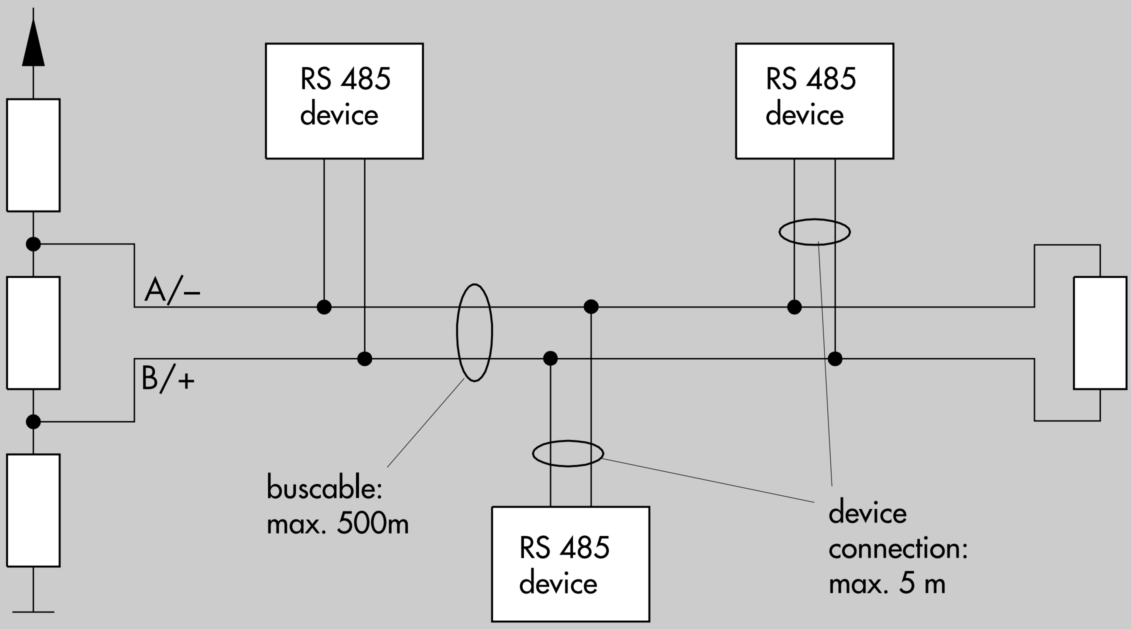
Technical Information

Serial Data Transmission

1



Part 1 Fundamentals

Technical Information

Should you have any further questions or suggestions, please do not hesitate to contact us:

SAMSON AG
V74 / Schulung
Weismüllerstraße 3
D-60314 Frankfurt

Phone (+49 69) 4 00 94 67
Telefax (+49 69) 4 00 97 16
E-Mail: schulung@samson.de
Internet: http://www.samson.de

Serial Data Transmission

CONTENTS

CONTENTS

Introduction

Serial transmission technology is increasingly used for the transmission of digital data. A large number of up-to-date communications networks apply serial transmission. The numerous applications include computer networks for office communications, fieldbus systems in process, building and manufacturing automation, Internet and, finally, ISDN.

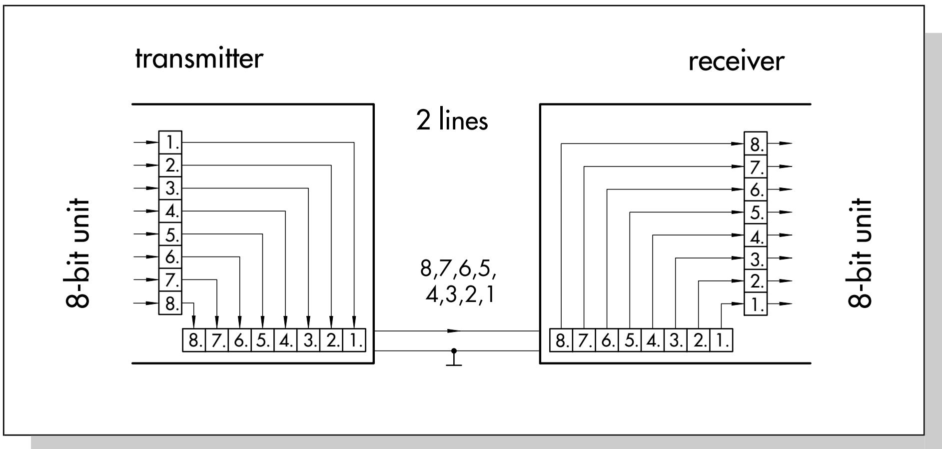
numerous applications

Serial data transmission implies that one bit is sent after another (bit-serial) on a single transmission line. Since the microprocessors in the devices process data in bit-parallel mode, the transmitter performs parallel-to-serial conversion, while the receiver performs serial-to-parallel conversion (Fig. 1). This is done by special transmitter and receiver modules which are commercially available for different types of networks.

transmission over a single line

Extremely high data rates are possible today so that the increased time consumption required by this technology is accepted in most cases. The reductions in costs and installation effort as well as user-friendliness, on the other hand, are points – not only for locally extended systems – in favor of serial data transmission.

high data rates at low costs



simple two-wire line for bit-serial data transmission

Fig. 1: Serial data transmission

Characteristics of a transmission system

direction, throughput, data rate

Serial data transmission is suitable for communication between two participants as well as between several participants. Characteristic features of a transmission system are the direction of the data flow and the data throughput, or the maximum possible data rate.

- Direction of data flow

Transmission systems differ as to the direction in which the data flow and when messages can be transmitted. Basically, there are three different ways of communication (Fig. 2).

e.g. radio relay system

- simplex: data exchange in only one direction,

telex and field networks

- half-duplex: the stations take turns to transmit data and

telephone network

- full-duplex: data can be exchanged in both directions simultaneously

- Point-to-point connection

data transmission in point-to-point systems

In two-point or point-to-point connections, the receiver and transmitter lines can be connected via two separate lines (Fig. 3: two anti-parallel simplex channels), the receiving line of one participant is the transmitting line for the other one. The communication in such two-point systems can be controlled either by software or via control lines (see page 25).

A, B: communication participants

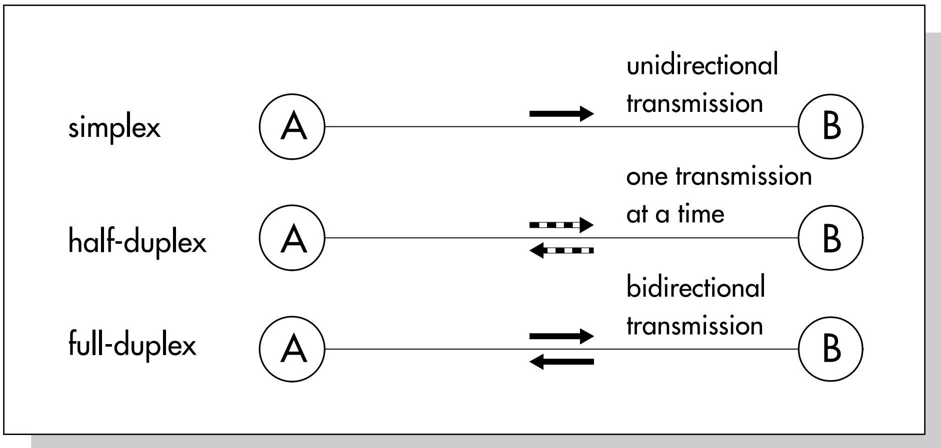


Fig. 2: Different communication techniques

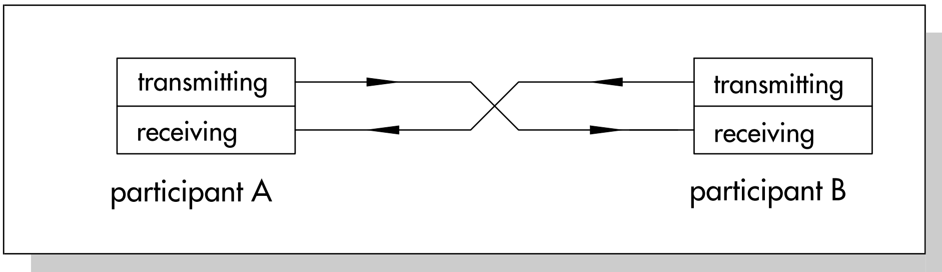


Fig. 3: Point-to-point connection between two participants

- Communications networks

In communications networks with several participants, the transmission medium often is a single line being used for transmitting and receiving data at the same time (Fig. 4). All devices are connected in the same manner, which is often a stub line. The sequence of communication is coordinated by additionally transmitted control data which are defined in the so-called transmission protocol. These control data help identify the user data as well as the source and the destination address upon each message transmission.

networked communication via common transmission medium

- Data transmission speed

An essential criterion for determining the capacity of communication lines is the data rate, i.e. the speed at which the data can be transmitted. The data rate is characterized by the number of bits transmitted each second, measu-

BPS, kbit/s and Mbit/s

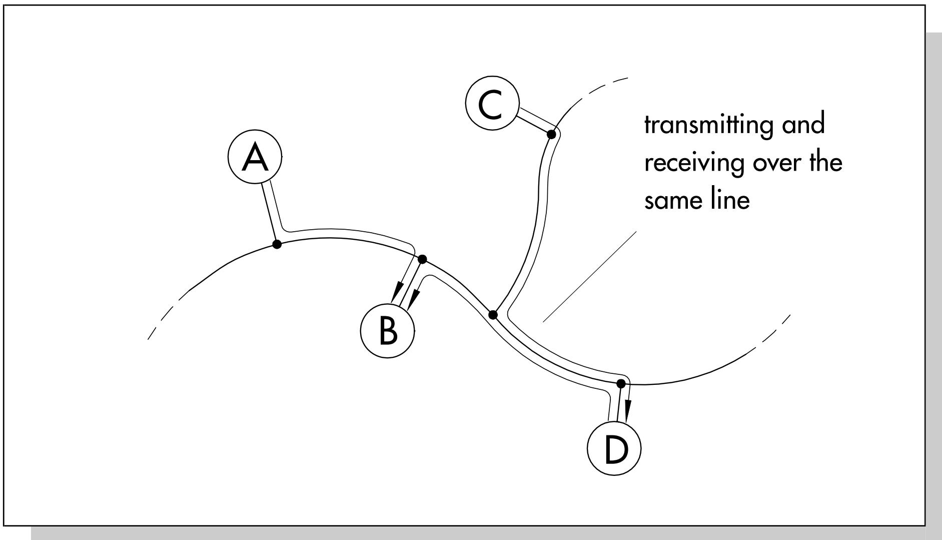


Fig. 4: Communications network with several participants

red in bps, bits per second. As data rates are extremly high nowadays, such units as »kilobit per second; kbit/s« and »megabit per second; Mbit/s« are not unusual.

When each bit is encoded and transmitted individually, the transmission line must be able to transmit frequencies that correspond to half of the bit transmission rate :

bit transmission rate:	100 kbit/s
transmission frequency:	50 kHz

encoding increases information density

When it is necessary to achieve a high data rate, even though the transmission bandwidth is limited, several bits can be grouped and encoded together. Fig. 5 shows how four different states (voltage levels) can be used to transmit two bits at a time. This method cuts the state changes in the signal line by half and, therefore, reduces the transmission frequency.

definition of Baud rate

To measure the switching speed, i.e. the "number of voltage or frequency changes per unit of time", the so-called "Baud rate" is used. When only one bit is transmitted per transmission unit, the Baud rate [Baud] is identical to the data rate 'bit per second' [bps].

bits	level [volt]
0 0	0 V
0 1	5 V
1 0	10 V
1 1	15 V

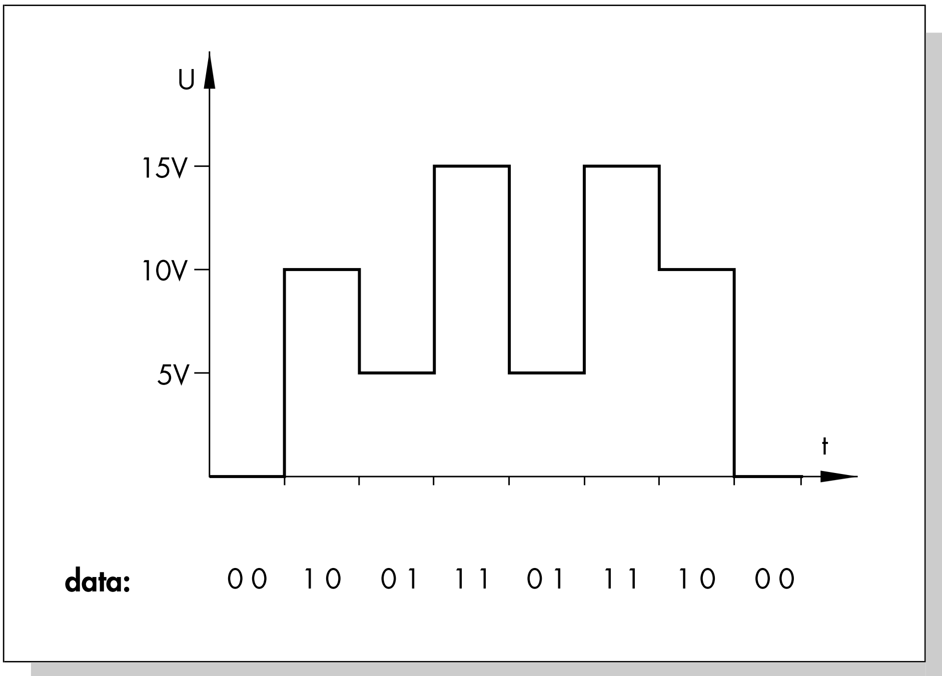


Fig. 5: More complex encoding reduces transmission frequency

The capacity of a communication line cannot sufficiently be defined by the data rate alone. The following parameters – especially for networks with several participants – are important as well:

- time period until the line is ready for transmission and
- the number of data to be transmitted in addition to the proper message, such as device address, control information, and so on (see also Lit./2/).

Transmission medium

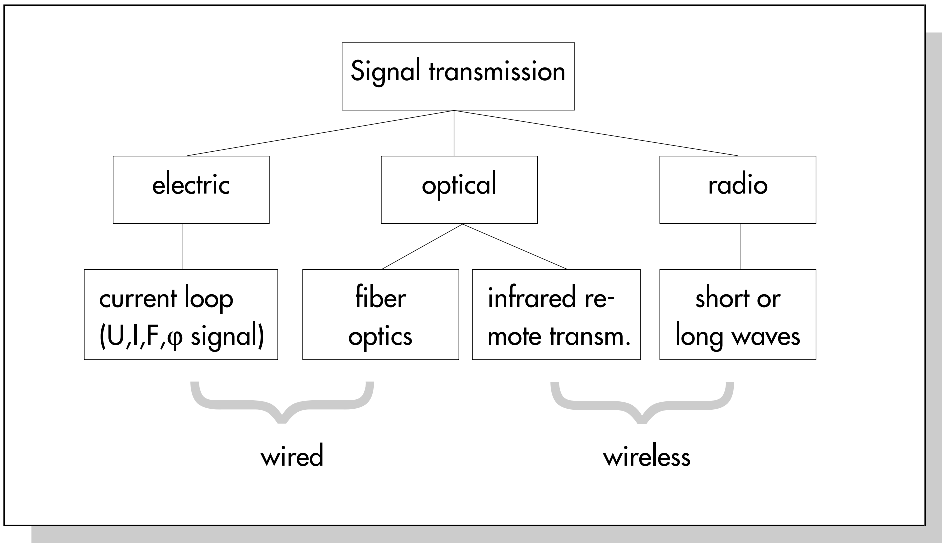


Fig. 6: Media for serial data transmission

For serial data transmission, quite different transmission media are available. The signals are transmitted either electrically, as light pulses or via radio waves. When selecting which medium is suitable, several factors should be kept in mind:

selection criteria

- costs and installation effort,
- transmission safety – susceptibility to tapping, interference susceptibility, error probability, etc.
- maximum data rate,
- distances and topological position of the participants, etc.

good signal quality and low interference susceptibility are desired

No medium has all the optimum properties so that the signals are more or less attenuated with increasing distance. To achieve high data rates, the transmission medium must fulfill specific requirements.
Another negative effect is the risk of data being corrupted by interference signals.

To compare the characteristics of the various transmission media, a difference should be made between wired and wireless transmission systems (Fig. 6). Some of the typical characteristics of wired media are listed in the Table in Fig. 7.

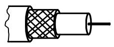
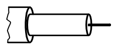
type	two-wire line	coaxial cable	optical fiber
design			
preparation, installation	very simple	simple	complex
installation properties	very good	good	good, limited bending radius
interference susceptibility	high, if not shielded	low	almost non-existent

Fig. 7: Properties of wired transmission media

• Electric lines

convenient handling

A great advantage of electric lines is their simple and cost-effective preparation (cutting to length and termination). However, there are some disadvantages which include the attenuation of signals and interference susceptibility. These drawbacks are not only influenced by the type of cable used – twisted-pair, coaxial, etc. – but also by the interface specification (data format, level, etc., see page 31f.).

transmission behavior of electric lines

To be able to determine the electric properties of a cable, the line is described as a sequence of sub-networks consisting of resistors, capacitors, and inductors (Fig. 8). While the resistors change the static signal level, capacitors and inductors create low passes which have a negative effect on the

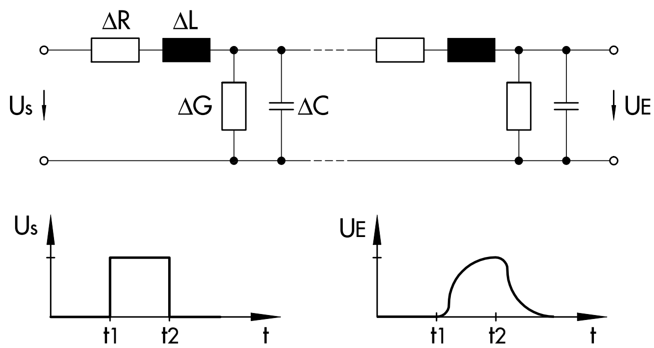


Fig. 8: Equivalent circuit diagram of a transmission cable

data rate [kbit/s]	9.6	187.5	500	1500	12 000
segment length[m]	1200	1000	400	200	100

Fig. 9: Line length dependent on the data rate (example: RS 485 standard)

edge steepness. The cable must therefore be selected to meet the following criteria:

attenuation and signal distortion cause interferences

- The line resistance must be low enough so that a sufficiently high signal amplitude can be guaranteed on the receiver side.
- The cable capacitances and inductances must not distort the signal edges to an extent that the original information is lost.

Both criteria are influenced by the electric line parameters and the influence increases with the length of the line as well as with the number of participants connected. As a result, each cable type is limited in its line length and maximum number of participants.

The higher the signal frequency, the stronger the effect the capacitances and inductances have on the signal. An increasing transmission frequency has therefore a limiting effect on the maximum line length. Fig. 9 illustrates this relationship referring to the RS 485 interface specification (see also page 35).

To limit the signal distortion occurring in long-distance lines and at high data rates, such applications frequently use low-inductance and low-capacitance cables, e.g. Ethernet with coaxial cable.

interference caused by line reflection

Signals transmitted over electric lines are subject to yet another phenomenon, which is important to be aware of when installing a line. The electric properties of a line can be influenced by

- changing the cable type,
- branching the cable,
- connecting devices or
- a line that is not terminated at the beginning or at the end.

This causes so-called line reflections. The term means that transient reactions take place on the line, that are caused by the finite signal propagation speed. Since transient reactions distort the signal levels, a signal can only be read accurately, when

avoiding transient reactions

- the transient reactions have largely died out or
- the effects of the transient reactions are small.

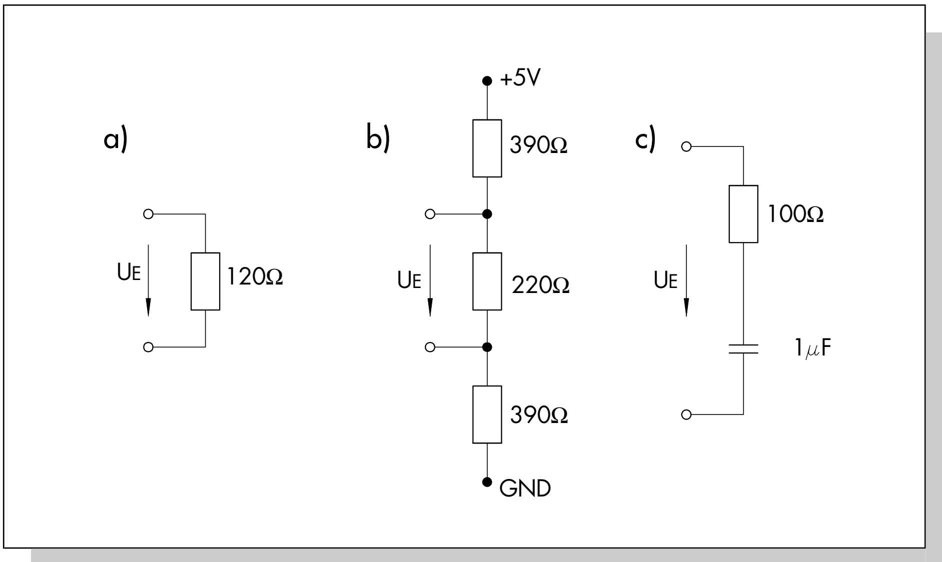
These reactions need not be considered when the lines are very short or the signal edges are not too high. This is the case when the duration of the signal edge is longer than the time the signal needs to be transmitted and returned.

terminating resistors reduce line reflections

To enable the use of long lines even for high data rates, the formation of line reflections must be prevented. This is achieved when the electric properties remain constant across the entire line. The line properties must be imitated as precisely as possible at the beginning and at the end of the line by connecting a terminating resistor.

The line properties are described by means of the so-called characteristic wave impedance of the cable. Typical values for the characteristic wave impedance and, hence, the terminating resistor are as follows:

- twisted-pair line: 100 to 150 ohms
- coaxial cable (RG 58): 50 ohms



a) twisted two-wire line

b) RS 485 standard

c) IEC 61158-2

Fig. 10: Terminating resistors for different lines

Fig. shows different line terminating resistors. Line termination according to the RS 485 specification (example b) includes two additional resistors defining the potential of the line when none of the participants are active.

• Fiber optics

An optical fiber consists of a light-transmitting core fiber embedded in a glass cladding and an external plastic cladding. When light hits the boundary layer in a small angle of incidence, the different densities of the core and the glass cladding cause total reflection (see also Fig. 12a). The light beam is reflected almost free of any loss and transmitted within the core fiber only.

low-attenuation transmission due to total reflection

The diameter of an optical fiber is approx. 0.1 mm. Depending on the version, the diameter of the light-transmitting core lies between 9 μm and 60 μm (Fig. 11). Usually, several – up to a thousand – of such fibers and a strain relief are grouped into a cable.

The light signals are usually supplied to the fiber via a laser LED and analyzed by photo-sensitive semiconductors on the receiver side. Since signals transmitted in optical fibers are resistant to electromagnetic interferences and only slightly attenuated, this medium can be used to cover extremely long distances and achieve high data rates. The advantages of optical data transmission are summarized in the following:

large distances and high interference immunity

advantages of fiber optics

- suitable for extremely high data rates and very long distances,
- resistant to electromagnetic interference,
- no electromagnetic radiation,
- suitable for hazardous environments and
- electrical isolation between the transmitter and receiver stations

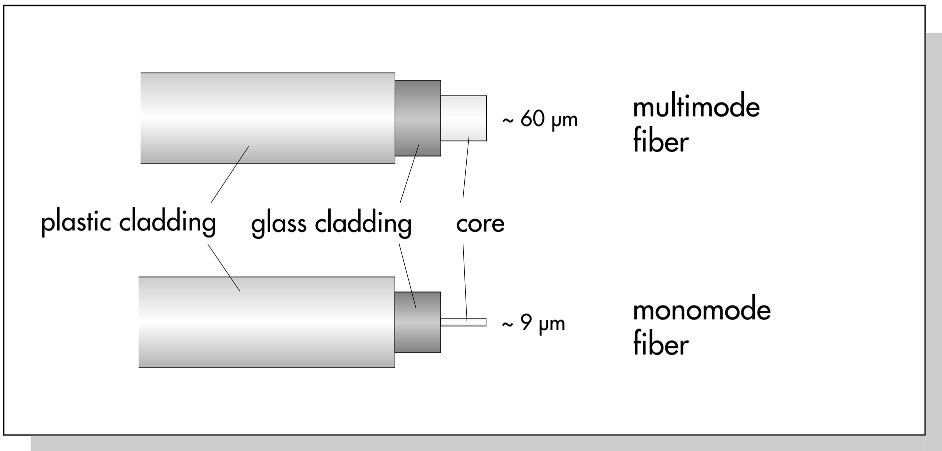


Fig. 11: Design of a multimode and monomode optical fiber

a) multimode step index fiber

b) multimode graded-index fiber

c) monomode fiber

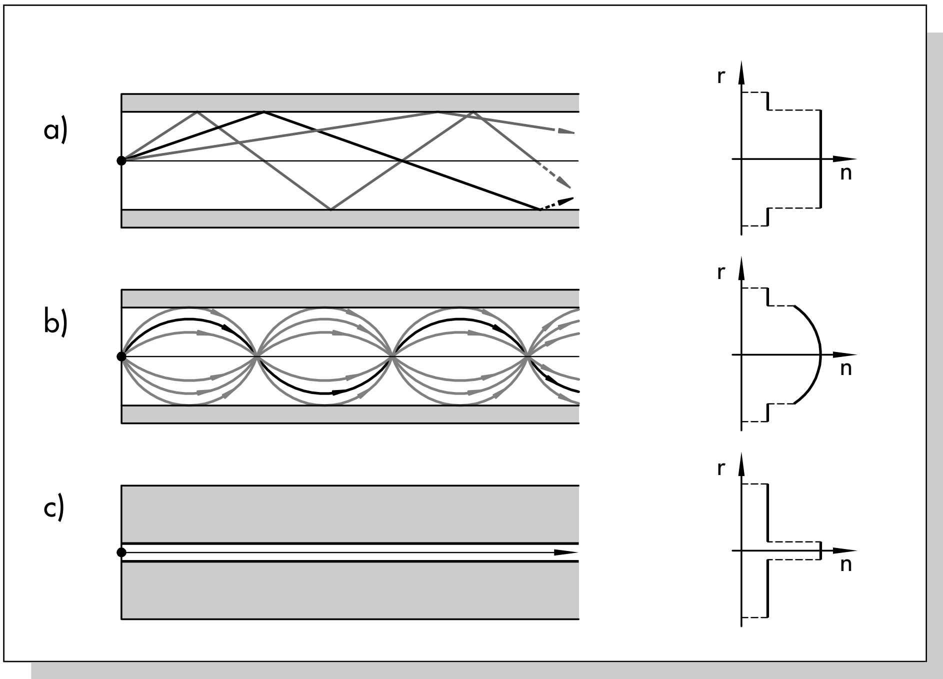


Fig. 12: Profiles and refractive indices of optical fibers

Like electric pulses, light pulses are increasingly attenuated when transmitted over a long distance. This is caused by the following phenomena:

origins of pulse distortion

- The light covers varying distances within the cable (different propagation times – see Fig. 12).
- Light with different wave lengths (color) propagates at different rates in the fiber – dispersion.

For high data rates and large transmission distances, excellent repeat accuracy of the light pulses during transmission is mandatory. Therefore, the optimum transmitter should be a light source with a spectral bandwidth (laser) that is as small as possible and with extremely small core fibers. Two different fiber types are available, multimode and monomode fibers (see Figs. 11 and 12).

monomode fiber meets highest requirements

Monomode fibers help achieve the best pulse repeat accuracy. The core diameter of these fibers is so small that only the paraxial light beam (mode 0) can be formed. The small diameter, however, requires particularly high precision when the light beam is supplied to the fiber.

multimode fiber with step index or grade index profile

If *multimode* fibers with a larger diameter are used, the number of possible propagation paths increases and, hence, the distortion of the pulses. However, this effect can be reduced by using specially manufactured fibers. These special fibers do not have a step index profile, i.e. a constant refractive index, but a so-called grade index profile. In this case, the refractive index of the core increases with the radius. The propagation rate which changes with the refractive index largely compensates for the different propagation times in the core, thus enabling higher pulse accuracy.

high costs limit application

The handling of optical fibers, i.e. cutting to length and termination, as well as coupling and decoupling of optical signals is comparably complex and therefore expensive. These are the reasons why fiber optics are only used when great distances must be covered at high data rates, or else when special EMC measures must be taken.

- Wireless data transmission

to freely communicate

Wireless transmission in communications systems is well-suited to extremely long distances (radio relay systems, satellite technology, etc.) and remote-controlled and/or mobile applications.

... in sight

When the participants communicate while in sight of each other and when the distances to be covered are small and the data rates low, the comparably simple optical transmission via infrared radiation can be used successfully.

... over the globe

Radio-based communication can be used for a lot more applications. In everyday life, mobile phones are a good example of the widespread use of radio-based communication. Radio communications extend not only to the field of telecommunications. There are also other communications networks – such as field and automation networks – which use this technology. In the latter case, we speak of radio LAN or wireless LAN (WLAN).

telecommunication link to extend automation systems

Wireless communication is usually combined with wired communication. The connection of automation networks over large distances or remote control often includes telecommunications (see Fig. 13).

The great variety of radio communications makes it almost impossible to give a general list of characteristic features. The transmission and interference behavior strongly depends on the frequency and capacity range used and also on the modulation technique.

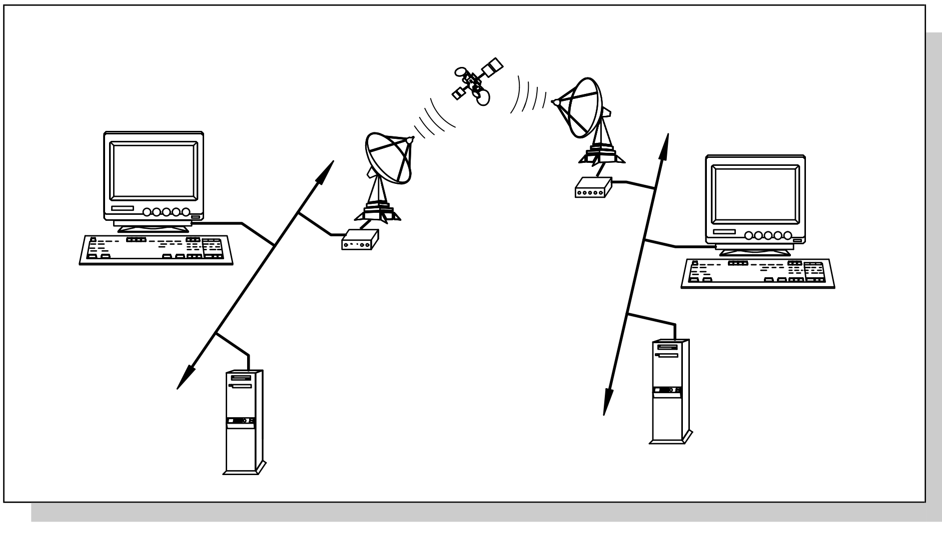


Fig. 13: Connection of networks via satellite telecommunication link

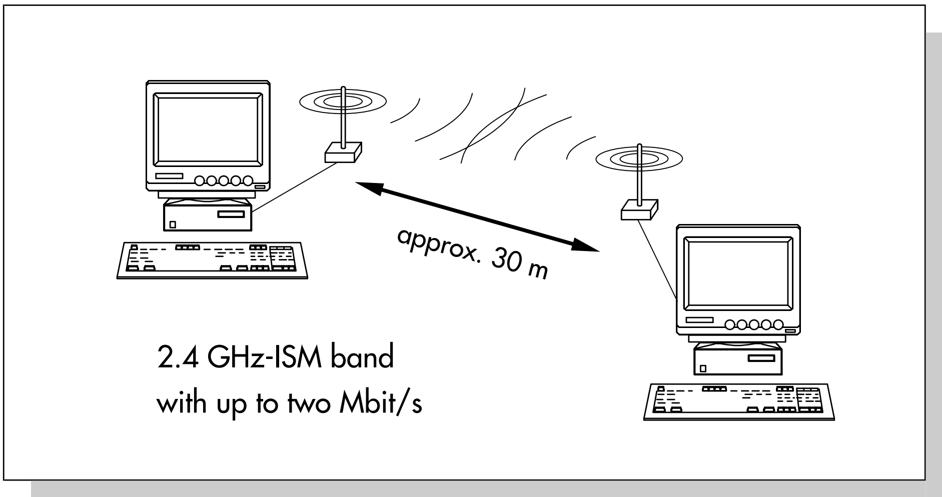


Fig. 14: Simple WLAN for use in the domestic field and industry

The standard for wireless communication IEEE 802.11 determines a 2.4-GHz-ISM band for the radio-based network. The electromagnetic radiation of this frequency penetrates solid matter, such as walls, windows, etc., enabling the devices to be arranged in any position.

applications of the ISM band: Industrial, Scientific, Medical

Presently, the standard specifies data rates only up to two Mbit/s. However, improved modulation techniques or extended frequency bands are supposed to help achieve and fix higher data rates ranging from 10 to 20 Mbit/s.

The transmission distances of a WLAN are influenced by a number of factors. Aligned directional antennas help cover several kilometers, while non-directional radiation in the house reaches only approx. 30 meters (Fig. 14). Metal shields, interference sources, undesired reflections, etc. – sometimes locally limited (areas not reached by the radio waves) – can reduce the achievable data rate considerably. When the communications protocol detects transmission errors, data can be retransmitted so that undisturbed communication is still possible in these cases on the user level , however, slower.

origins of radio transmission failures within a cell

Binary coding of data

The transmission medium determines whether the data are transmitted electrically, optically or via radio signals. However, it is not defined how the two binary states (0 and 1) are distinguished.

Depending on how the »0's and 1's« are assigned to the states »low and high«, we speak of

positive or negative logic

- positive logic: 0 ⇔ low, 1 ⇔ high or
- negative logic: 0 ⇔ high, 1 ⇔ low.

The transmission medium represents the states »high« and »low« in a certain manner, which is the so-called format of the data. The following variables can be analyzed:

coding technique

- amplitude values
- edges (level changes),
- phase relationships or
- frequencies.

specific characteristics are also possible

Depending on the application, it is sometimes desired or even required that the format provides certain characteristics:

... with clock pulse

- With synchronous data transmission (see page 24), the clock pulse rate of the transmitter must also be transmitted to the receiver. To save an additional line for transmitting the clock, a self-clocking format can be used. With this format, the receiver can derive the clock pulse rate directly from the data flow.

When electric lines are used for data transmission, additional conditions must often be fulfilled:

... and few side effects

- A format without mean values can be superimposed onto another signal without influencing its direct component. In this way, data can be transmitted over energy supply lines or lines with slowly changing analog signals (e.g. 4 to 20 mA current loop). Another asset is that such codings enable simple electrical isolation of network segments via transformers.

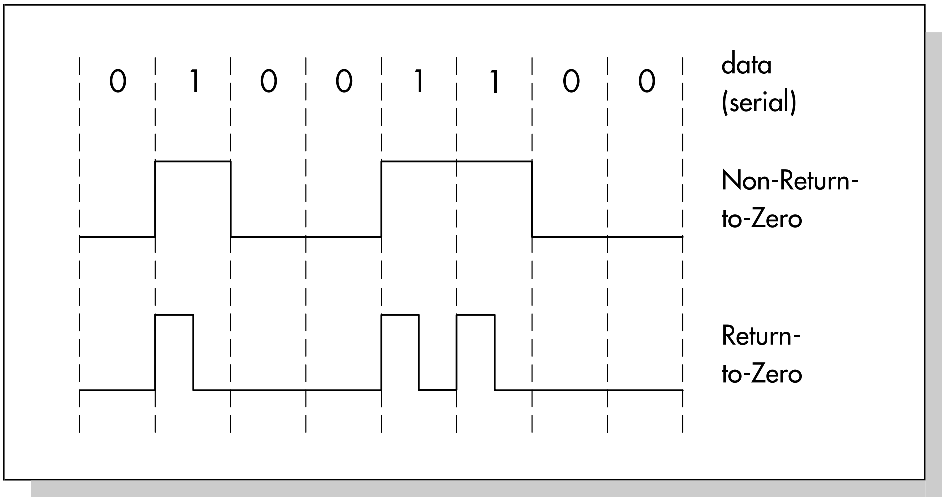


Fig. 15: NRZ and RZ coding with positive logic

- When good electromagnetic compatibility (EMC) is required, the noise radiation of the electric transmission medium must be kept low. It is low when the frequency of the data flow is low or when sine-wave pulses are used for the coding instead of square-wave pulses.

... good EMC behavior

- NRZ and RZ format

A widespread format for data transmission is the NRZ-format (Fig. 15: Non-Return-to-Zero). Each bit is represented by a square-wave pulse whose duration is predetermined by the Baud rate. Pulse indicates the high state, while zero pulse represents the low state.

Non-Return-to-Zero

With the RZ-format (Fig.15: Return-to-Zero), the pulses last only for a half bit period, thus enabling a switch back to the reference potential when still in high state.

Return-to-Zero

Both formats are neither self-clocking (no clock information in the low state) nor without mean values (mean value changes dependent on the bit sequence).

- Manchester coding

The characteristic feature of Manchester coding is that the bit information is included in the phase angle of the signal. A rising edge occuring in the middle of the bit time indicates 'high' state, while a trailing edge stands for 'low' state. Since the receiver can determine the clock pulse rate of the transmitter

phase coding

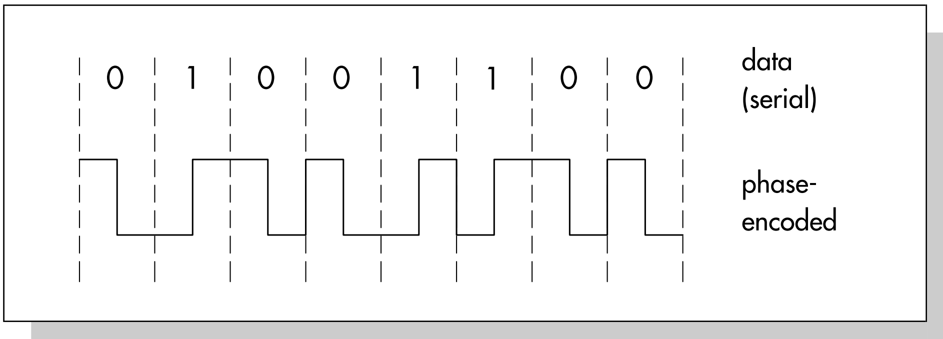


Fig. 16: Manchester coding

from the duration of the signal period, this coding is self-clocking (Fig. 16). If a bipolar signal (e.g. +/- 5 volts) is used for the levels of the Manchester coding, the mean value of the data signal equals zero, i.e. this bit code has no mean values.

- Amplitude and FSK coding

encoding via sine-wave signals

Instead of digital square-wave pulses, sine-wave signals can also be used for encoding data signals by modulating their amplitude, frequency and phase.

amplitude modulation

Amplitude modulation (Fig. 17 middle) is accomplished by assigning two different amplitude values to the states low and high. As is the case for square-wave pulses, large amplitude differences ensure better interference immunity, however, power consumption increases proportionally. Analyzing amplitude-modulated signals could become difficult because – espe-

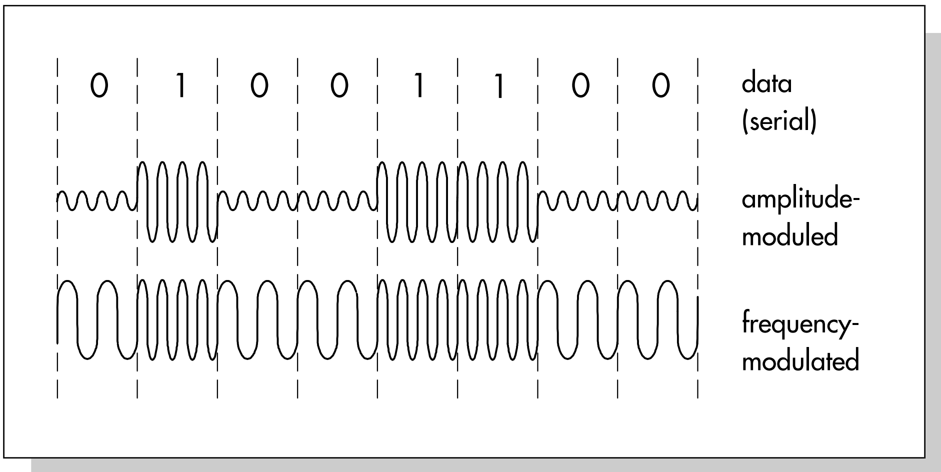


Fig. 17: Encoding by means of amplitude and frequency modulation

cially over large distance – the signal amplitude changes while being passed on across the network.

frequency modulation less susceptible to interferences

The FSK method (Frequency Shift Keying) uses varying frequencies to distinguish the binary states (Fig. 17 bottom). As this method largely operates independent of the level, high interference immunity is guaranteed even when signals are attenuated and loads are changing.
Of course, the transmission medium must be able to transmit the frequencies that are used for encoding the signals.

advantages of sine-wave signals

In amplitude or frequency modulation, sine-wave signals are used because their signal spectrum does not include harmonic waves. So it is easier to comply with specifications concerning "Electromagnetic Compatibility (EMC)". Superimposition with other signals containing direct components is also possible because the mean value of time of sine-wave signals equals zero, hence, the coding has no mean values.

Transmission techniques

how does the receiver recognize bits and bytes

During digital transmission, a message packet is sent as bit data flow over the signal line. From the receiver's point of view, such a bit data flow looks like a sequence of pulses varying in length. To reconvert the pulse sequence into the original digital state, the receiver must know when the transmitted signals are valid, i.e. when they represent a bit and when not. To accomplish this, the transmitter and the receiver must be synchronized during transmission. The different data transmission methods solve this task either by

- providing clock-synchronous data transmission or
- performing asynchronous, time-controlled sampling.

• Synchronous transmission

clock transmission simplifies data acquisition

In synchronous transmission, the signals on the data lines are valid whenever a clock signal, which is used by both stations, assumes a certain predefined state (e.g. edge triggering as shown in Fig. 18). The clock signal must either be transmitted separately on an additional line or can be derived from the data signal, as explained in the chapter 'Binary coding of data'.

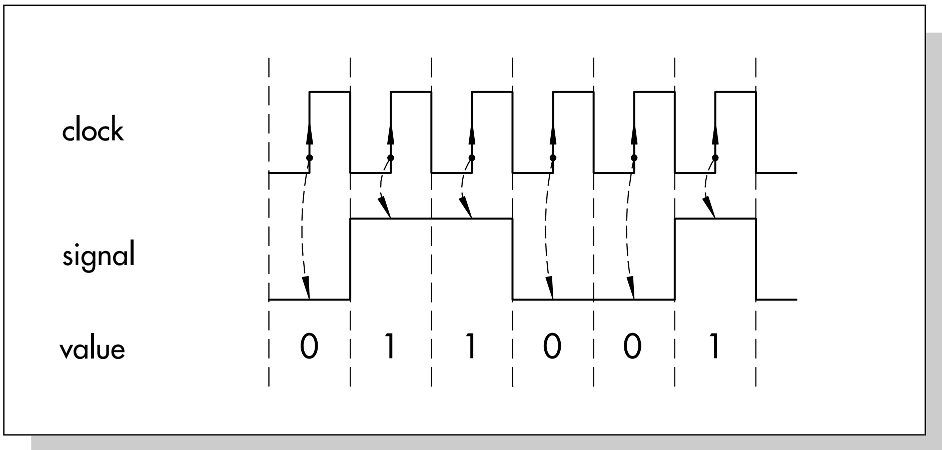


Fig. 18: Synchronous signal sampling with positive edges

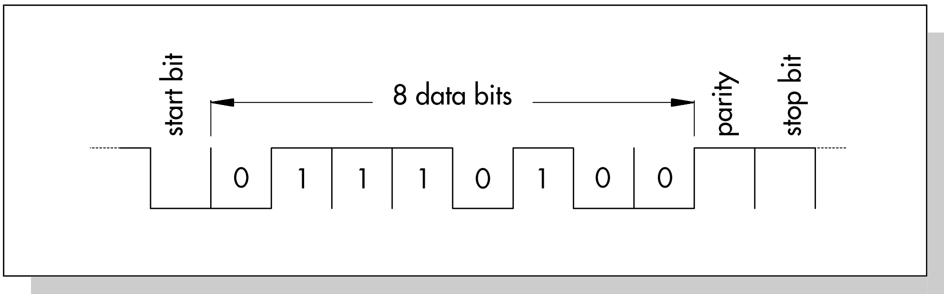


Fig. 19: Asynchronous transmission using the UART character (universal asynchronous receiver transmitter)

• Asynchronous transmission

In asynchronous transmission, no clock signal is transmitted. Even when the receiver and the transmitter use the same frequency, the slightest difference can stop them running synchronously.

clock synchronism is required

This can be avoided when the receiver synchronizes with the transmitter frequency in intervals that should be as short as possible. Synchronization takes place at the beginning of each character that is marked with an additional start and stop bit. A so-called UART character, which is defined by the German standard DIN 66022/66203, is used for this purpose (see Fig. 19).

UART: Universal Asynchronous Receiver and Transmitter

Beginning with the first signal edge of the start bit, the receiver synchronizes its internal clock with that of the receiving data. The following bits are sampled in the middle of the bit time. After the seven or eight data bits, a parity bit is appended for error detection and one or two stop bits to mark the end. The message is only accepted when the parity bit as well as the polarity of the stop bit comply with the format defaults.

synchronization begins with the start bit

Since the receiver resynchronizes constantly, the time consistency of the clock frequency between the transmitter and the receiver need not be high.

• Communications control

Synchronous or asynchronous transmission provide the basis for the receiver to read the bits and bytes correctly. However, there is no check whether the receiver is ready for data reception at all.

ready for communication

To coordinate the data transmission in this respect, an additional control is necessary. This can be achieved by implementing software or installing additional control or handshaking lines. In both cases, the receiver must signal-

coordination with control data or signals

data transmission with handshaking control line

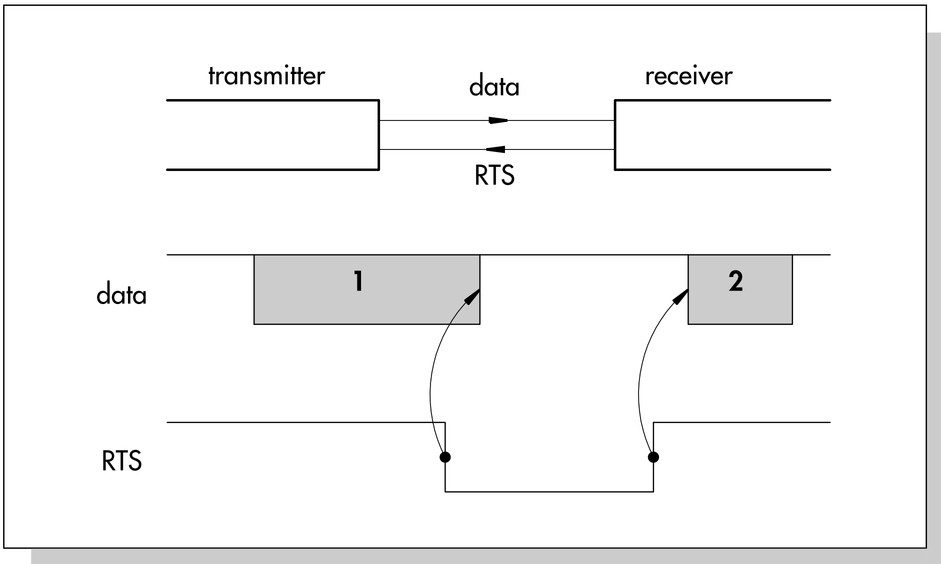


Fig. 20: Hardware handshaking: RTS demands interruption of data transmission between block 1 and 2

ize its readiness for data reception to the transmitter prior to data transmission.

software handshaking using XON/XOFF

Software handshaking requires a bidirectional communication line to be installed between the transmitter and the receiver. To stop the data flow or forward it again, the receiver sends special command bytes to the transmitter. Frequently, the reserved special characters XOFF and XON are used for this purpose.

control lines for hardware handshaking

Using hardware handshaking, data transmission must be controlled via additional control lines. Fig. 20 illustrates such a handshaking procedure with the control signal RTS 'Request To Send' as an example:

- The condition RTS = 1 signifies that the device is ready to receive data. If the receiver becomes overloaded with too much data and the receiving data buffer risks to overflow, the device will cancel the RTS signal. Then, the transmitter stops sending data and resumes transmission only when the RTS signal is released again.

Hardware handshaking is not restricted to point-to-point connections, as shown here. Special measures (wired-OR and wired-AND logic) can be taken to coordinate communication between several participants as well.

- Characteristics of a typical two-wire communication

minimizing the amount of instruments

For applications in which devices communicate over great distances, simple and cost-effective wiring is a decisive selection criterion. Therefore, a transmission technique will be chosen that omits additional clock and/or control lines, as provided by the following:

- asynchronous transmission in which the receiver synchronizes through the start and stop bits
- synchronous transmission in which the format transmits clock information together with the data over the same line

Additionally,

- the communication sequence (who sends when?) must be either predetermined or
- controlled through software via suitable commands (software handshaking).

Most communications networks, whether WAN or LAN – either in the field, automation or control level – operate according to these specifications (Fig. 21).

Typical interface specification for communications networks

two-wire line

asynchronous transmission using UART characters

application-oriented format:
– simple: NRZ
– without mean values: Manchester
– good EMC: FSK

protocol- or time-controlled communication sequence:
– XON/XOFF
– cyclic, time-controlled polling,
– telegram-controlled, etc.

Fig. 21: Example of an interface specification

Error detection

With any transmission technique, whether synchronous or asynchronous transmission, with or without handshaking lines, incorrect transmission of individual bits could occur, i.e. the receiver reads 1 instead of 0 or 0 instead of 1. Although, the probability of accurate data transmission can be increased by technical means, it is nevertheless possible that errors may be caused by electromagnetic interference, increase in potential and aging of the components.

detecting errors and reacting adequately

To ensure correct data transmission, several error-detection techniques are available. How the system reacts to errors depends on the type of system and can be solved in many different ways. One possible reaction is to correct the error. Error correction, however, can only be accomplished when the coding is sufficiently complex (lots of bits). In network communications, the erroneous message is simply requested once more (or acknowledged as invalid data), with the hope that the message will be retransmitted accurately.

parity checking

The different techniques used to detect transmission errors each perform checking on a different level. On the character level, the parity-checking method is frequently used (Fig. 22). The EVEN parity method requires the number of 1's of a unit – including the parity bit – to be always even, whereas the ODD parity technique checks for an odd number of bits. Since two errors cancel each other out, this method is able to detect only one (bit) error with certainty.

EVEN parity	sum of all 1's must be even	
data bits:	parity bit	Σ 1's
0110 1100	0	4
0110 1101	1	6
ODD parity	sum of all 1's must be odd	
data bits:	parity bit	Σ 1's
0110 1100	1	5
0110 1101	0	5

Fig. 22: Error detection through additional parity bit

SAMSON AG · V74/ DKE

Hamming distance

A measure for the interference immunity of a transmission is the Hamming distance (HD). It is calculated by determining the number of errors which can still be detected:

Hamming distance	=	number of detectable errors plus 1
HD	=	e + 1

Fig. 23: Calculation of the Hamming distance

With the parity checking method, the Hamming distance is therefore HD=2.

block checking with longitudinal parity

Parity checking is not only used on single characters, but also checks entire blocks of characters. Apart from the parity checking of single characters, the so-called longitudinal parity is formed. After a block of, e.g. 7 characters, an eigth character which is formed by the parity bits of the preceded bit columns is transmitted (Fig. 24). The Hamming distance of this checking technique is HD=4 while the probability of detecting extended or multiple errors is high.

error detection through CRC

transmission of data and remainder of division

Another widespread method for checking data, which is suitable for larger character strings, is the Cyclic Redundancy Check (CRC). The message is interpreted independent of its length as binary number, which is then divided by a specific generator polynominal. Only the proper message and the remainder of the division are transmitted to the receiver. Transmission was accurate when the received data can be divided by the same polynominal

	data bits:	character parity
	1 0 1 1 0 0 0 1	0
	0 1 1 0 0 0 1 0	1
	1 1 0 0 1 1 1 1	0
	0 0 1 1 1 0 0 0	1
	0 1 1 0 0 1 0 1	0
	1 1 1 0 1 0 0 1	1
longitudinal parity:	**1 0 1 0 1 0 0 0**	**1**

Fig. 24: Block checking via longitudinal – even – parity

without leaving a remainder. The number of detectable errors depends on the polynominal used. The polynominal value 345 (DIN 19244), for example, helps achieve a Hamming distance of HD=4, signifying that up to three errors can be detected with certainty.

Transmission standards – interface specifications

The various coding techniques (NRZ, Manchester, etc.) define how the binary states are represented, i.e. how the signal states change during the transmission of a serial bit flow. However, associated level and frequency specifications, possible data rates, permissible line lengths, control lines and so on, are not yet defined.

precise specification of an interface: version, principle of operation, parameters

These specifications are frequently adopted by – mostly internationally standardized – transmission standards. In the field of telecommunications, many interface specifications have been defined by the ITU (International Telecommunication Union) or adopted from other standards. Some of these standards which are frequently used for computer and control applications will be introduced briefly. For further information, please refer to the relevant specification sheets.

- RS 232 or V.24 interface

RS 232 for two-point connections

Point-to-point connections between two devices usually apply the RS 232 interface. The complete specification for four-wire full-duplex transmission as well as definitions for the handshaking lines are presented in the US standard RS 232C, or in the almost identical international standard ITU-T V.24.

Data and control signals are transmitted differently by the RS 232 interface:

level definitions

- data in negative logic (0: high; 1: low)
- control signals in positive logic (1: high; 0: low)

As a result, the voltage values for the data bits and the control signals are opposed to each other:

data	control signal	level	voltage range
'0'	'1'	high	+3 to +15 volts
'1'	'0'	low	-3 to -15 volts

Fig. 25: Level of RS 232 for data and control signals

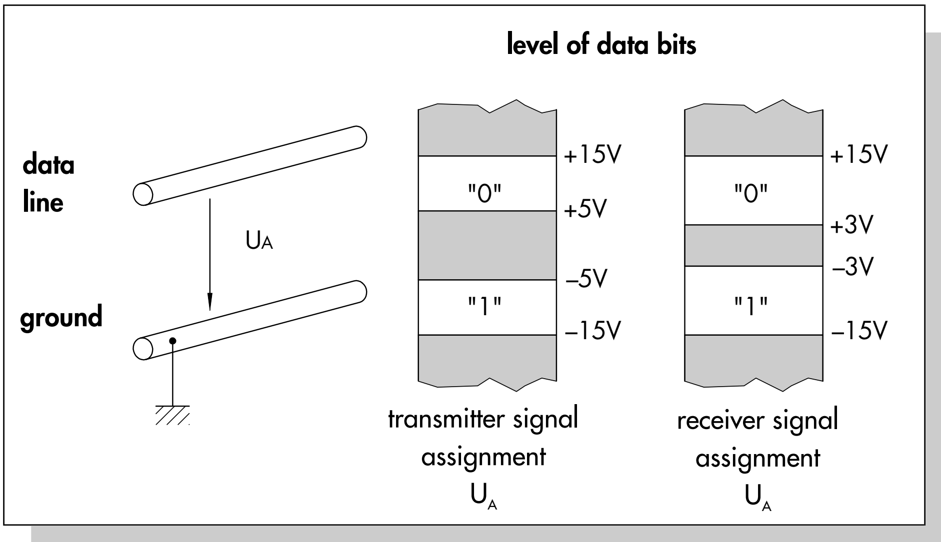


Fig. 26: RS 232 transmitter and receiver level

unbalanced transmission technique

Since the signal levels refer to ground (Fig. 26), this signal is termed 'unbalanced to ground'. With this signal transmission technique, compensating currents risk being formed since ground loops are generated when there is no electrical isolation. Therefore and also because the susceptibility to errors is growing with increasing line lengths, maximum line lengths should not exceed 15 meters (for low-capacitance cables 50 meters).

Data are transmitted asynchronously by the RS 232, and the UART character is used (Fig. 19). The transmitter and the receiver must be configured to have the same transmission parameters. Adjustments to be made are:

parameterization of the UART characters

- Baud rate (between 50 and 19.2 kbit),
- parity (without, even or odd parity) and
- number of stop bits (1, 1.5 or 2).

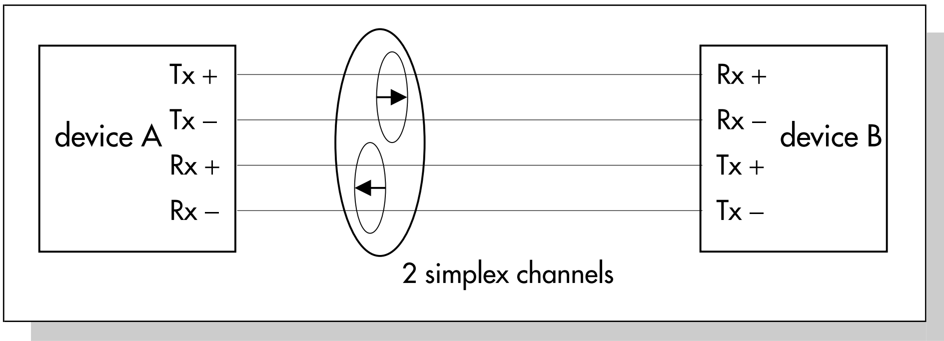


Fig. 27: 4-wire full-duplex connection with RS 422 wiring

- RS 422 interface

fast, also over long distances

The RS 422 interface is particularly suitable for fast serial data transmission over long distances. Within a transmission facility, maximum ten RS 422 receivers may be connected in parallel to one transmitter.

simplex or full-duplex

For short lines, a maximum data rate up to 10 Mbit/s is allowed, whereas for lines up to 1200 m, the data rate is limited to 100 kbit/s. The RS 422 can be implemented as 2-wire simplex or as 4-wire full-duplex interface. Upon installation, the transmitter outputs (Tx) must be connected – while observing the polarity – to the receiver inputs (Rx) (see Fig. 27).

balanced signal transmission

The RS 422 interface is balanced to ground because the logic states are represented by a differential voltage applied between the two associated lines A and B. The considerable advantage of balanced data transmission is that externally coupled-in noise signals cause exactly the same interference am-

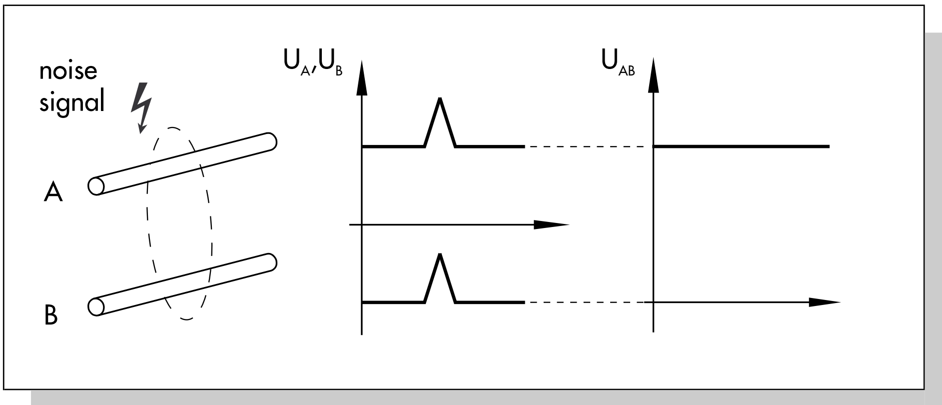


Fig. 28: Noise-resistant balanced transmission technique

noise-resistant transmission technique

plitudes on both lines. The useful signal – the differential voltage U_{AB} – is therefore not affected (Fig. 28).

electrical isolation protects interface

To prevent the formation of compensating currents between several participants and protect the receiver modules from increases in potential, optocouplers should be used to provide electrical isolation.

level definitions for load

The specification distinguishes between the transmitter and the receiver signal assignment (Fig. 29), while the transmitter levels must be guaranteed up to a load of 54 ohms. This high load is produced when the lines are terminated at both ends with their characteristic wave impedance. This is necessary when data are transmitted at high speed over great distances (see section: Transmission medium – Electric lines).

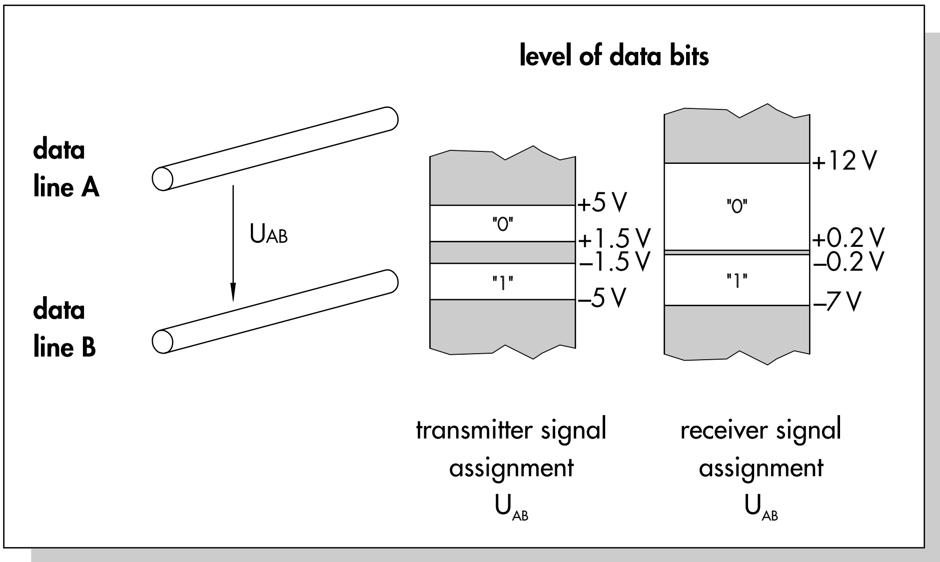


Fig. 29: Signal level of balanced RS 422 interface

- RS 485 interface

The electrical specifications and the wiring regulations of RS 485 largely correspond with the RS-422 standard (see page 33f). Additionally, RS 485 enables bidirectional bus communication between up to 32 participants. So this interface is frequently used for multi-point connections in field networks.

RS 485 for networked links

RS 485 can be designed as 2-wire bus or 4-wire full-duplex interface (see Figs. 30 and 31). The two-wire bus is only half-duplex capable as only one participant is allowed to transmit at a time. If several transmitters use a single line, a protocol must ensure that only one transmitter is active at a time. In the meantime, the other transmitters must release the line by switching their outputs in high-resistance condition.

two variants

transmission protocol coordinates transmission rights

The permissible line length decreases with increasing data rate. The table in Fig. 9 lists the permissible line lengths for data rates from 9.6 to 12,000 kbit/s. High data rates require termination of the lines (see also page 13: Fig. 10b). Two additional resistors serving as voltage divider define the potential of the lines when none of the participants are active.

line termination required

As is the case for RS 422, the 4-wire interface differentiates between the transmitter outputs (Tx) and the receiver inputs. Only participants whose Tx outputs and Rx inputs are mutually connected can establish communication with each other. The participants in the bus system below (Fig. 31) can there-

4-wire connection for master/slave communication

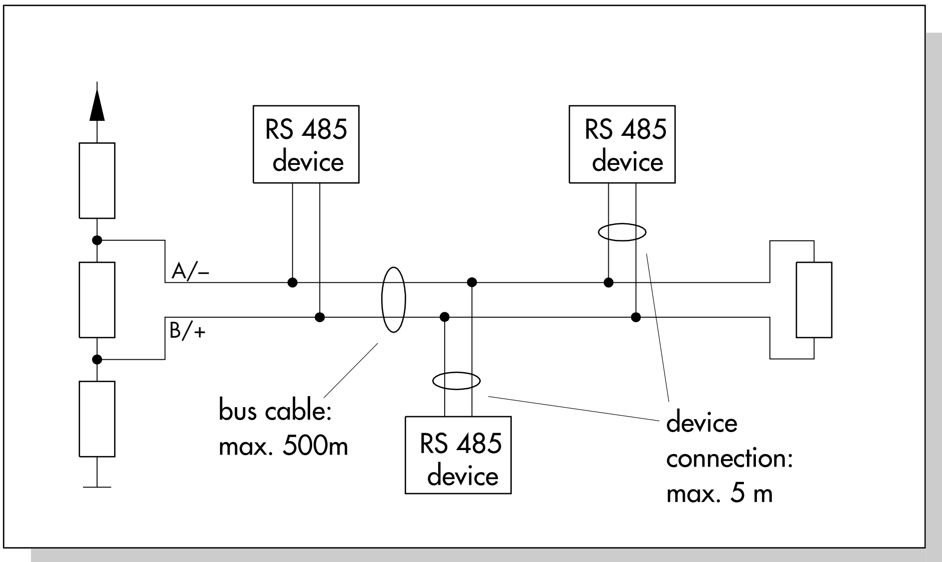


Fig. 30: Two-wire bus with terminations (RS 485 interface)

fore not communicate with one another, only the master is able to communicate with its slaves and vice versa.

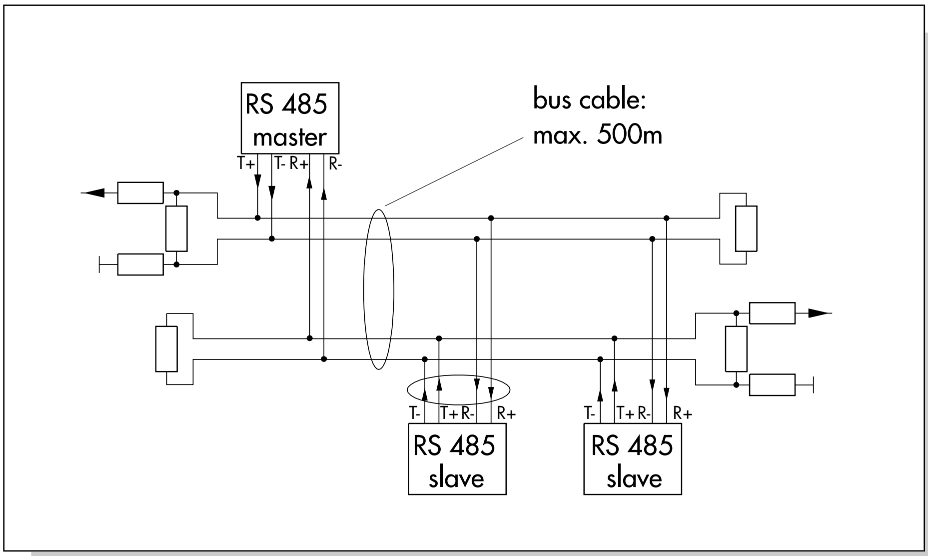


Fig. 31: 4-wire connection with RS 485 interface (master/slave communication)

• IEC 61158-2

Efforts have been undertaken to define an international fieldbus specification which led to the IEC 61158-2 specification for bus physics. This specification determines the cable design, the data coding as well as the electric parameters of transmission.

Here, fiber optic cables providing different data rates are approved as transmission media. Wired transmission includes four variants:

four wired variants

- voltage mode using 31.25 kbit/s; 1.0 Mbit/s and 2.5 Mbit/s
- current mode using 1.0 Mbit/s

Data transmission in 'voltage mode' running at 31.25 kbit/s is preferably used in process automation because it is suitable for intrinsically-safe communications systems and bus supply (two-wire devices). The coding used for data transmission is the Manchester coding which is self-clocking and without mean values. The power supply is modulated by an amplitude of ± 9 mA (Fig. 32). Explosion-protection for such systems, however, must be explicitly approved while observing yet further aspects (example: FISCO model; see Technical Information L450 EN).

for bus supply and intrinsic safety: 31.25 kbit/s voltage mode

The bus cable, a twisted – preferably shielded – two-wire line, must be terminated at both ends. Depending on the cable version (shielded or unshielded) and the capacity (cable capacity, attenuation, etc.), a total length of up to 1900 m is permissible.

shielded twisted-pair line up to 1900 m

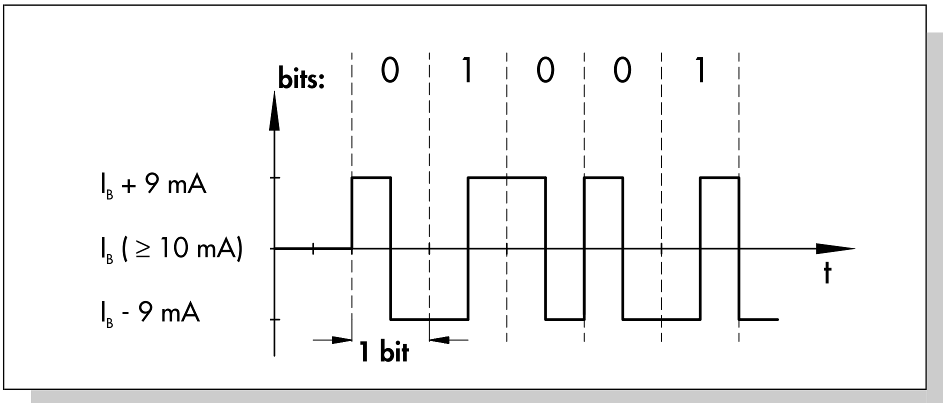


Fig. 32: IEC 61158-2 with Manchester coding using ± 9 mA

- Bell 202

standard from telecommunications

Bell 202 is a US standard for asynchronous data transmission via the telephone network established by AT&T (American Telephone and Telegraph). The standard defines a 4-wire full-duplex line providing 1800 bit/s as well as a 2-wire half-duplex line ensuring a data rate of 1200 bit/s.

The modulation technique used is the FSK coding, i.e. the binary states are encoded by alternating currents. In half-duplex operation, the following frequencies are used:

frequencies in half-duplex transmission

logical "1":	1200 Hz
logical "0":	2200 Hz

Coding is performed in the form of sine waves, hence, Bell 202 transmission is without mean values and independent of the signal polarity (Fig. 33). As the total harmonic content is low, the spectrum provides favorable EMC behavior.

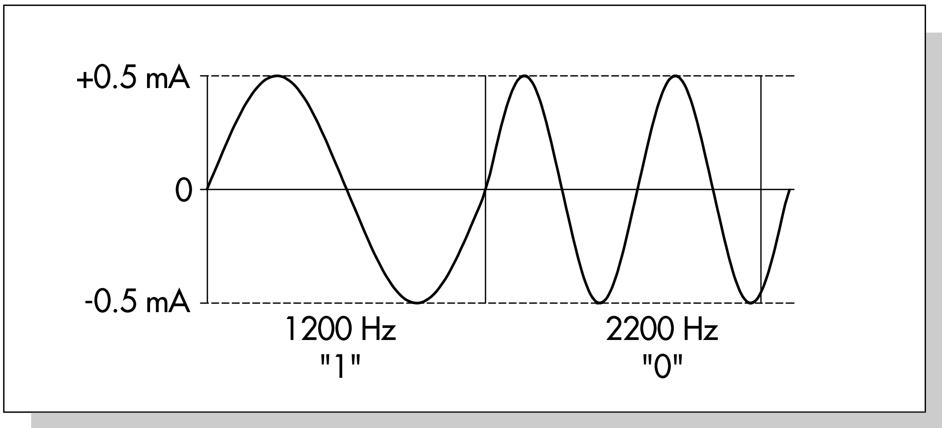


Fig. 33: FSK-coded data transmission based on Bell 202 (half-duplex)

Networks for long-distance data transmission

When data must be transmitted over long distances, it is often practical not to install completely new transmission lines, but to make use of the already existing network. Networks, such as the energy supply network, cable-TV networks, the telephone network, ISDN and the Internet are well-suited to serve this purpose.

using existing communications networks

- Power supply network (Powerline)

Data transmission over the power supply network is particularly interesting because this network extends into every single house, and even into every single room. In the future, this medium is intended to be used for voice as well as online communications.

networks even extending into rooms

Powerline operates on the low-voltage level (see Fig. 34). It is important to note that only the participants connected to the same segment can communicate directly. Further subdivision of the network is provided by the three phases which are electrically isolated. This isolation can be eliminated by installing a capacitive coupling unit.

great number of sub-networks

What is also difficult to achieve is the required data rate because the 230-volts network sets limits to data transmission. High noise levels must be accepted and the strong line attenuation reduces the transmission radius. Also, current laws restrict the usable transmission frequency range to 3 to 148.5 kHz and the maximum transmission power to 5 mW.

high noise levels impede communication

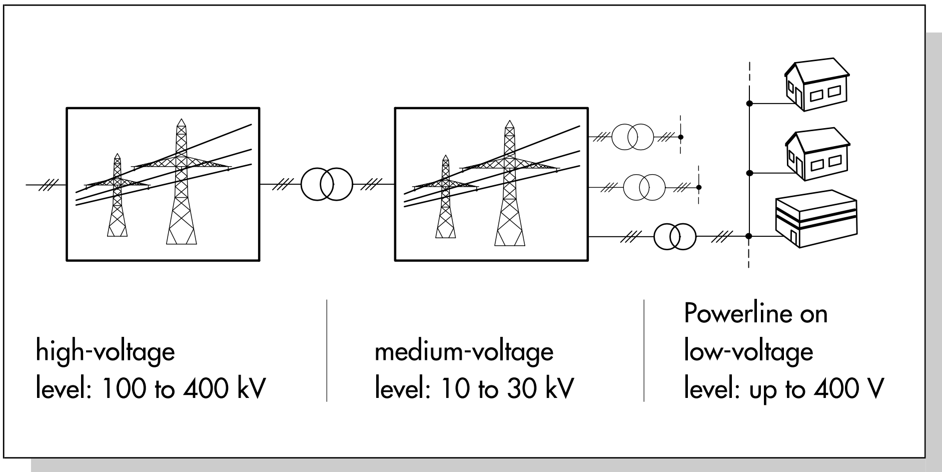


Fig. 34: Powerline uses low-voltage power supply network

Despite these restrictions, the power supply network is an important medium for data communications as it can use the already existing and widely branched networks. Powerline is particularly well-suited to applications in the field of building automation. In existing buildings, communication systems can be easily established without the need for additional cabling. LON (Local Operating Netzwork), for example, provides:

Powerline in building automation

limit values of LON for example

- data rates up to 10 kbit/s (standard 5 kbit/s),
- maximum network extension 6.1 km.

For many applications in building automation, these values are absolutely sufficient.

- Telephone network

modems modulate and demodulate analog signals

To transmit digital data over the analog medium 'telephone line', an appropriate conversion is needed. This task is performed by modems which are connected between the communication participant and the telephone line. The modem modulates the analog signal, adapting it to the data to be transmitted, and demodulates the incoming signal at the receiver (Fig. 35).

Communication via modem can only be established when the transmitter and the receiver are adjusted to the same transmission parameters. This includes:

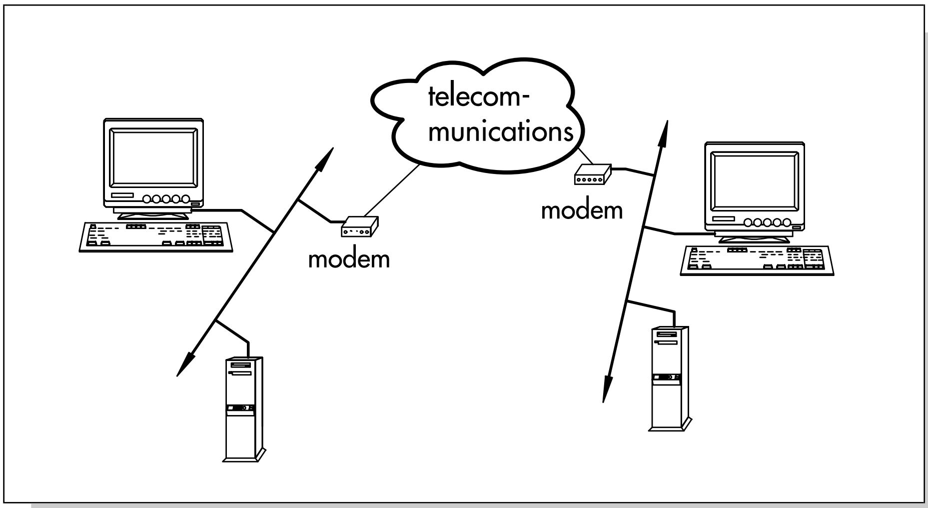


Fig. 35: Modems as coupler between telephone and digital network

- data rate (see page 7),
- modulation technique (see 'Binary coding of data') and
- data format (see 'Transmission techniques').

matching transmission parameters

As the transmission bandwidth of telephone lines is limited (approx. 3.1 kHz), the data rate of modem links was restricted to values ranging from 300 to 2 400 bit/s. Modern devices are now able to reach data rates of 56 kbit/s thanks to complex modulation techniques providing multiple and/or superimposed amplitude, phase and frequency modulation. The modems also automatically provide training (a process by which two modems determine the correct protocols and transmission speeds to use) in the initialization phase of the start-up procedure.

high data rates and automatic training

- ISDN

ISDN (Integrated Services Digital Network) is a digital network designed for the transmission of voice as well as data. The physical transmission medium used by ISDN is, among others, the telephone network.

digital network for voice and data transmission

Due to time-interleaved transmission, also termed time multiplexing, various services seem to be available to the user at the same time. This includes: telephony, telefax, video text systems, video communication, data transmission, teletex, data dialog and TC systems.

ISDN services

ISDN operates on two information channels (B) each running at 64 kbit/s as well as a 16 kbit/s signalling channel (D) for control signals (see Fig. 36). The proper information is transmitted over the information channels, while the signalling channel transmits the data associated with the signal itself.

three channels for different tasks

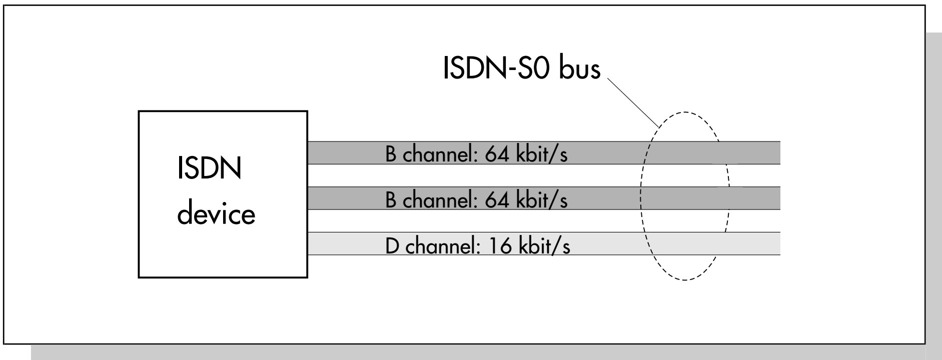


Fig. 36: Data channels of an ISDN connection

To interconnect single computers or autonomous communications networks via ISDN, a special ISDN interface is required. Note that this is not a modem as frequently but mistakenly termed. The ISDN interface supports data rates of 64 kbit/s, or even 128 kbit/s when both information channels are combined in a high-speed channel (sometimes known as inverse multiplexing).

- Internet

famous network for long-distance data transmission

An extremely powerful network fulfilling the specific demands of data transmission is the Internet. The term 'Internet' stands for an internationally linked group of computer networks which in turn can comprise many subnetworks.

The Internet ensures high availability and is used for an increasing number of applications. Access to the Internet is provided and charged for by service providers (T-Online, AOL, Compuserve, and so on). They offer connections via ISDN, mobile radio telephone or telephone/modem, which can be used with leased lines as well as time-limited dial-in connections.

provider, the interface to the Internet

TCP/IP: Transmission Control Protocol/ Internet Protocol

When the devices connected to the Internet communicate with each other, they use quite different media (electric, optical, radio signals). Nevertheless, the language they use is always identical, the protocol family with the acronym TCP/IP. The TCP/IP and the multiple options offered by the Internet will not be covered in this paper because practical exercises and applications are more helpful in understanding this complex medium.

Appendix A1: Additional Literature

[1] Digital Signals
Technical Information L150EN; SAMSON AG

[2] Networked Communications
Technical Information L155EN; SAMSON AG

[3] Communication in the Field
Technical Information L450EN; SAMSON AG

[4] HART-Communication
Technical Information L452EN; SAMSON AG

[5] PROFIBUS PA
Technical Information L453EN; SAMSON AG

[6] FOUNDATION Fieldbus
Technical Information L454EN; SAMSON AG

Figures

FIGURES

FIGURES

NOTES

NOTES

SAMSON AG · MESS- UND REGELTECHNIK · Weismüllerstraße 3 · D-60314 Frankfurt am Main
Phone (+49 69) 4 00 90 · Telefax (+49 69) 4 00 95 07 · Internet: http://www.samson.de

1999/12 · L153 EN