DISTRIBUTION LINE CARRIER EQUIPMENT

TYPE NDLC-1

PRODUCT DESCRIPTION

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SAFETY SYMBOLS

!

!

WARNING OR CAUTION:

This symbol denotes a hazard. Not following the indicated procedure, operation or alike could mean total or partial breakdown of the equipment or even injury to the personnel handling it.

NOTE:

Information or important aspects to take into account in a procedure, operation or alike.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 COMMUNICATIONS NEEDS OF ELECTRICITY UTILITIES

Power supply networks have grown to such an extent that a communications network has become an indispensable tool for the network operation. The communications network is used to transmit information concerning…

- Telecontrol of certain parts of the system.
- Supervision of the power network: remote measurement of certain magnitudes such as voltage or frequency.
- Teleprotection signals.
- Service telephony.
- User data.

...providing reliable operation and high quality of service.

The transmission network most widely used by Electricity Utilities is the power network itself. There are a number of reasons for this:

- Low cost and higher spectrum availability.
- Operation independent from public Telecom operators.
- Inherent easy accessibility to remote locations.

For all of these reasons transmission over the power line conductors has been successfully used as a communications system for Electricity Utilities.

1.2 THE MEDIUM VOLTAGE DISTRIBUTION NETWORK

In medium voltage networks the use of the power conductors as a transmission channel is even more interesting. Part of the network consists of underground cables, making it very difficult to use a parallel communications network. In addition, the medium voltage network has a rather complex topology, with a number of branches, stations and substations. All of these critical points are already interconnected by the power network, so its use as a transmission channel is the most convenient solution.

However, the behaviour of medium voltage power conductors as transmission channels is far from being ideal. Though a cable alone can be characterized as a transmission channel over a certain frequency range, when this cable is included in a certain network its behaviour will be affected by a series of unpredictable phenomena which will modify its transmission parameters. In fact the topology of the network does not remain constant but is time-varying according to service requirements; the distribution transformer secondary load is strongly time-variant and the number of cables connected to a distribution busbar and its connections could change.

The strong frequency response distortions which result from these topology changes are often unpredictable and cannot be avoided by means of line traps and by-passes, given the high number of connecting points. These distortions result in strong variations with both time and frequency of important parameters, such as input impedance, insertion loss or amplitude distortion. This erratic behaviour poses a problem for traditional modulation schemes; though the channel may be in good condition at certain times an in-band attenuation peak might suddenly appear, degrading the received signal-to-noise ratio and even interrupting the communications. These unpredictable channel impairments prevent the designer from using traditional narrow-band modulation schemes for the transmission. The solution to this problem is a Spread Spectrum modulation.

2 NDLC-1 TYPE DISTRIBUTION LINE CARRIER EQUIPMENT

2.1 GENERAL

The NDLC-1 type distribution line carrier equipment for medium voltage distribution lines is a communications equipment designed to tolerate strong distortions in the frequency response of the transmission channel, as occurs in medium voltage lines. These distortions can attenuate the band of interest and degrade the Signal/Noise ratio; they prevent the use of the traditional narrow-band modulation schemes. The adopted solution is the *Direct Sequence Spread-Spectrum*, DSSS.

This type of modulation basically consists of distributing the transmitted signal power in a bandwidth that is much broader than strictly necessary, in order to protect the information against the amplitude and group delay distortions in the channel by introducing redundancy. If the transmitted power is evenly distributed in the used band, that is, if the spectrum of the transmitted signal is flat, the loss of any fraction of the spectrum is mainly translated into a reduction of the received power. Ideally, this power reduction is equal to the fraction of lost spectrum.

The technique used to perform the DSSS modulation consists of multiplying the sequence of data to be transmitted by a code sequence whose data rate is several times higher than the speed of the original sequence; therefore, it has the bandwidth broader. This binary stream is transposed to the desired frequency band modulating it by a Digital Up/Down converter (DUC/DDC) block. At the receiver the signal is demodulated and the code sequence detected and the data recovered by means of digital signal processing algorithms.

The code sequence should have a very high auto-correlation in the origin, and very low outside it so that the resulting spectrum is as flat as possible. White noise, whose auto-correlation is only different from zero at the origin, is the ideal case although it has an infinite bandwidth. Since it is necessary to limit the bandwidth, the coding is performed through pseudorandom binary sequences chosen such that its auto-correlation looks as much like white noise as possible.

The bandwidth available in the channel is the limiting factor, which -together with the ***data rate*** (**R_d**)- determines the sequence length. The larger the bandwidth, and the smaller R_d, the longer the code sequence and its auto-correlation properties may be better. The band widening factor is equal to the length of the pseudorandom code sequence used, which is known as ***Processing Gain*** (**G_p**). The larger G_p, the better the protection against channel distortions, at the expense of using a broader bandwidth.

A characteristic of DSSS modulation is that an increase in the bandwidth does not imply a loss, or gain, of performance versus the noise as the increase of noise power is compensated exactly with the coding properties. Therefore, the Signal/Noise ratio does not change.

In addition to performing this modulation, the NDLC-1 equipment has several features, among which is data scrambling and descrambling, with selection of R_d and the length of the transmitted word, selection of G_p and the used sequence, and the inclusion of training sequences at the beginning of the transmission.

To configure and supervise the NDLC-1 terminal, the *NDLC-1 management software* must be installed in the management PC. The connection between the management computer and the equipment is done via *USB* interface.

2.2 NDLC-1 CONSTITUTION

The NDLC-1 is made up of a mechanical set, which houses the base modules, ***FASS*** and ***MPSS***, which are described below (see FIGURE 1).

As shown in FIGURE 2, the general dimensions of the NDLC-1 mechanical set are 129 mm high, 50 mm wide, and 192 mm deep.

The main power-supply switch, test points, optical indicators, user interfaces, and the configuration and supervision interface are at the front part of the NDLC-1 equipment.

The connector related to the line interface is on the back part of the NDLC-1. The said connector allows the equipment to be inserted inside a 3 standard units (s.u.) high shelf (133 mm).

FIGURE 1 Arrangement of the modules in the NDLC-1 equipment

FASS ***POWER SUPPLY AND DSSS AMPLIFIER***

This module contains the power supply and the main power-supply switch, the Spread Spectrum output amplifier of 6 W, and the line and input filters.

Likewise, it has the user interface for the telecontrol (TC), line interface, optical indicators for the equipment basic operation (PWR and AMP), and the reception signal test points (LINE).

The power supply contains the DC/DC converter that generates the +12 V_{DC}, -12 V_{DC} and 3.3 V_{DC} internal power-supply voltages from the 48 V_{DC} input voltage. The power supply is protected against polarity inversion, and it has a filter at the input to suppress disturbance caused by fast transient bursts.

It also has four auxiliary relays, AUX 1,3 (output) and AUX 2,4 (input).

In the transmitter, this module amplifies and filters the signal from the signal processing unit. In reception, it filters the signal received from the line.

MPSS ***SPREAD SPECTRUM MAIN MODULE***

It has the signal processing unit that generates the pseudorandom code sequence in the transmit side; it performs the modulation in the spread spectrum, the conversion from digital to analog and the modulation to high frequency through a DUC (Digital Up Converter) block. In the receive side, it performs the automatic gain control (AGC), analog to digital conversion, demodulation through a DDC (Digital Down Converter) block, the filtering that explores the received signal in search of the programmed code sequence, and the data extraction.

This module also has the control, management and communications unit.

The control unit controls and supervises the parameters and events that affect processing and communications. The management unit is in charge of the configuration, through a console or Windows interface, of the communications parameters and of the process. The communications unit applies / extracts headers, synchronizes speeds, etc.

In addition, the MPSS module has the Ethernet bridge, the optical indicators related to the telecontrol (TC) signals, the equipment status optical indicator (STATUS), and the test points for signal quality monitoring (MON).

2.3 TECHNICAL CHARACTERISTICS

2.3.1 General characteristics

Type of modulation	Direct Sequence Spread Spectrum (DSSS)
Operation mode	2 wire half duplex transmission with independent configuration for each direction of the transmission
Management interface (user)	USB 2.0 device mode. A-type connector (flat). Speed of 115200 bit/s.
Telecontrol (TC) channel	V.24/V.28 (EIA RS-232) of the ITU-T with flow control (RTS, CTS, DCD, DTR, DSR) with programmability of delay in signal activation. Physical interface: front 9-pin SUB-D female connector and rear DIN 41612 male connector. The telecontrol channel has priority over the remote measurement channel
Communications protocol	Telecontrol: selectable among DLC, SAP20 and IEC 870-5-104
Transmission frequencies	From 100 kHz to 1 MHz
Nominal bandwidth	It depends on the data rate. See TABLE 1
CTS activation and deactivation delay	To be programmed between 1 ms and 23 ms
DCD activation and deactivation delay	To be programmed between 1 ms and 23 ms

Error rate	It depends on the S/N ratio, the line attenuation, and the interfering tones
Data rate (R_d)	There are different transmission rates with their corresponding bandwidths (BW). See TABLE 1
Output power	6 W
Minimum S/N ratio	-3 dB

TABLE 1 Data rate (Rd) with its corresponding bandwidth (BW)

Bandwidth (BW)	Transmission rate
600 kHz	38400 bit/s
300 kHz	19200 bit/s
150 kHz	9600 bit/s
75 kHz	4800 bit/s

AGC action margin	From -20 dB_v to +15 dB_v
Output transformer	
Transformation ratio	1:1
Insulation	>5 kV_{rms}
Output impedance of the transmitter	28 Ω
Input impedance of the receiver	1.2 kΩ (in the available band)
Test devices	➢ Frequency sweeps to analyze the line attenuation (start point selectable by the user). ➢ It helps to select the frequencies.
Configuration of the operation parameters	By means of *NDLC-1 management software*.
Capacity of chronological register	100
Resolution of chronological register	1 s
Front-plate visual indications	
Signalling	➢ Equipment powered (PWR). ➢ Active transmitter (AMP). ➢ Software is OK (STATUS). ➢ Logical level of the signals related to telecontrol (TC): TD line, RD line, RTS line, CTS line, DCD line. ➢ Internal channel activity (ACI)

Indications via management	➢ Channel data rate ➢ Port data rate ➢ *Processing Gain* in the receiver ➢ *Processing Gain* in the transmitter ➢ Bandwidth in the receiver ➢ Bandwidth in the transmitter ➢ Level of received signal ➢ Level of transmitted signal ➢ Central transmission frequency ➢ Central reception frequency ➢ Frequencies of the 2 notch filters ➢ Temperature ➢ Data and Time

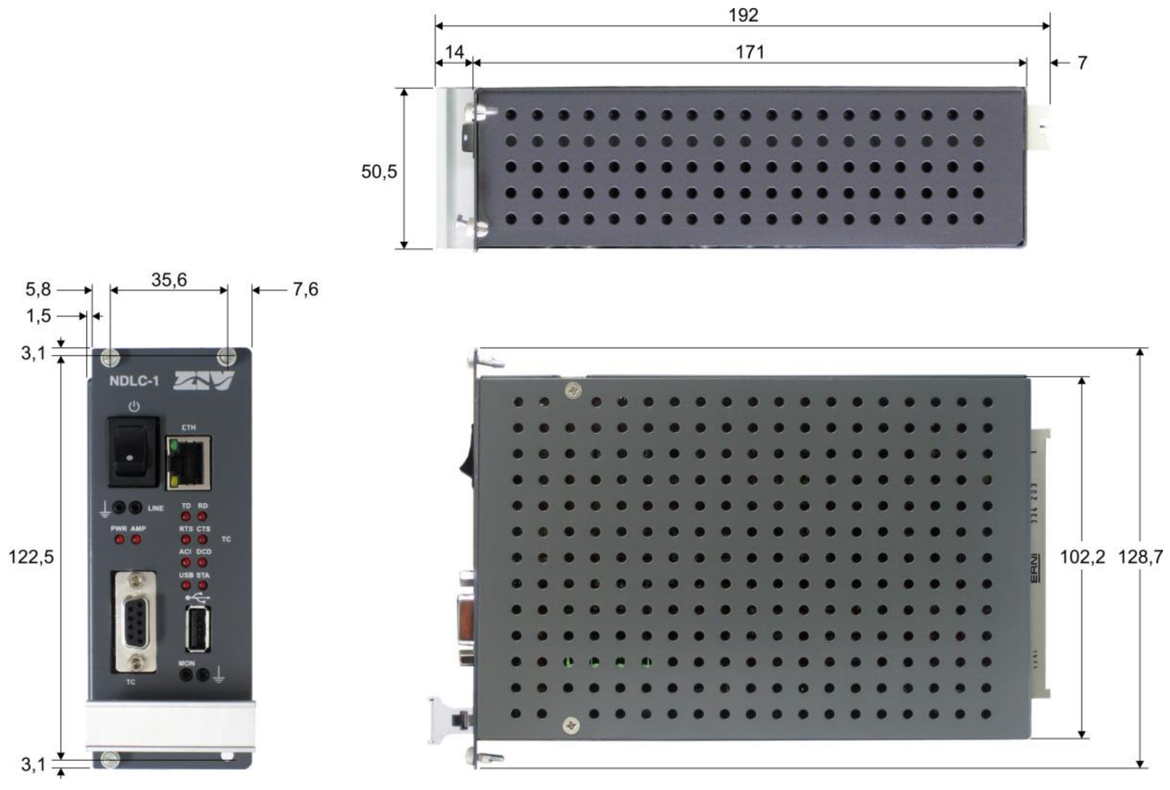
2.3.2 Operating conditions

Temperature and humidity	From –10 °C to +60 °C and relative humidity not greater than 75%, in accordance with IEC 255-6
Maximum temperature	+60 °C during a period of not more than 24 hours
Storage temperature	From –25 °C to +75 °C, according to IEC 255-6
Power supply	48 V_{DC} ±20% (floating from chassis)
Consumption at 48 V_{DC} (in transmission)	0.7 A

2.3.3 Mechanical characteristics

Dimensions	Height: 129 mm; Width: 50 mm; Depth: 192 mm. See FIGURE 2
Weight	1 kg
Module arrangement	See FIGURE 1
Connection to line	Through DIN 41612 male connector. Possibility of installation inside a 3 standard units (s.u.) high shelf (133 mm).

FIGURE 2 NDLC-1 general dimensions in mm



2.3.4 Management computer characteristics

Type	Compatible personal computer (PC)
Model	Pentium III 350 MHz processor or higher
RAM memory	512 MBytes
Graphic adapter	1 Mbyte SVGA
Communications	USB port (A-type connector)
Additional hardware	CD-ROM unit and mouse
Operating system	Microsoft Windows 2000, Microsoft Windows XP, Microsoft Windows Vista or Microsoft Windows 7
Additional software	*Microsoft.NET Framework* version 4 or higher

3 OPERATING PRINCIPLE

The purpose of the NDLC-1 type distribution line carrier equipment is to allow the transmission of telecontrol signals over the medium voltage power conductors in spite of any time-varying amplitude and group delay distortion which might appear.

In order to achieve this goal, the NDLC-1 makes use of a Spread Spectrum Direct Sequence scheme (DSSS) combined with a modulation to high frequency by means of a Digital Up/Down converter (DUC/DDC) block. See *Appendix A*, *The spread spectrum concept.*

The system may be configured to transmit at different transmission rates and with different protection levels.

The telecontrol (TC) user interface complies with Recommendations V.24 and V.28 (EIA RS-232) of the ITU-T.

3.1 NDLC-1 EQUIPMENT

FIGURE 3 shows a simplified block diagram of the NDLC-1.

At the transmit side, the MPSS module performs the user interface tasks and it is in charge of generating the Training and scrambling the data, if thus ordered.

The data sequence is delivered to the signal processing unit, where it is multiplied by the selected code sequence of the set G_p. Later, it is band limited to obtain the spread spectrum signal in base band. The DUC (Digital Up Converter) block transposes the signal to the desired frequency band. The modulated signal is delivered to the FASS module, where it is amplified and filtered. The transmitted signal is delivered to the medium voltage line coupling circuit through a transformer that isolates the equipment.

The receiver filters the received signal and adjusts its level. The demodulation is performed in the MPSS module using a DDC (Digital Down Converter) block. The demodulated signal is taken to the matched filter, which explores the received binary stream in search of the code sequence. The output of this filter is compared with a threshold to decide if a bit and its logic level have been received.

If necessary, the control, management and communications unit eliminates the Tracking sequence (synchronism preamble) and delivers the data to the user according to the speed and appropriate protocol. See structure of the internal frame in FIGURE 4.

The user has a selection of code sequences c(t), all of them of the chosen length.

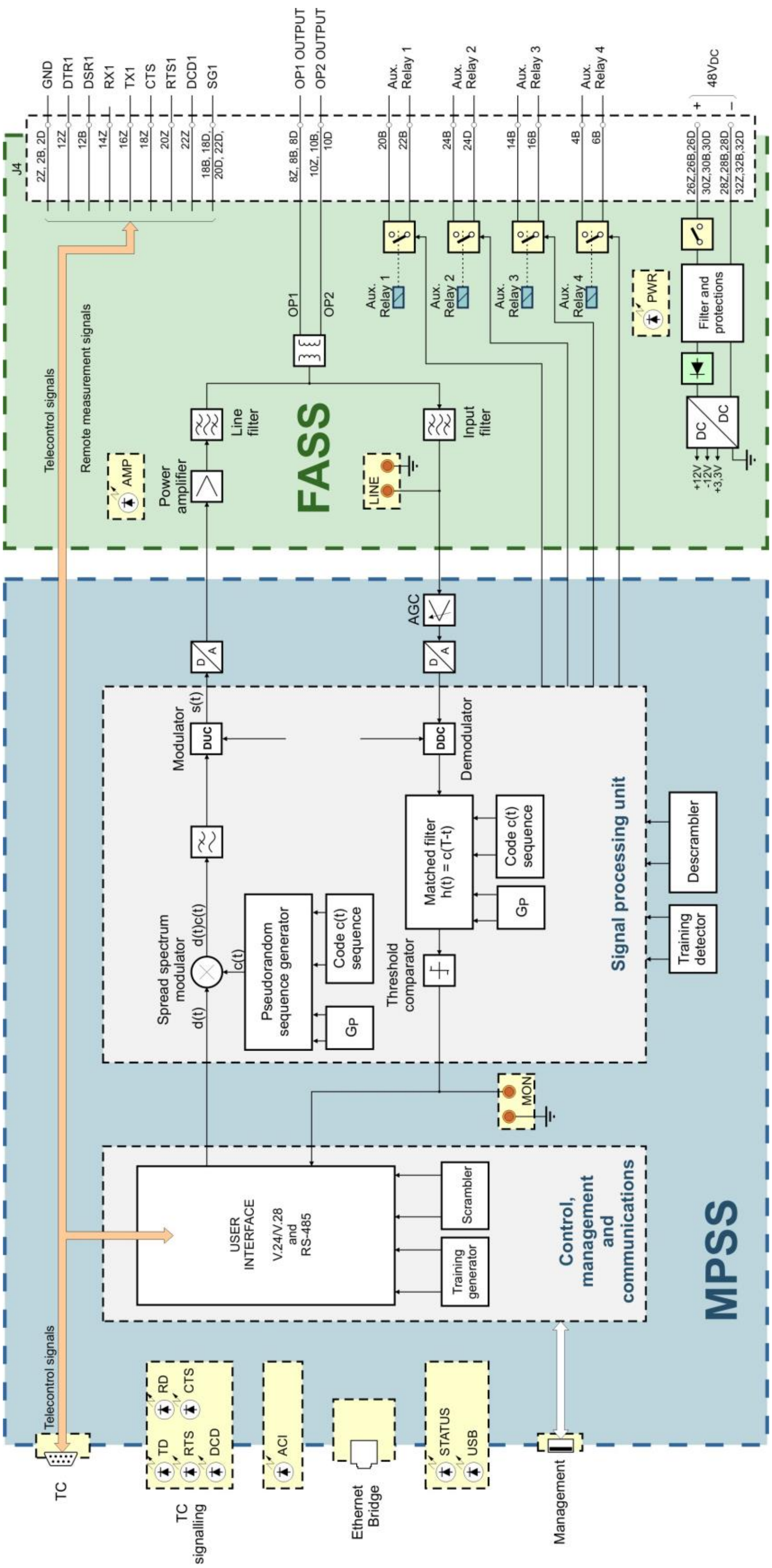
By assigning different sequences with the same length (same G_p), the system provides capacity of selective addressing and automatic identification to different transmitters and/or receivers in the same network. This characteristic simplifies the management and extension of multipoint networks; in order to add a new user to the network it will be enough to assign the new user a sequence not used by the already existing channels, without modifying the other transmitters and receivers.

On the other hand, the equipment has an internal service channel that checks the quality of the communications channel, as well as the link attenuation.

The FASS module has four auxiliary relays, AUX 1,3 (output) and AUX 2,4 (input), whose functions are mainly designed for the input and output commands.

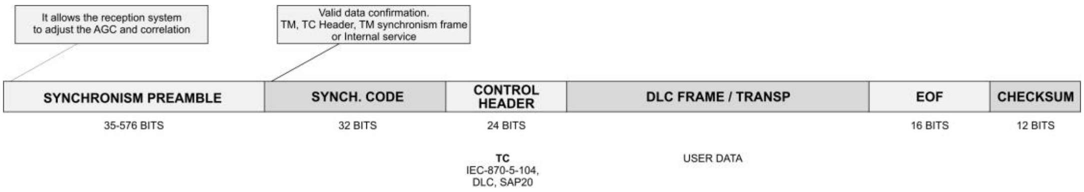
NDLC-1

FIGURE 3 NDLC-1 simplified block diagram



SMART GRID Solutions by

FIGURE 4 Internal frame structure

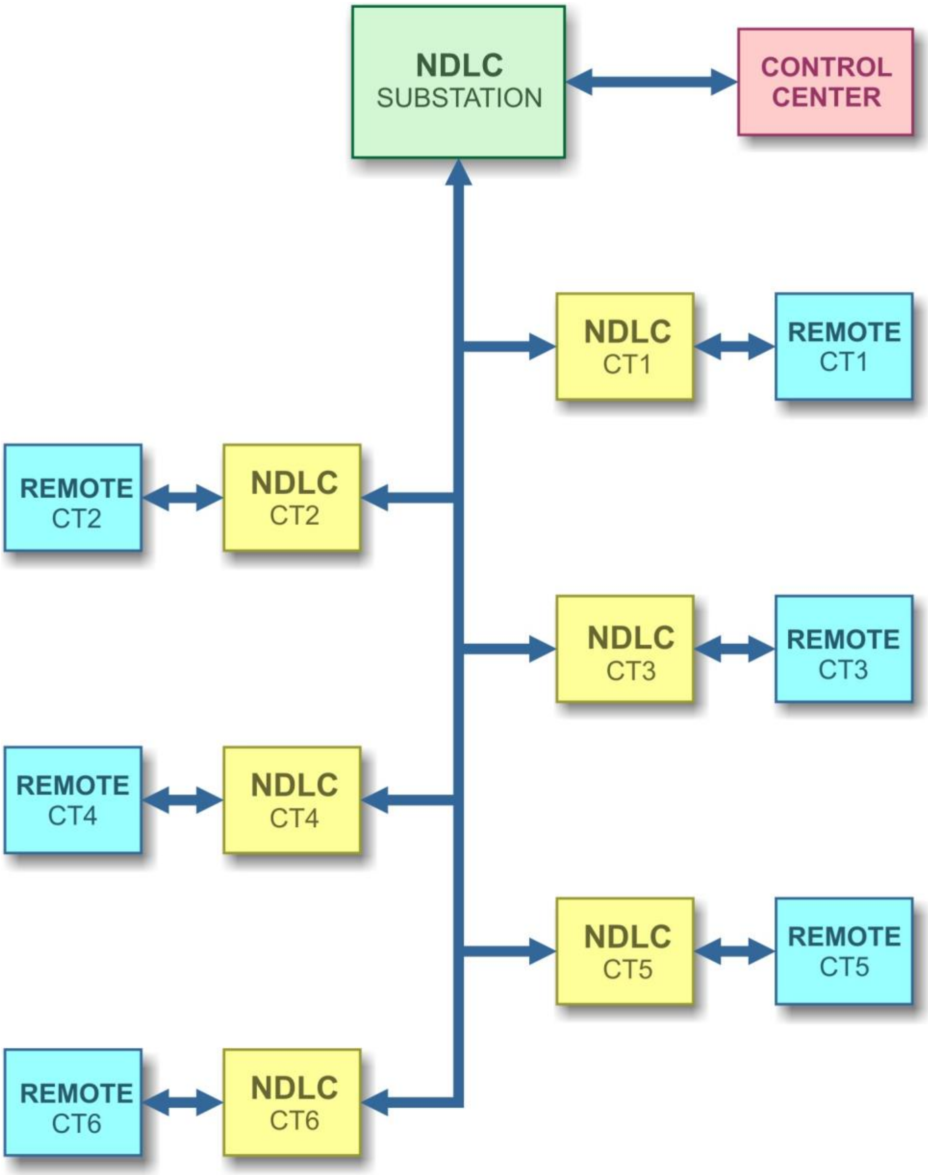


3.2 NDLC-1 SYSTEM OPERATION

The NDLC-1 system is based on a master NDLC-1 equipment, usually located in a substation, together with several NDLC-1 units in the transformer centers (TC), which are accessed through the medium voltage line. See FIGURE 5.

The telecontrol starts with a request from the Control Center addressed towards a Transformer Center, waiting for the answer from the remote unit of the Transformer Center. The transmission is half duplex since the master equipment and the remote unit of the transformer center do not try to transmit at the same time.

FIGURE 5 NDLC-1 system



4 FRONT-PLATE ELEMENTS

FIGURE 6 shows the front view of the NDLC-1 equipment. All the elements that can be accessed from it are described below.

I/O switch	General power-supply switch.
PWR LED	Red. When lit, indicates power-supply module operative.
AMP LED	Red. When lit, indicates active transmitter, that is, that a signal is transmitted to the line
LINE / ⏚ test points	Signal level at the output of the reception filter.
MON / ⏚ test points	Monitoring of the code sequence at the output of the correlation matched filter.
	Threshold comparator output signal.
STATUS LED	Red. When lit, indicates that the control, management and communications unit operates correctly.
	It stays off when the control, management and communications unit does not work properly.

FIGURE 6 Front view of the NDLC-1 equipment

TC (telecontrol) LEDs	TD	Red. It indicates data input. When lit, indicates that the logical level of the line is "0".
	RD	Red. It indicates data output. When lit, indicates that the logical level of the line is "0".
	RTS	Red. It indicates request to transmit and lights up when the signal is in active state (logical level "0").
	CTS	Red. It indicates that the modem is ready to transmit and lights up when the signal is in active state (logical level "0").
	DCD	Red. It indicates the detection of line signals. When lit, indicates that a frame has been received.
ACI LED	Red. When lit, indicates the operation of the internal channel.	
TC	Connection of the user signals related to telecontrol. SUB-D 9-pin female type connector for the V.24/V.28 (EIA RS-232) signals of the ITU-T. TABLE 2 indicates the use of the connector.	
Ethernet bridge	Ethernet connection (10/100Base-Tx). RJ-45 connector (straight-through cable)	
USB	Connection to the management PC. A-type connector (flat)	
USB LED	Red. Lights up when there is data transfer through the USB.	

TABLE 2 Use of TC connector for V.24/V.28 (EIA RS-232) signals

SUB-D 9 Pin	V.28 signal	Circuit no.	DTE / DCE	Electrical interface
Chassis	Protective ground	101	–	
1	DCD	109	⇐	V.28
2	RD	104	⇐	V.28
3	TD	103	⇒	V.28
4	DTR	108	⇒	V.28
5	GND	102	–	
6	DSR	107	⇐	V.28
7	RTS	105	⇒	V.28
8	CTS	106	⇐	V.28
9				

5 EXTERNAL CONNECTIONS

The signal input and output from/to the coupling circuit with the medium voltage line is done through the DIN 41612 male type connector located at the back part of the NDLC-1; see FIGURE 7.

TABLE 3 describes the use of the contacts for the external connection.

This connector allows the equipment to be inserted in a 3 standard units high shelf (133 mm).

The braided earth cable located on the lower part of the front plate of the equipment, see FIGURE 6, should be connected to earth.

FIGURE 7 Equipment connector for external connections

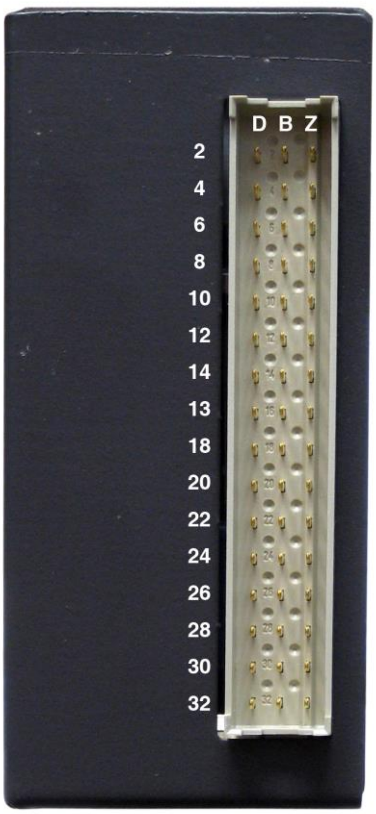


TABLE 3 Use of contacts in the Input/Output DIN 41612 connector

DIN 41612 F48 connector	D row use	B row use	Z row use
2	GND	GND	GND
4		AUX4 RELAY (Input)	
6		AUX4 RELAY (Input)	
8	OP1 OUTPUT	OP1 OUTPUT	OP1 OUTPUT
10	OP2 OUTPUT	OP2 OUTPUT	OP2 OUTPUT
12		DSR1	DTR1
14		AUX3 RELAY (Output)	RX1
16		AUX3 RELAY (Output)	TX1
18	SG1	SG1	CTS1
20	SG1	AUX1 RELAY (Output)	RTS1
22	SG1	AUX1 RELAY (Output)	DCD1
24	AUX2 RELAY (Input)	AUX2 RELAY (Input)	
26	+VDC	+VDC	+VDC
28	-VDC	-VDC	-VDC
30	+VDC	+VDC	+VDC
32	-VDC	-VDC	-VDC

TC: 1 TM: 2

6 EQUIPMENT MANAGEMENT

To configure and supervise the NDLC-1 terminal, the *NDLC-1 management software* must be installed in the management PC.

The connection between the NDLC-1 and management computer is done via USB.

The USB connection (A-type USB cable) between the NDLC-1 and the management computer should be made once the NDLC-1 has started.

The management computer will assign a virtual COM port to the USB connection. To identify the port associated to the NDLC-1, the device manager should be opened.

It is also necessary that the management computer will have the *Microsoft.NET Framework* program version 4 or higher.

To install the *NDLC-1 management software*, decompress the installation file and then execute the SETUP.EXE file.

Once installed in the computer, the program creates a shortcut icon on the desktop and a link in the *Start* menu.

The *NDLC-1 management software* contains ten main menus:
- *CFG PARAMS*
- *MODEM LIST*
- *PORTS*
- *LOG*
- *XML FILES*
- *TERMINAL*
- *SW/FW*
- *AUTOSAFE*
- *AUTOFREQ*
- *SUPERVISION*

These menus are described in the manual *Program Guide for Windows*.

7 GENERAL FEATURES FOR COMMISSIONING

The NDLC-1 may be configured to adapt its operation to the used channel and to the user data terminal.

The following points should be observed for the correct operation of the link:

- Each transmission direction may be configured independently.
- The common parameters are necessary for proper decoding of the transmitted signal; therefore, they should be configured in the same way in the transmitter and receiver used in the same link. These parameters are R_d, pseudorandom sequence, and data scrambling.
  Transmission through a transmitter and receiver whose common parameters are not consistent is not possible.
- The independent parameters may be configured differently at both ends of the same link. These parameters are: channel data speed, port data speed, transmission and reception frequencies, frequencies and activation of the two notch filters.
- The advanced configuration parameters should not be modified by the user.
  The parameters allow the restoration of the default factory values, in case of an accidental modification.
- Training sequence.
  As the transmission mode is half-duplex, the transmitter should send a Training sequence before starting the data transmission in order to start the receiver descrambling and to facilitate the AGC establishment and the recovery of the carrier as well.
  The selection of the Training sequence is done through the TRACKING parameter within the communications submenu. This parameter is configurable from 48 to 588 bits, and its value will depend on each line. The default value is 48 bits, which is the minimum value necessary.

As alignment help, the modem step-by-step configuration using an emulator communications program is described in the *Fast Installation Guide* manual.

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APPENDIX A

THE SPREAD SPECTRUM CONCEPT

APPENDIX A

THE SPREAD SPECTRUM CONCEPT

A.1 SPREAD SPECTRUM SYSTEMS

Spread Spectrum is a means of transmission in which the signal occupies a much broader bandwidth than the minimum necessary to send the user information. The bandwidth spreading is accomplished by means of a code independent of the message. The receiver uses a synchronized code for the bandwidth compression and subsequent recovery of the original information.

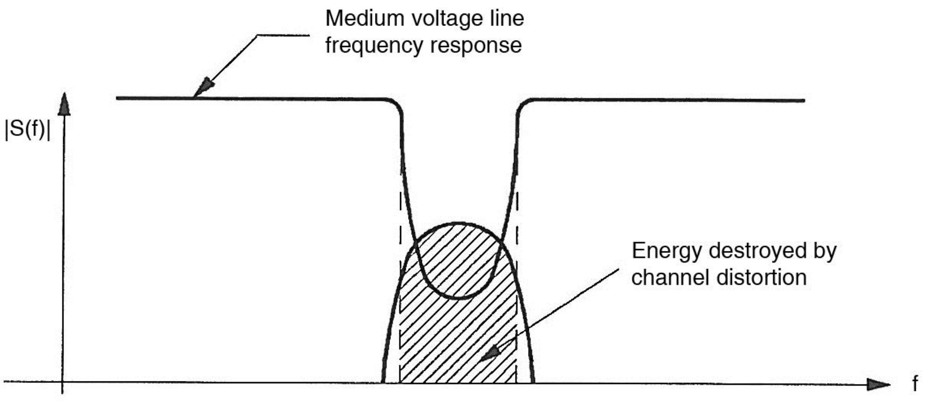
The robustness against channel distortion is based on the fact that the transmitted signal occupies a much broader bandwidth than necessary. This means that the transmitted signal has been provided with a high degree of redundancy, so any narrow-band channel distortion will destroy a reduced amount of signal energy (FIGURE 8). This fact allows the continuity of the transmission in spite of the severe distortions which may suddenly appear in the medium voltage line frequency response because of topology changes.

There are several methods to achieve the bandwidth spreading, of which the most common are the following:

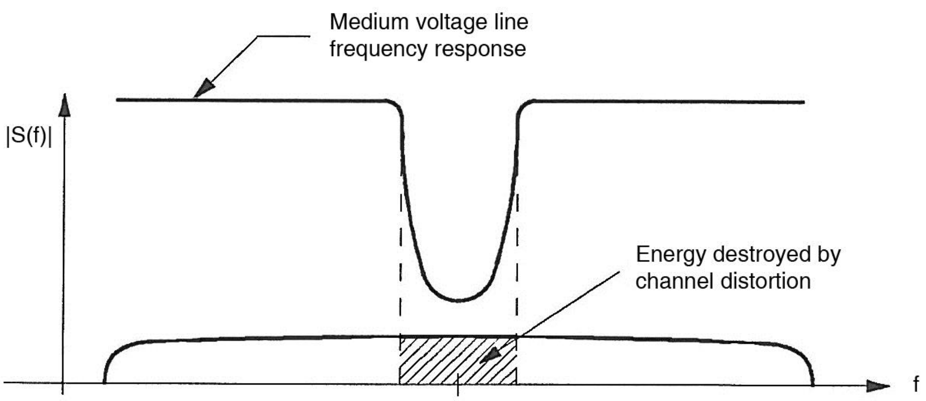
- Direct Sequence (DS); it is based on the use of high-speed pseudorandom binary sequences.
- Frequency Hopping (FH); the carrier frequency is changed several times per second according to a certain pattern.

The intrinsic robustness against channel impairments of Direct Sequence systems is higher than that offered by Frequency Hopping techniques, so Direct Sequence Spread Spectrum seemed the best choice to solve the problem of transmitting over medium voltage power distribution lines.

FIGURE 8 Basic principle of protection against channel distortion



(a) NARROW-BAND TRANSMISSION



(b) SPREAD SPECTRUM TRANSMISSION

A.2 DIRECT SEQUENCE SPREAD SPECTRUM MODULATION

In Direct Sequence systems the message to be transmitted consists of user data d(t) at a speed of Rd bits/s. This binary stream is multiplied by a pseudorandom binary sequence c(t) which is running at Rc bits/s, Rc>>Rd (FIGURE 9). The code sequence c(t) is known to both the transmitter and the receiver. This process is carried out in such a way that each of the incoming bits is multiplied by a complete period of the pseudorandom sequence.

The result of this multiplication is a third binary sequence d(t)c(t) which is also running at Rc bits/s. This sequence consists of a series of successive periods of the pseudorandom code multiplied by "+1" if the corresponding user bit is a logical "1" or multiplied by "-1" if the corresponding user bit is a logical "0". The bandwidth spreading comes from the fact that the overall process yields a binary stream running at Rc bits/s and so the Spread Spectrum bandwidth is BW_{SS}=RC Hz, much broader than the information bandwidth BWi=Rd Hz (FIGURE 10).

FIGURE 9 Spread spectrum direct sequence modulation (time domain)

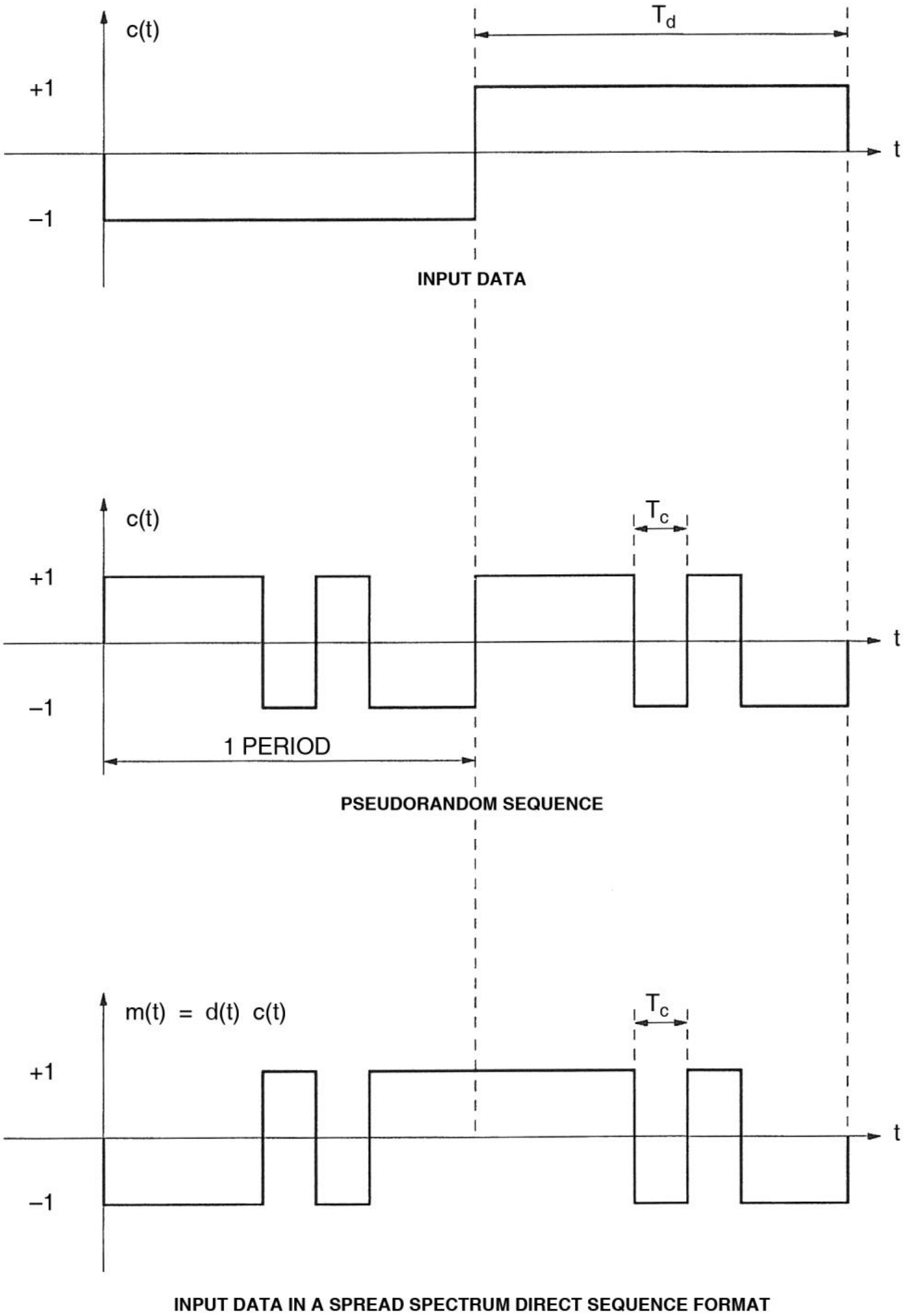
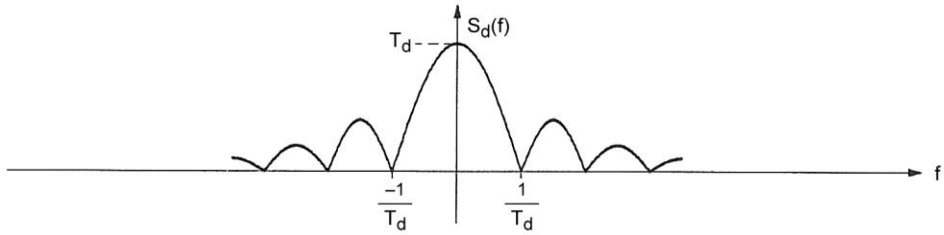
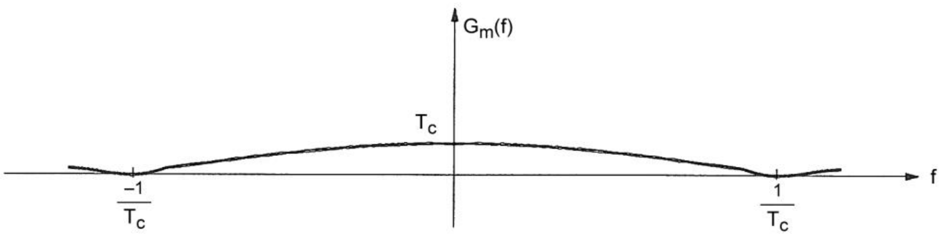


FIGURE 10 Spread spectrum direct sequence modulation (frequency domain)



POWER SPECTRUM OF INPUT DATA



POWER SPECTRUM AFTER THE SPREAD SPECTRUM MODULATION

$$G_p = \frac{\frac{1}{T_c}}{\frac{1}{T_d}} = \frac{R_c}{R_d} = n$$

A useful parameter in Spread Spectrum systems is the Processing Gain Gp, defined as the ratio between the Spread Spectrum bandwidth and the user information bandwidth. In Direct Sequence systems the Processing Gain equals...

$$Gp = BWss / BWi = Rc / Rd = n$$

...where n is the number of bits in a period of the pseudorandom sequence. Given a certain information rate Rd, the higher the Processing Gain the broader the Spread Spectrum bandwidth, so the more redundancy is given to the signal and the easier it is to overcome the channel distortions.

After the bandwidth spreading the signal is modulated at the desired channel frequency by means of a DUC (Digital Up Converter) block. The bandwidth occupied in the channel is...

$$BWchannel = 2\ BW_{\text{Spread Spectrum}} = 2\ Gp\ Rd\ (Hz)$$

This equation illustrates the fundamental trade-off of all Spread Spectrum systems. From the user's point of view both the data rate (Rd) and the degree of protection against channel impairments (Gp) should be as high as possible, while the channel bandwidth (BWchannel) should remain as low as possible. However, if we increase either Rd or Gp the channel bandwidth will also increase. There is a trade-off, then, between data rate (Rd), protection against distortions (Gp) and bandwidth (BWchannel); if we improve two of these magnitudes the third factor will worsen.

FIGURE 11 Transmitted signal (time domain)

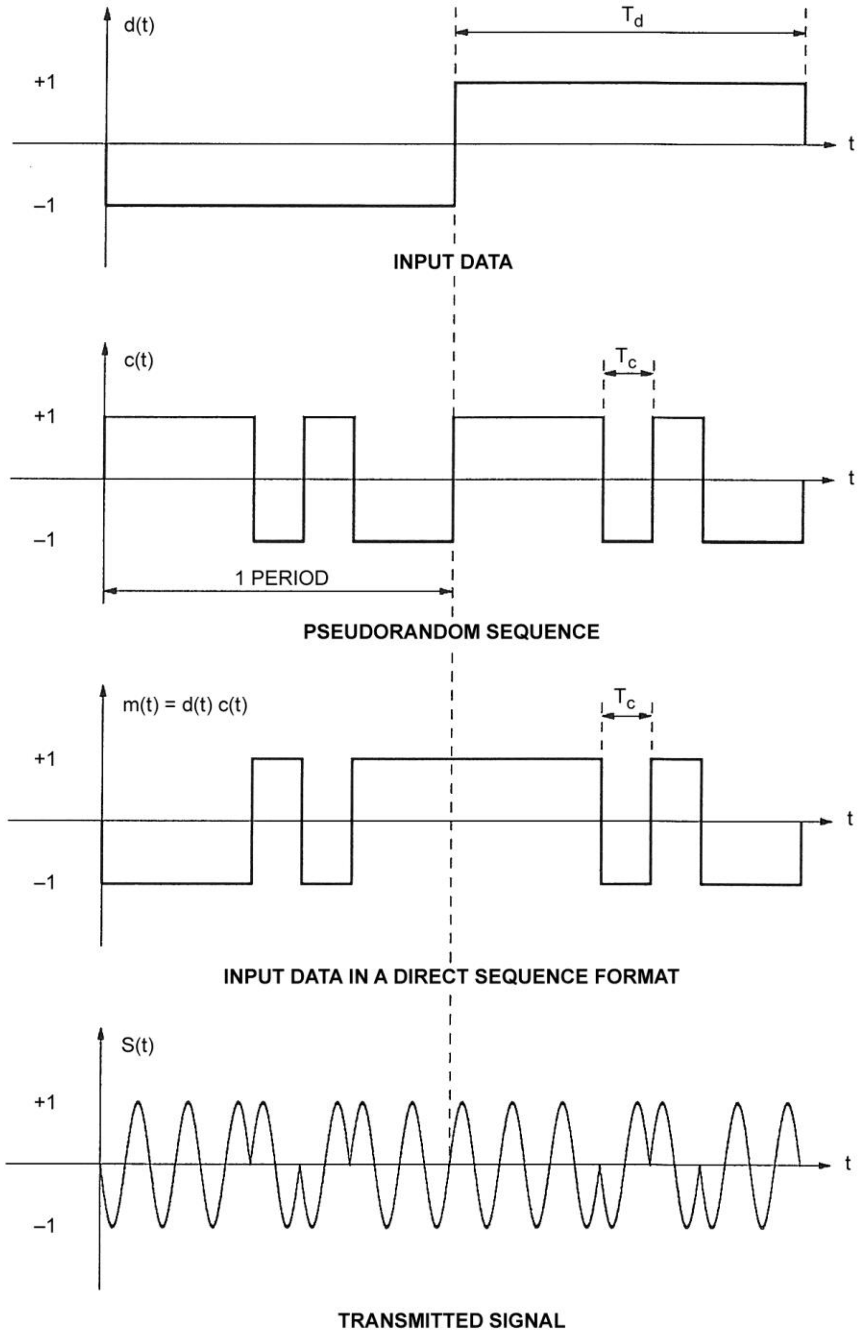
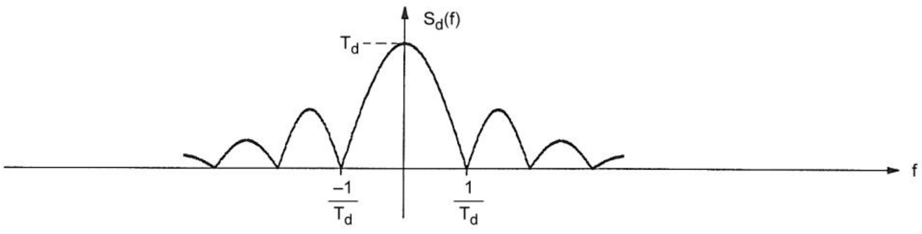
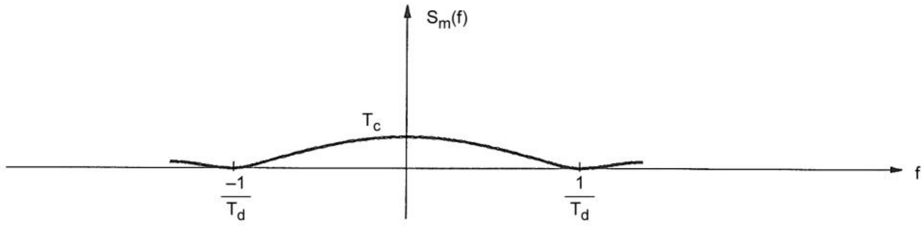


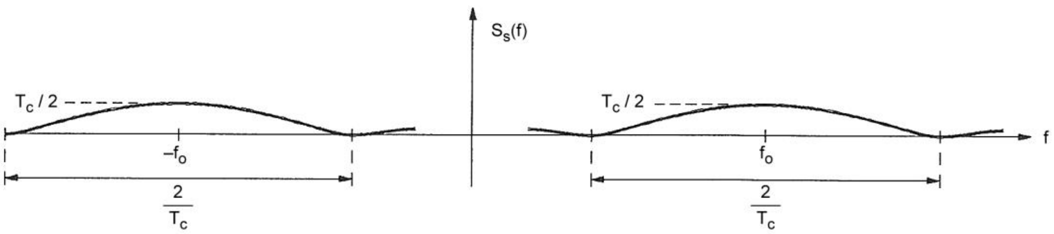
FIGURE 12 Transmitted signal (frequency domain)



POWER SPECTRUM OF INPUT DATA



POWER SPECTRUM AFTER THE SPREAD SPECTRUM MODULATION



POWER SPECTRUM AFTER THE HF MODULATION

The first stage of the receiver is a demodulator which converts the received signal to a base band format. The output of the demodulator is then fed to a filter matched to the pseudorandom sequence c(t). The impulse response of the matched filter is ...

$$h(t) = K\, c(T-t)$$

...where K is an amplitude factor and T is the time duration of a period of c(t). If c(t) is properly designed then the output of the matched filter, the autocorrelation of c(t), will be a series of high peaks spaced Td=1/Rd seconds apart and affected by a positive sign if the user bit is a logical "1" or by a negative sign if the user bit is a logical "0" (FIGURE 13). It can be shown that the level of these peaks is equal to the Processing Gain Gp; so the higher the value of Gp the easier it is to detect the peaks at the output of the matched filter.

The effect of any in-band channel distortion is to reduce the energy of the received signal and so to reduce the level of the peaks below their maximum theoretical value of Gp. However, if the theoretical value of Gp is high enough the actual peaks will still cross the threshold in spite of the distortion, and the user information will be detected. To sum up, the higher the Processing Gain the more distortion the system will be able to overcome.

FIGURE 13 Output of matched filter