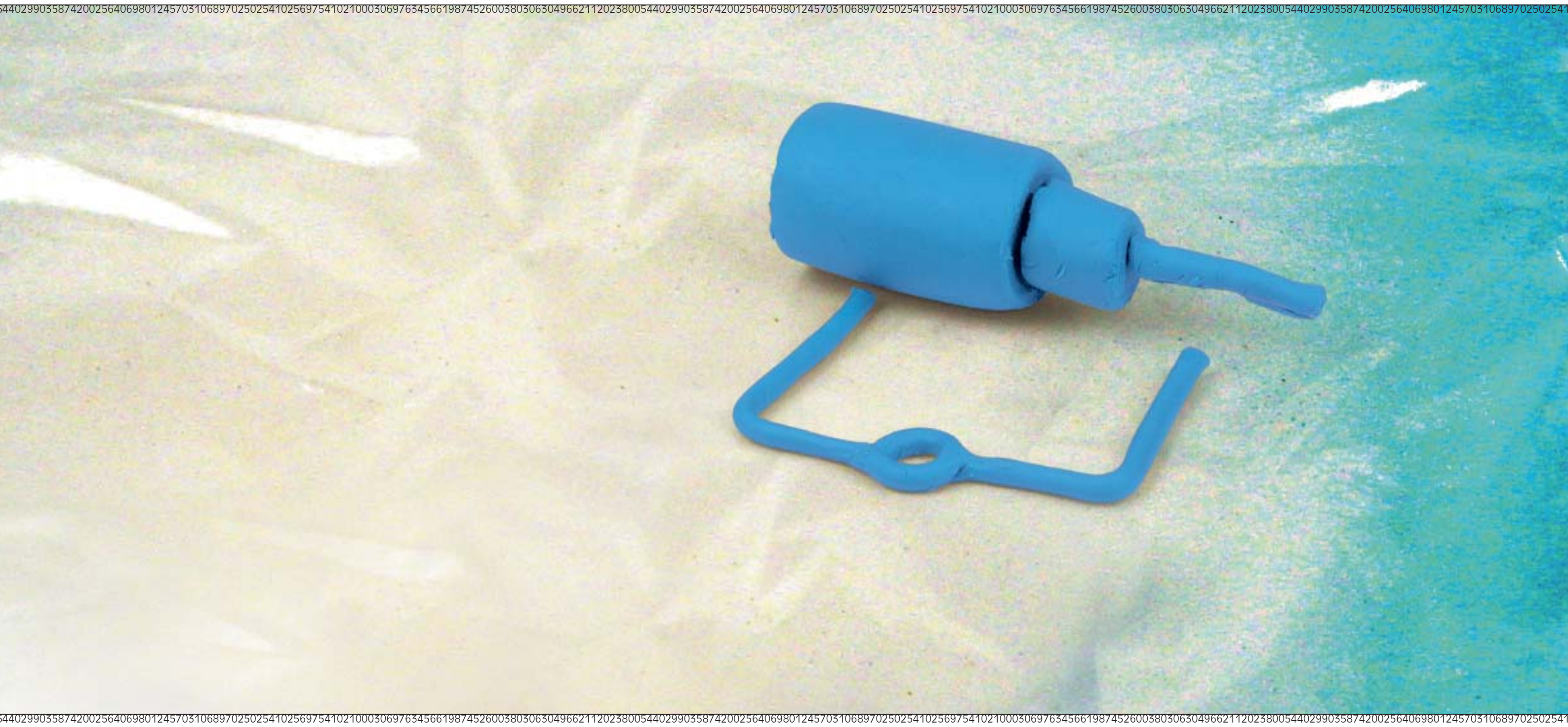

Cable Monitoring

Technical Bases and Examples

ESN Bahngeräte GmbH

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Basic Cable Monitoring Principles

The cable insulation monitoring of the devices from ESN-Bahngeräte GmbH is based on the idea of monitoring and evaluating the voltage between the shield and the return circuit/earth (shield standing voltage U_{shield}) in relation to the voltage between the conductor and the shield (U_a).
For this reason it is also only possible to monitor a cable with shield.
To measure the shield standing voltage U_{shield} in the cable monitoring device, which amounts to approx. 40V DC in case of a contact line voltage of U_{FL} = 750V DC, a terminating resistor of R_A =1.12 MΩ is connected in parallel to the conductor insulation R_{ILS} ($R_{Conductor\text{-}Shield\ Insulation}$) and a terminating resistor of R_S = 68 kΩ is connected in parallel to the shield insulation R_{ISRL} ($R_{Shield\text{-}Earth\ Insulation}$).
Due to the reduction of the total resistance achieved in that way a shield standing voltage U_{shield} of approx. 40V DC is reached, which serves as a measuring criterion for the fault conditions to be detected.

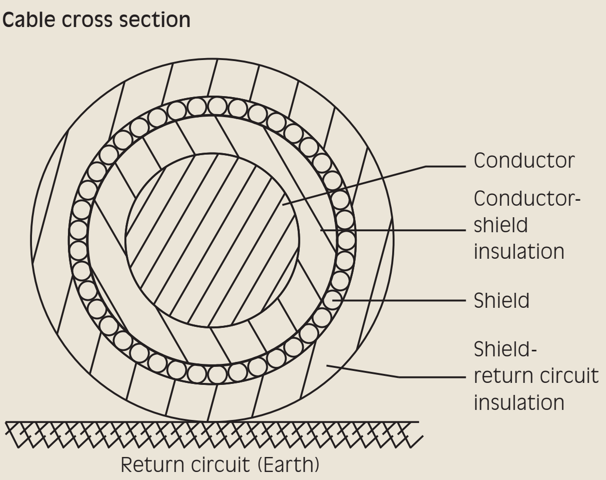


Fig 1. | Schematic representation of the cable design

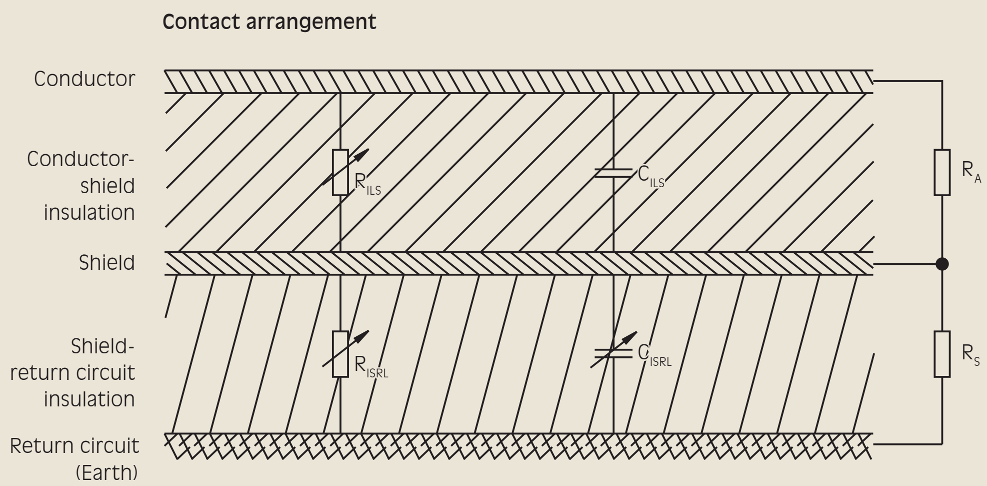


Fig. 2 | Equivalent circuit diagram with the terminating resistors R_A und R_S connected in parallel

Bridge Circuit

The two parallel connections of the insulation resistances (R_{ILS} and R_{ISRL}) with the terminating resistors (bridge resistors) R_A and R_S are interconnected to a Wheatstone bridge with the help of the measuring instrument.

$U_{Threshold}$ is the voltage set as the threshold voltage between the shield and the return cable in a **faultless cable**.

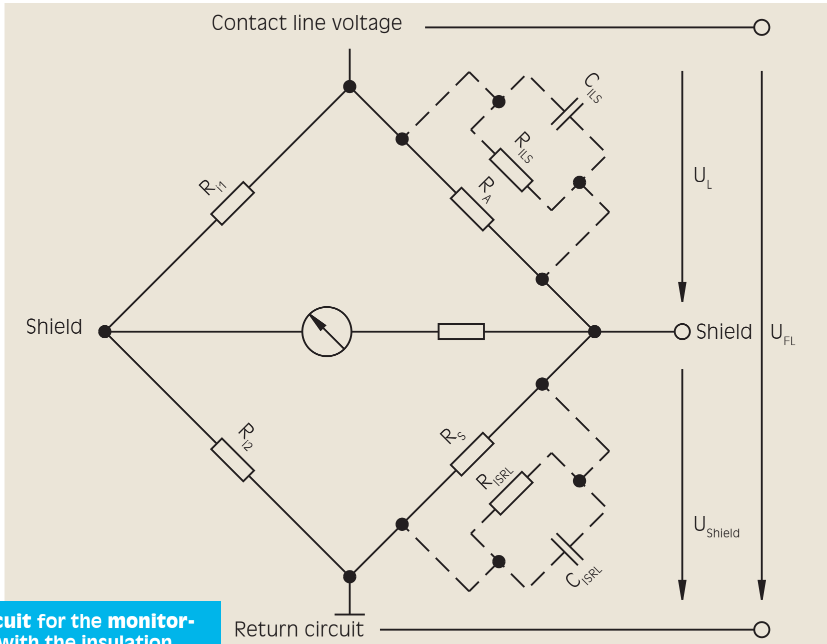


Fig. 3 | Bridge circuit for the monitoring of the feeder with the insulation resistances conductor-shield and shield-return circuit as well as the terminating resistors in the bridge branches

Terminating resistor between conductor and shield	R_A =1.12 MΩ
Terminating resistor between shield and return circuit	R_S = 68 kΩ
Ohmic resistance between conductor and shield	R_{ILS}
Capacitive resistance between conductor and shield	RC_{ILS}
Ohmic resistance between shield and return circuit	R_{ISRL}
Capacitive resistance between shield and return cable	RC_{ISRL}
Inner flow resistance of the bridge of the cable monitoring device	R_{i1} and R_{i2}

Instead of the instrument there is an operational amplifier in the cable monitoring device with an adjustable response threshold for the two insulation faults to be monitored: internal fault and earth fault.

The measured bridge resistance corresponds to the parallel connection of insulation resistances and terminating resistors (R_A= 1.12 MΩ between the conductor and the shield and R_S= 68 kΩ between the shield and the return cicuit). The terminating resistors are either fitted in the device or connected to the cable ends for monitoring of the shield. The following examples are to show that the voltages drops of the feeder or the return cable are included in the measurement in these cases, which means that the conductor quality can be monitored.

The changes in the insulation and thus in the insulation resistances of the cable between the conductor and the shield, on the one hand, and the shield and the return cable, on the other hand, influence the measurement of the bridge resistance and indicates the following fault conditions:

1. Internal fault between shield and conductor

In case of an internal fault the conductor-shield insulation resistance is **reduced** and thus also the conductor voltage U_A with the result that the shield standing voltage U_{Shield} is increased:

$\mathbf{U_{Shield} > U_{Threshold}}$ → Internal fault
→ signal "internal fault"

2. Earth fault

In case of an earth fault the shield-return circuit insulation resistance is **reduced**, which means that the shield standing voltage U_{Shield} is also reduced:

$\mathbf{U_{Shield} > U_{Threshold}}$ → earth fault
→ signal „earth fault"

3. Evaluation

In many cases the evaluation follows so that the action "**internal fault**" leads to **disconnection**, whereas the action "**earth fault**" only leads to a **signal** and not to disconnection so that there is enough time to locate and eliminate the fault without automatic disconnection of the installation.

Cable Monitoring Device
Type 8531, nominal voltage 750V DC. This device does not need auxiliary voltage, a display unit cannot be connected.

4. Insulation Resistances

Fig. 4 shows the insulation values R_{ILS} (conductor-shield) and R_{IRL} (shield-return circuit) for a contact line voltage of 750V DC as a function of the shield standing voltage U_{Shield}.

Of course, $U_{Shield} \rightarrow U_{Shield\ at\ FL}$ (U_{FL} = contact line voltage) changes if the contact line has got another voltage than 750V DC. The shield voltage value $U_{Shield\ at\ FL}$ measured now has to be multiplied with the ratio 750V/ U_{FL} to use the standardised graph and determine the insulation resistances at this operating value.

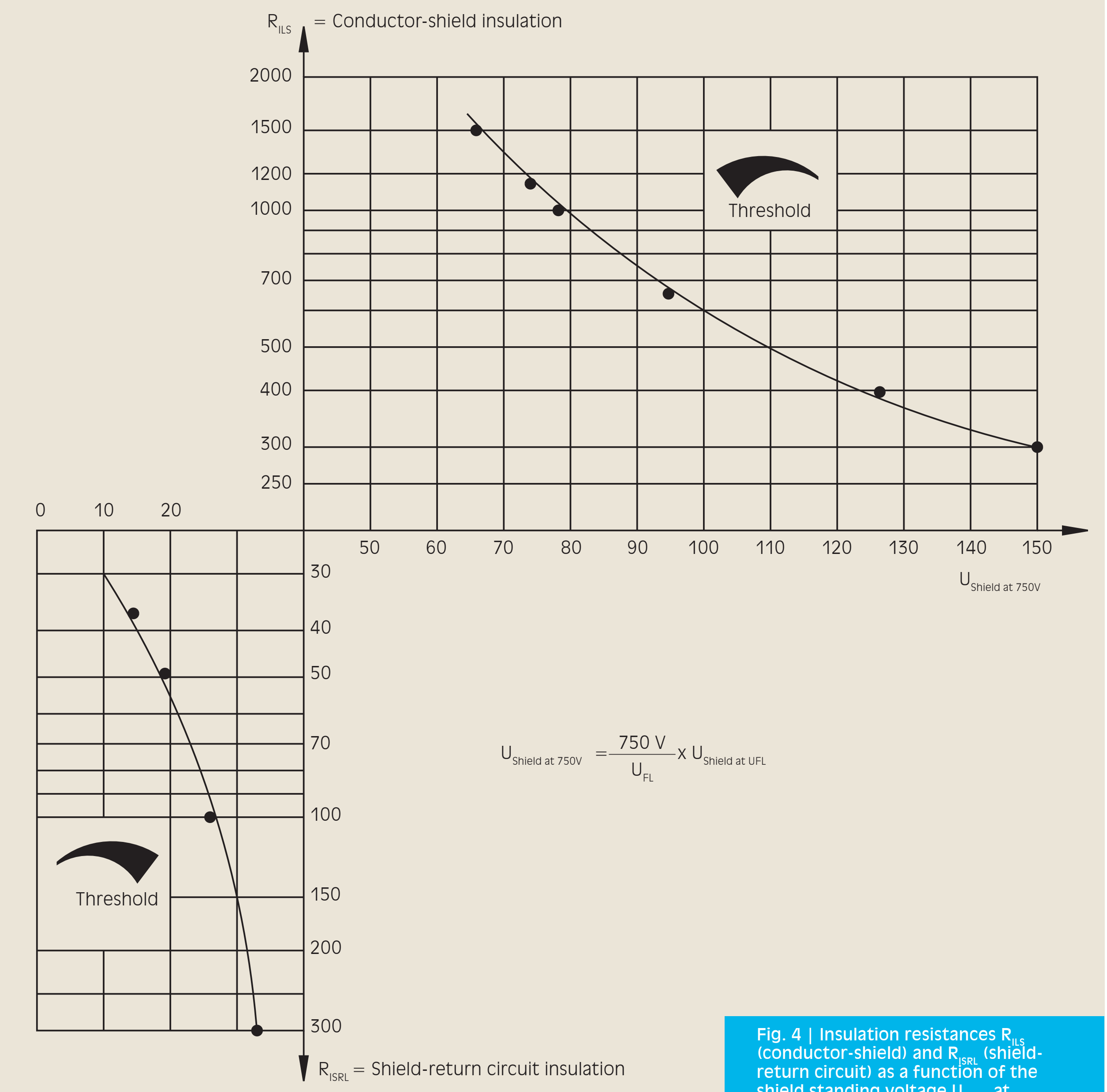


Fig. 4 | Insulation resistances R_{ILS} (conductor-shield) and R_{ISRL} (shield-return circuit) as a function of the shield standing voltage U_{Shield} at U_{FL}=750V DC contact line voltage.

The following examples show the various possibilities of monitoring the feeder and the return cable. Dependent on where the terminating resistors are fitted, the voltage drops on the feeder or the return cable are included in the measurement and used for the assessment. The same applies to the monitoring of the shield for interruption.

...to the examples

Cable Monitoring Device
Type 8532/8533, nominal voltage 750V DC.
This device needs an auxiliary voltage of 18-80V DC, a display unit can be connected.

Display Unit
Type 853291, showing the actual and limit values of the resistance between conductor and shield and the resistance between shield and return circuit. The display unit can only be used with the cable monitoring device of the types 8532/8533.

Cable Monitoring

Example 1: **Monitoring of the feeder for internal fault and earth fault** (standard monitoring)

The terminal S of the monitoring device is connected with the shield of the feeder, the terminating resistors R_A = 1.12 MΩ and R_S = 68 kΩ are integrated into the cable monitoring device.

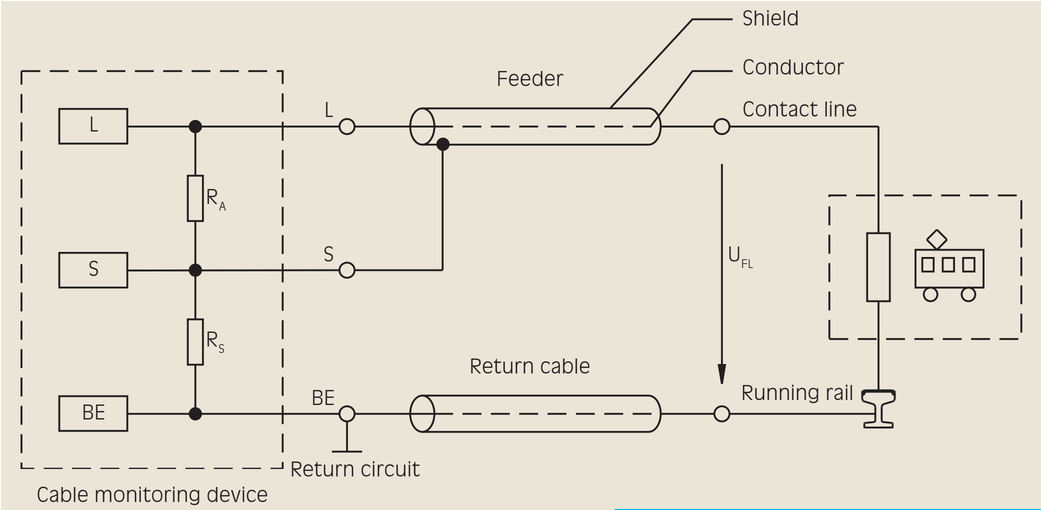


Fig. 5 | Schematic sketch

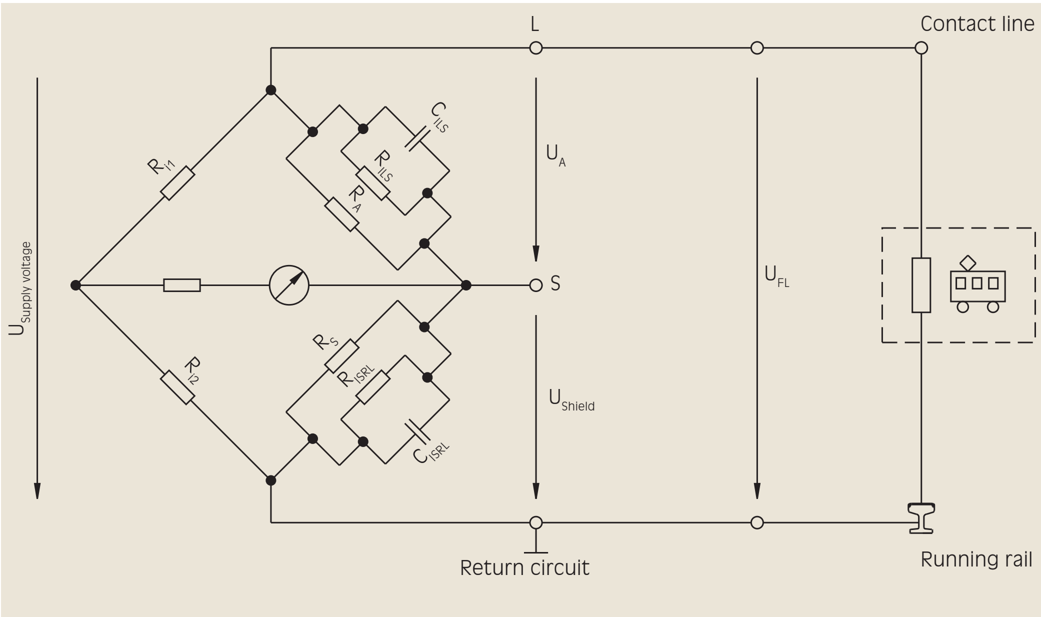


Fig. 6 | Equivalent circuit diagram

Mode of operation

Internal fault:

The insulation resistance R_{ILS} between the conductor and the shield is reduced or zero:

R_{ILS} = reduced or 0 → U_A reduced → U_{Schirm} increased

→ $\mathbf{U_{Shield} > U_{Threshold}}$ → internal fault → signal „internal fault"

Earth fault:

The insulation resistance R_{ISRL} between the shield and the return cable is reduced or zero:

R_{ISRL} = reduced or 0 → U_{Shield} reduced

→ $\mathbf{U_{Shield} < U_{Threshold}}$ → earth fault → signal „earth fault"

Loss of voltage both on the feeder and on the return cable does not influence the measurement

Features: **Cable monitoring device**

- monitors the conductor-shield insulation
- monitors the shield-return circuit insulation
- no monitoring of the shield for interruption
- no monitoring of the shield connection and the connection line

Terminating resistors for cable monitoring devices of types 8531, 8532 and 8533, nominal voltage 750V DC.
Available with the values 68kΩ and 1.12MΩ as well as in several cases for fitting inside and outside.

Example 2: **Monitoring of the feeder for internal fault, earth fault, interruption of the cable shield, shield connection and connection line**

The terminal S of the monitoring device is connected with the shield of the feeder, the terminating resistor R_A = 1.12 MΩ is **not** connected with the monitoring device any more, but with the shield at the end of the feeder. Nevertheless, it has to be imagined as a shunt resistor to the conductor and the shield in the measuring bridge. The terminating resistor R_S = 68 kΩ remains between the shield and the return circuit in the monitoring device.

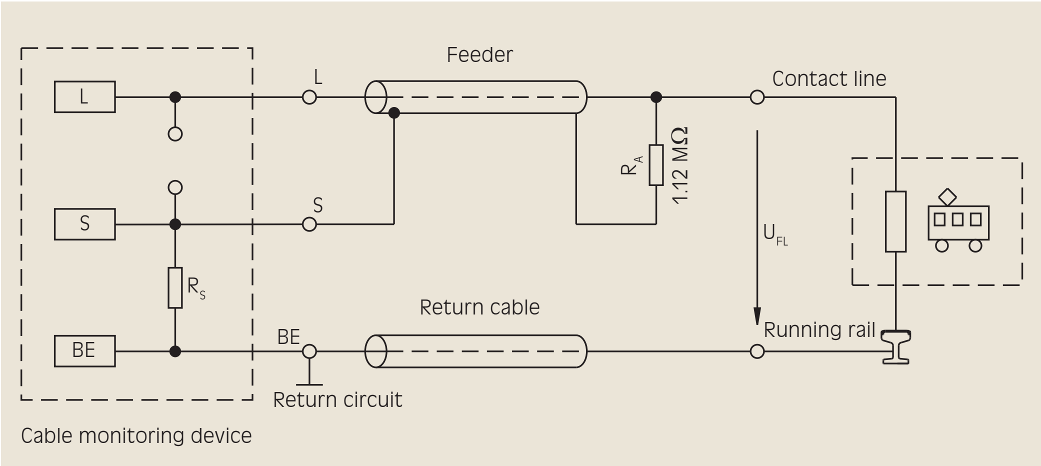


Fig. 7 | Schematic sketch

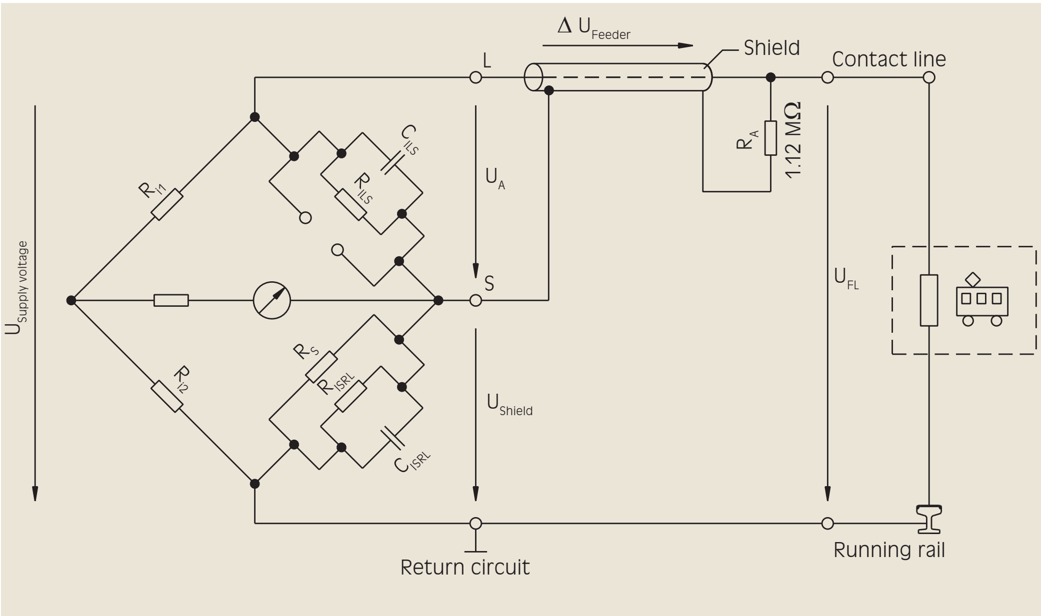


Fig. 8 | Equivalent circuit diagram

Mode of operation

Internal fault:

The insulation resistance R_{ILS} between the conductor and the shield is reduced or zero:

R_{ILS} = reduced or 0 → U_A reduced → $\mathbf{U_{Shield}}$ increases
→ $\mathbf{U_{Shield} > U_{Threshold}}$ → internal fault → signal „internal fault"

Earth fault:

The insulation resistance R_{ISRL} between the shield and the return circuit is reduced or zero:

R_{ISRL} = reduced or 0 → U_{Shield} reduced
→ $\mathbf{U_{Shield} < U_{Threshold}}$ → earth fault → signal „earth fault"

Shield interruption:

In case of shield interruption or interruption of the connection lines the bridge resistance between the conductor and the shield is increased with the result:

→ U_A increases, U_{Shield} decreases
→ $\mathbf{U_{Shield} < U_{Threshold}}$ → earth fault → signal „earth fault"

Loss of voltage on the return cable does not influence the measurement, loss of voltage on the feeder only influences the monitoring a little.
Even if the feeder is severely overloaded (ΔU_{Feeder} increases), the shield voltage is not increased, but reduced → $U_{Shield} < U_{Threshold}$ → earth fault

Features: Cable monitoring device

- monitors the conductor-shield insulation
- monitors the shield-return circuit insulation
- monitors the shield for interruption
- monitors the shield connection and the connection line
- activation of the interruption monitoring does not lead to disconnection of the operating voltage, but only to an earth fault signal

Test and Adjusting Device
for cable monitoring devices of types 8531, 8532 and 8533, nominal voltage 750V DC

Cable Monitoring

Example 3: **Monitoring of the return cable for insulation defects between the conductor and the shield as well as between the shield and the return circuit**

The terminal S of the monitoring device is connected with the shield of the return cable, the terminating resistors R_A = 1.12 MΩ and R_S = 68 kΩ remain in the cable monitoring device. Electrically, both isolating distances, i.e. return cable shield – return circuit and return cable conductor – return cable shield, are switched in parallel because the return cable conductor is earthed.

This leads to the below equivalent circuit diagram.

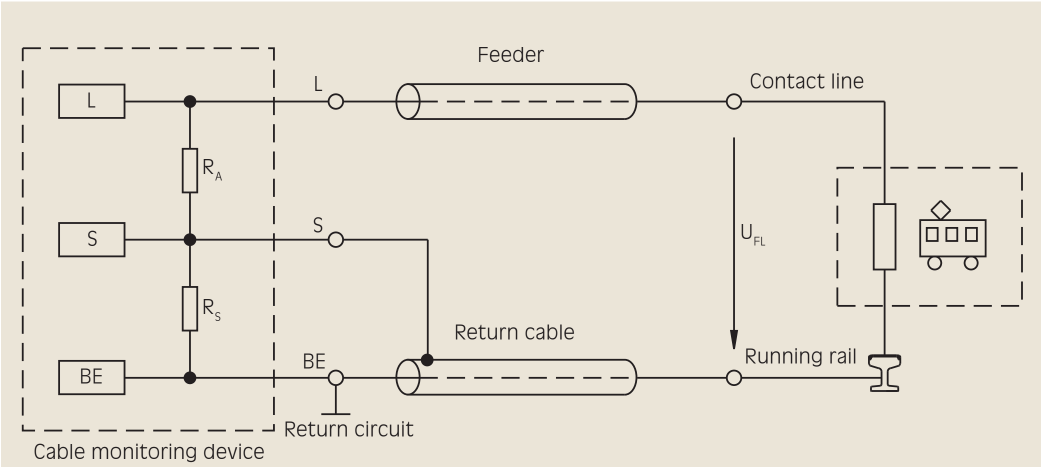


Fig. 9 | Schematic sketch

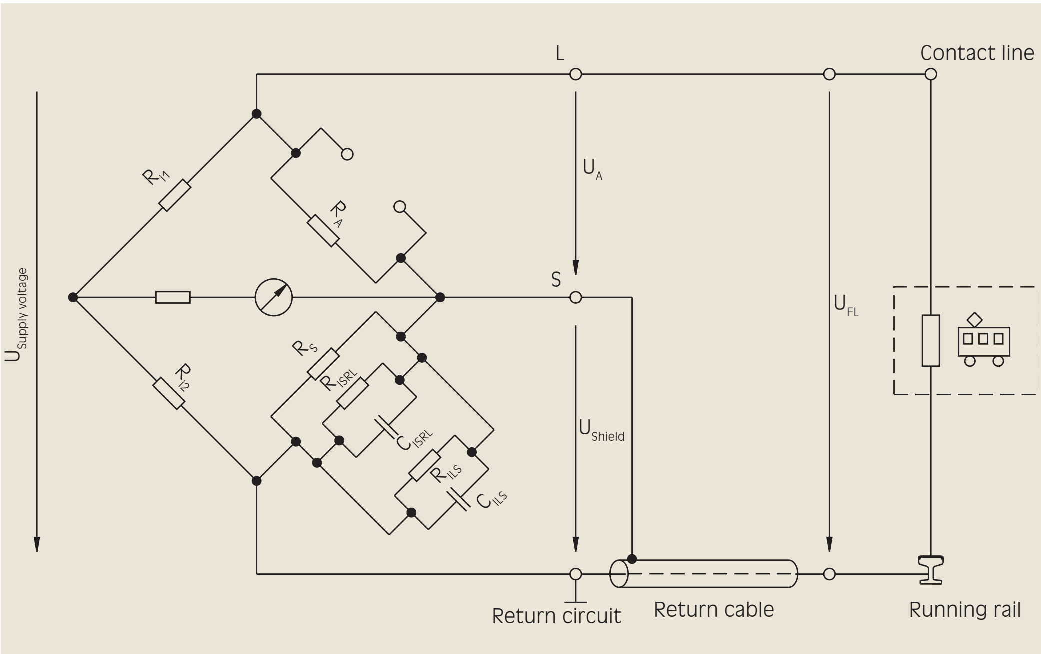


Fig. 10 | Equivalent circuit diagram

Specific feature of the return cable monitoring

Both the insulation defect shield-conductor and the insulation defect shield-return circuit are "earth faults" by measurement (due to the parallel connection of both isolating distances) and only lead to earth fault signals and not to disconnection.

Insulation defect:

R_{ISRL} or R_{ILS} = reduced or 0 → U_{Shield} reduced or
→ $\mathbf{U_{Shield} < U_{Threshold}}$ → earth fault → signal „earth fault"

Loss of voltage both on the return cable and on the feeder does not influence the insulation monitoring.

Features: Cable monitoring device

- monitors the conductor-shield insulation
- monitors the shield-return circuit insulation
- no monitoring of the shield for interruption
- no monitoring of the shield connection and the connection line

Cable monitoring devices can also be delivered for higher voltages, e.g. 1500V DC and 2400V DC. The devices operate with an external voltage divider.

Cable Monitoring

Example 4: **Monitoring of the return cable for insulation defects between the conductor and the shield as well as between the shield and the return circuit, interruption of the cable shield, shield connection and connection line**

The terminal S of the monitoring device is connected with the shield of the return cable. The terminating resistor R_S = 68 kΩ is **not** connected with the monitoring device any more, but with the shield and the conductor of the return cable (or – even better – with the running rail if it is the intention also to monitor the connection line for interruption) at the end of the feeder. Nevertheless, it has to be imagined as a shunt resistor of the two isolating distances, i.e. conductor-shield and shield-return circuit, which are now switched in parallel in the measuring bridge (see example 3). The isolating distances conductor-shield and shield-return circuit are connected in parallel electrically because the conductor is earthed. The terminating resistor R_A = 1.12 MΩ remains between the conductor and the shield in the monitoring device.

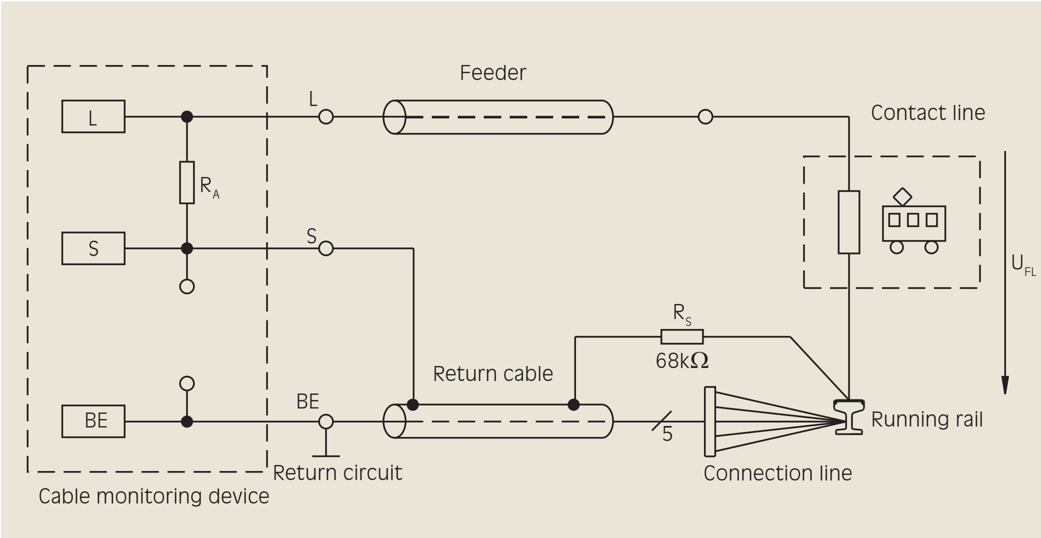


Abb. 11 | Schematic sketch

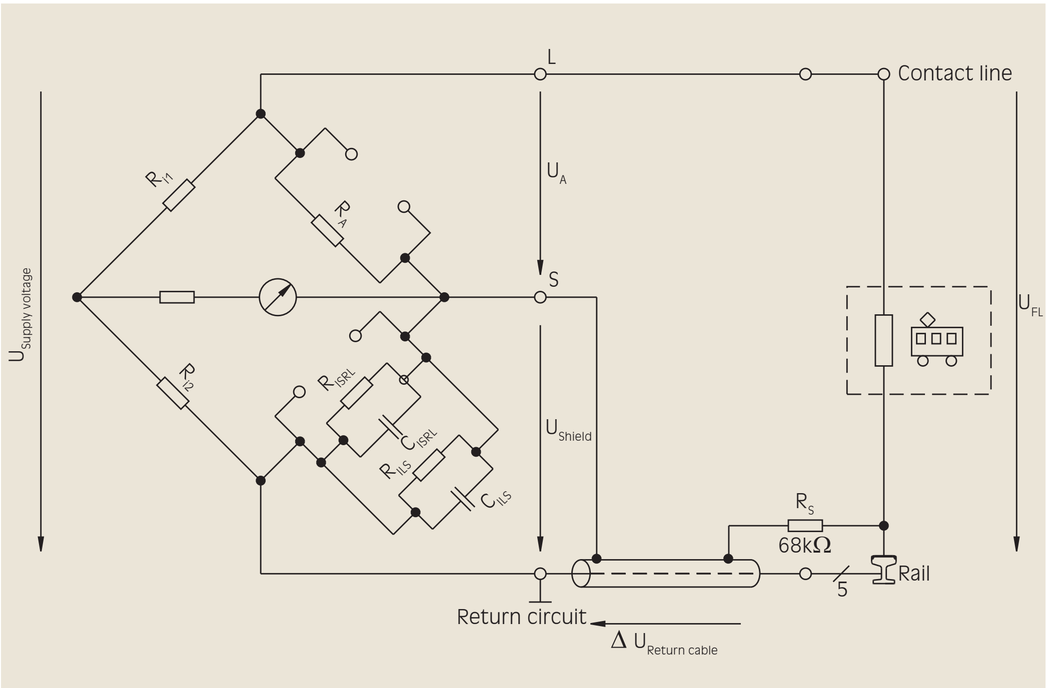


Abb. 12 | Equivalent circuit diagram

Specific feature of the return cable monitoring

Both the insulation defect shield-conductor and the insulation defect shield-return circuit are “earth faults” by measurement (due to the parallel connection of both isolating distances) and only lead to earth fault signals and not to disconnection.

Insulation defect:

R_{ISRL} or R_{ILS} = reduced or 0 → U_{Shield} reduced

→ $\mathbf{U_{Shield} < U_{Threshold}}$ → earth fault → signal „earth fault“

Loss of voltage on the return cable does not influence the insulation monitoring.

Loss of voltage on the return cable ($\Delta U_{Return\ cable}$)

The voltage on the cable shield is increased directly by the sum of the loss of voltage on the return cable. As the signalling contact of the cable monitoring device is activated if the shield standing voltage is “bigger than”, this method makes it possible to realise monitoring of the return cable for an impermissible increase in the voltage due to a defect of material.

→ $\mathbf{U_{Shield} > U_{Threshold}}$ → internal fault
→ signal: $\Delta U_{Return\ cable}$ **impermissible** or
interruption of the shield,
the shield connection or
the connection line (see below).

Interruption of the shield, the shield connection or the connection line

In case of a shield interruption or interruption of the connection lines the bridge resistance between the conductor and the shield is increased with the result → U_{Shield} increases.

→ $\mathbf{U_{Shield} > U_{Threshold}}$ → internal fault
→ signal: $\Delta U_{Return\ cable}$ unpermissible or
interruption of the shield,
the shield connection or
the connection line (see below).

Features: Cable monitoring device

- monitors the core-shield insulation
- monitors the shield-earth insulation
- monitors the shield for interruption[1)]
- monitors the shield connection and the connection line[1)]
- monitors the voltage rise via the return cable connection (quality of the connection)

If a separate connecting point is used at the rail, the complete return cable distance from the running rail to the busbar via the cable can be monitored qualitatively in that way.

1) For these faults the contact for the signal “internal fault” is used in the cable monitoring device, but in this case this shall not result in disconnection either.

Combinations in case of Multiple Monitoring

The below figures show several ways in which the cable shield can be connected with the cable monitoring device.

1. Monitoring of the feeder

If there is no monitoring of the shield interruption and if several cables lie in parallel, it is recommended to connect the shields in parallel at both ends. This has got the advantage that the cable is actually monitored "backwards" for insulation in case of an interruption of a shield.

Special case: If there is an odd number of feeders and there is no terminating resistor on the spot, but in the rectifier substation, two cable shields can be connected in parallel. This means that there is only a signal for interruption for these two cables if both shields are interrupted.

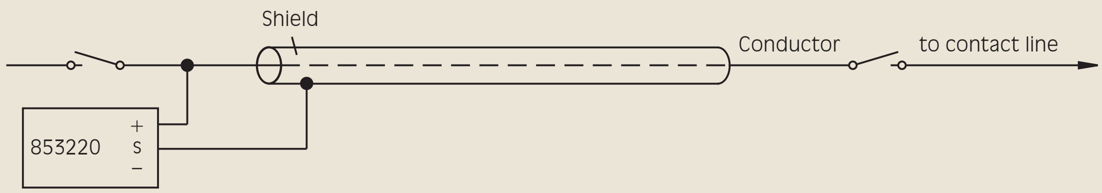


Fig. 1

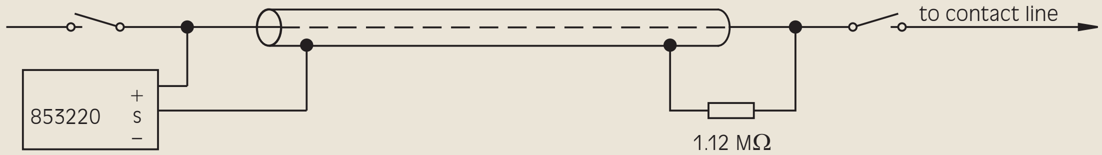


Fig. 2

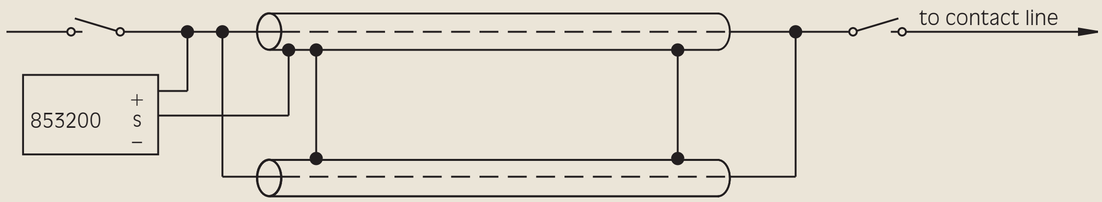


Fig. 3

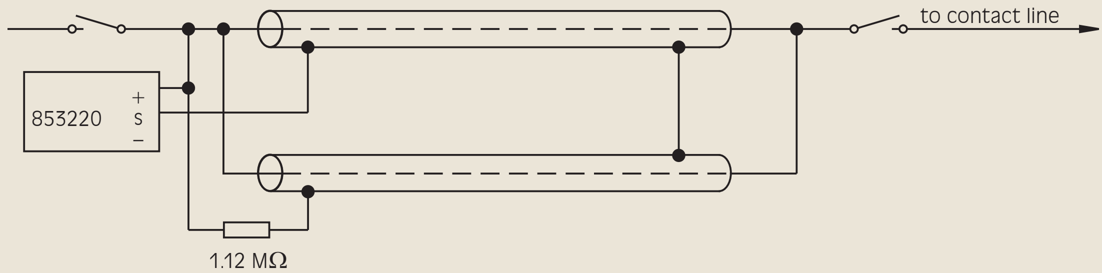


Fig. 4

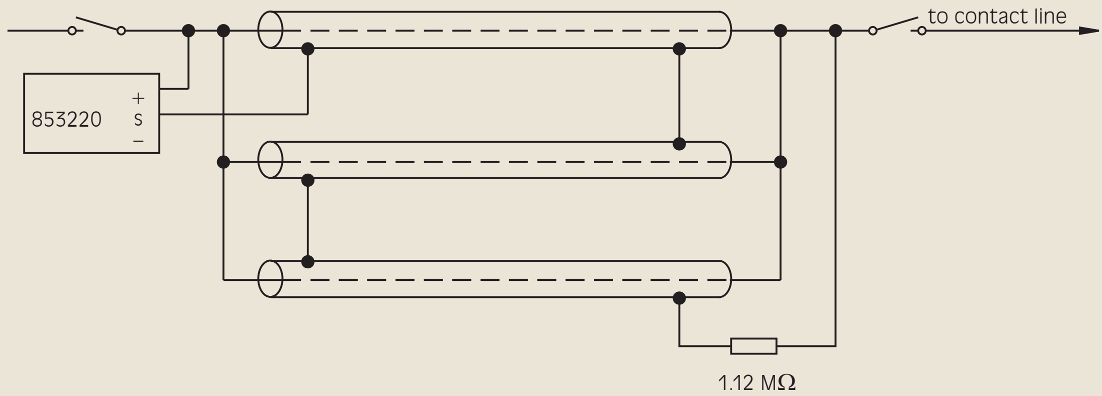


Fig. 5

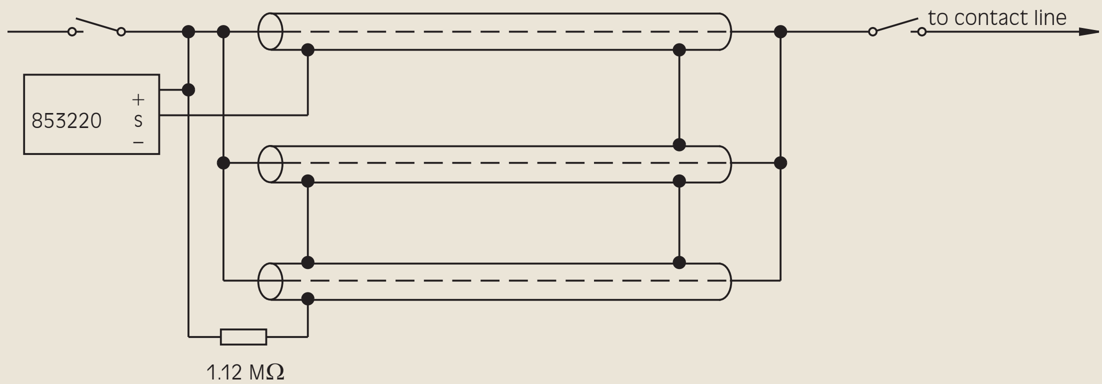


Fig. 6

2. Monitoring of the return cable

In principle, it applies to return cables that an insulation defect either between the shield and the return circuit or between the shield and the conductor is reported as an "earth fault".
Only if use is made of the possibility of monitoring for shield interruption and for connection of the terminating resistor to the running rail, can the increase in voltage on the line also be monitored in the form of the signal "internal fault".
If the shield is not monitored for interruption, it is recommended to interconnect the shields of parallel cables so that the cables are actually monitored "backwards" in case of an interruption of the cable shield.
The below figures show some possibilities of shield connections in case of an even or odd number of cables.

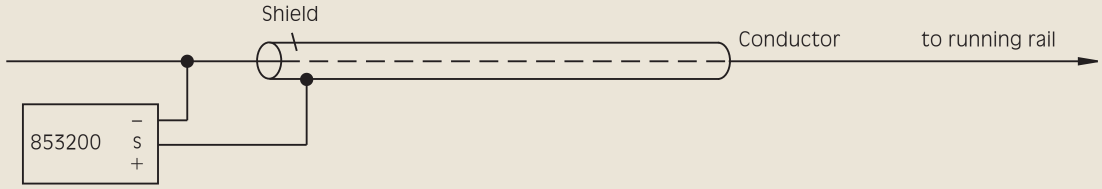


Fig. 1

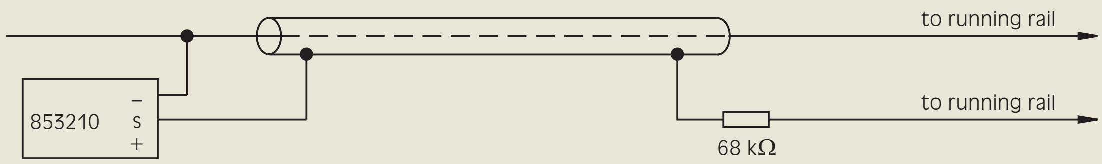


Fig. 2

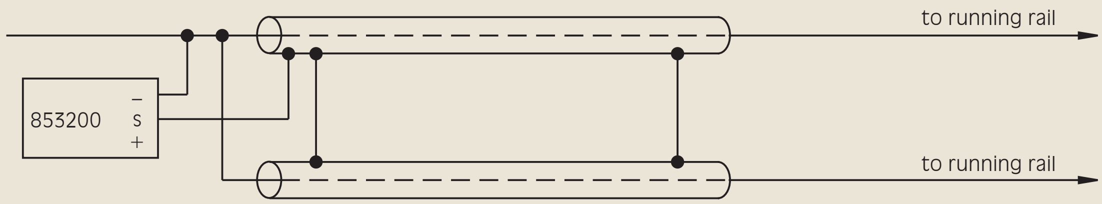


Fig. 3

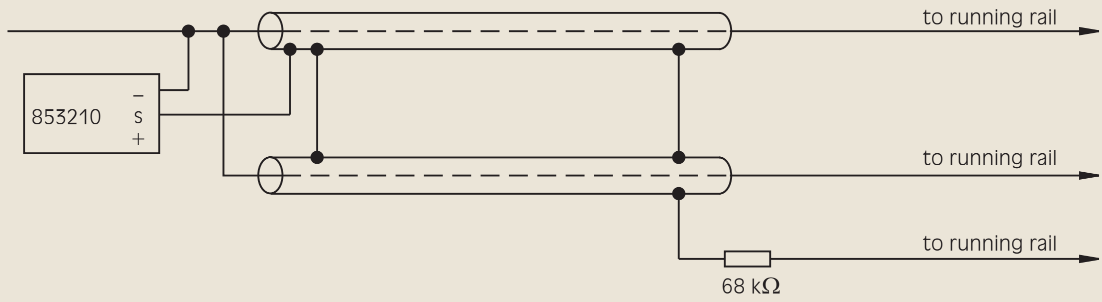


Fig. 4

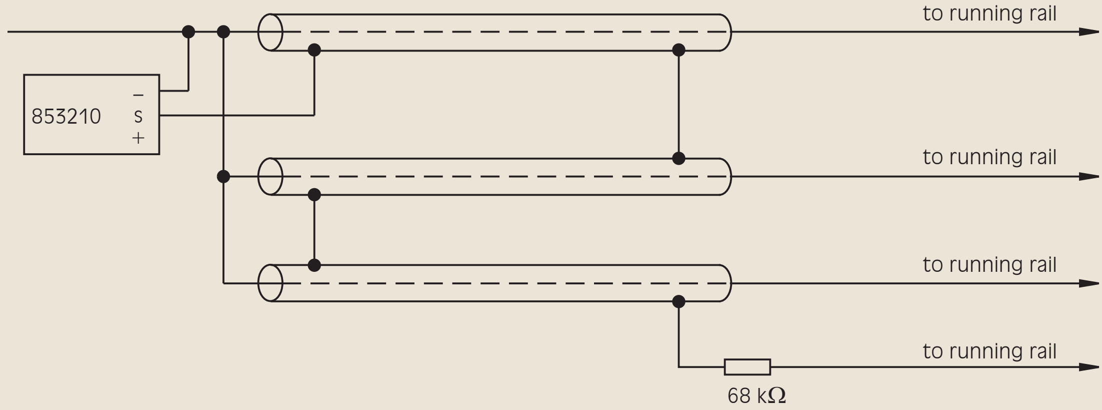


Fig. 5

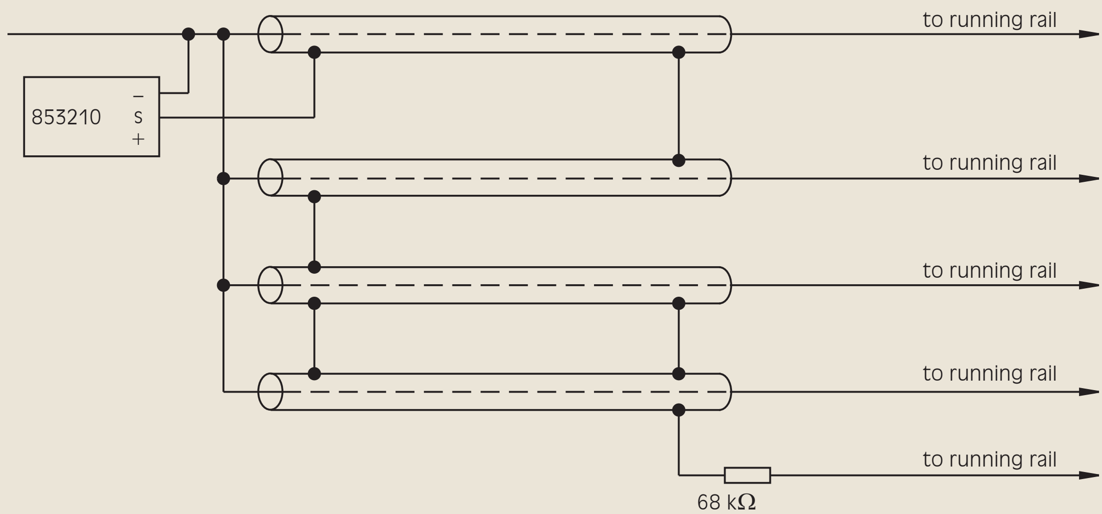
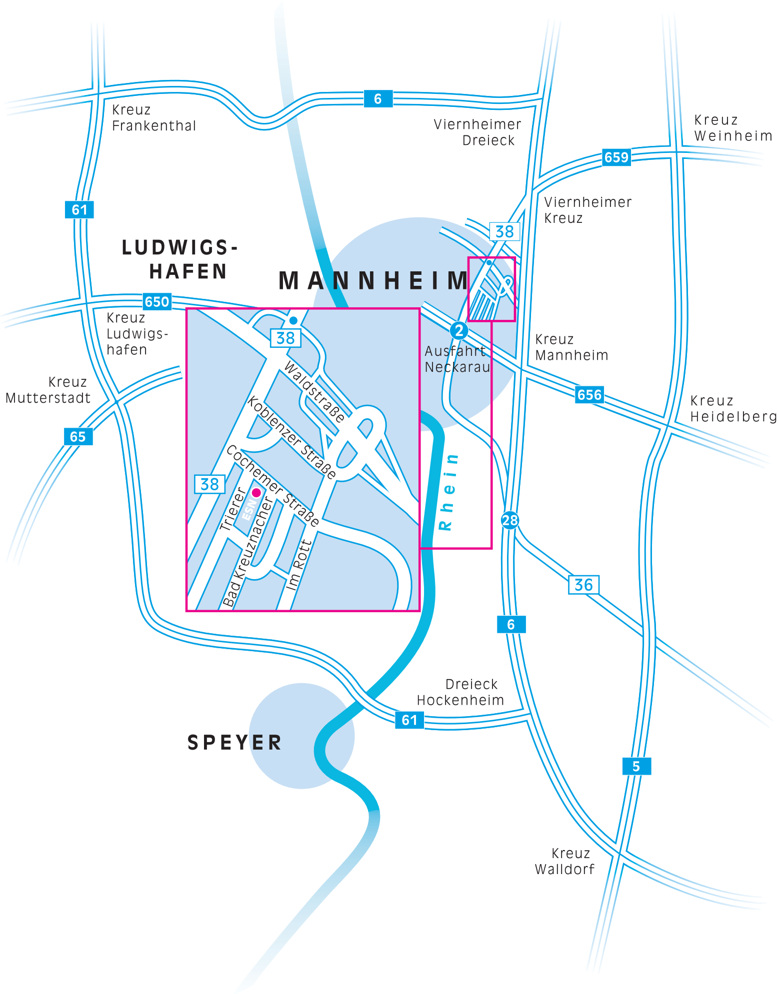


Fig. 6



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