance to fault | l_g = Overall cable length | l = Transit time in µs

Pre-location pulse reflection process

The possible *measuring accuracy* is mainly influenced by external factors. It is only slightly influenced by the pulse-echo measuring device. External factors primarily include inaccurate knowledge of the v/2 diffusion speed, whose values are especially influenced by the insulation material of the cable.

The diffusion speed changes according to the following factors:

- Impedance
- Dielectric materials (e.g. XLPE, PVC, PILC, insulation colour)
- Age of the cable
- Temperature
- Moisture content (water inside cable) - reduces v/2 to approx. 65 m/µs
- Wire position inside cable (communication cable)
- Cable manufacturer (composition of insulation material and additives)

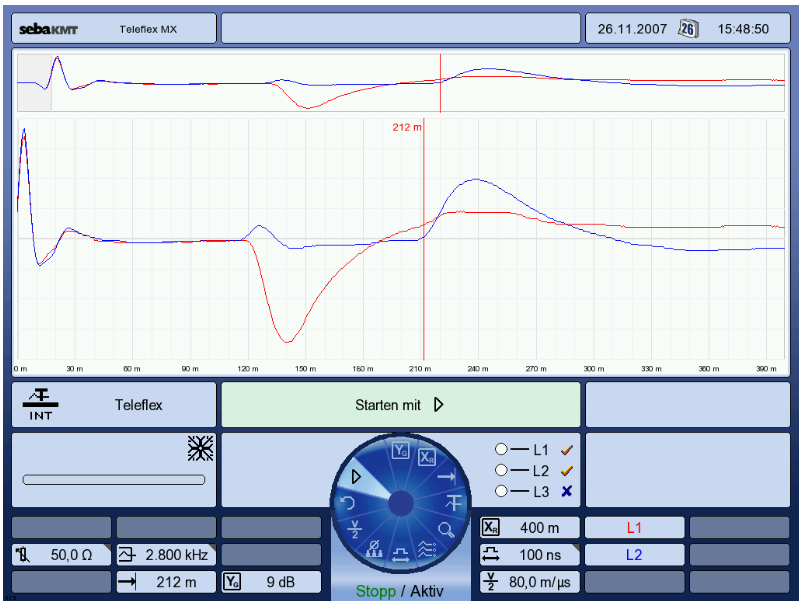


Fig. 2: Length measurements at different diffusion speeds (v/2)

Reflection factor "r"

Each change to the homogenous cable construction leads to a change in inductivity or capacity (also in feeder G) at this position, which then leads to a change in the characteristic impedance "Z". The pulse location and impedance change reflects a certain amount of the incoming measurement pulse towards the feed source. If only a part of the pulse is reflected, then the remaining pulse continues to the next reflection position, where it then runs back to the beginning of the cable. The size of the reflected pulse is determined by both the reflection factor (r) and the cable insulation. Cables with small cross-sections and longer lengths require much more accentuated faults (either with very low or high resistance) in order to be measured accurately.

Pre-location pulse reflection process

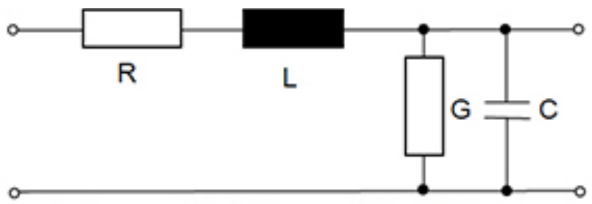


Fig. 3: Replacement circuit diagram of electrical lines

R = Longitudinal resistance
L = Inductance
G = Conductivity
C = Capacity

No impedance change in cable	No reflection
Large impedance change in cable	Large reflection
Short circuit and interruption	Total reflection

Cable faults often have resistances that lay significantly over 2 kOhm and have virtually endless values. These faults are then often not visible when using a normal reflection measurement. Fault conversion has an effect in this case.

Pulse width

Pulses of different widths must be used depending on the cable length (fault distance). Narrow pulses lead to short ranges but a very high resolution. Wide pulses must be used on long cables. The resolution decreases and the dead zone is expanded. The pulse width is connected to the measuring range on most reflection measuring devices, but can be adjusted.

Typical pulse widths:

1 ns – 3 µs	High-resolution reflectometers for communication cables (e.g. Digiflex Com)
35 ns – 5 µs	Reflectometers for power cables (e.g. Teleflex T 30-E, Teleflex MX)
50 ns – 20 µs	Special models for long cables (e.g. undersea cables and overhead lines)

Dead zone / pulse width:

5 ns	approx.	2 m
500 ns	approx.	90 m
3 µs	approx.	400 m

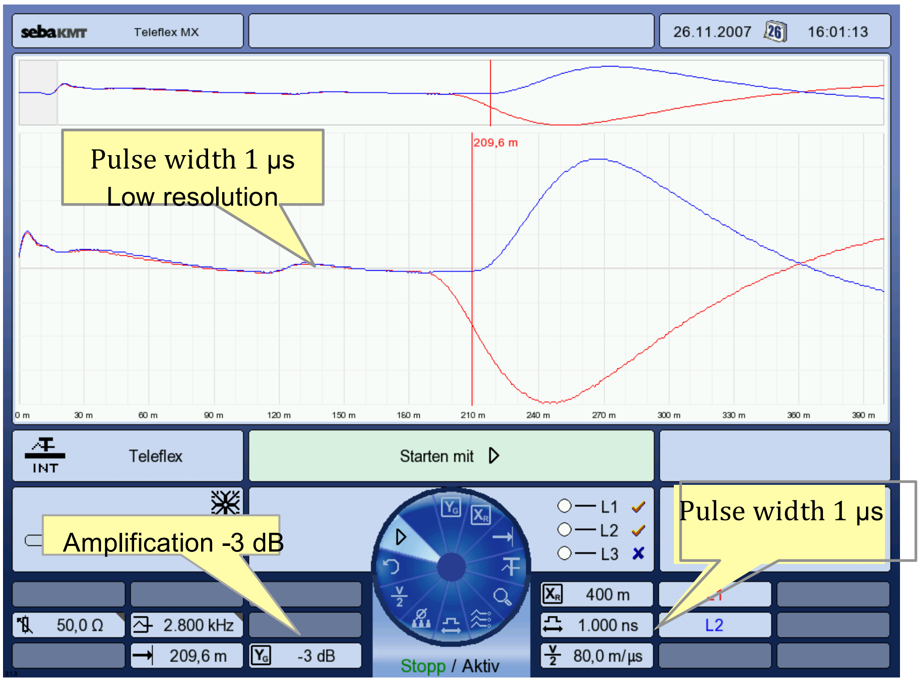
This means that the sent measurement pulse can even cover an area of this size. Depending on the construction of the reflectometer, virtually no other effects (e.g. faults) can be seen within this area. This area is therefore known as the "dead zone". However, a dead zone does not automatically mean that absolutely no details can be seen within the area. For example, the changes within the start pulse can be seen. Additionally, the sent pulse is immediately suppressed (compensation) by the input terminating sets used by SebaKMT. This means that all other changes can be seen immediately.

Pre-location pulse reflection process

Pulse range	Transit time range	Distance range (at V/2 = 80 m/µs or NVP = 0.533)
100 ns	Up to 6.25 µs	Up to 500 m
200 ns	6.25 µs … 31.25 µs	500 m … 2.5 km
500 ns	31.25 µs … 93.75 µs	2.5 km … 7.5 km
1 µs	93.75 µs … 375 µs	7.5 km … 30 km
2 µs	375 µs … 750 µs	30 km … 60 km
5 µs	750 µs … 2 ms	60 km … 160 km

An automatic switching of the pulse width always ensures the optimal adjustment of the measurement pulse according to the distance. These adjustments can also be made manually. By reducing the pulse width, the operator can attempt to create more details.

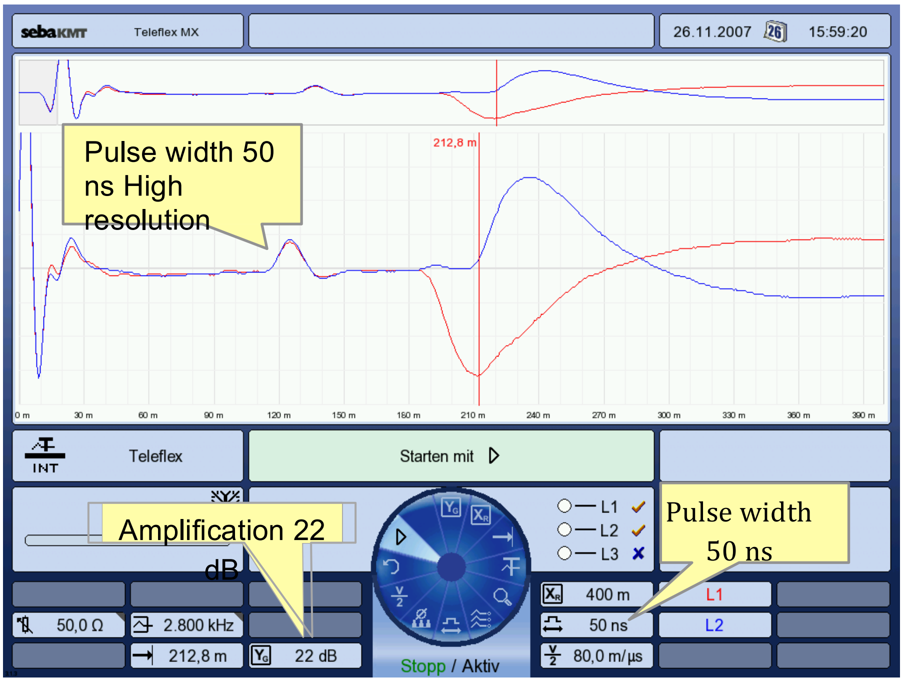
As seen in the following diagrams, a wide measurement pulse shows all reflections clearly and on a large scale. If higher levels of accuracy are required, then the pulse width must be reduced. Only then can smaller changes be seen clearly.
Limits are provided by the insulation. This means that an endless reduction of the pulse width is not possible and is also not supported by the system.


Pulse width 1 µs
Low resolution

Amplification -3 dB

Pulse width 1 µs

Pre-location pulse reflection process



Pulse width 50 ns High resolution

Amplification 22 dB

Pulse width 50 ns

Fig. 4:Reflections with pulse widths of 50 ns (amplification = 22 dB) and 1 µs (amplification = -3 dB)

Cable insulation and dispersion

The cable cross-section and length both lead to changes in the amplitude and form of the sent pulse in the cable

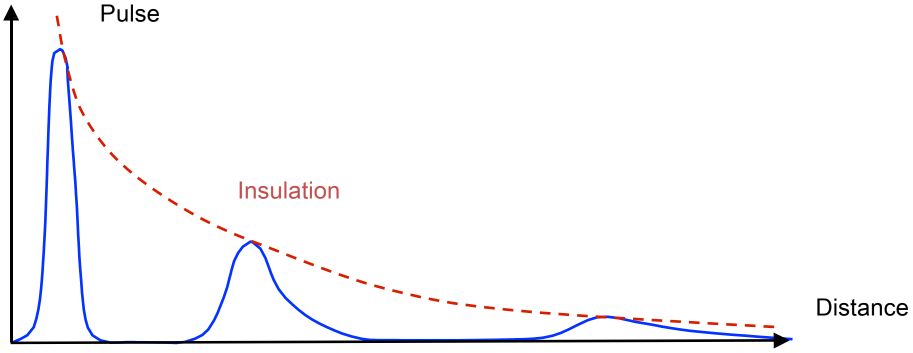


Fig. 5: Cable insulation and dispersion

The insulation leads to a reflected signal becoming smaller as the distance increases. The insulation is shown by a red line in the diagrams. As the insulation applies to a natural (exponential) function, it can also be calculated and corrected.

Dispersion is another factor that influences the pulse image. As high signal frequencies are absorbed more that low frequencies, far-off pulses appear much wider than nearer ones. Due to the combination of insulation and dispersion, these signals can only be determined with difficulty.

Pre-location pulse reflection process

This amplitude correction depending on distance is shown in figure 6.

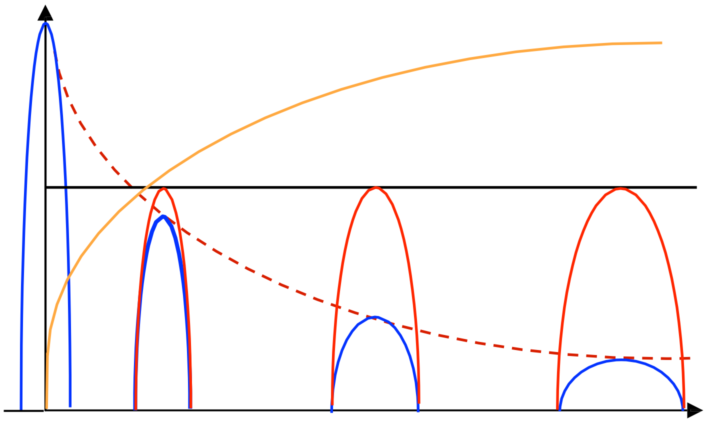


Fig. 6: Amplitude correction depending on distance

The amplitude correction depending on distance allows all results to be displayed in the appropriate corrected size independent of the distance. This means that a relatively exact evaluation of the results can be made.

Compensation is one of the basic measurement methods. The size to be measured is compared to a compensation size. This size is physically identical, settable and has definable values. The measurement is constantly readjusted until consistency can be determined (comparison).
The resistance is compared to the impedance of the cable using the "R" potentiometer. The send pulse is suppressed by a terminating set. In practice, the send pulse in the smallest measurement area should be set using compensation so that positive and negative reflections are equal in size and have zero values (ideal scenario).

Adjustment is the setting or alignment of one state to another. On the reflectometer, impedance adjustment is made on the cable (usually using a transformer) so that the maximum pulse energy can be transmitted. This applies to both send and receive pulses.

Pre-location pulse reflection process

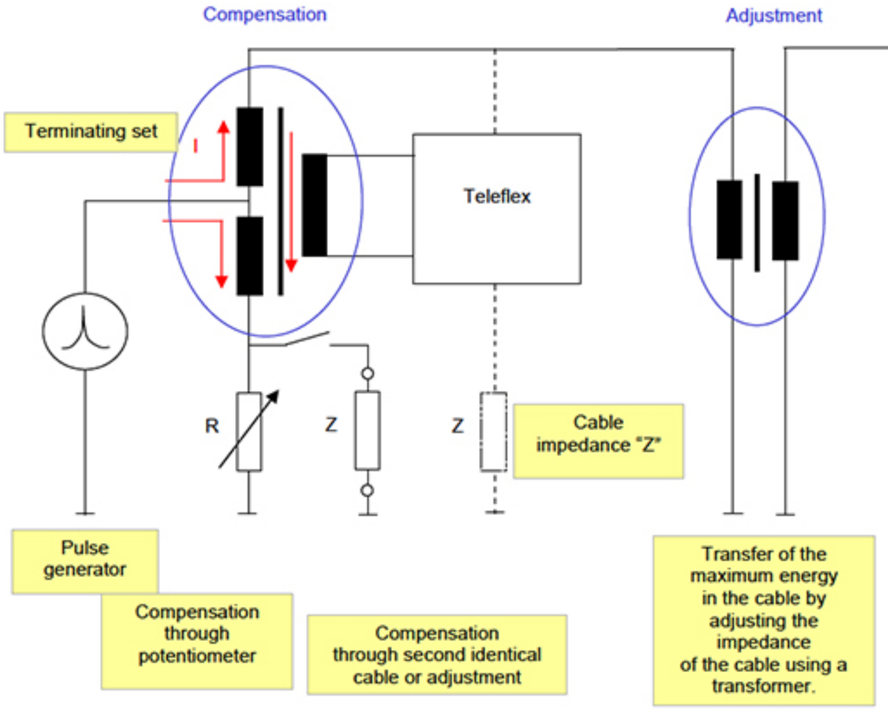


Fig. 7: Terminating set, compensation and adjustment in reflectometer

3. Measuring methods – Examples

Improvements in measurement evaluation can be made using comparative measurements, as these show the fault positions more clearly. If echograms can be saved, then one-wire cables must also be compared to themselves when the measurements are not made at the same time. Cable manipulation (e.g. burning) is possible between both measurements. The following devices are available for intermittent faults that can be located using the ARM procedure, coupled oscillating method or pulse method: Teleflex 30 E, Teleflex MX.

Reflection measurement process

1. Determine the fault resistance using an ohmmeter. This must have a measurement area of less than1 kOhm in order to recognise a resistance of 10 Ohm. Connect the pulse-echo measuring device on the defective cable and set the typical propagation rate for the cable.
2. Select the measurement area so that the entire cable length is visible at the start of measurement. When needed, check on a fault-free wire.
   Important: Ensure that the cable end is visible!
3. Set the compensation so that a horizontal curve is set at the start of the echogram where possible. The remaining visible deflections (upwards and downwards) should be generally symmetrical. Avoid overcontrolling.
4. Make the fault position visible using the amplifier setting and measure it. Reduce the measurement area when necessary.
5. Measure the fault position with a digital displayof the distance to the fault. The exact measurement to the fault position is made using the vertical cursor.
6. A comparison of defective and fault-free wires should always be made whenever possible. As shown here, the splitting of both echograms at the fault position can be measured especially well, which leads to high levels of accuracy.

Pre-location pulse reflection process

Measuring methods

Direct reflection measurement

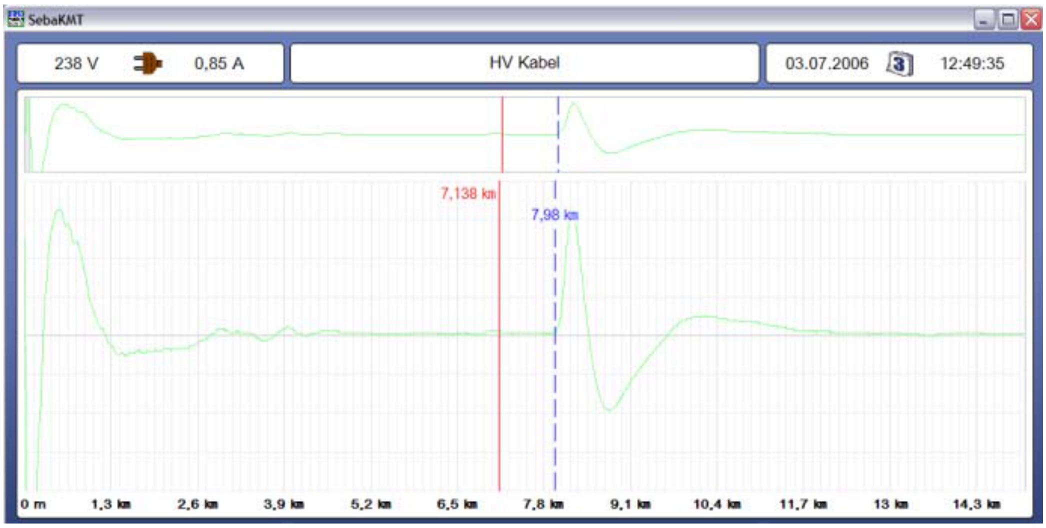


Fig. 8: Reflection measurement - 8 km cable

Wire comparison

A fault-free wire is necessary for wire comparison. The reciprocal switching of the defective wire and fault-free wire shows a difference between both echograms that points clearly to the fault position.

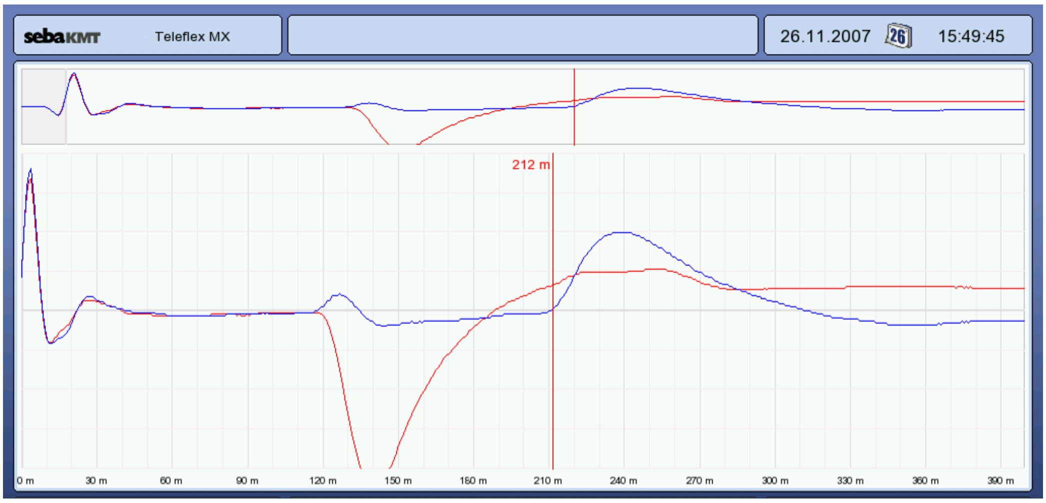


Fig. 9: L2 positive reflection - Cable end, sleeve visible
L1 negative reflection - Short circuit in sleeve

IFL mode (fault location on loose connections)

Pre-location pulse reflection process

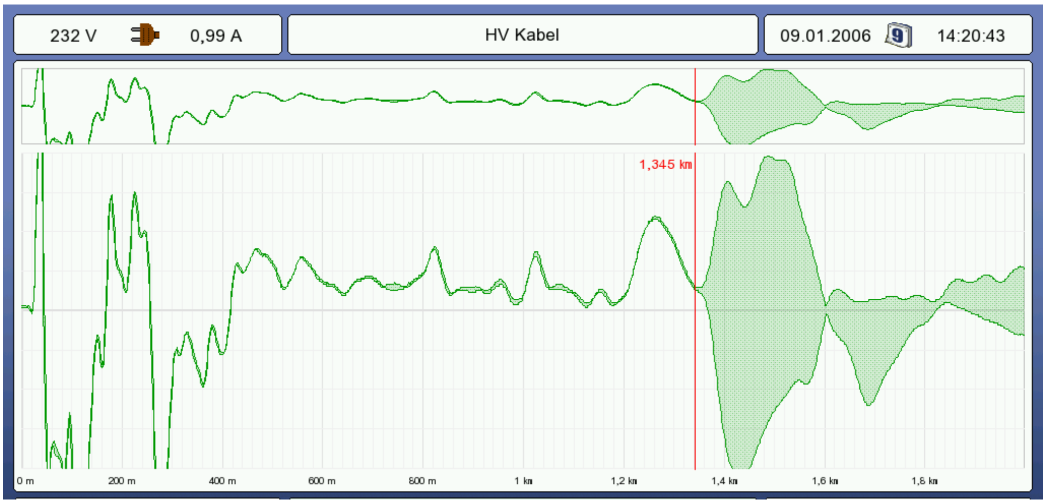


Fig. 10: Teleflex MX - Brief short circuit created at cable end

Differential measurement

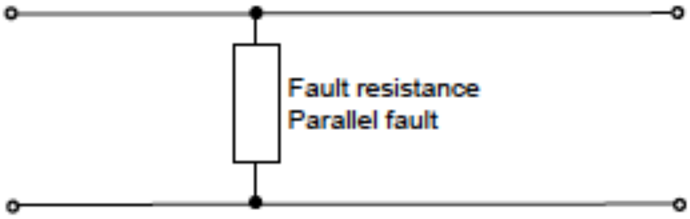
When the differential method is used, the defective and fault-free wires are connected simultaneously to the pulse-echo measuring device using a differential transformer. In this mode, one wire is measured normally. However, when measuring the other wire in comparison, the polarity of all reflections is switched by the differential transformer. This means that only the actual differences are shown in differential switching mode. Faults of the same size or completely severed cables cannot be seen as no difference exists.

Note: When using the differential method, always ensure clean guidance of the measuring cables. Interchanging leads to changes in the polarity of the fault echo.

Averaging

Inductive couplings generate errors during image formation. This can be compensated using the averaging mode over 256 measurements.

Parallel faults with different resistances (negative reflection)



Pre-location pulse reflection process

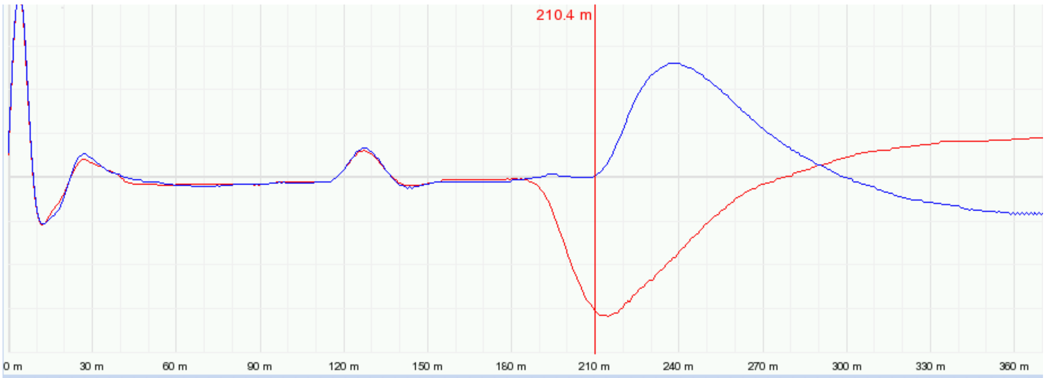


Fig. 11: Cable sleeve, parallel fault R = 0 Ohm, end of cable

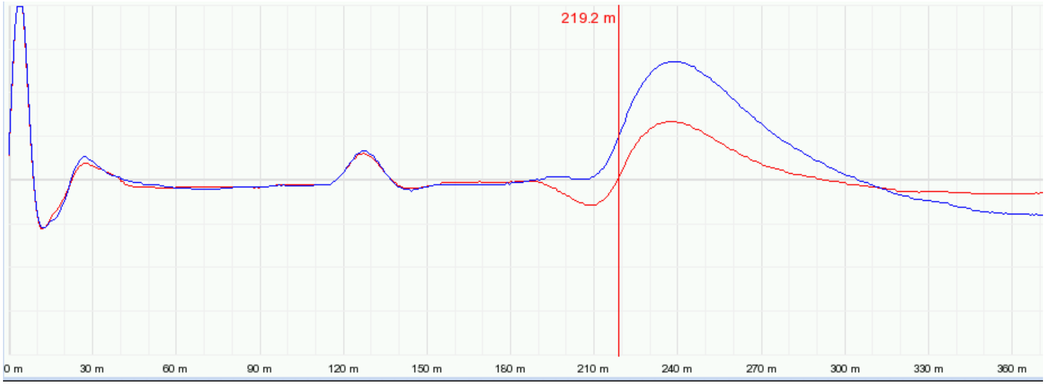
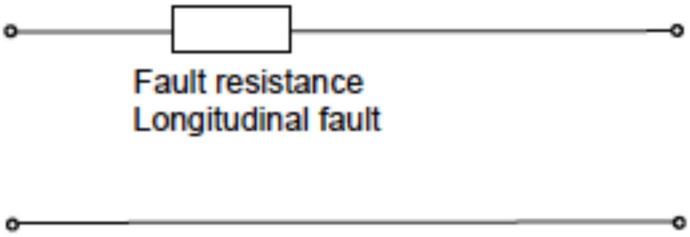


Fig. 12: Sleeve, parallel fault R = 100 Ohm

Longitudinal faults with different resistances (positive reflection)



Pre-location pulse reflection process

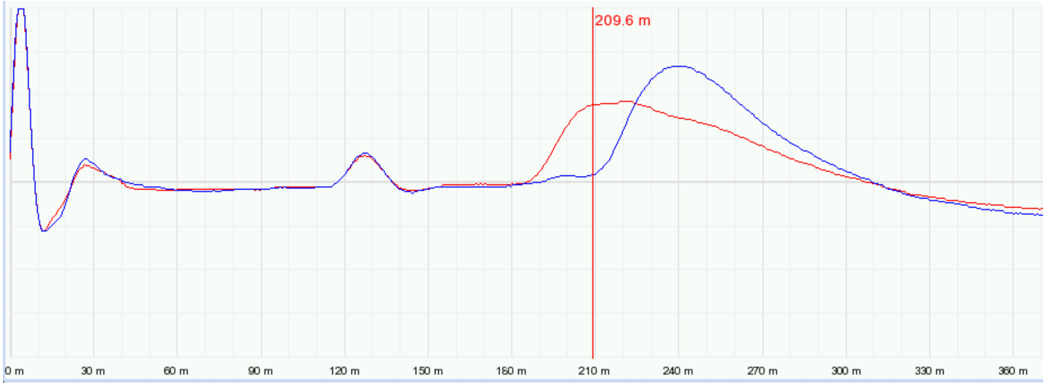


Fig. 13: Sleeve, longitudinal fault R = 100 Ohm

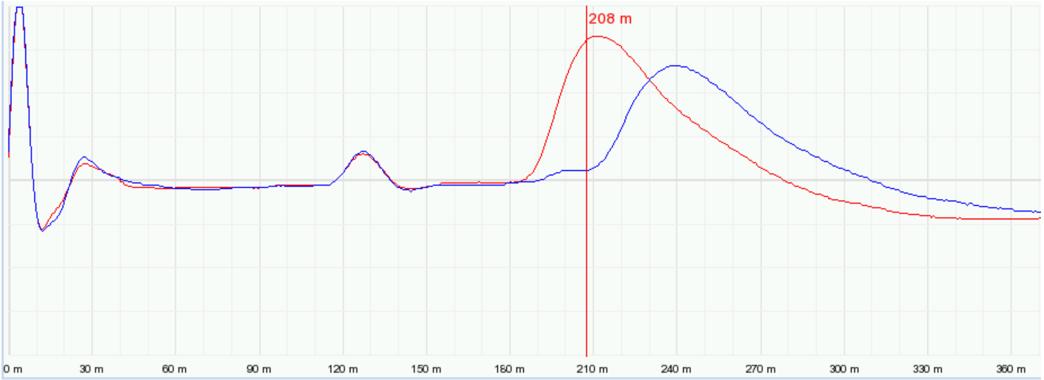


Fig. 14: Sleeve, longitudinal fault R = unlimited, open cable end

Equipment

TDR-Microflex

The TDR Microflex measures the cable length and can display fault distances of up to 3500 metres in virtually all cable types.

TDR-Miniflex

The TDR Miniflex is a portable TDR (Time Domain Reflectometer). It weighs only 350 grams and is used to detect faults in metallic electrical, data and communication cables with lengths of up to 6000 metres. This device is particularly suited to detecting close range faults due to its range of 7 metres and dead zone of 0.5 metres.

Pre-location pulse reflection process

TDR-Easyflex Com

The Easyflex Com is a compact, light and easy-to-use digital pulse-echo device. It is used for fault location on symmetrical remote lines, control cables, street lighting networks and low-voltage networks. This device is particularly suited to detecting close range faults (e.g. main cable on service entrance boxes) due to its range of 10 metres and dead zone of 1 metre.

TDR-Digiflex Com

The Digiflex Com is a compact, light and easy-to-use digital pulse-echo device. It is used for fault location on symmetrical remote lines, control cables, street lighting networks and low-voltage networks. This device is particularly suited to detecting close range faults (e.g. main cable on service entrance boxes) due to its range of 5 metres and dead zone of 0.5 metres (smallest pulse width = 5 ns).

Pre-location pulse reflection process

Teleflex T 30

The T 30-E is a portable, digital TDR (Time Domain Reflectometer). It is designed for use in cable pre-location in middle and low-voltage cable networks. The device comes equipped with a stable, weatherproof housing, and has both a mains and battery power supply, meaning it can be used individually or as a permanently installed fixture on a cable test van.

The Teleflex T 30-E offers five different fault detection modes:

- Reflection measurement (transit time / pulse-echo measurement)
- ARM (Arc Reflection Method)
- ICE (current catching)
- Decay (coupled oscillating method)
- ARM Quick Steps (simplified ARM operation)
- Partial discharge location

Pre-location pulse reflection process

Teleflex MX

The Teleflex MX can be used as a central control element in various SebaKMT test vans (e.g. Centrix, Classic, R30). The available fault location methods are used according to the test van version and equipment.

Additionally, the Teleflex MX "Portable" can also be used as a stand-alone version or can be connected to the relevant HV equipment (independent of the test van).

The Teleflex MX "Portable" can also be equipped with a multiplexer, which offers diverse switching possibilities for HV equipment and test objects.

The following TDR measurements can be made using the Teleflex MX without additional equipment:

Teleflex – three-phase TDR measurements
Teleflex IFL (Intermittent Fault Locating)

When used in conjunction with external HV equipment (e.g. test van), the Teleflex MX also supports a wide range of other technologies:

ARM (Arc Reflection Method)
Decay method
Current catching methods and power burning

Pre-location pulse reflection process

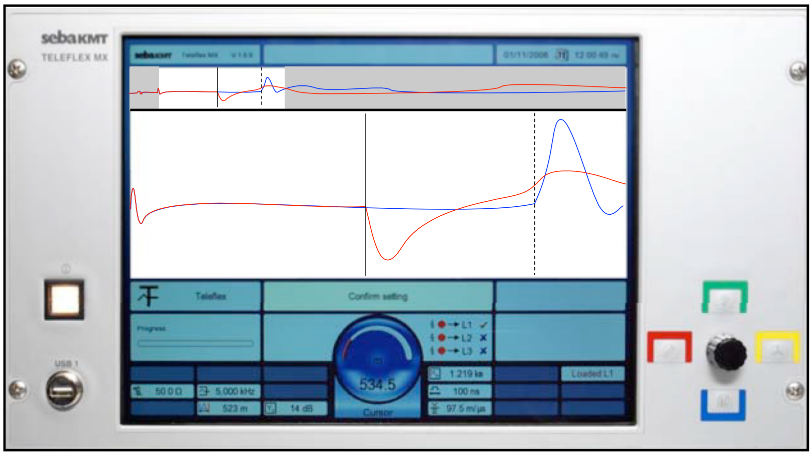


Table of diffusion speeds (v/2)
Communication and control cables

Cable (kx = coaxial cable)	Insulation (stranding)	Note	v/2 [m/µs]
A2YF(L)2Y A- 2YF(St)2Y A- PMbc A-PWE2Y switching cable	PE PE Paper Paper PVC	Controls	96 96 112 118 85
TF cable	Paper	0.4 mm wire, test cable	105
Coaxial switching cable	Full PE	0.5/3.0	96
TF switch wire		Symm. cable	98
Kx-RGU 220	Full PE	50 Ohm	99
KX-179BU	Teflon	75 Ohm	99
Coaxial switching cable	Full PE	0.7/4.4	99
Coaxial switching cable	Full PE	1.0/6.5	99
Domain and long-range cable	Plastic PE (SLK)	Symm.	99
TN cable	Plastic	Symm.	100
Coaxial HF cable	Full PE	2.3/10 60 Ohm	100
TN cable	Plastic (filled)	Symm.	104
TN cable	Paper	Symm.	107
Domain and remote cable	Paper	Symm.	110
Paper cable	Stranded in pairs	0.6 mm wire	112
TF cable	Star, polystyrene foam	Carrier frequency	113.5
Domain and remote cable	Plastic	TF quad	117
Paper cable	DM, star, paper	0.8 mm wire	117
Paper	Star, paper	1.2 mm wire	119
Paper	DM, paper	1.4 mm wire	120
Coaxial mini 0.6 / 2.7	Cell PE	75 Ohm	120
Kx CATV 1.7/11.5 2.0/9 0.8/3.7	Full PE/Al Cell PE/Al Cell PE/Cu	75 Ohm	124
Kx5/12	Styroflex	65 Ohm	126
Kx5/18	Styroflex or Frequenta	70 Ohm	136
Kx 1.2/4.4		75 Ohm	140
Kx 2.6/9.5		75 Ohm	141
Kx 2.6/9.5	Styroflex	75 Ohm	144

Pre-location pulse reflection process

Cable type	Insulation	Cross-section in mm^2	Voltage (kV)	Pulse speed v/2 [m/µs]
StYHS2Y (filter cable)	PE	1 x 25 rm/10	Up to 110	69.6
A2YHS2Y	PE	1 x 300 rm/50	110	86.7 - 87.6
A2YHS2Y	PE	1 x 300 rm/50	30	86.7
NHEKBA	Paper / oil	3 x 70 rm	30	80
NHEKEBA	Paper / oil	3 x 95 rm	30	80
NHKBA	Paper / oil	3 x 70 rm	30	80
A2YHSY	PE	1 x 50 rm/16	20	85
A2XHS2Y	PE	1 x 120 rm/16	20	83.5 - 84
A2YHSY	PE	1 x 150 rm/25	20	86.1 - 87
A2YHSY	PE	1x185 rm	20	87
NHEKBA	Paper / oil	3 x 50 rm	20	73
NHEKBA	Paper / oil	3 x 120 rm	20	73.5
NAKLEY	Paper / oil	1 x 120 rm		
NKBA	Paper / oil	3 x 25 sm	10	81.5 - 82.5
NKBA	Paper / oil	3 x 35 sm	10	82.5 - 83.5
NKBA	Paper / oil	3 x 70	10	79
NKY	Paper / oil	3 x 50	10	58.5
NA2YSY	PE	3 x 150/16	10	76
NA2XS (F) 2Y	VPE	3 x 150 rm/25	10	81
NAKBA	Paper / oil	3 x 95 sm	10	81.5
NAKBA	Paper / oil	3 x 185 sm	10	82
NAKBA	Paper / oil	3 x 240 sm	10	81.5
NEKBA (triple)	Paper / oil	3 x 120 rm	10	74
NKBA	Paper / oil	4 x 10 re	1	73
NKBA	Paper / oil	4 x 25 sm	1	78.5
NKBA	Paper / oil	4 x 50 sm	1	74.5 - 80
NKBA	Paper / oil	3 x 70/35 sm	1	87 - 88
NAKLEY	Paper / oil	3 x 95 sm	1	87.5
NAKLEY	Paper / oil	3 x 95 se	1	81.5
NYY	PVC	4 x 1.5 Cu	1	90
NYY	PVC	4 x 4 Cu	1	79
NYY	PVC	4 x 10 Cu	1	76
NYY	PVC	4 x 16 Cu	1	74.5
NYY	PVC	4 x 70 Cu	1	86.5
NYCY	PVC	3 x 16/16	1	75
NYCY	PVC	4 x 120/70	1	79
NAYCWY	PVC	3 x 95 /95	1	69
NA2XY	VPE	4 x 95	1	80
NA2XY	VPE	4 x 95+1.5	1	80
NA2XY	VPE	4 x 150	1	

Conductor material is aluminium,
unless otherwise stated

Conversion: NVP ⇔ v/2

Conversion of NVP ⇔ v/2 (in m/µs)
EQ \ F(v,2) = \ F(NVP · 299.79 \ F(m,µs),2)

Pre-location pulse reflection process

Conversion of NVP v/2 (in mµ/s⇒)

EQ NVP = \ F(2 · \ F(v,2) , 299.79 \ F(m,µs))

Insulation	Typical shortening factor or pulse speed		
	$^{v}/_{2}$ in m/µs	$^{v}/_{2}$ in ft/µs	Ratio
Oil-impregnated paper	75 … 84	246 … 276	0.50 … 0.56
Poly (networked)	78 … 87	256 … 286	0.52 … 0.58
Poly with petroleum jelly filling	96	316	0.64
Polyethylene	100	328	0.67
PTFE	106	346	0.71
Paper	108 … 132	354 … 433	0.72 … 0.88
Poly (foamed)	123	403	0.82
Air	141 … 147	463 … 482	0.94 … 0.98

Table of reflection factors

Parallel faults

R Ohm	0.5	1	2	5	10	20	50	100	200	500	1000
Z = 20 r%	95	91	83	66	50	33	16	9	5	2	1
Z = 60 r%	98	96	93	85	75	60	37	23	13	5	3
Z = 120 r%	99	98	96	92	85	75	54	37	23	10	5

Longitudinal faults

R Ohm	2000	1000	500	200	100	50	20	10	5	2	1
Z = 20 r%	98	96	92	83	71	55	33	20	11	5	3
Z = 60 r%	94	89	80	62	45	29	14	8	4	2	1
Z = 120 r%	89	80	67	45	29	17	8	4	2	1	