Version 1.21
September 1997

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1 LINE DIFFERENTIAL PROTECTION

NOTE! The line differential function in the protection of the version 1.1 and 1.2 are not compatible! The communication protocol differs!

1.1 Application

The line differential protection function can be used on two terminal lines. It can be applied on MV, HV as well as on EHV overhead lines and cables. The measurement is phase segregated, which gives correct phase selection for all types of faults, including simultaneous faults on double circuit lines, and faults between lines at different voltage levels.

The differential protection is neither affected by voltage and current reversal at series compensated systems, nor by harmonics produced by HVDC or SVC installations.

Transformers or tapped loads in the protected zone are normally **not** allowed.

A direct transfer trip signal can be exchanged between the terminals. This signal can be persistent, when used for other than tripping purposes.

The differential protection requires a 56/64 kbit/s digital communication link, which can be achieved either by dedicated optical fibres or by multiplexed channels. Communication is required in both directions.

Dedicated optical fibres can be used on distances of up to 30 km, and with additional equipment up to 120 km.

The maximum transmission time for which the differential function will operate is 12 ms. For longer transmission times, the differential function will be blocked and an alarm “Communication Failure” will be given. The tripping function will not be blocked at route switching, as long as the communication time is in the range of 12 ms, neither will a false operation be caused by any changes in the communication time.

The exchanged message is controlled by added check-sum information and corrupted telegrams are not evaluated.

1.2 Theory of operation

The line differential protection operates with exchange of the three-phase currents in both directions every 5 ms, integrated in a common digital message.

The currents are evaluated in both terminals.

The protection is a phase segregated current phasor differential protection of master/master type.

The phase currents are sampled with 2000 Hz sampling frequency. Of two consecutive samples, one sample is achieved after an interpolation to achieve a set of samples related to the same instant (skew adjustment).

After the interpolation, one set of samples is achieved every ms.The phase currents are Fourier filtered, and the fundamental (50/60 Hz) component in the current, is represented with the Fourier coefficients **a** and **b.** These coefficients represent the *sin* and *cos* components, related to a local fundamental frequency reference. This reference is controlled by the local time/ clock. The Fourier filters produces a set of **a** and **b** coefficients every ms.

The primary sampling is not synchronised in the two terminals and thus, neither is the Fourier filtering.

The transmitted current information consists of the **a** and **b** coefficients. These coefficients carry the entire amplitude and phase angle information. For a static current, the coefficients do not change their value during the cycle, and the whole information can be transmitted, regardless of an unknown transmission time. During dynamic conditions, the “primary” current changes, and thus also **a** and **b** change with time. To exchange current information that can be compared, the transmitted set of Fourier coefficients **a** and **b** are time tagged at the sending terminal. At the evaluation, the received **a** and **b** coefficients are compared with the locally calculated **a** and **b** coefficients that are related to the same instant as the received ones.

By utilising Fourier filtering, the influence of non-fundamental frequency currents is reduced. The inrush current at energization, and the outfeed current at external faults caused by the capacitively stored energy in the line, are dominated by non-fundamental frequency components. The minimum operating current must be set high enough to achieve stability at these two conditions. The filtering allows a lower set operating value than unfiltered quantities would allow.

The use of Fourier quantities makes the scheme independent of the communication transmission time delay, as long as the local clocks are synchronised or the time difference is known. Therefore, the communication delay is of interest only for the synchronisation of local clocks.

Naturally, the transmission time is added to the basic operating time.

The transmission time is measured continuously by sending time-tagged signals from one terminal to the other. The received signal in the remote terminal is echoed back, together with the local time when the signal was received. In this process, one of the terminals is given the role of master by a configuration setting. The maximum transmission delay that can be measured is 20 ms (at greater delay, a value that is a multiple of 20 ms too short will be assumed). For example, a transmission delay of 23 ms will be measured as 3 ms, 48 ms measured as 8 ms etc. In order to have margins during all circumstances, the maximum allowed transmission delay is, as previously mentioned, limited to 12 ms.

Synchronisation of the local clocks is achieved as an integral of a number of successive measurements to eliminate spurious changes in the communication delay.

Owing to this design, the measurement does not need to be blocked to avoid false tripping when the communication delay is changed. The protection will be blocked if the communication delay not can be identified within 200 ms, due to disturbances in the communication. The stability of the local clocks allows operation without synchronisation for a time period of more than 200 ms. If the protection is blocked due to communication disturbances, the protection is automatically deblocked when the communication is established and the local clocks are synchronised again.

The **a** and **b** coefficients for the three-phase currents are transmitted every 5 ms together with check bits, to detect false information. A message that does not pass the check is rejected, and will neither be evaluated for tripping nor used for synchronisation of the clocks. A new message will be received 5 ms later. When a message is rejected during an internal fault, the operation time is prolonged by 5 ms.

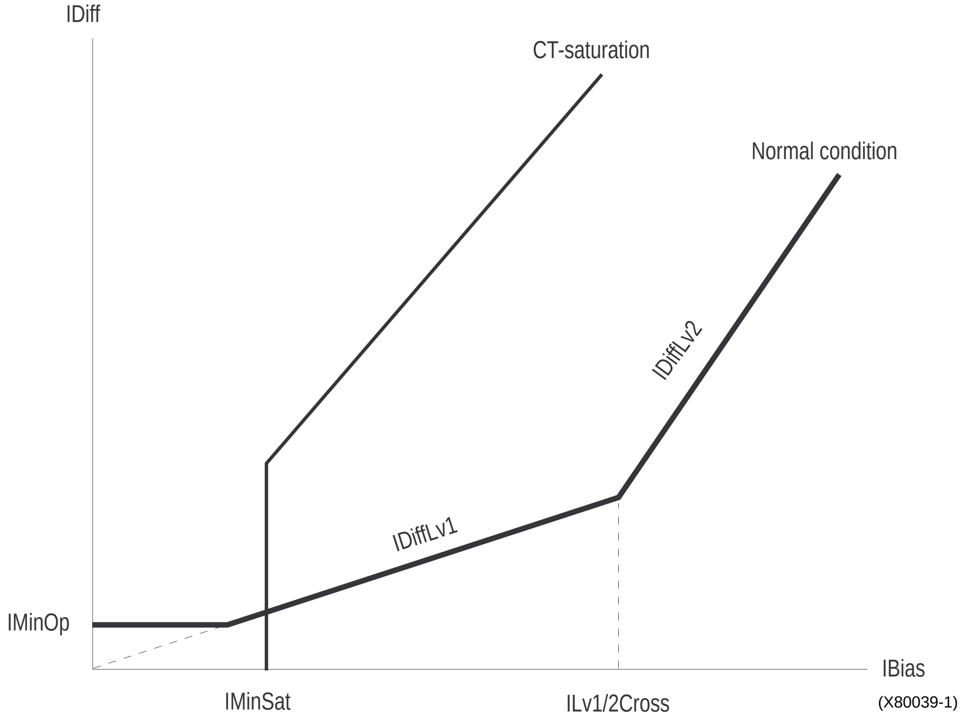
The differential protection evaluation is carried out in both terminals and performed individually for each phase. By using phase segregated evaluation, correct phase selection is achieved for **any** type of fault.

At the evaluation, a differential and a bias current are calculated for each phase by vectorial and scalar summation of the local and remote currents, represented by the **a** and **b** coefficients. The scalar sum is divided by two in order to achieve the bias current. See Fig. 1. The differential and bias currents are compared and a trip is issued according to the characteristic in Fig. 1.

For tripping, 2 or 3 out of 4 consecutive measurements are required to indicate a trip. The 2 or 3 evaluations do not have to be consecutive. The selection between the required 2 or 3 evaluations, is set on the Man machine interface (MMI) under:

Settings
  Group n
    Differential
      Evaluate

The minimum operate current (IMinOp), the two slopes (IDiffLvl1 and IDiffLvl2) and the intersection between slope 1 and 2 (ILvl1/2Cross) can be set. This characteristic takes care of the measuring errors in the primary current transformer and the protection, when the current transformer is **not** saturated. When the current transformer is saturated, the stabilisation is increased, seeFig. 1.



$$IDiff = \left|\overline{I_A} + \overline{I_B}\right| \qquad IBias = \frac{|I_A| + |I_B|}{2}$$

$$I_{\text{Bias per phase}} = max \cdot [(I_{\text{Bias own phase}}),(0,5 \cdot I_{\text{Bias other phases}})]$$

Fig. 1 Stabilisation characteristic

At current transformer saturation, stabilisation is increased at both terminals in the saturated phase. Therefore, phase segregated “saturation” signals are included in the transmitted message.

The patented saturation detectors evaluate each phase current locally, utilising the unfiltered samples issued every ms. The detection is based on the secondary current behaviour. In case of a saturation, the current decreases abruptly, from a high amplitude value to a low one, followed by a low rate of change. This condition is checked by means of three consecutive current samples.

The use of saturation detectors enables minimum current transformer requirements, together with maximum sensitivity.

1.3 Design of communication system

The line differential function is designed to work with digital communication systems. To ensure compatibility with a wide range of communication equipment and media, the relay is designed to work within the signalling bandwidth of a standard CCITT PCM channel at 64 kbits/s. To enable the use in North American EIA PCM systems working at 56 kbits/s, some of the interfacing modules can be adapted to this bit rate.

A data message is sent every 5 ms. Each data message is 22 bytes long. To this message, start and stop flags are then added, together with a 16 bit Cyclic Redundancy Check (CRC) word.

HDLC is a protocol for the flow management of the information on a data communication link. The protocol is widely used. The basic information unit on an HDLC link is a frame. A frame consists of:

- start (or opening) flag
- address and control fields (if included)
- data to be transmitted
- CRC word
- end (or closing) flag

HDLC is a bit-oriented protocol, which means that the receiver must be able to recognise a flag at any time. For this reason, all flags have the binary configuration 01111110. To avoid problems with other bytes having the same pattern, a technique called “zero bit insertion” is used. This techniques specifies that after every succession of five consecutive 1’s, a binary 0 is inserted. Thus, no pattern 01111110 is ever transmitted by chance, except for the flags. At the receiving end, when the start flag is recognised, a 0 is removed after 5 consecutive 1’s.

The address field is used for checking that the received message originates from the correct equipment. There is always a risk of multiplexers occasionally mixing up the messages. Each terminal is given different terminal numbers. The terminal is then programmed to accept messages only from a specific terminal number.

If the CRC function detects a faulty message, the message is thrown away and not used in the evaluation. No data restoration or retransmission are implemented.

1.3.1 Communication alternatives

Following communication alternatives exists:

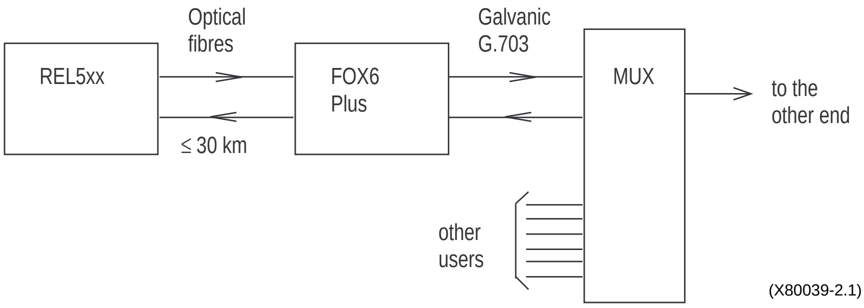


Fig. 2 Multiplexed link, fibre optical-galvanic connection

Fig. 3 Dedicated link, fibre optical connection

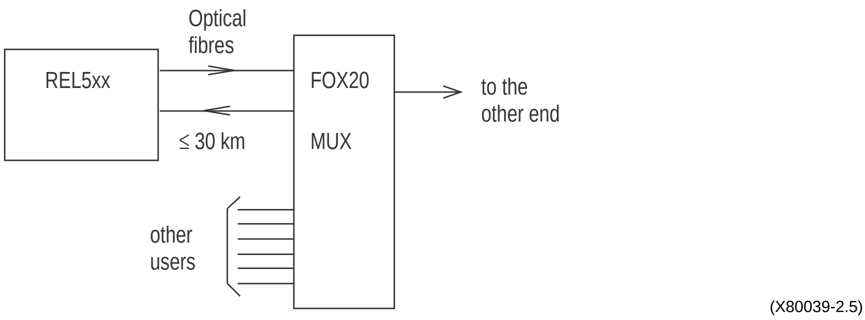


Fig. 4 Multiplexed link, fibre optical connection

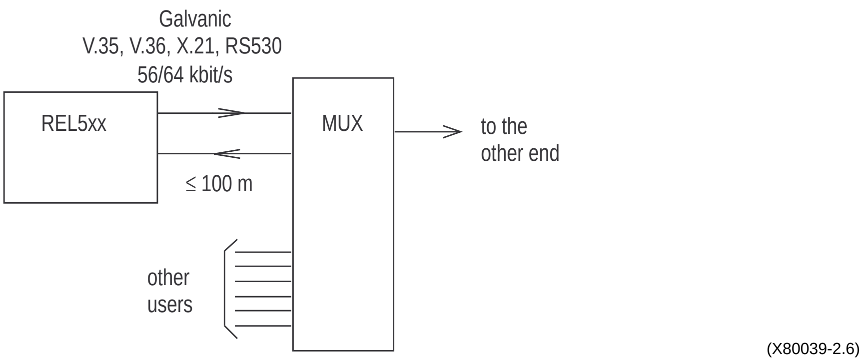


Fig. 5 Multiplexed link, galvanic connection

Fig. 6 Dedicated link, short range galvanic modem

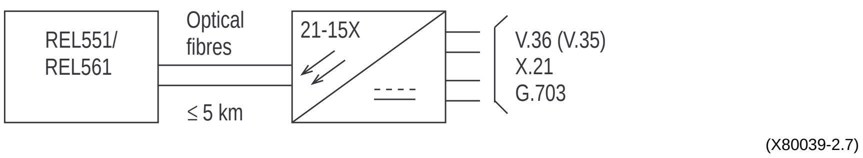


Fig. 7 Multiplexed link, short range fibre optical connection

1.3.2 Fibre optical modem

The optical communication module is designed for both 9/125 μm single mode fibres, and 50/125 or 62,5/125 μm multi mode fibres at a wavelength of 1300 nm. The connectors are of type FC-PC (SM) or FC (MM) respectively. Two different levels of optical output power are used to cover distances from 0 to approximately 30 km.

1.3.3 Short range fiber optical modem

The short range fiber optical modem is used for synchronous 64 kbit/s data transmission at distances up to 5 km. It can also be used together with fibre optic transceiver type 21-15X from FIBERDATA in order to get an optical link between the protection terminal and a remotely located communication equipment as in figure 7.

Transmission is performed simultaneously in both directions, full duplex, over two optical fibres. The fibres shall be of multi mode type, preferable 50/125 mm or 62,5/125 mm.

Table 1: Technical data for the short range fiber optical modem

Data transmission	**Synchronous; full duplex**
Transmission rate	64 kbit/s
Optical fibre	1300 nm, multimode fibre
Optical connectors	ST
Optical budget	15 dB
Clock source	Internal or derived from received signal
LED indications	RTS, CTS, DSR, DCD, TXD, RXD, LO, LA, MA, RA

1.3.3.1 Reach

The reach will depend on the properties of the used optical fibre. In the optical budget also has to be accounted for losses in splices, connectors and also ageing of the cable. The connection to the protection terminal shall not be accounted for in the optical budget. 15 dB optical budget gives up to 5 km reach under normal conditions.

1.3.4 Short range galvanic modem

The short range galvanic modem are used for synchronous data transmission at 64 kbit/s at distances up to 4 km.

Compared to normal data transmission standards, for example V.36, X21 etc., the short range modem increase the operational security and admits longer distances of transmission. This is achieved by a careful choice of transmission technology, modified M-3 balanced current loop, and galvanic isolation between the transmission line and the internal logic of the protection terminal.

Transmission is performed simultaneously in both directions, full duplex, over four wires in the transmission line.

Table 2: Technical data for short range galvanic modem

Data transmission	**Synchronous; full duplex**
Transmission rate	64 kbit/s (256 kBAud; code transparent
Range	See diagram 1. Maximum permitted capacitance within each pair is 140 nF. The modem is not recommended to be used on distance above 4 km.
Line interface	Balanced symmetrical three-state current loop. 5-pin divisible connector with screw connection
Clock source	Internal or derived from received signal
LED indications	Clock, Send and Receive
Isolation	Galvanic isolation through opto-couplers and isolation DC/DC. converter
Test voltage	2 500 Vrms; 1 minute

1.3.4.1 Range

The reach will depend on the used cable. Higher capacitance between conductors and higher resistance will reduce the reach. The use of screened cables will increase the capacitance and thereby shorten the reach but this will most often be compensated for by the reduced noise giving a better operational security. Maximum ranges as a function of cable parameters is given in below diagram, Figure 10.

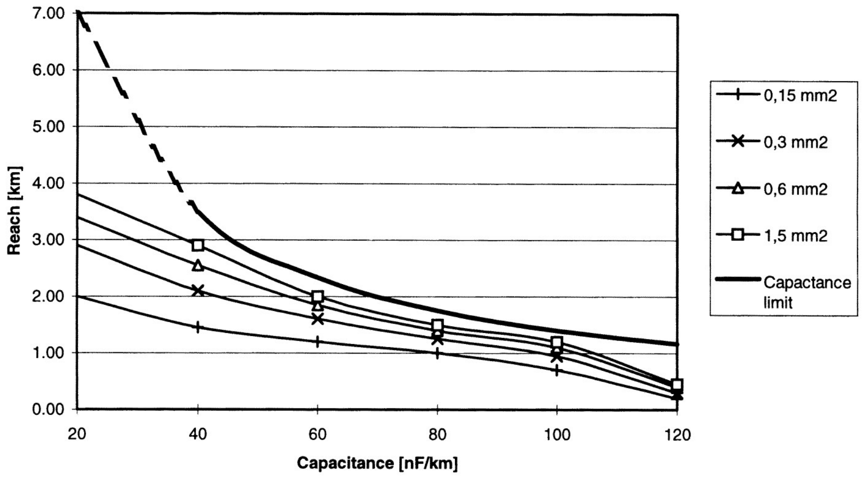


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Fig. 8 Maximum reach

Note! The reaches in the diagram, Fig 10, is given for twisted-pair and double-screened cables, one screen for each pair and one common outer screen. For non twisted-pair cables the reach has to be reduced by 20%. For non pair-screened cables the reach also has to be reduced by 20%. For non twisted and single screened, one common outer screen, cables the reach will therefor be reduced by 40%.

1.3.5 Galvanic interfaces

If the relay is in the same building as the multiplexing equipment, within a distance of less than 100 m, and the environment is relatively free of noise, the relay may be connected directly to the multiplexer via shielded and properly earthed cables with twisted pairs.

Since the protection communicates continuously, a permanent communication circuit is required. Consequently, the call control and handshaking features specified for some interfacing recommendations are not provided.

Equipment is available for the following interfacing recommendations, specifying the interconnection of the digital equipment to a PCM multiplexer:

- V.35/36 co-directional galvanic interface
- V.35/36 contra-directional galvanic interface
- X.21 galvanic interface
- RS530/422 co-directional galvanic interface
- RS530/422 contra-directional galvanic interface
- G.703 co-directional galvanic interface(via additional interface converter)

For the signals used by the protection, the communication module for V.36 also fulfils the older recommendation for V.35.

The connection is established by DSUB connectors, 15 pins for X.21 and 25 pins for V.35/36 and RS530. The use of the different pins are shown in Fig. 9. The G.703 converter connection is performed by screw connection.

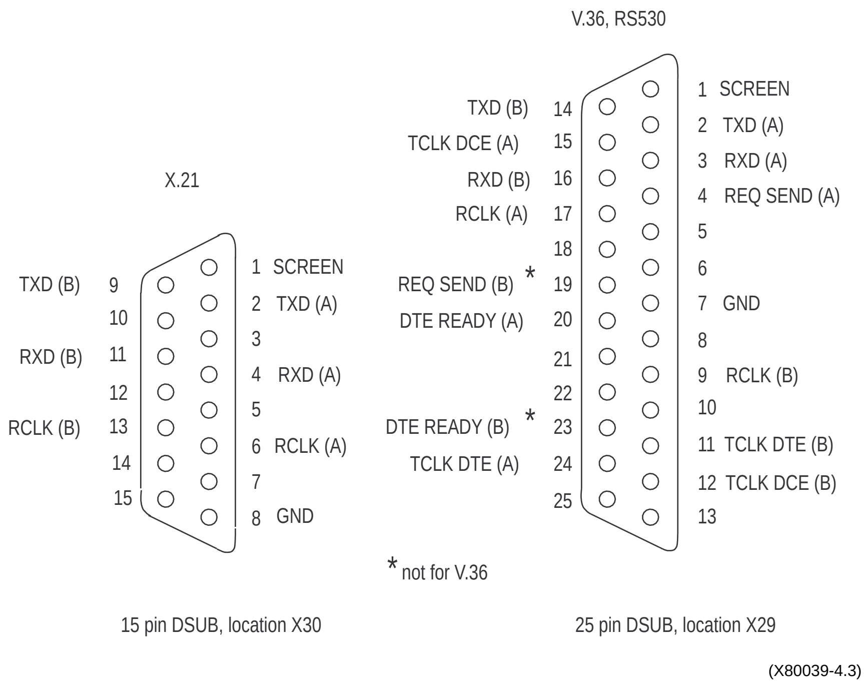

Fig. 9 DSUB connectors

The following abbreviations are used in Fig. 9:

A	Designations of terminals according to CCITT, EIA etc.
B	Designations of terminals according to CCITT, EIA etc.
DCE	Data communication equipment (= multiplexer, etc.)
DTE	Data terminal equipment (= protection)
DTE READY	Data terminal ready (follows auxiliary voltage)
GND	Earth (reference for signals)
RCLK	Receiver signal timing
REQ SEND	Request to send (follows auxiliary voltage)
RXD	Received data
SCREEN	Connection of cable screen
TCLK DCE	Transmitter signal timing from DCE
TCLK DTE	Transmitter signal timing from DTE
TXD	Transmitter data

If the relay is at a long distance from the multiplexer, or if the cables run through a noisy area, optical cables should be used to interconnect the relay and the multiplexer. In this case, the relay contains the module used for dedicated optical links.

If the multiplexer is of type FOX20 from ABB Netcom, the protection can be connected optically to the multiplexer, provided it is equipped with an Optical Terminal Module of type N3BT.

In other cases, an optical-to-electrical converter, FOX6Plus, has to be used at the multiplexer. The FOX6Plus supports the G.703 co-directional interfacing. The distance between the FOX6Plus and the multiplexer should be kept less than 100 m.

1.4 Setting procedure

1.4.1 Choice of protection parameters

The rated secondary current of the primary current transformer must be equal to the rated current of the protection.

The secondary current that is to be compared in both terminals, must be related to a common current transformer ratio. With a CTFactor default setting of 1,00, this is achieved when the current transformers at both terminals have the same rated primary current. When one of the terminals has a higher primary rated current then the other one, this can be numerically equalised by the CTFactor setting. By setting the CTFactor (settable 0,40-1,00) in the terminal with the higher primary rated current to the quote between the lower and the higher rated current, the difference is equalised. The nominal primary current for the whole differential protection function ($I_{nominal}$), to which all function data is related, is the lower rated current.

If the primary rated current is much higher than the maximum load current, the differential nominal current ($I_{nominal}$) can be reduced by the CTFactor at both terminals. In this case, the nominal primary current ($I_{nominal}$), to which all function data is related for the differential protection, is equal to the rated primary current multiplied by the CTFactor.

Identical settings for IMinOp, IDiffLvl1, IDiffLvl2, ILvl1/2Cross and IMinSat should be used at both terminals.

The minimum operating current, IMinOp (settable 20-150% of $I_{nominal}$), is chosen in relation to the fundamental frequency charging current. The primary minimum operating current must not be lower then 2,5 times the total charging current (practically, the charging current when the line is fed from only one terminal).

Current transformers of type TPX or TPY can be used. Generally, linearised current transformers of type TPZ can not be used. In case this type of current transformer is used, contact ABB Relays AB.

When current transformers of the same type are used at both terminals, and they are dimensioned according to item 4, “Requirements and technical data”, the default settings: IDiffLvll=40% of IBias , IDiffLvl2=60% of IBias and ILvl1/2Cross=500% of IBias are applied.

The IDiffLvl is increased to 160% of IBias at detected saturation. With current transformers dimensioned according to item 4, Technical data, the default value IMinSat=300% of IBias is used. When the current transformer margin $E2_{max}$>3 times, the IMinSat can be increased to 500%.

By setting the Evaluate 2 of 4 instead of the default setting 3 of 4, the operating time can be reduced by 5 ms. The setting 2 of 4 is recommended only when high quality communication is used. The reason for this is the slightly increased risk of false tripping, due to corrupt messages.

To make sure that the differential protection communicates with the correct protection at the opposite terminal, the terminals are numbered. By giving **all** differential protections transmitting over a common multiplexer **individual** identification numbers, this type of communication failure can be detected. The terminals are given identification numbers 0-7 by a setting parameter. The identification number of the opposite terminal must also be set. This is always necessary.

For the synchronisation of the local clocks, one terminal has to be master, and the other one slave. This is set with the Master-Slave setting under:

Configuration
Differential
System
DiffSync

1.4.2 Choice of communication parameters

For the optical module, the optical output power has to be set according to the attenuation of the fibre optic link.

For multimode fibres:

- If the attenuation is less than 6 dB, use Low setting
- If the attenuation is higher than 10 dB, use High setting
- If the attenuation is between 6 and 10 dB, use either High or Low setting

For single-mode fibres:

- If the attenuation is higher than 5 dB, use High setting
- If the attenuation is between 0 and 5 dB, use either High or Low setting

To achieve the best operation, the optical communication modules at both terminals must be synchronised. To fulfil this, one terminal acts as a Master and the other as a Slave. This is set under:

Configuration
Differential
Communication
CommSync

It should not be mixed up with the earlier mentioned Master-Slave setting.

When communicating with FOX20 or FOX6Plus, the setting should be:

- Slave on the protection at both terminals

When operating over dedicated fibres the setting shall be:

- Master at one terminal and Slave at the other

When using the modules for X.21, V.35/36 contra-directional and RS530/422 contra-directional, no setting has to be carried out.

For the modules with V.35/36 co-directional and RS530/422 co-directional communication, the bit rate has to be set. The choice is between 56 and 64 kbits/s. This is set under:

Configuration
Differential
Communication
Bitrate

1.5 Setting

The setting parameters for the differential protection function are available in the menu tree in the local MMI under the menu:

Setting
Function
Group n
Differential

For remote setting and local MMI via personal computer, please refer to the corresponding SMS or SCS documents.

The configuration parameters for the differential protection communication are available in the menu tree in the local MMI under:

Configuration
Differential
System and Communication

The setting and configuration parameters are described in 1.5 and 1.6.x.

The input signals and produced output signals are tabulated in 1.9.1.

1.6.1 Fibre optical

The optical power is set in the MMI under:

Configuration
Differential
Communication

The optical power for the different possibilities is shown in the table below.

Table 1:

Type of fibre	Output power	Optical Transm. Output power	Optical Rec. Sensitivity	Maximum attenuation
Multimode	Low	-28 dBm	-40 dBm	10 dB
	High	-16 dBm	-40 dBm	21 dB
Single-mode	Low	-33 dBm	-40 dBm	5 dB
	High	-21 dBm	-40 dBm	16 dB

The attenuation in fibres is normally approximately 0,8 dB/km for multimode, and 0,4 dB/km for single-mode fibres. Additional attenuation due to the installation can be estimated at 0,2 dB/km for multimode and 0,1 dB/km for single-mode fibres. For a single-mode fibre with high output power, this results in a maximum distance of 32 km.

1.6.2 Short range fibre optical modem

Normally all setting can be made on a DIP-switch located behind the cover around the fibre optic connectors at the back of the terminal according to Figure 12. After the fibres has been disconnected, if attached, the cover plate can be removed just by pulling at the middle of the cover plate. NOTE! If handled carefully the cover plate can be removed also with the fibres attached.

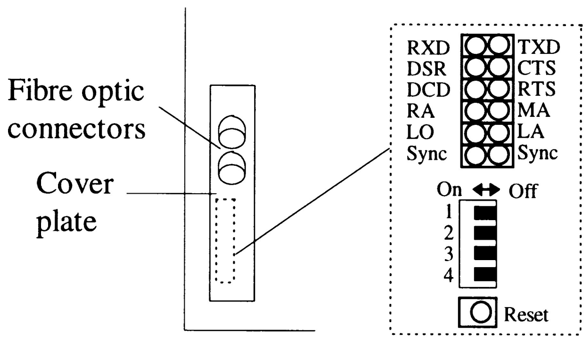

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Fig. 10 Setting and indications

Switch 1 and 2 are used to set the source of timing. The function is according to setting of timing signal, Figure 13.

When using the modem for optical point-to-point transmission, one modem should be set for locally created timing and the other for timing recovered from received signal.

When the modems are communicating with a transceiver 21-15X the modems shall be set for timing recovered from received optical signal, see setting of timing signal, Fig. 13:

Table 2: Setting of timing signal

Switch No		Function
1	2	
OFF	OFF	Timing created by the modem
OFF	ON	Timing created by the differential function
ON	OFF	Timing recovered from received optical signal
ON	ON	No timing, the data transmission will not work

The module can synchronise received data with the send clock. Synchronisation ON/OFF is controlled by switch 3.

When the module is set for synchronisation (switch 3 = ON) switch 4 must be set in the position corresponding to the Sync LED that is brightest. If both have the same brightness the switch can be set in any position.

NOTE !! After any change of settings, the modem has to be reset by the Reset button located below the DIP-switch NOTE !!

1.6.2.1 Indications

There are ten LED's indicating the status of the transmission link. These LED's are found above DIP-switch described in the Setting section, see also Figure 12. The function of the LED's are explained in Figure 14.

Table 3: Indications

LED	Colour	Explanation
RTS	Yellow	Request to send
CTS	Yellow	Clear to send
DSR	Yellow	Data communication correct
DCD	Yellow	Detection of carrier signal
TXD	Yellow	Transmitted data
RXD	Yellow	Recieved data
RA	Red	Remotely detected problem with link
MA	Red	Memory function for problem with link
LO	Green	Link operation correctely
LA	Red	Locally detected problem with link
Sync	Green	Used when synchronisation is selected

The memory function is reset with the Reset button below the DIP-switch. The reset command is also transmitted to the other end of the optical link.

The two green LED’s, Sync, at the bottom is used to set the synchronisation function correctly with switch 4 as described in the Setting section.

1.6.2.2 Jumper settings

NOTE! All jumpers are set in correct location from factory. No change of jumper settings should be made without contacting ABB Networ Partner AB. NOTE!

The jumpers are accessible after the modem has been pulled out. This is done by first removing all green 18-pin connectors at the back, then remove all screws holding the back plate. After the back plate has been removed the modem can be pulled out. NOTE! Only pull out the modem not the whole double size Euro-card. After the jumper settings has been changed put everything back in reverse order.

NOTE! All electronic are sensitive to electrostatic discharge. Proper action must be taken at the work place to avoid electrostatic discharge!

There are two locations of jumpers, S3 and S5 according to figure 15.

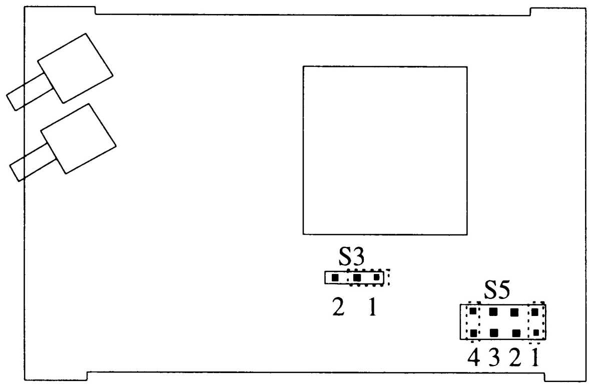

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Fig. 11 Jumper locations

S3 is used for selecting timing function. A jumper is inserted in position 1.

S5 is used for setting the transmission rate at timing created by the modem. Two jumpers are inserted, one in position 1 and the other in position 4. This gives 64 kbit/s which is the rate used by the differential protection function.

1.6.3 Short range galvanic modem

There is only one setting to be made, if the timing signal (Clock) are to be locally created or recovered from the received signal. This setting is performed by a DIP-switch located behind the cover around the line connector at the back of the terminal according to Figure 16. After the line connector has been pulled out, the cover plate can be removed just by pulling at the middle of the cover plate.

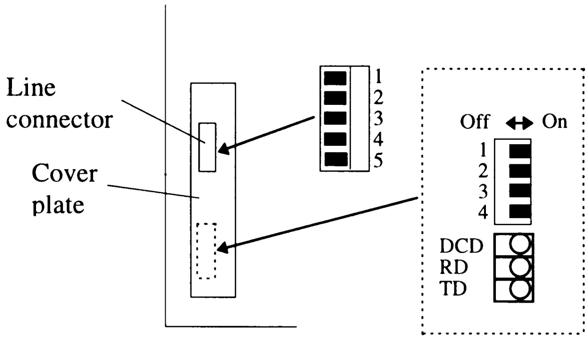

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Fig. 12 Settings and indications

Only switch 1 and 2 are used on the DIP-switch. The function is according to the setting of timing signal, see Figure 17.

Table 4: Setting of timing signal

Switch No		Function
1	2	
OFF	OFF	Unpredictable, normally locally created timing
ON	OFF	Unpredictable, normally locally created timing
OFF	ON	Timing recovered from received signal
ON	ON	Timing recovered from received signal
OFF	OFF	Unpredictable, normally locally created timing

In normal operation switch 1 is set in ON position at one end and switch 2 is set ON at the other end, rest of the switches is set OFF.

1.6.3.1 Indications

There are three LED's indicating the status of the transmission link. These LED's are found below DIP-switch described in the Setting section, see also Figure 16. The LED's are denoted DCD, RD and TD with indications according to the Indications table, see Figure 18.

Table 5: Indications

LED	Explanation
DCD	Data and Carrier Detect. Indicates that a correct timing signal is received. Shall show a steady green light.
RD	Receive Data. Indicates that a “one” is received. Shall show a flickering yellow light
TD	Transmit Data. Indicates that a “zero” is sent. Shall show a flickering yellow light.

1.7 Testing

1.7.1 General

At commissioning and after changes in the current circuits, the tripping at both terminals must be blocked permanently before the dc supply is connected. This blocking can not be done by the COMBITEST switch, it has to be on the station side of the test switch. The blocking of the trip signal must be maintained, until the test below has been performed at both terminals.

Any work in any of the terminals, such as injecting current or short-circuiting the current during load transfer on the line, will result in a local and a **REMOTE** end trip.

When the current balance is disturbed by any action, the protections at both line ends must be blocked.

Before performing any work in the current circuit to the differential protection, the “TestMode” must be activated and “Saved”. The protection will **not** enter into “Test” mode without “Saving” the “Test” command. See the MMI instruction for saving.

The TestMode is available in the menu tree in the local man machine interface under:

Test
- **TestMode**
  - **Operation**

When the protection is in the “Test” mode, the yellow LED flashes.

It is sufficient if one of the terminals is set in “Test” mode. The trip function is blocked automatically at both line ends, when one of the protection terminals is in “Test” mode.

When the protection is equipped with a COMBITEST test switch, inserting the test handle will automatically force the protection into “Test” mode. This function is also achieved by activating the “Test” digital input.

During the test, the command “Local trip” will allow activation of the trip outputs. This command is used when the operating time has to be measured and is found under

Test
- **TestMode**
  - **Differential**

Thus, the protection can be tested without any manual actions in the remote station.

For a complete test of the protection, the tests must be repeated at both terminals.

Testing can be performed only when the terminals communicate with each other and **one and only one** of the terminals is in “Test” mode.

When one of the protections is in “Test” mode, the tripping is blocked at both terminals, and the opposite terminal mode of operation is changed. In the opposite terminal, the received current values (a and b Fourier coefficients) are echoed back to the other terminal, but transposed in the following way: the received value for the L1 phase is returned as the L2 current, L2 is returned as L3, and L3 as L1.

When a current is injected into phase L1 in the terminal, which is set in “Test” mode, it will appear as an IDiff in phase L1 and L2 and as an IBias in phase L1, L2 and L3. When the current is sufficiently high, the protection will operate in phase L1 and L2 in the terminal in “Test” mode, but it will not operate in the remote terminal. For the actual reading of IDiff and IBias, see under step 1.4 and 1.6 below in how to perform a test. See also equations in fig. 1.

To activate the local trip relays during the test for operating time measurement, the blocking of the trip is overridden in the terminal in “Test” mode by the command “Local trip”.

The testing is performed by injecting a single and a symmetrical three-phase current and requires a three-phase test equipment.The test is performed in the following steps:

1.1 Set the protection in “Test” mode by the MMI unit. The “Test-Mode” is found in the menu under:

Test
TestMode
Operation

The “TestMode” command must be “Saved” in order to be activated. When the protection is equipped with COMBITEST test switch, the “Test” mode is automatically activated but not saved when the test handle is inserted.

1.2 Set the protection in “TestMode”, “No DisturbanceReport” and “ReleaseLocal”. This command is found in the menu under:

Test
TestMode
Operation, DisturbReport, Differential

This command must be “Saved” in order to be activated. Observe that the command “ReleaseLocal” will allow the trip outputs to be activated during the tests

1.3 Connect the test equipment for current injection. When a COMBITEST test switch is not fitted, the current transformer must be short-circuited before being disconnected.

1.4 Inject a current in L1 and increase the current until operation in phase L1 and L2 takes place. The injected operation value must correspond to the set IMinOp $\times$ I_r $\times$ CTFactor. This value is to be read as IDiffL1 and IDiffL2, and 50% of IDiffL1 as IBiasL1 and IBiasL2. The IDiffL3 should be zero and IBiasL3 25% of IDiffL1. These values are read on the MMI under:

Service Report
Diff Values

1.5 The same measurements as under 2 are repeated in phase L2 and L3. The result shall be transposed one, respectively two steps.

1.6 Inject a symmetrical three-phase current, and increase the current until operation is achieved in all three phases.
The IMinOp $\times$ I_r $\times$ CTFactor value shall be obtained for operation and read for IDiff in all three phases. 100% of IDiff shall be read for IBias in all three phases.

1.7 Read the transmission delay, found on the MMI under:

Service value
DiffCommunic
Channel Info

This delay is not allowed to exceed 12 ms.

1.8 The operating time is measured at the injection of a single-phase current in phase L1. The injected current should be 4 times the operating current. The time measurement is stopped by the trip output from the protection. To achieve this function, the blocking of the trip has to be overridden by the setting “ReleaseLocal” under the “Test” menu. Open the trip circuit to the breaker. The operating time should be 28-33 ms + 2 times the communication transmission delay.

1.9 Disconnect the test equipment and reconnect the current transformer.

1.10 Read and check the three-phase current under the menu “Service value”

1.11 When the current transformers are connected, the protection is put in operation by switching off the “Test” mode. After the “Test” mode is set at “Off”, the command must be “Saved” to activate the protection. The yellow LED should stop flashing.

1.12 With a through load current of minimum 20% of the I_r $\times$ CTFactor, the IDiff and IBias are read in all phases. The IDiff should be lower than 10% of the actual secondary current divided by the CTFactor, the IBias should be equal to this current. This measurement is necessary at commissioning to guarantee that there is no phase shift between the terminals.

1.13 When this test has been successfully performed, the external blocking of the trip signal can be removed, and the trip connected.

1.14 A complete commissioning or maintenance test requires that the test is repeated at both terminals.

1.15 When the direct transfer trip is used, this function has to be tested by activating its input, to check that trip is achieved at the remote terminal. During this test, the trip circuit has to be blocked.

1.8 Technical data

Table 6: Differential protection

Function	Setting range
Current scaling (CTFactor)	(0,4-1,0) in steps of 0,01
Minimum operate current (IMinOp) Slope 1 (IDiffLvl1) Slope 2 (IDiffLvl2) Slope 1/Slope 2 intersection (ILvl1/2Cross) Slope at saturation Saturation min current (IMinSat)	(20-150) % of (CTFactor x I_r) in steps of 1 % (20-150) % of I_{bias} in steps of 1 % (30-150) % of I_{bias} in steps of 1 % (100-1000) % of (CTFactor x I_r) in steps of 1 % 1,60 x I_{bias} (100-1000) % of (CTFactor x I_r) in steps of 1 %
Function	**Value**
Operate time I_{diff} > 2 x I_{bias} and I_{diff} > 4 x IMinOp	 Typical 28 ms
Reset time at I_{diff} = 0	max 55 ms
Transfer trip operating time	max 35 ms
Data communication between the terminals transmission type data transfer rate	 synchronous 56 or 64 kbit/s For G.703 only 64 kbit/s

Table 7: Communication for differential protection

Galvanic interface	Connection	
Interface type	V.36/V11 Co-directional V.36/V11 Contra-directional X.21/X27 RS530/RS422 Co-directional RS530/RS422 Contra-directional G.703	According to CCITT According to CCITT According to CCITT According to EIA According to EIA According to CCITT
Connector type	D-sub 15 or 25 pins (G.703 screw)	
Short range galvanic modem		
Range Line interface Connector Isolation	max 4 km Balanced symmetrical three-state current loop 5-pin divisible connector with screew connection Galvanic isolation through optocouplers and isolating DC/DC-converter	
Optical interface Terminal dedicated fibre Terminal - FOX 6 PLUS (G.703)		
Type of fibre	**Graded-index multimode 50/125μm**	**Single mode 9/125 μm**
Optical connector Wave length Optical transmitter injected power Optical receiver sensitivity Transmission distance	Type FC e.g. Diamond HFC-13 1300 nm LED -16 dBm PIN diode -40 dBm max 20 km	Type FC-PC, e.g. Diamond HPC-10 1300 nm LED -21 dBm PIN diode -40 dBm max 30 km
Short range fibre optical modem		
Transmission distance Optical fibre Optical connectors Optical budget	max 5 km 1300 nm, multimode fibre ST 15dB	

1.9 Appendix

1.9.1 Signal list

CONNEC-TIONS:	**TO:**	**SETTING:**	**DESCRIPTION:**
DIFF-BLOCK	BI	-	Block differential protection
DIFF-TRTRIN	BI	-	Transfer trip input signal (to remote end)
IMPORTS:	**ORIGIN:**	**SETTING:**	**DESCRIPTION:**
-	-	-	
PRODUCTION	**TO:**	**SETTING:**	**DESCRIPTION:**
DIFF-COMOK	BO		Communication operates correctly
DIFF-TRDIF	BO		Trip diff any phase
DIFF-TRDIFL1	TRIP, BO		Trip diff phase L1
DIFF-TRDIFL2	TRIP, BO		Trip diff phase L2
DIFF-TRDIFL3	TRIP, BO		Trip diff phase L3
DIFF-TRTROUT	BO		Transfer trip output signal (from remote end)
DIFF-CTSAT	BO		CT saturation detector

1.9.2 Setting table

PARAMETER:	SETTING RANGE:	SETTING				
		ACTUAL				
		Group 1	Group 2	Group 3	Group 4	DESCRIPTION:
Operation	On / Off					Activation of differential protection
CTFactor	0,40 - 1,00					Factor for matching Current Transformers (C.S)
IMinSat	(100 - 1000)% of (I_r x C.S)					Current saturation detection cut-off
IMinOp	(20 - 150)% of (I_r x C.S)					Minimum differential operating current
IDiffLvl1	(20 - 150)% of Ibias					Slope 1 stabilisation
IDiffLvl2	(30 - 150)% of Ibias					Slope 2 stabilisation
ILvl1/2Cross	(100 - 1000)% of (I_r x C.S)					Cross-over point between slope 1 and slope 2
Evaluate	2 of 4 3 of 4					Tripping when 2 of 4, or 3 of 4 consecutive messages indicate trip condition
Config / Diff / System (only one setting possible)						
DiffSync	Master / Slave					Select if the terminal shall be Master or Slave for the clock synchronisation
TerminalNo	0 - 31					Set identification number of this terminal
RemoteTerminalNo	0 - 31					Set identification number of the terminal at the other line end
Config / Diff / Communication (only one setting possible)						
BitRate for V36 Codir	56 / 64 kb/s					Select bit rate for Codir communication for the galvanic communication module
OptoPower	Low / High					Select high or low power for the optical communication module
CommSync	Master / Slave					Select Master or Slave for synchronisation of the optical communication module
Test / TestMode/Differential (only one setting possible)						
Diff test mode	Block all Release local					Setting of test mode for test of the differential protection

1.10 Optical/electric converter for short range optical modem

1.10.1 Transciever 21-15x for interface standard V.35/V.36

1.10.1.1 Interfaces

The transceiver 21-15X can be used for interface standards V35, V36 and RS232. The transmission can be synchronous at different transmission rates (see below in section 2) or asynchronous with a maximum transmission rate of 256 kBaud (12% jitters). Following signals are supported in the interface:

Table 8: Interface signals

Signal name	V24	V35	V36	RS232	Direction[1]
TXD	103	P/S	4/22	2	-> DCE
RXD	104	R/T	6/24	3	-> DTE
TXC	114	Y/AA	5/23	15	-> DTE
RXC	115	V/X	8/26	17	-> DTE
TXCE	113	U/W	17/35	24	-> DCE
RTS	105	C	7	4	-> DCE
CTS	106	D	9	5	-> DTE
DSR	107	E	11	6	-> DTE
DCD	109	F	13	8	-> DTE
DTR	108/2	H	12	20	-> DCE
SGND	102	B	2)	7	<-->
PGND	101	A	1	1	<-->

1) DCE stands for Data Circuit terminating Equipment and DTE for Data Terminal Equipment. The transceiver is normally a DCE.

2) = 19, 20, 25, 27, 29, 30, 31, 37

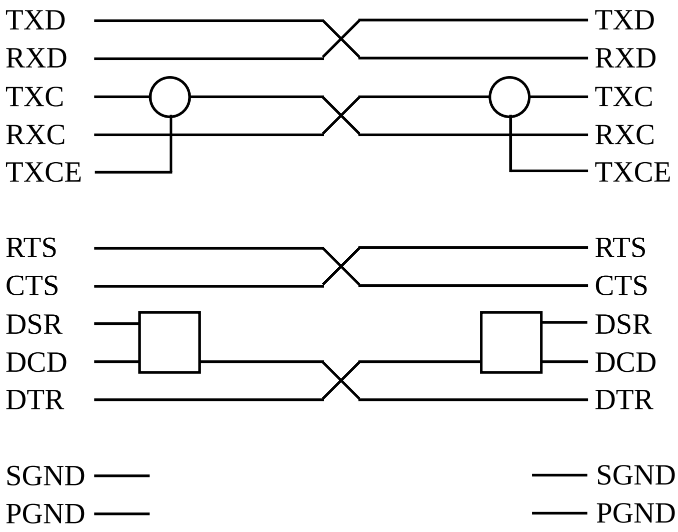


Fig. 13 Connection between the tranceiver and other equipment

V35, V36 and RS232 are using a common output module and the choose between the three interface standards are done by placing a jumper in one of three possible positions according to figure 20. Only one interface standard can be chosen simultaneously but different standards can be chosen at the two ends.

The optical contact is ST for multi mode fibre, 50/120 µm or 62.6/120 µm.

The electrical contact is a 34-pin connector according to ISO 4902 DCE for V35, a 37-pin connector according to ISO 2593-1984 DCE for V36 and a 25-pin connector according to ISO 2110 DCE for V24 / V28 (RS232).

1.10.1.2 Transmission rates

The transceiver can transmit synchronous data with transmission rates according to table 20.

Table 9: Transmission rates

Transmission rate [kBaud]	Position
2048	0, E, F
1536	1
1024	2
768	3
512	4
384	5
256	6
196	7
128	8
64	9
38,4	A
19,2	B
9,6	C
4,8	D

The transmission rate is set by a rotary switch, see figure 20.

Asynchronous data transmission can be used with a sampling rate of 2048 k sample /s which gives a maximum transmission rate of about 256 kBaud.

1.10.1.3 Timing

The timing of the transceiver can be set for three alternatives:

- Internal timing, the transceiver will create the timing
- External timing, the transceiver is controlled by the DTE via signal 113
- Loop timing, the timing is derived from the received optical signal

The choice is done by two jumpers, see figure 20.
The transceiver can synchronize received data with transmit timing. This function is controlled by a jumper, see figure 20. When the transceiver is set for synchronization of data, the jumper for selection of phase must be correctly set. The jumper has to be placed closest to the brightest LED, see figure 20.

1.10.1.4 Indications

10 LED’s with following color code: Alarm = Red, Status = Yellow, Function = Green.

The transceiver is supervising its own receiving function and announce it by indicating and signaling with DCD and DSR. The transceiver is supervising the receiving function of the remote end and announce this by indicating and signaling with DSR. The reading of fault indication is interrupted by pressing the reset button, the signaling can not be read. The reset is also transmitted to the transceiver at the remote end.

Following indication exists:

RTS	status		CTS	status	
DSR	status		DCD	status	
TXD	status		RXD	status	
LO	function	(Link operational)	LA	alarm	(Link Alarm)
MA	status	(Memory Alarm)	RA	alarm	(Remote Alarm)

1.10.1.5 Dissembling / Assembling

For making the jumpers accessible to perform the above mentioned settings the unit must be opened.

NOTE! All electronic are sensitive to electrostatic discharge. Proper action must be taken at the work place to avoid electrostatic discharge!

The unit is dissembled by unscrewing three screws located under the unit at the back holding the back plate in position. The back plate with connection for the auxiliary voltage can now be pulled backwards. The upper cover is now pushed backward about 2 cm and when lifted up from the unit. The printed circuit board will now be visible according to figure 20.

The unit is assembled by placing the cover on the unit about 2 cm behind the front. The cover is gently pushed downwards and then pushed forward. The back plate with connection for the auxiliary voltage is put in position from behind and the three screws holding the back plate are put back.

1.10.1.6 Setting description

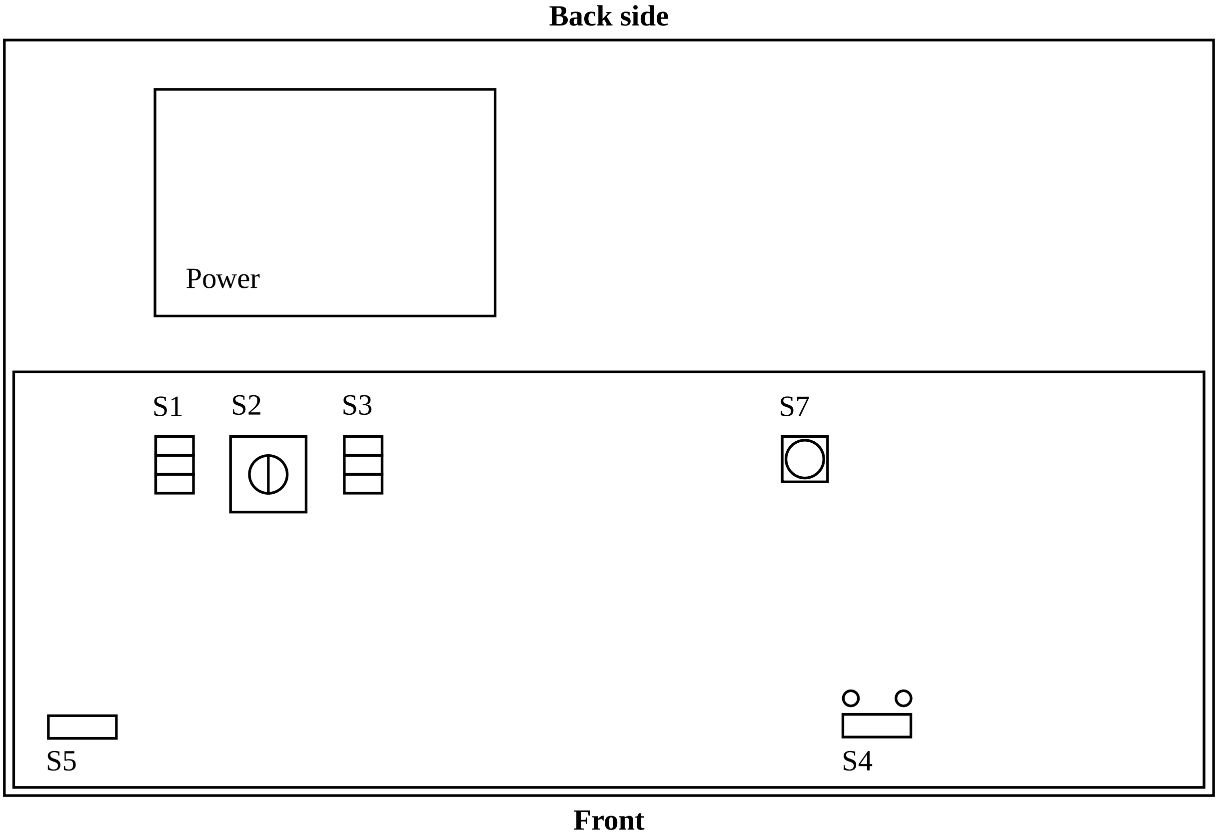


Fig. 14 Setting location on printed circuit board

Choice of interface standard, unit for V35 / V36 / RS232, jumper S1:

- RS232 : put the jumper in upper position
- V35 : put the jumper in middle position (factory setting)
- V36 : put the jumper in bottom position

Choice of transmission rate, rotary switch S2:

- Turn S2 in wanted position. For asynchronous transmission put S2 in position 0. (factory setting).

Choice of timing function. jumper S3:

- Internal timing: No jumper on the two bottom positions (factory setting).
- External timing: One jumper in the middle position.
- Timing retrieved from received optical signal: One jumper in the bottom position.

Choice of synchronization, jumper S3:

- Synchronization: One jumper in the top position.
- No synchronization: No jumper in the top position (factory setting).

When synchronization has been selected jumper S4 is placed closest to the brightest LED.

NOTE ! After any change in the setting the transceiver it has to be reset by pressing button S7 (Reset) NOTE !

Choice of protective grounding, jumper S5:

- No connection between protective grounding and signal ground:
- no jumper (factory setting)
- Soft connection between protective grounding and signal ground: jumper inserted to the left
- Hard connection between protective grounding and signal ground: jumper inserted to the right

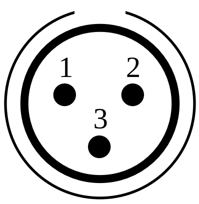
1.10.1.7 Specification

Casing
Dimensions: width 380mm, height 44mm, depth 240mm
Can be mounted in 19" rack, on wall or free standing.

Electrical interface:
34-pin connector according to ISO 4902 DCE for V35,
37-pin connector according to ISO 2593-1984 DCE for V36,
25-pin connector according to ISO 2110 DCE for V24/V28 (RS232)

Optical interface:
Optical connectors are ST or SMA for multi mode fibre and ST for single mode fibre.
Optical budget is 10 dB for 1300 nm single mode fibre and 15 dB for 850/1300 nm multi mode fibre.

Auxiliary voltage:
110-230 Volt ± 20%, 50-60 Hz
Standard AC line connector
or
48-110 Volt DC ± 20%
XLR audio connector



Connector for DC-supply

1 = 48-110 V DC
2 = 0 V
3 = Screen

1.10.2 Tranciever 21-16x for interafce standard X.21/G.703

1.10.2.1 Interfaces

The transceiver 21-16X can be used for interface standards X.21, RS530 and three variants of G.703 (the 2048 kbit/s protocol on coaxial cable, codirectional according to the 64 kbit/s protocol from 64 up to 2048 kbit/s and contradirectional according to the 64 kbit/s protocol from 64 up to 2048 kbit/s, the last two on twisted pair cable. The transmission can be synchronous at different transmission rates (see below in section 2) or asynchronous with a maximum transmission rate of 256 kBaud (12% jitters). Following signals are supported in the interface:

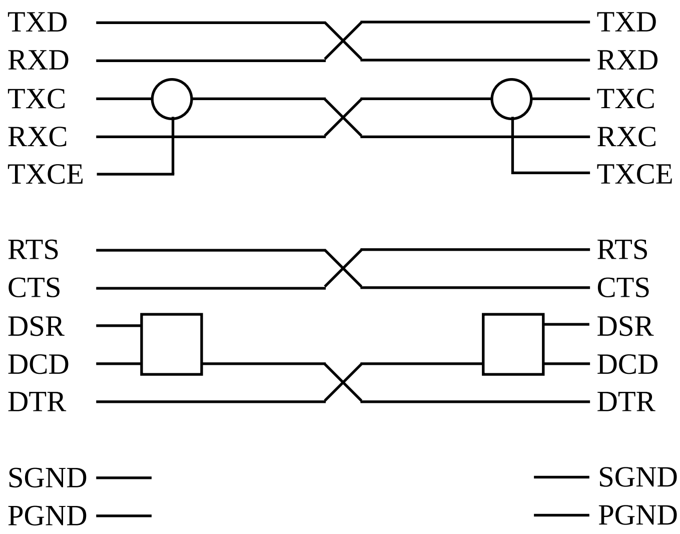
Table 10: Interface signals

Signal name	X.21	RS530	G.703[2)] (co)	G.703[2)] (contra)	G.703 (BNC)	Direction[1)]
TXD			3, 4	3, 4		-> DCE
RXD			1, 2	1, 2		-> DTE
TXC			--	5, 6 & 7, 8[3)]	--	-> DTE
RXC			--	5, 6 & 7, 8[3)]	--	-> DTE
TXCE			--	--	--	-> DCE
RTS			--	--	--	-> DCE
CTS			--	--	--	-> DTE
DCD			--	--	--	-> DTE
DTR			--	--	--	-> DCE
SGND			--	--	--	<-->
PGND			9, 10 (terminal)	9, 10 (terminal)	--	<-->

1) DCE stands for Data Circuit terminating Equipment and DTE for Data Terminal Equipment. The transceiver is normally a DCE.

2) Numbered from left the connection points will get this number

3) Depending if the transceiver is acting as receiver or transmitter of reference timing. This is set by jumpers on the PCB.



(X80039-13)

Fig. 15 Connection between the tranceiver and other equipment

Choosing interface standard is done by placing a jumper in one of four possible positions according to section 7. Only one interface standard can be chosen simultaneously but different standards can be chosen at the two ends.

Optical connectors are ST or SMA for multi mode fibre and ST for single mode fibre.

The electrical contact is for:

X.21	15-pin DSUB
RS530	25-pin DSUB
G.703 (co and contra)	8-pin modular RJ45 jack and/or
	10 pin divisible screw connector
G.703 (BNC)	BNC female with 75 ohms signal
	impedance

1.10.2.2 Transmission rates

The transceiver can transmit synchronous data with transmission rates according to table 25.

Table 11: Transmission rates

Transmission rate [kBaud]	Position
2048	0, E, F
1536	1
1024	2
768	3
512	4
384	5
256	6
196	7
128	8
64	9
38,4	A
19,2	B
9,6	C
4,8	D

Asynchronous data transmission can be used with a sampling rate of 2048 k sample /s which gives a maximum transmission rate of about 256 kBaud. The transmission rate is set by a rotary switch according to section 8.

1.10.2.3 Timing

The timing of the transceiver can be set for three alternatives:

- Internal timing:the transceiver will create the timing
- External timing:the transceiver is controlled by the DTE via signal 113
- Loop timing:the timing is derived from the received optical signal

The choice is done by two jumpers according to section 8.

The transceiver can synchronize received data with transmit timing. This function is controlled by a jumper, see section 8. When the transceiver is set for synchronization of data, the jumper for selection of phase must be correctly set. The jumper has to be placed closest to the brightest LED according to section 8.

1.10.2.4 Indications

12 LED’s with following color code:

- Alarm = Red
- Status = Yellow
- Function = Green.

The transceiver is supervising its own receiving function and announce it by indicating and signaling with DCD and DSR. The transceiver is supervising the receiving function of the remote end and announce this by indicating and signaling with DSR. The lock-in of fault indication is interrupted by pressing the reset button. Note that signaling is not locked-in.

Following indication exists:

RTS	status		CTS	status	
DSR	status		DCD	status	
TXD	status		RXD	status	
CO	status (G.703 co)		CONTRA	status (G.703 contra)	
LO	function	(Link operational)	LA	alarm	(Link operational)
MA	status	(Memory Alarm)	RA	alarm	(Memory Alarm)

1.10.2.5 Setting possibility for G.703

The interface for G.703 for twisted pair cable demands certain jumpers to be inserted depending on type of transmission. following possibilities exists:

- co- or contradirectional
- sending or receiving of timing signal for contradirectional mode

Insertion of jumpers are done according to section 10.

1.10.2.6 Dissembling / Assembling

For making the jumpers accessible to perform the above mentioned settings the unit must be opened.

NOTE! All electronic are sensitive to electrostatic discharge. Proper action must be taken at the work place to avoid electrostatic discharge!

The unit is dissembled by unscrewing three screws located under the unit at the back holding the back plate in position. The back plate with connection for the auxiliary voltage can now be pulled backwards. The upper cover is now pushed backward about 2 cm and when lifted up from the unit. The printed circuit board will now be visible according to figure 2.

The unit is assembled by placing the cover on the unit about 2 cm behind the front. The cover is gently pushed downwards and then pushed forward. The back plate with connection for the auxiliary voltage is put in position from behind and the three screws holding the back plate are put back.

1.10.2.7 Configuring type of interface

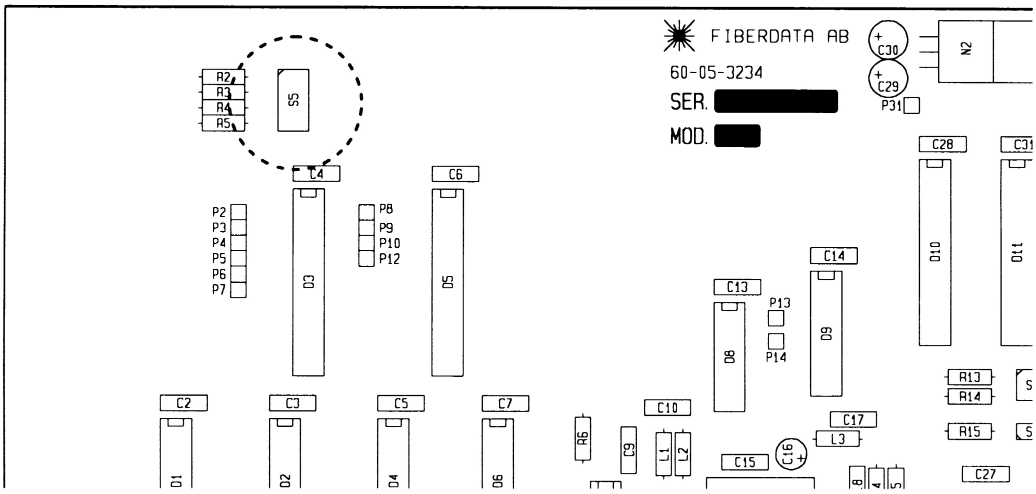


Fig. 16 Jumper location for interface standard selection

Jumper field S5 chooses the interface type. Note! Only <u>one</u> interface type can be chosen. From top to bottom according to figure , an inserted jumper will give the following interface type:

- G.703, 2048 kbit/s with BNC connection
- G.703, 64 to 2048 kbit/s, co- or contradirectional with twisted pair cable connection
- X.21
- RS530

1.10.2.8 Configuring transmission rate, timing and synchronization

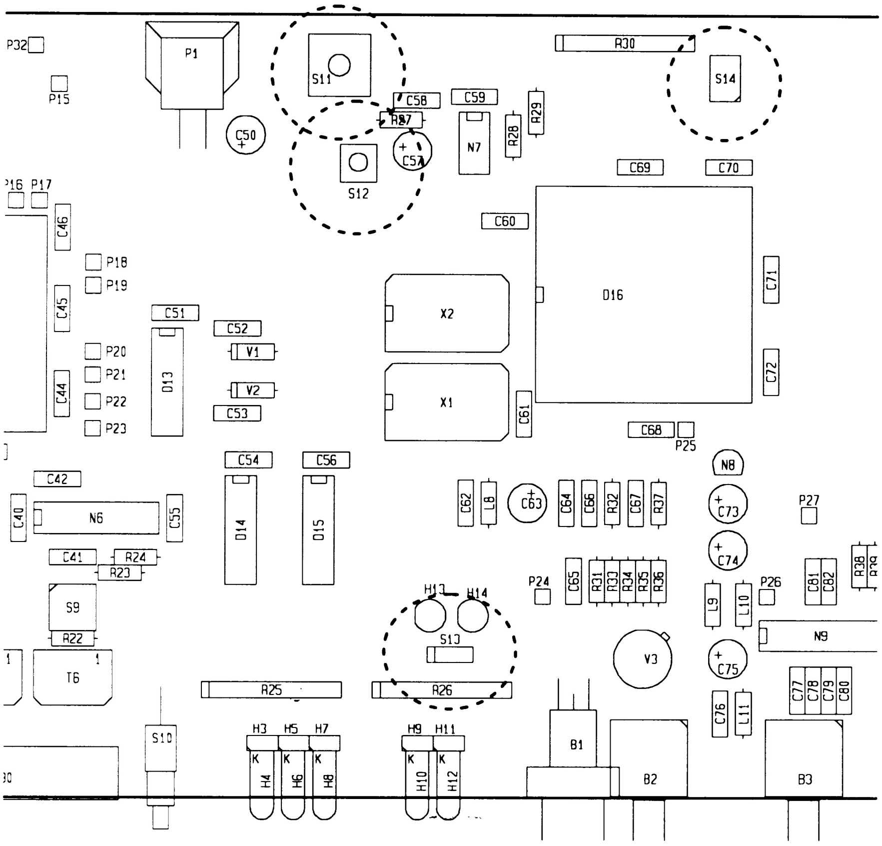


Fig. 17 Setting locations for rate, clock and synchronisation

Choice of transmission rate:

- Turn S11 in wanted position according to section 2.
- Choice of timing function, jumper S14:
- Internal timing: No jumper on the two bottom positions
- External timing: One jumper in the middle position
- Timing retrieved from received optical signal: One jumper in the bottom position

Choice of synchronization, jumper S14:

- Synchronization: One jumper in the top position
- No synchronization: No jumper in the top position

When synchronization has been selected jumper S13 is placed closest to the brightest LED.

NOTE! After any change in the setting the transceiver it has to be reset by pressing button S12 (Reset) NOTE!

1.10.2.9 Configuring X.21

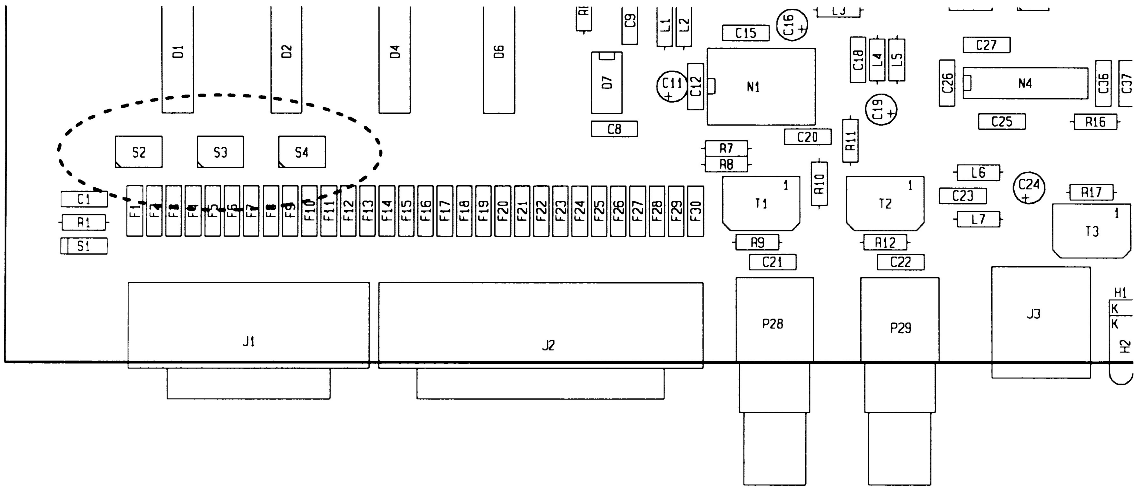
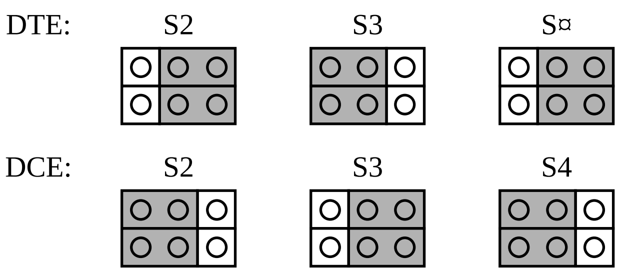


Fig. 18 Jumper location for interface standard X.21

The insertion of jumpers in fields S2, S3 and S4 shall be done considering if the unit shall act as a DCE or a DTE according to following:



How to choose X.21 see section 7.

1.10.2.10 Configuring G.703 co- and contradirectional

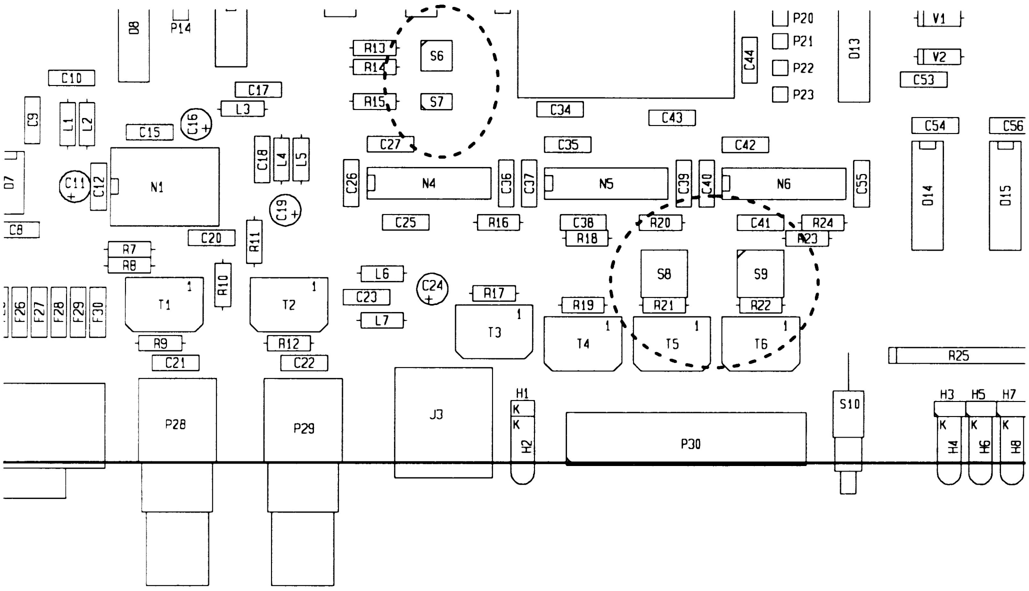


Fig. 19 Jumper locations for G.703 co- and contradirectional operation

Jumper field S6:

- G.703 codirectional: One jumper in the top position
- G.703 contradirectional: One jumper in the bottom position

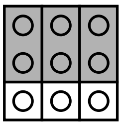
Jumper field S7, S8 and S9:

- Jumper at S7 gives transmission of timing at G.703 contradirectional operation
- No jumper at S7 gives reception of timing at G.703 contradirectional operation

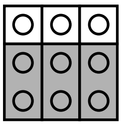
Note! S7 has no influence at G.703 codirectional operation

S8 and S9 reconnects the pulse transformer for transmission or reception of timing signal.

Note! S8 and S9 must be equally configured and in accordance with setting of S7.



Jumper in upper field gives transmission of timing



Jumper in bottom field gives transmission of timing

How to choose G.703 co- and contradirectional operation, see section 7.

1.10.2.11 Choice of protective earthing

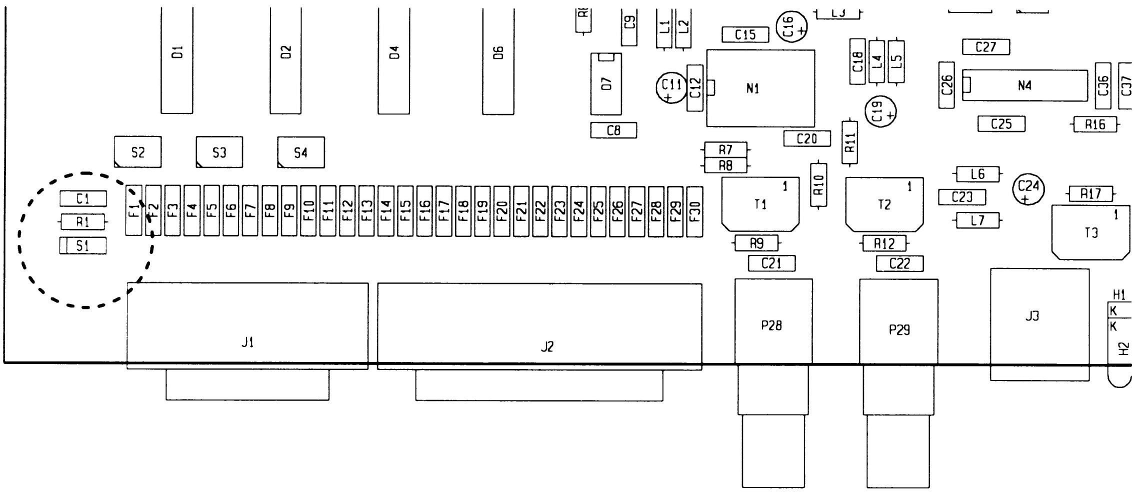


Fig. 20 Jumper location for protective earthing

Jumper field S1:
No connection between protective earth and signaling earth:

No jumper

Soft connection between protective earth and signaling earth:

Jumper inserted to the left

Direct connection between protective earth and signaling earth:

Jumper inserted to the right

1.10.2.12 Specification

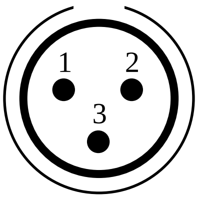
Casing
Dimensions: width 380mm, height 44mm, depth 240mm
Can be mounted in 19" rack, on wall or free standing.

Electrical interface:

X.21	15-pin DSUB
RS530	25-pin DSUB
G.703 (co and contra)	8-pin modular RJ45 jack and/or 10 pin divisible screw connector
G.703 (BNC)	BNC female with 75 ohms signal impedance

Optical interface:
Optical connectors are ST or SMA for multi mode fibre and ST for single mode fibre.
Optical budget is 10 dB for 1300 nm single mode fibre and 15 dB for 850/1300 nm multi mode fibre.

Auxiliary voltage:
110-230 Volt ± 20%, 50-60 Hz
Standard AC line connector
or
48-110 Volt DC ± 20%
XLR audio connector



Connector for DC-supply

1 = 48-110 V DC
2 = 0 V
3 = Screen