11

HART protocol

HART is a smart instrumentation system designed for collecting data from instruments, sensors, and actuators by means of digital communication techniques.

Objectives

After studying this chapter you will be able to:

- Describe the origin and benefits of the HART system
- Describe implementation of HART in terms of the OSI model

11.1 Introduction to HART and smart instrumentation

Smart (intelligent) instrumentation systems are designed for applications where data is collected from instruments, sensors, and actuators by digital communication techniques. These components are linked directly to the controlling host (master) via some form of bus or 'highway'.

HART (Highway Addressable Remote Transducer) is a typical smart instrumentation concept that operates in a hybrid 4–20 mA/digital fashion. The HART protocol, known as HART Communication, is a bi-directional industrial field communication protocol used to communicate between intelligent field instruments and host systems such as PCs, PLCs or DCSs. It was originally developed by Rosemount but is now regarded as an open standard, available to all manufacturers.

Its main advantage is the retention of the existing 4–20 mA instrumentation cabling and the use of the same cabling to carry digital information superimposed on the analog signal. This allows users to capitalize on their existing investment in 4–20 mA instrumentation cabling and associated systems; and to add the further HART capability without incurring major costs.

HART is a hybrid analog and digital system, as opposed to most field bus systems, which are purely digital. It is, however, by no means the only competitor in this sphere. There are many smart implementations produced by various manufacturers, for example Honeywell, that compete with HART.

At a basic level, most smart instruments provide core functions such as:

- Control of range/zero/span adjustments
- Diagnostics to verify functionality
- Memory to store configuration and status information such as tag numbers etc.

Accessing these functions allows major gains in the speed and efficiency of the installation and maintenance process. For example, the time consuming 4–20 mA loop check phase can be achieved in minutes, and the device can be readied for use in the process by zeroing and adjustment for any other controllable aspects such as the damping value.

HART can be used in three ways:

- In conjunction with the 4–20 mA current signal in point-to-point mode
- In conjunction with other field devices in multi-drop mode
- In point-to-point mode with only one field device broadcasting in burst mode

Traditional point-to-point loops use ‘0’ for the smart device polling address. Setting the smart device polling address to a non-zero number zero switches the smart device to multi-drop mode. The device is then ‘parked’, i.e. it sets its analog output to a constant 4 mA to conserve power, and communicates only by digital means.

The HART protocol has two formats for the digital transmission of data, viz.:

- Poll/response mode
- Burst (or broadcast) mode

In the poll/response mode the master polls each of the field devices on the highway (i.e. the loop) and requests the relevant information. In burst mode the field device continuously transmits process data without the need for the host to send request messages. Although this mode is fairly fast (up to 3.7 times/second) it cannot be used in multi-drop networks since collisions may occur.

The system is implemented according to the OSI model (see Chapter 9**)** using layers 1, 2 and 7.

11.2 Highway addressable remote transducer (HART)

This protocol was originally developed by Rosemount and is regarded as an open standard, available to all manufacturers. Its main advantage is that it enables an instrumentation engineer to keep the existing 4–20 mA instrumentation cabling and to use simultaneously the same wires to carry digital information superimposed on the analog signal. This enables most companies to capitalize on their existing investment in 4–20 mA instrumentation cabling and associated systems; and to add the further capability of HART without incurring major costs.

HART is a hybrid analog and digital protocol, as opposed to most Fieldbus systems, which are purely digital.

The HART protocol uses the frequency shift keying (FSK) technique based on the Bell 202 communications standard. Two individual frequencies of 1200 and 2200 Hz, representing digits 1 and 0 respectively, are used. The average value of the sine wave (at the 1200 and 2200 Hz frequencies), which is superimposed on the 4–20 mA signal, is zero. Hence, the 4–20 mA analog information is not affected.

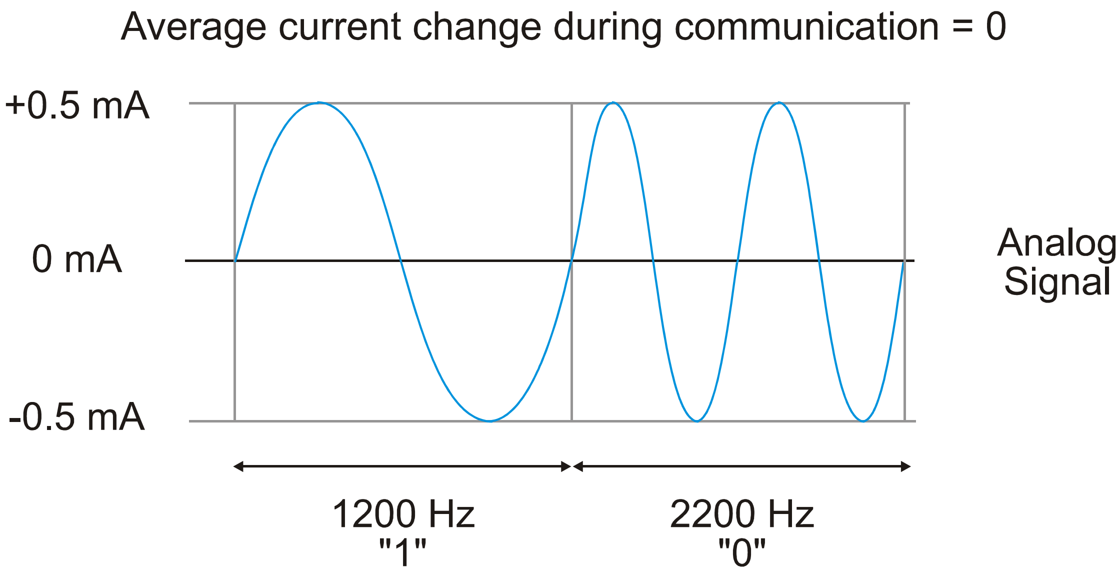


Figure 11.1
Frequency allocation of HART protocol

The HART protocol can be used in three ways:

- In conjunction with the 4–20 mA current signal in point-to-point mode
- In conjunction with other field devices in multidrop mode
- In point-to-point mode with only one field device broadcasting in burst mode

Traditional point-to-point loops use zero for the smart device polling address. Setting the smart device polling address to a number greater than zero creates a multidrop loop. The smart device then sets its analog output to a constant 4 mA and communicates only digitally.

The HART protocol has two formats for digital transmission of data:

- Poll/response mode
- Burst (or broadcast) mode

In the poll/response mode the master polls each of the smart devices on the highway and requests the relevant information. In burst mode the field device continuously transmits process data without the need for the host to send request messages. Although this mode is fairly fast (up to 3.7 times/second) it cannot be used in multidrop networks.

The protocol is implemented with the OSI model (see Chapter 9**)** using layers 1, 2 and 7. The actual implementation is covered in this chapter.

11.3 Physical layer

The Physical layer of HART is based on two methods of communication, viz. 4–20 mA analog and a version of digital Frequency Shift Keying (FSK)

Analog communications

The following figure shows a typical HART application. The power supply is typically 24 volt, and the value of the series resistor varies between 230 ohm and 1100 ohm, with a typical value of 250 ohm. The PC (controller) is not directly wired into the loop, but connected via an RS-232 or USB HART interface. From the perspective of the FSK signal the field device and power supply appear as short circuits, therefore any device connected across the two wires of the loop is effectively connected across the resistor and will 'see' the signal i.e. the voltage drop across the resistor. It must be understood that all devices signal by means if injecting *current into* the loop; the signal becomes a voltage only due to the resistance in the loop.

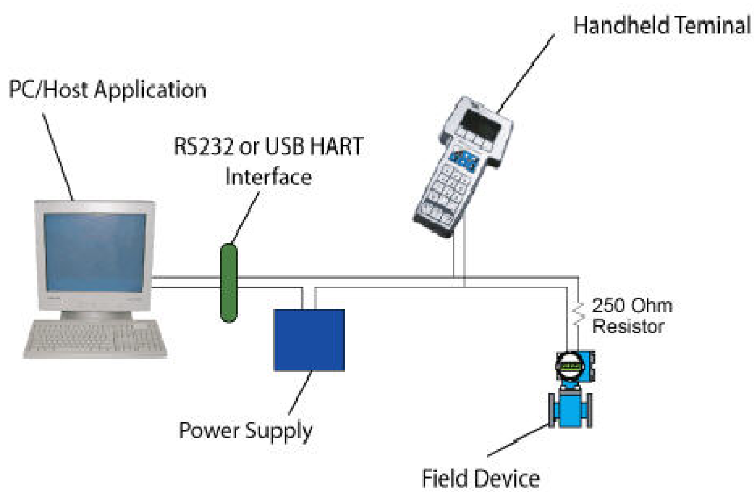


Figure 11.2
Typical HART application (courtesy HART Communication Foundation)

In a 4–20 mA loop the sensor outputs a current value somewhere between 4 and 20 mA that represents the analog output value of the sensor. For example, a water tank that is half full – say 3400 kilolitres – would put out 12 mA. The receiver would interpret the 3 volt (12 mA x 250 ohm) across the resistor as 3400 kilolitres.

This type of communication is always point-to-point, i.e. from one device to one other, as it is impossible to do multi-drop communication using this method. If two or more devices put some current on the line at the same time, the resulting current value would not be valid for either device.

Digital communications

To communicate with the transducer irrespective of the DC current in the loop, HART uses an FSK technique based on the Bell 202 modem standard. The correct name for this technique is Continuous Phase Frequency Shift Keying (CPFSK) since there is no discontinuity in the output when the input alternates between 1 and 0. Two individual frequencies of 1200 and 2200 Hz (1 mA peak-to-peak), representing '1' and '0' respectively, are used. The alternating current creates an alternating voltage across the series resistor, allowing it to be measured. The voltage generated across a 250 ohm resistor will be 250 mV peak-to-peak. The 4–20 mA analog information is not affected since the average value of the sine wave superimposed on the 4–20 mA signal is always zero.

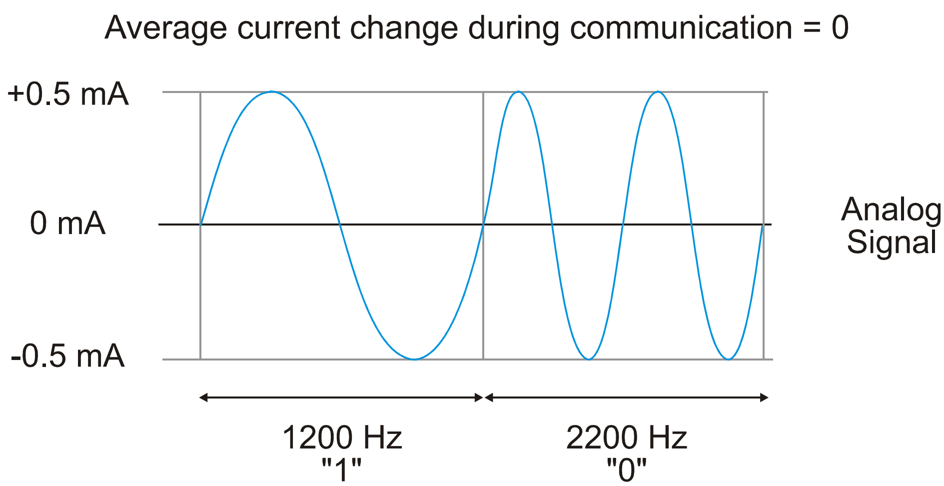


Figure 11.1
HART FSK frequency allocation

HART also supports a multi-drop configuration, wired as a star or a bus. In this case the 4-20 mA current is meaningless, and all communications takes place via FSK.

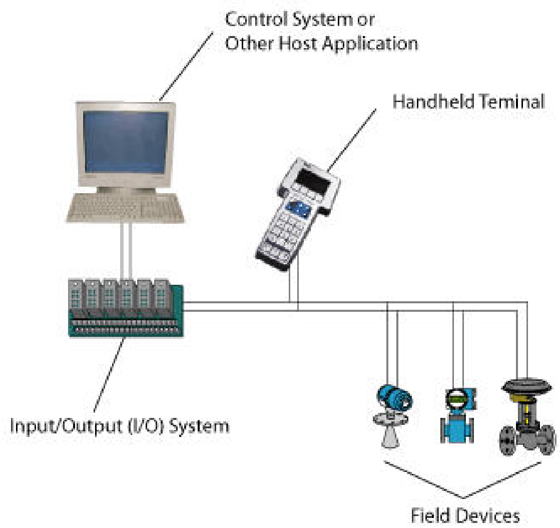


Figure 11.3
HART multi-point communication (Courtesy HART Communication Foundation)

The theoretical maximum length of the cable is 3,000 m, although this can be influenced by many factors. The wire recommended for HART is the same as that used for conventional 4-20 mA instrumentation. The minimum recommended size is a 0.51 mm conductor (#24) up to 1524 m (5000 ft) and 0.81 mm (#20) beyond that. Category 5 shielded, twisted pair wire is recommended by most manufacturers. Devices can be powered by the bus, or individually. If the bus powers the devices, only 15 devices can be connected.

As the cable gets longer, its own resistance increases and the voltage drop across the external resistor decreases. The capable capacitance also creates a filter for the 1.2 kHz/2.4 kHz signal, and the capacitance is directly proportional to the cable length. For this reason the maximum allowable length for specific cables should be calculated, using software such as H-Sim.

The HART handheld communicator

Figure 11.4
375 Field Controller (courtesy Emerson)

The HART system includes a battery-powered handheld control device that can operate as a secondary master on the system. It is used to read, write, range and calibrate field devices, and can be taken into the field for temporary communications. T%he Emerson 375 Field Controller shown here can also be used with FOUNDATION Fieldbus.

11.4 Data Link layer

HART implements layers 1, 2 and 7 of the OSI model. Layer 2 handles the transmission and reception of the data frames, and Layer 7 supports the HART commands.

Layer		Description	HART™
7	Application	Serves up formatted data	Hart Commands
6	Pesentation	Translates Data	
5	Session	Controls Dialogue	
4	Transport	Ensures Message Integrity	
3	Network	Routes Information	
2	Data Link	Detects Errors	Protocol Rules
1	Physical	Connects Device	Bell 202

Figure 11.6

HART addressing

Each HART field instrument has a unique address and each command sent by a master device contains the address of the desired field instrument. All field instruments examine the command sent down the wire, and the one that recognizes its own address returns a response.

The first version of the HART protocol used only a 4-bit address, which resulted in a maximum of 16 field instruments (addresses 0-15) per network. Later, HART was modified to use a combination of the 4-bit address and a new 38-bit address. In this scenario the 4-bit is known as a 'polling address' or 'short address'. The 38-bit address is known as the 'long address', and is derived from a 40-bit address permanently set by the manufacturer. A 38-bit address allows 2^{38} field instruments with unique addresses.

Older field devices that use only a 4-bit address are also known as 'rev 4' field instruments. Modern devices, using the combined addresses, are known as 'rev 5' instruments. These designations correspond to the revision levels of the HART Protocol documents. The current revision is 6 and Revision 4 devices are now considered obsolete.

The two forms of address co-exist in modern field instruments in order to quickly identify a device. Despite all HART commands requiring the long address, HART Command 0 ('READ UNIQUE IDENTIFIER') may be sent to any device by using the short address. This command instructs a field instrument to divulge its long address.

The long address consists of the lower (least significant) 38 bits of a 40-bit unique Manufacturer's ID as shown in the following Figure. The Manufacturer's ID is administered in such a way that no two field instruments will have the same 40-bit identifier.

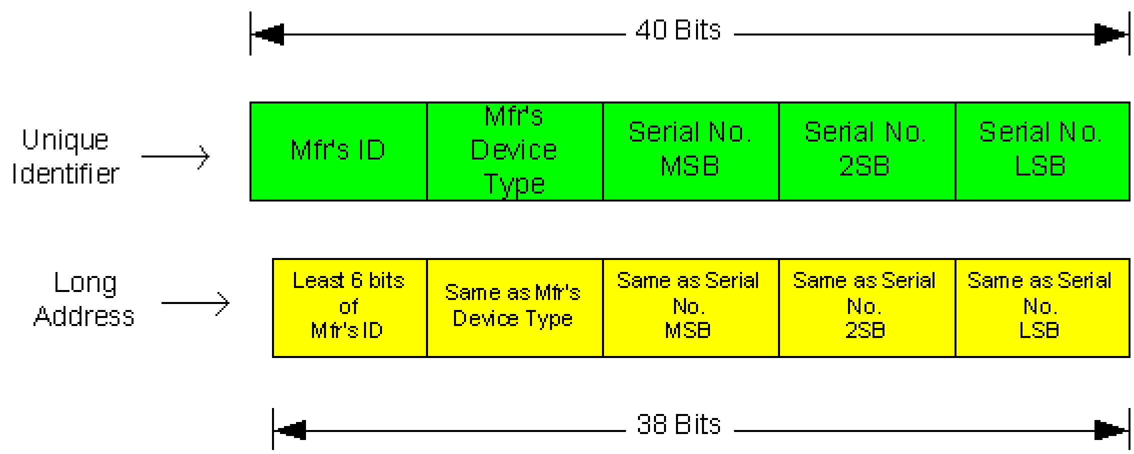


Figure 1.13
Unique Identifier and long address

A field instrument can also be requested to divulge its long address, by using its tag. This is a 6-byte identification code that an end-user may assign to the instrument. Once this assignment is made, Command 11 ('READ UNIQUE IDENTIFIER ASSOCIATED WITH TAG') will provide the same information as command 0, but Command 11 requires a long address, which is what the user wants to ascertain in the first place.

The solution is to use a broadcast address. This has all 38 bits equal to zero and consequently addresses all field instruments simultaneously. When a field instrument sees the broadcast address and Command 11, it compares its own tag against the one included in the command. If they match, it sends a reply.

The short address in both older and newer field instruments can also be used to 'park' a device by setting its short address to any non-zero value. A parked field instrument has its analog output current fixed at a low value such as 4 mA, which is necessary for multi-dropped instruments to avoid a large and meaningless current consumption. Some HART-only field instruments have no analog signal output (digital only) and are effectively parked at all times regardless of the short address.

Message structure

The message frame is transmitted synchronously as a continuous string of 1s and 0s, encoded as differential Manchester. Each byte is, however, also packaged as an 11-bit entity with its own start, odd parity and stop bits, although there is no gap between the stop and start bits of successive byte frames.

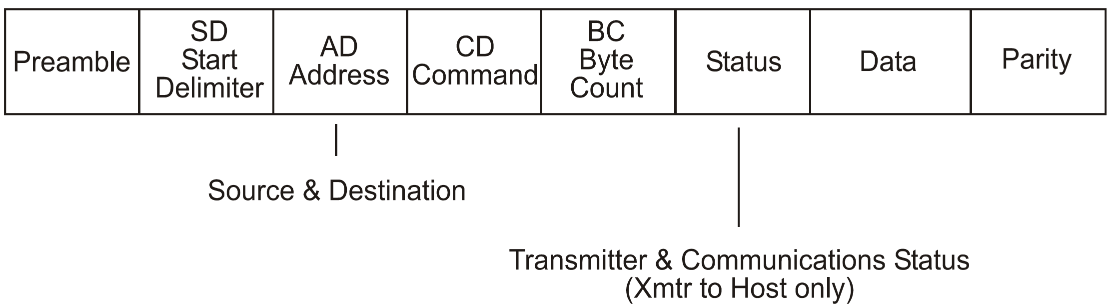


Figure 11.7
HART data link frame format

The various fields in the message are as follows:

- Preamble: (5 - 20 bytes). This consists of repetitive bytes containing 0xFF, and allows the receiver(s) to synchronize
- Start Delimiter (1 byte): This indicates the end of the preamble. It can have one of several values, indicating the type of message viz. master to slave, slave to master, or burst message from the slave. It also indicates the address format i.e. short frame or long frame
- Address (1 or 5 bytes): This includes the master address (a single '1' for a primary master, '0' for a secondary master) and the slave address. In the short frame format, the slave address consists of 4 bits containing the polling address (0 to 15). In the long frame format, it consists of 38 bits containing the 'unique identifier' for that particular device. Another single bit is used to indicate if a slave is in 'burst' mode
- Command (1 byte). This contains the HART command. Universal commands are in the range 0 to 30, Common Practice commands are in the range 32 to 126, and Device-specific commands are in the range 128 to 253

- Byte Count (1 byte). This contains the number of bytes to follow in the status and data bytes. This is needed by the receiver to know when the message is complete, since there is no special character to indicate the end of the message
- Status (2 byte). This is also known as the 'response code' and is only present in response messages from a slave. It contains information about communication errors in the outgoing message, the status of the received command, and the status of the device itself
- Data (0-253 bytes). The data field may or may not be present, depending on the particular command. A maximum length of 25 bytes is recommended, to keep the overall message duration reasonable, although some devices have device-specific commands that use longer data fields. The 253 quoted above is the theoretical limit as the Byte Count field can not contain more than 0xFF or 255, and two bytes are taken up by 'Status'
- Checksum (1 byte). This contains the 'longitudinal parity' of all previous bytes, from the start character onwards)

11.5 Application layer

The application layer allows the host device to obtain and interpret field device data. There are three classes of commands:

- Universal commands
- Common practice commands
- Device specific commands

Examples of these commands are listed below.

Universal commands

- Read manufacturer and device type
- Read primary variable (PV) and units
- Read current output and per cent of range
- Read up to 4 predefined dynamic variables
- Read or write 8-character tag, 16-character descriptor, date
- Read or write 32 character message
- Read device range, units and damping time constant
- Read or write final assembly number
- Write polling address

Common practice commands

- Read selection of up to 4 dynamic variables
- Write damping time constant
- Write device range
- Calibrate (set zero, set span)
- Set fixed output current
- Perform self-test
- Perform master reset
- Trim PV zero

- Write PV units
- Trim DAC zero and gain
- Write transfer function (square root/linear)
- Write sensor serial number
- Read or write dynamic variable assignments

Instrument specific commands

- Read or write low flow cut-off value
- Start, stop or clear totalizer
- Read or write density calibration factor
- Choose PV (mass flow or density)
- Read or write materials or construction information
- Trim sensor calibration

11.6 Typical specification for a Rosemount transmitter

Communication specifications

Method of communication:	Continuous Phase Frequency Shift keying (CPFSK). Conforms to Bell 202 modem standard with respect to baud rate and binary ‘1’ and binary ‘0’ frequencies.	
Baud rate:	1200 bps	
Binary ‘0’ frequency:	2200 Hz	
Binary ‘1’ frequency:	1200 Hz	
Data byte structure:	1 start bit	
	8 data bits	
	1 odd parity bit	
	1 stop bit	
Digital process variable rate:	Poll/response mode:	2.0 per second
	Burst mode:	3.7 per second
No. of multi-dropped devices:	Loop powered:	15 max.
	Individually powered:	no limit
Multi-variable specification:	Max. 256 process variables per smart device	
Communication masters:	Max. 2	

Appendix A

Numbering systems

A generalized number system

A number system is formed by allocating symbols to specific numerical values. Any group of symbols can be used with the total number of symbols for a number system called the **base** of the system.

The three most common bases are:

- Binary, with two symbols (0 and 1) and hence a base of 2
- Hexadecimal, with sixteen symbols (0,1,2...9,A, B....F) and hence a base of 16
- Decimal, with ten symbols (0,1,2...9) and hence a base of 10

When numbers with different bases are being used in the same descriptive text they sometimes have the subscript referring to the base being used, as in 3421.19_{10} for a decimal or base 10 number.

Numerical symbols have to be combined in a certain way to represent other combinations of numbers. The decimal numbering system has the structure laid out in Table A.1 for weighting each digit in the number 3421.19_{10} in a combination of numbers written together.

Exponential notation is used here, for example: 10^2 means 100 and 10^{-3} means 0.001.

Weight	10^4	10^3	10^2	10^1	10^0	.	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
	0	3	4	2	1	.	1	9	0	0	0

Table A.1
Decimal weighting structure

The Most Significant Digit (or MSD) in this number is 3. This refers to the left-most digit that has the greatest weight (10^3 or 1000) assigned to it.

The Least Significant Digit (or LSD) in this number is 9. This refers to the right-most digit that has the least weight (10^{-2} or 0.01) assigned to it.

This represents the number calculated below:

$$\ldots 0\times10^{4}+3\times10^{3}+4\times10^{2}+2\times10^{1}+1\times10^{0}+1\times10^{-1}+9\times10^{-2}+0\times10^{-3}+\ldots$$

Binary numbers

Binary numbers are commonly used with computers and data communications because they represent two states – either ON or OFF. For example, the RS-232 standard has two voltages assigned for indicating '1' (say, –5 Volts,) or '0' (say, +5 Volts). Any other voltages outside a narrow band around these voltages are undefined.

The word **bit**, referred to often in the literature, is a contraction of the words **binary digit**.

The same principles for representing a binary number apply as in section 1 above. For example, the number 1011.1_2 means the following using Table A.2.

Weight	2^4	2^3	2^2	2^1	2^0	.	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}
	0	1	0	1	1	.	1	0	0	0	0

Table A.2
Binary weighting system

This translates into the following number:

$$\ldots\ldots 0\times2^{4}+1\times2^{3}+0\times2^{2}+1\times2^{1}+1\times2^{0}+1\times2^{-1}+0\times2^{-2}+\ldots\ldots$$

The Most Significant Bit (MSB) in the above number is the left-most bit and is 1 with a weighting of 2^3. The right-most bit is the Least Significant Bit (LSB) and is valued at 1 with a weighting of 2^{-1}.

Conversion between decimal and binary numbers

Table A.3 gives the conversion between decimal and binary numbers. Note that the binary equivalent of decimal 15 is written in binary form as 1111 (using 4 bits). This-4 bit binary grouping will have significance in hexadecimal arithmetic later. As expected, binary 0 is equivalent to decimal 0.

Decimal number	Binary equivalent
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001

10	1010 contd…
contd… 11	1011
12	1100
13	1101
14	1110
15	1111

Table A.3
Equivalent binary and decimal numbers

The procedure to convert from a binary number to a decimal number is straightforward. For example, to convert 1101.01_2 to decimal; use the weighting factors for each bit to make the conversion.

$$1101.01_2=1\times(2^3)+1\times(2^2)+0\times(2^1)+1\times(2^0)+0(2^{-1})+1\times(2^{-2})$$

This is equivalent to:

$$1101.01_2=1\times(8)+1\times(4)+0\times(2)+1\times(1)+0\times(½)+1\times(¼)$$

This then works out to:

$$1101.\ 01_2=8+4+0+1+0.25$$

$$1101.\ 01_2=13.25$$

The conversion process from a decimal number to a binary number is slightly more complex. The procedure here is to repeatedly divide the decimal number by 2 until the quotient (the result of the division) is equal to zero. Each of the remainders forms the individual bits of the binary number.

For example, to convert decimal number 43_{10} to binary form:

2	43 remainder 1 (LSB)
2	21 remainder 1
2	10 remainder 0
2	5 remainder 1
2	2 remainder 0
2	1 remainder 1 (MSB)
	0

Table A.4
Illustration of decimal to binary conversion

This translates a number 43_{10} to 101011_2.

Hexadecimal numbers

Most of the work done with computers and data communications systems is based on the Hexadecimal number system, with the base of 16 and uses the sequence of symbols:

0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F

Hence, the number of $FA9.02_{16}$ (also written as 0xFA9.02) would be represented as below in Table A.5

Weight	16^4	16^3	16^2	16^1	16^0	.	16^{-1}	16^{-2}	16^{-3}	16^{-4}	16^{-5}
	0	0	F	A	9	.	0	2	0	0	0

Table A.5
Hexadecimal weighting structure

This translates into the following number:

$$.....0\times16^4+0\times16^3+F\times16^2+A\times16^1+9\times16^0+0\times16^{-1}+2\times16^{-2}+.....$$

The MSD in the above number is the left-most symbol and is F with weighting of 16^2. The right-most symbol is the LSD and is valued at 2 with a weighting of 16^{-2}.

Conversion between binary and hexadecimal

The conversion between binary and hexadecimal is effected by modifying Table A.6 to Table A.6 below:

Decimal number	Hexadecimal equivalent	Binary equivalent
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

Table A.6
Relationship between decimal, binary and hexadecimal numbers

In converting the binary number 1000010011110111_2 to its hexadecimal equivalent the following procedure should be adopted. First, break up the binary number into groups of four commencing from the least significant bit. Then equate the equivalent hex symbol to it (derived from Table A.6 above).

1000010011110111 becomes:

1000	...	0100	...	1111	...	0111_2
8	...	4	...	F	...	7_{16}

or $84F7_{16}$.

In order to convert a hexadecimal number back to binary the procedure used above must be reversed.

For example, in converting from C9A4 to binary this becomes:

C	...	9	...	A	...	4_{16}
1100	...	1001	...	1010	...	0100_2

or 1100100110100100_2.

Binary arithmetic

Addition

Knowledge of binary addition is useful although it can be cumbersome. It is based on the following four combinations of adding binary numbers:

0	0	1	1
$\underline{0}$	$\underline{1}$	$\underline{0}$	$\underline{1}$
0	1	1	0 and carry 1

The carry 1 (or bit) is the only difficult part of the process. This addition of the individual bits of the number should be done sequentially from the LSB to the MSB (as in normal decimal arithmetic).

An example of addition is given below:

1010001001_2
$\underline{0011101010}_2$
1101110011_2

Subtraction

The most commonly used method of binary subtraction is to use 2's complement. This means that instead of subtracting two binary numbers (with the attendant problems such as having 'carry out' bits); the addition process is applied.

For example, take two numbers and subtract the one from the other as follows:

12	which is equivalent to:	1100
$-\underline{4}$	Subtrahend	$-\underline{0100}$
8	Result	1000

The two's complement is found by first complementing all the bits in the subtrahend and then adding 1 to the least significant bit.

Complementing the number results in 0100 becoming: 1011.

Add 1 to the least significant bit gives a two's complement number of: 1100.

Add 1100_2 to 1100_2 as follows:
1100
<u>1100</u>
1000 carry 1
(This is the same result as above).

Exclusive-OR (XOR)

Exclusive-OR is a procedure very commonly used with binary numbers in the error detection sequences of data communications. The result of an XOR operation on any two binary digits is the same as the **addition** of two digits **without the carry bit**. Consequently, this operation is sometimes also called the Modulo-2 adder. The truth table for XOR is shown below:

Bit 1	Bit 2	XOR
0	0	0
0	1	1
1	0	1
1	1	0

Table A.7
Exclusive-OR truth table

Hardware/firmware and software

The hardware refers to the physical components of a device, such as a computer, sensor, controller or data communications system. These are the physical items that one can see.

The software refers to the programs that are written by a user to control the actions of a microprocessor or a computer. These may be written in one of many different programming languages and may be changed by the user from time to time.

The firmware refers to the 'microprograms', usually residing in a read-only memory (ROM) and which normally cannot be changed by the user. The firmware usually controls the sequencing of a microprocessor. Consequently, it is a combination of hardware and software.

A port is the place of access to a device or a network used for the input or output of digital data signals.

Appendix B

Practical Exercises

PART 1: Serial communications

Exercise 1: Setting up

1.1 Overview

This section deals with setting up the software used for the USB-based serial communications exercises.

1.2 Software/ documentation required

- Listen32.zip (Win-Tech software)
- Quick Installation guide for Moxa UPort 1110/1130 USB-to-Serial adaptors
- Driver/documentation CD for Moxa UPort 1110/1130 USB-to-Serial adaptors
- Driver CD for PicoScope
- Virtual Serial Port Driver (Eltima)

NB The same driver disk is used for both the RS-232 and RS-485 converters (just install once). However, please ensure that you use only version 2.2 or later (and not 2.0) as the older version seems to cause hardware conflicts. The version number can be seen in the 'Readme' file on the CD. Also, do not use the old driver CD that was shipped with the PicoScope. Ensure that you have a CD with the latest version downloaded from the Internet.

1.3 Implementation

1.3.1 Moxa UPort adaptors

The following steps assume that the adaptor driver has not been installed yet. Please check before proceeding.

The installation procedure is very well documented in the Quick Installation Guide as well as the PDF version of the manual on the CD, hence it will not be repeated here. Basically just follow the prompts and ignore messages indicating that the software has not been tested to run on XP.

With the converter UNPLUGGED from the computer, run the installation program. This is located on the CD; go to *UPort 1100 ->Software->[Your operating system]*. Follow the prompts as per the Quick Installation Guide.

After installing the driver, plug in the UPort 1110 converter. Windows will detect the new hardware and proceed with the installation. Follow the prompts as per the Quick Installation Guide.

Run the Device Manager (*Start->Settings->Control Panel->Hardware*) and confirm that there are no conflicts (yellow circles with exclamation marks). This might occur if you use an older version of the driver disk.

The actual configuration of the converter will be covered in the next exercise.

1.3.2 Listen32

The following steps assume that Listen32 has not been installed yet. Please check before proceeding.

For the sake of consistency (and to help the next person using the machine), please create a folder *C:\Listen32* and then unzip Listen32.zip into this folder. You will notice the following components:

LISTEN32.EXE
This is the executable. Right-click and create a shortcut. Move the shortcut to the desktop.

LSTN32.DLL
This is a hooking DLL for tracing COMM API calls from third-party applications.
It should be copied to the Windows search path (C:\Windows or C:\Windows\System).

LISTEN32.HLP
This represents the on-line help menu support for the application and should remain in the same directory as Listen32.exe.

LISTEN32.CFG
Represents configurable parameters modified during execution of the application. It will automatically be created in the working directory upon exiting the application.

At this point Listen32 will run, but in demo mode only. Please type in the registration info to be found in a Word file on the distribution CD.

1.3.3 PicoScope

With the Scope unplugged from the computer, run the PicoFull setup program from CD. This will be on a CD supplied by IDC. Please do not use the CD that came with the device, as that is out of date. The following shortcut will appear on the desktop.

Plug the Scope into the USB port. Windows will detect the new hardware TWICE (once for each channel).

1.3.4 Virtual Serial Port Driver

Run the installation program (‘vspdxp’) from the distribution CD. The program will be fully functional, but for 14 days only. Please type in the registration info to be found in a Word file on the distribution CD. The following **shortcut** will appear on the desktop.

This concludes the software setup.

Exercise 2: RS-232 basics

2.1 Overview

The objective of this exercise is to give delegates an understanding of how asynchronous data serial data communications operate, using a breakout box on the COM port of a laptop computer. Since most laptops nowadays do not have physical COM ports, we will use a USB-to-Serial converter to accomplish this. The MOXA adapter used actually has on on-board UART, so the UART has simply been relocated from the motherboard to the USB adapter. The output of the serial port will be monitored by means of an oscilloscope and a voltmeter.

2.2 Hardware required

- 1x Laptop with at least two USB ports. If it has only one port, you may have to run the USB oscilloscope on a different machine
- 1x MOXA NPort U1110 (a.k.a UPort 1110) USB-to-serial (RS-232) adapter
- 1x 9-pin D-type female to 25-pin D-type male adapter plug (‘straight’) (DB-9F/DB-25M)
- 1x breakout box
- 1x Voltmeter
- 1x PicoScope 2202 USB oscilloscope, or similar, with probes

2.3 Software required

It is assumed that all software and drivers have been installed as per Exercise 1.

2.5 Implementation

2.5.1 Basic port setup

The keystrokes described here are for Windows XP.

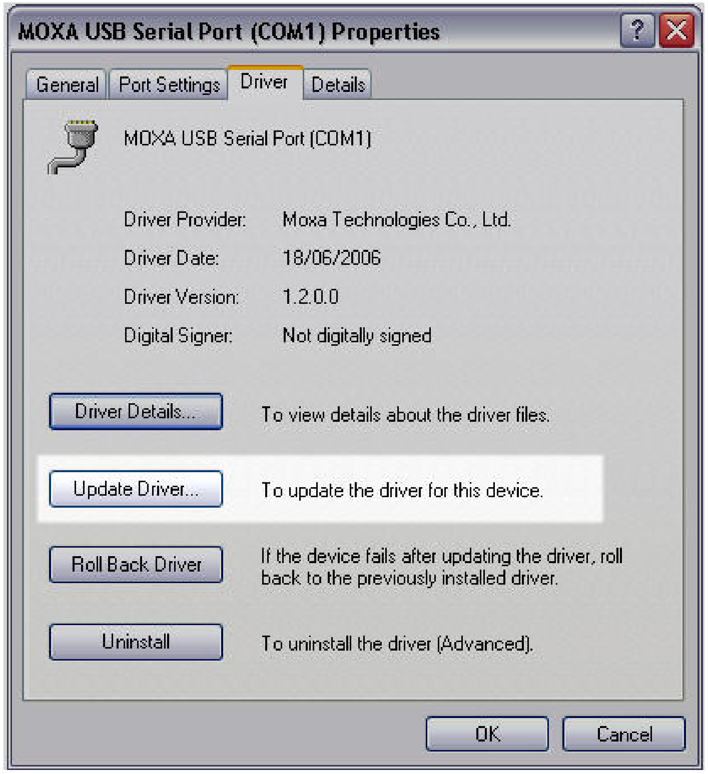
Turn on the computer

Plug the RS-232 adapter into the USB port and visually confirm that the red LED on the converter lights up.

The purpose of the three LEDs are as follows (refer to the operating manual on CD)

Name	Description
Active	This LED indicates normal operation. If the driver is installed correctly and the adaptor is plugged into a functioning USB port, the Active LED will light up and remain on. If the LED does not light up, there may be a problem with the adaptor, the driver installation, or PC configuration.
TxD	This LED blinks when the adaptor transmits data through its COM port.
RxD	This LED blinks when the adaptor receives data through its COM port.

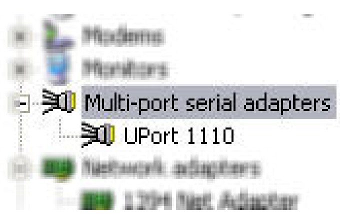
If the red LED on the converter did not light up earlier, or a yellow exclamation mark shows up against the MOXA entries in the Device Manager, it could be that the driver settings have been altered because someone has previously used the MOXA UPort 1130 USB-to-RS-485 converter on this machine.



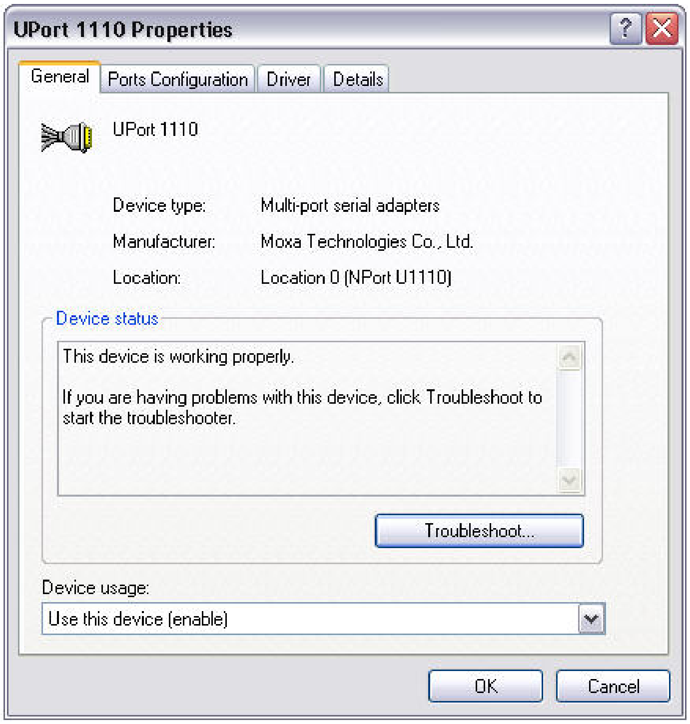
In this case, simply select the Divers tab and click on ‘Update Driver’.

Let’s assume that the LED lights up.

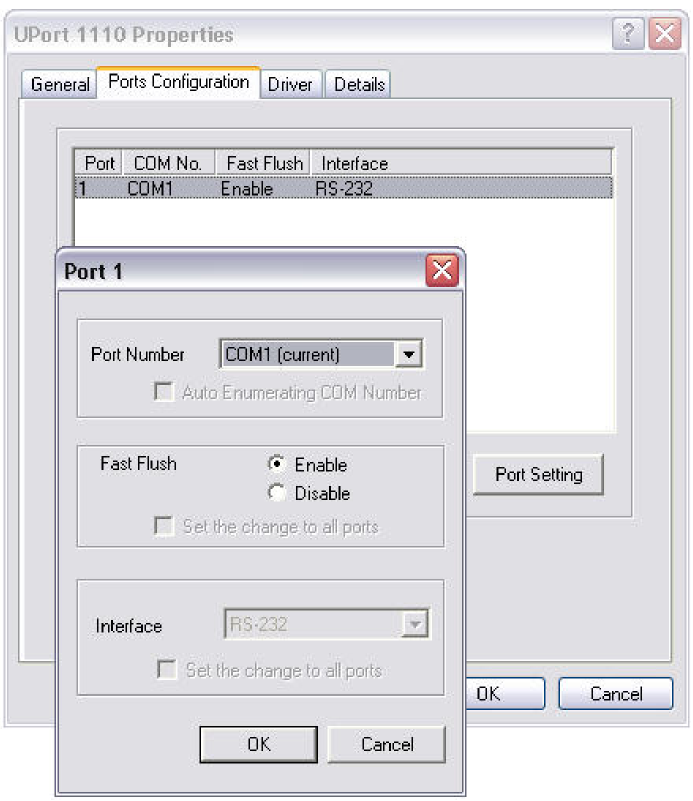
Click: Start->Control Panel ->System->Hardware->Device Manager.
Locate the entry that reads: ‘Multi-port serial adapters’ and expand it to show the UPort 1110.



Double-click (or right-click->Properties) on ‘UPort 1110’ to obtain its properties window.

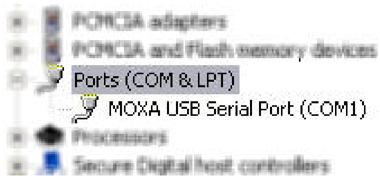


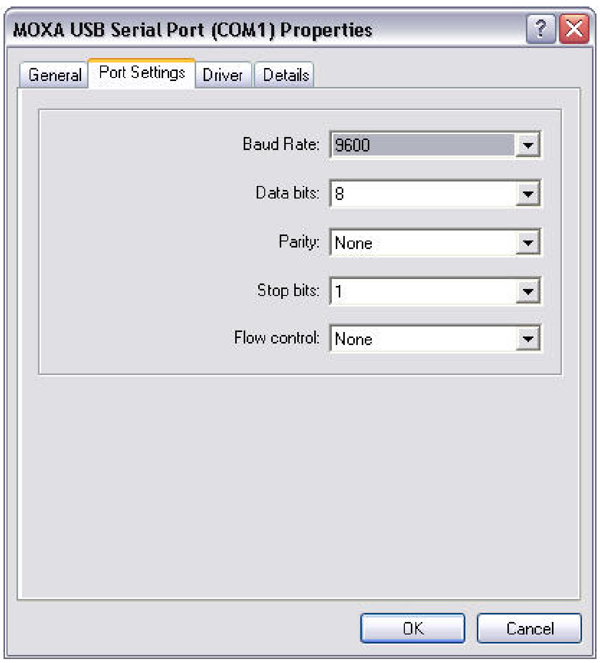
Select the ‘Ports Configuration’ tab and confirm that the correct COM port has been allocated to the UPort 1110.



If the port number is incorrect, click on ‘Port Setting’ and select an appropriate one. On a machine without any COM ports any one could be selected, but on machines with existing COM ports you have to select a different one to avoid conflicts. On this particular machine there are no physical COM ports, so we selected COM1.

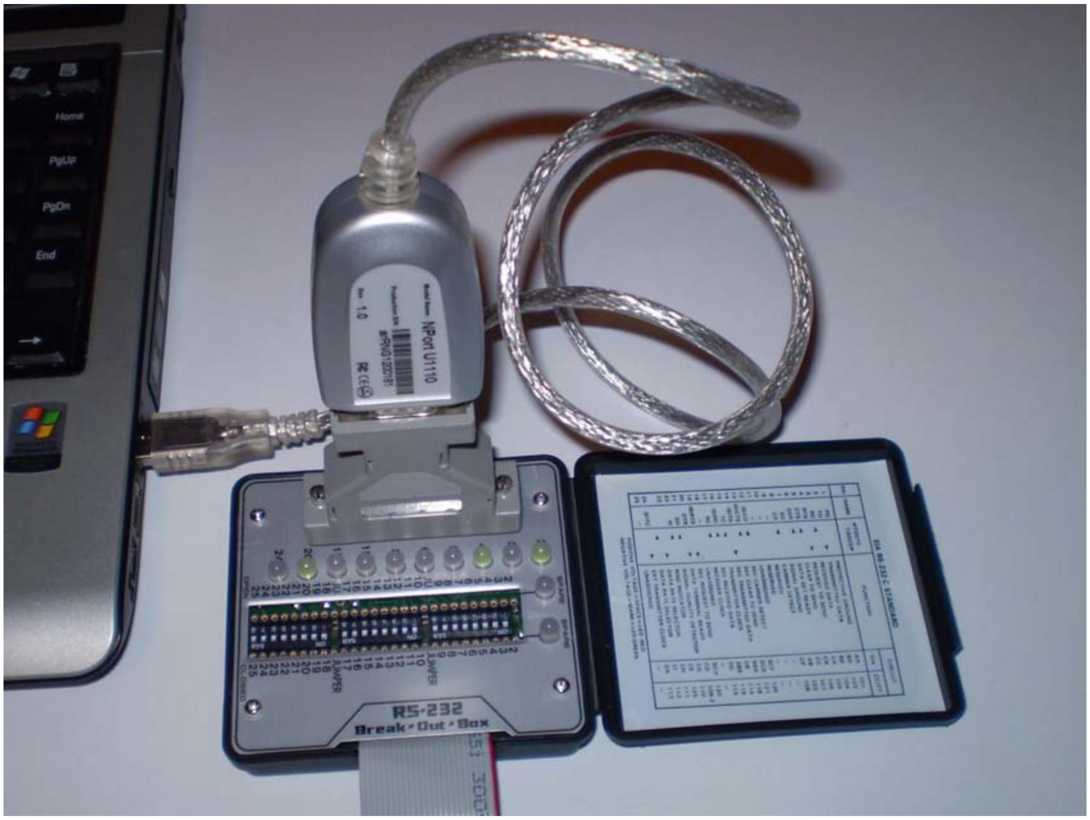
As an additional check, go back to the Device Manager and locate 'MOXA USB Serial Port (COM1)' (this is the COM port number we selected earlier). Double-click (or right-click->Properties) on the MOXA entry to obtain the MOXA serial port properties. Select the 'Port Settings' tab and check the Universal Asynchronous Receiver Transmitter (UART) settings. These settings can, however, be overwritten by application programs such as Listen32.





2.5.2 Confirmation of idle voltages

Connect the USB converter to the breakout box by means of the DB-9/DB-25 plug. You may have to remove the two hexagonal lock nuts on the 9 pin connector as they interfere with those on the adaptor.



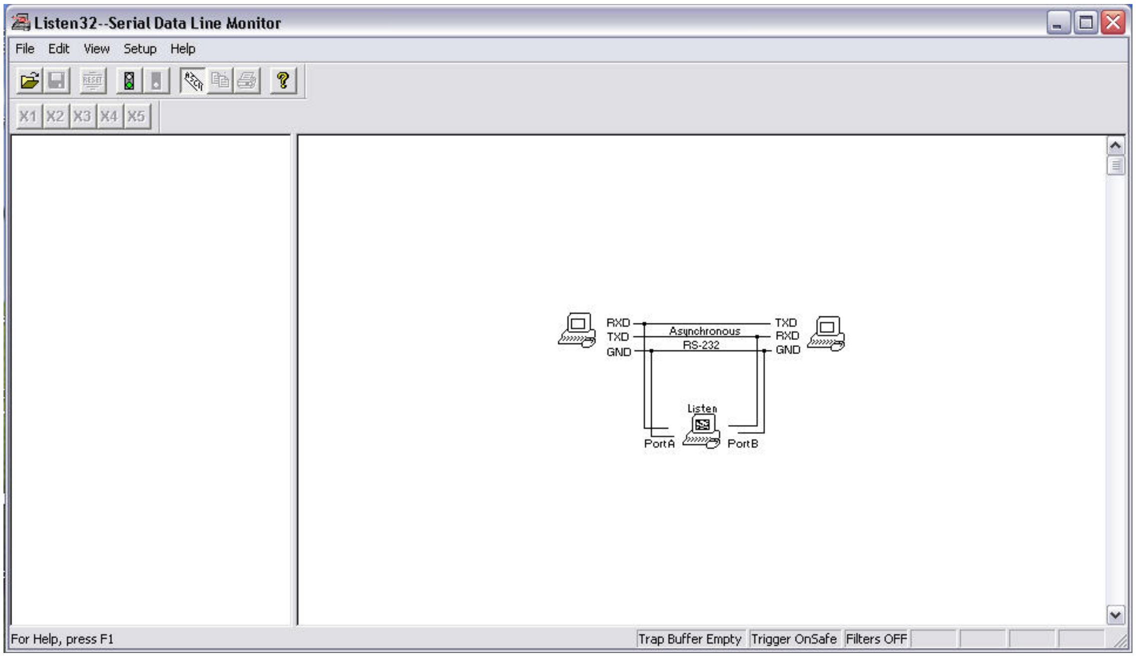
Verify the following:

- TxD is a '1' i.e. between -5V and -25V with respect to ground (note value) and corresponding LED is green
- RxD is zero (not connected to DCE)
- RTS is '0' i.e. between -5V and -25V with respect to ground and corresponding LED is green
- CTS is zero (not connected to DCE)
- DTR is '0' i.e. between -5V and -25V with respect to ground and corresponding LED is green
- DSR is zero (not connected)

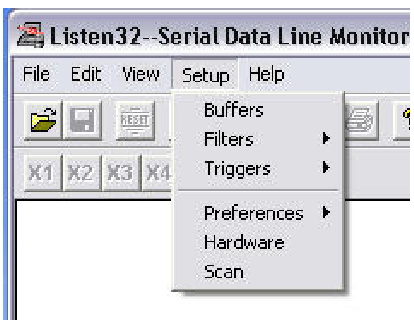
2.5.3 Transmitting a single character

Invoke Listen32 by clicking on the desktop icon.

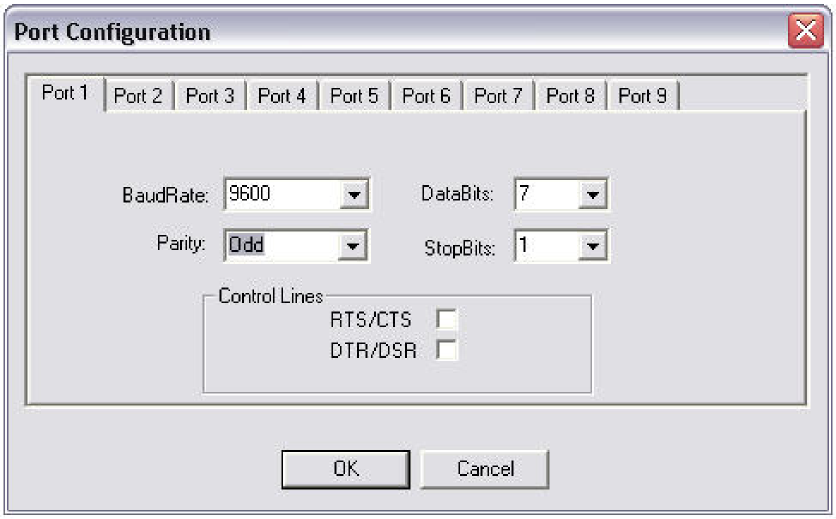
Listen32 will open up:



Click Setup->Hardware:

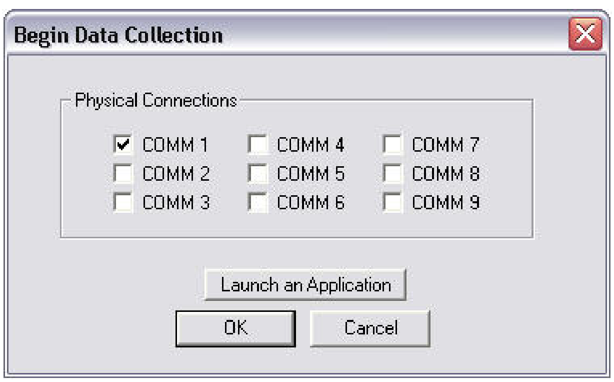


Then set the UART parameters for the appropriate COM port (COM1 in this case). Set the parameters exactly as per the following figure: 9600, 7, O, 1.

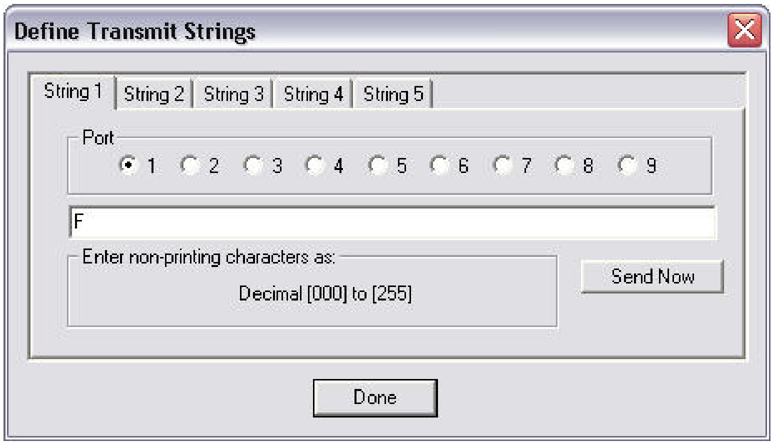


Next, start the port monitoring process by clicking on the green traffic light (click red to stop).

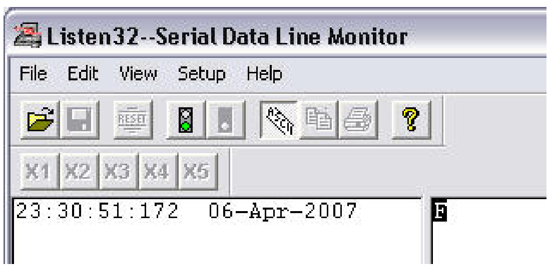
The ‘Begin Data Collection’ window will appear. Select the appropriate port (COM1 in this case).



Ten click Edit->Transmit string. The ‘Define Transmit Strings’ window will appear.



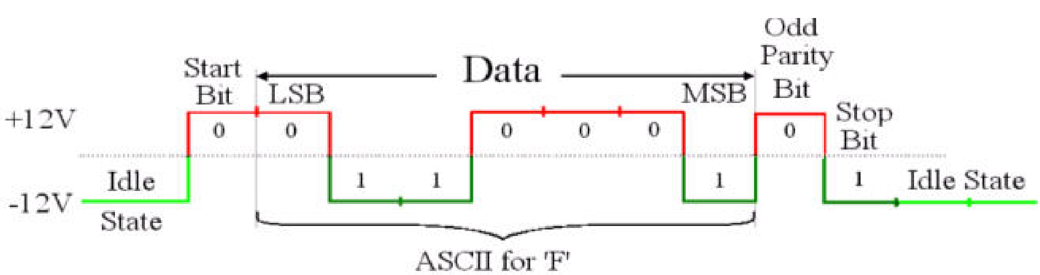
Select String 1 for the appropriate, and enter upper case F. Click 'Send Now' to transmit. The transmission will be logged. Note: At 9600 baud the flickering of the TxD LED on the converter due to a single character will not be noticed. However, sending several Fs (say, 20 to 30) will allow you to visually confirm that transmission is actually taking place.



Send a single 'F' again, but this time monitor the TxD output (against ground) with the PicoScope. If the machine running Listen32 has only one USB port, run the scope on an adjacent machine. Set the PicoScope as follows:

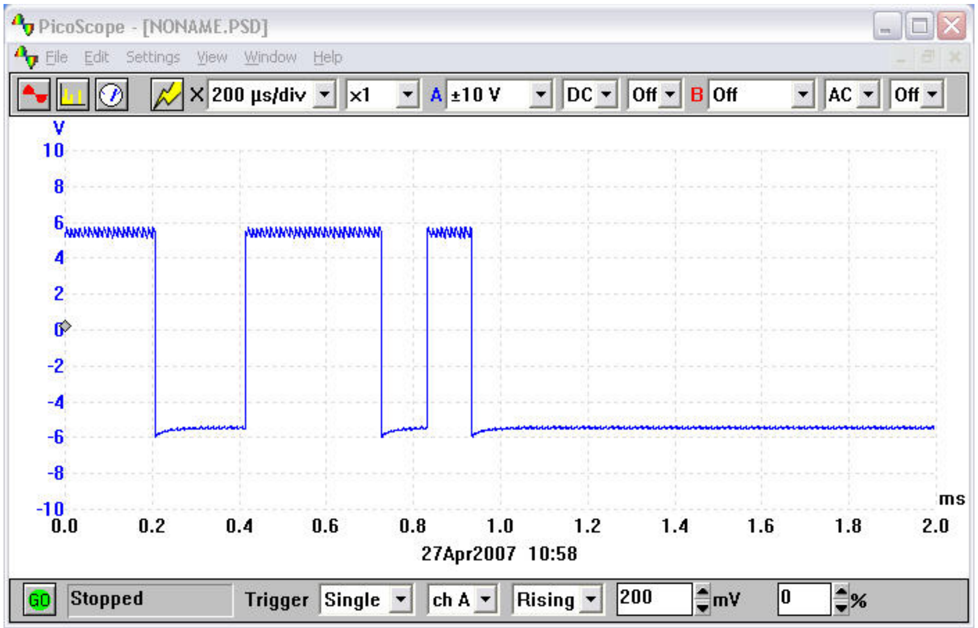
- Trigger: Single trigger, Channel A , rising edge
- X-axis: 200 microseconds per division
- Magnification: X1
- Y-axis full scale: +/-10V
- Coupling: DC

Click 'Go' in the bottom left hand corner and then send 'F' again. In theory, the waveform should look like this.



The actual waveform is shown in the following figure. The voltage levels are around -5.5V, +5.5V due to the specific machine (Toshiba Satellite) to which the converter is connected. For laptops, these voltages seem to vary from around +/- 5.5V to +/-9V and they are often not symmetrical with respect to ground.

Do not worry too much about attaching the ground clip on the probe, as the PicoScope and the USB converter are connected to the same ground via USB.



2.5.4 Other exercises involving single character transmission

Choose an arbitrary number from the ASCII table, draw its waveform on a piece of paper, then press the corresponding key and corroborate the waveform. You may change the parity setting. Click on View->ASCII table (in Listen32) if you do not have a copy of the ASCII table handy.

Next, select a character (change the port settings if necessary) that will produce a square wave with a 50% duty cycle.

2.5.5 Loop-back test

Perform a loop-back test by inserting a jumper between pins 2 and 3 of the breakout box. What do you see on the screen when you type a character? What do you see on the breakout box in terms of pins 2 and 3?

Exercise 3: RS-232 point-to-point communication

3.1 Overview

The objective of this exercise is to set up communications at 9600 Baud between two laptops (DTEs) by means of a null modem cable

3.2 Hardware required

- 2 x Laptop with MOXA UPort 1110 already set up.
- 1x null modem cable

3.3 Software required

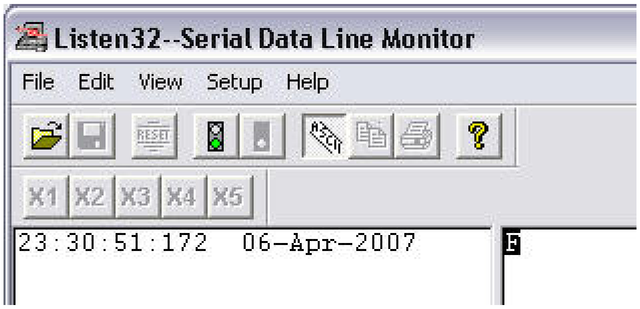
It is assumed that Listen32 and the USB-to-serial adapter driver have already been installed

3.4 Implementation:

Interconnect the two COM ports with a null modem cable.

Follow the steps outlined in the previous exercise and set the ports up to 9600,7,N,1

Type any characters and check of the communication is working. The transmitted character(s) should show up on both machines.



Now click on Setup->Preferences->Num base, and alternate the display between decimal, hex and binary; each time verifying the letter(s) that you have typed against the ASCII table.

Exercise 4: RS-232 via virtual null modem

4.1 Overview

The objective of this exercise is to demonstrate the use of a virtual null modem to check communications between two applications on the same PC.

4.2 Hardware required

- 1 x Laptop

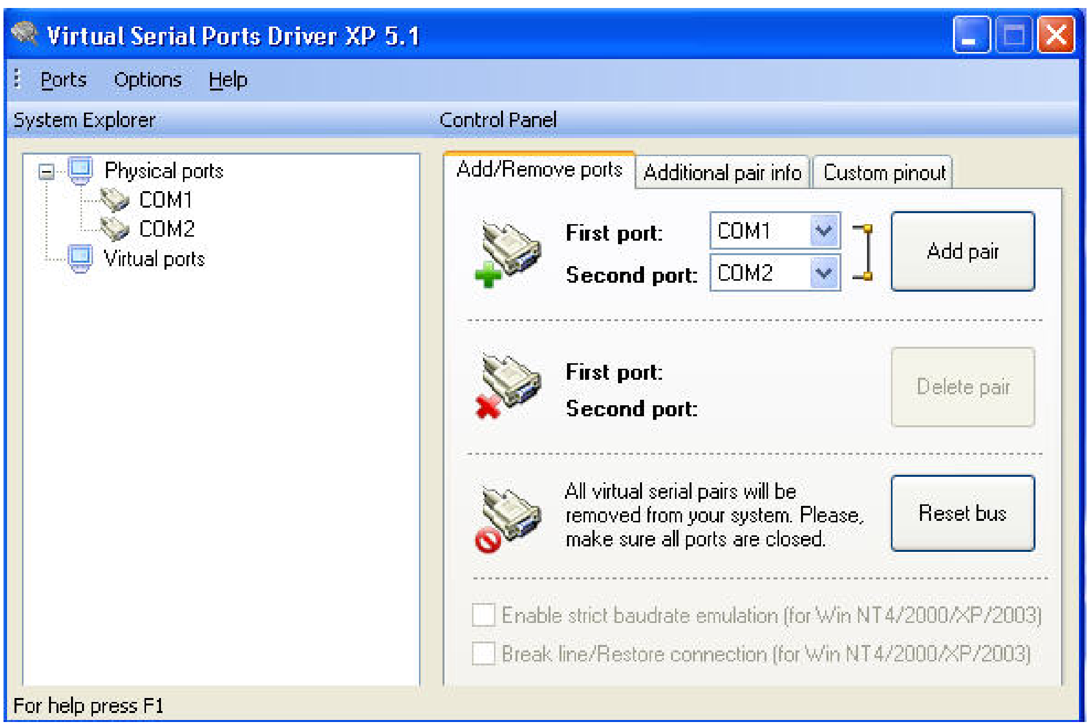
4.3 Software required

It is assumed that Listen32 and the Eltima software have already been installed in Exercise 1.

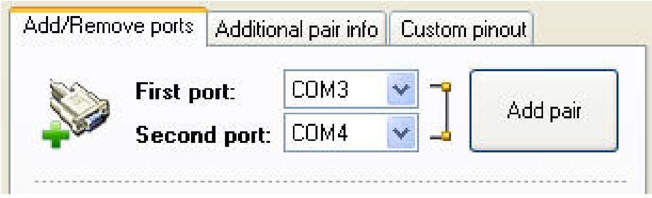
4.4 Implementation:

4.4.1 Setting up the virtual null modem

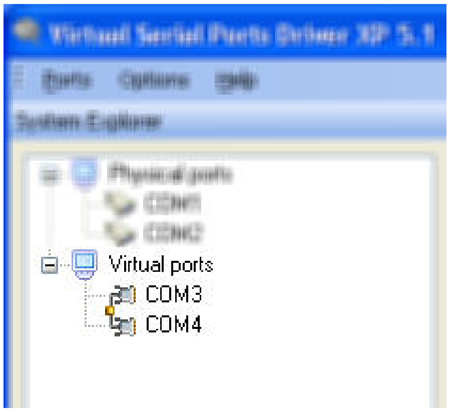
Run VSPD CP 5 from the desktop by clicking on the  icon.



Notice the two physical ports (COM1 and COM2) detected on the computer, and shown under 'Physical Ports' in the System Explorer box. Now select any two non-conflicting ports for the 'First port' and 'Second port' in the top right-hand corner. In this case we have selected COM3 and COM4.

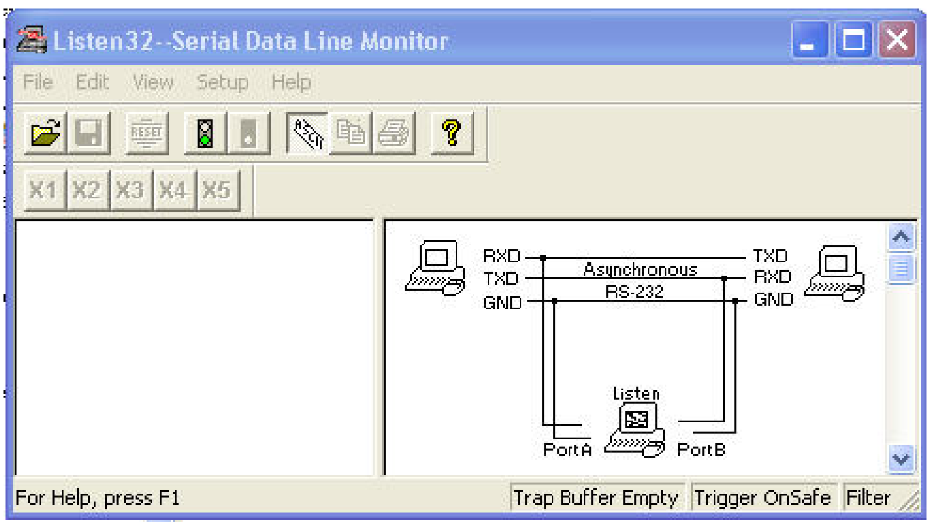


Click 'Add pair'. COM3 and COM4 will now appear as 'Virtual Ports' in the System Explorer box, with a null modem connection between them.

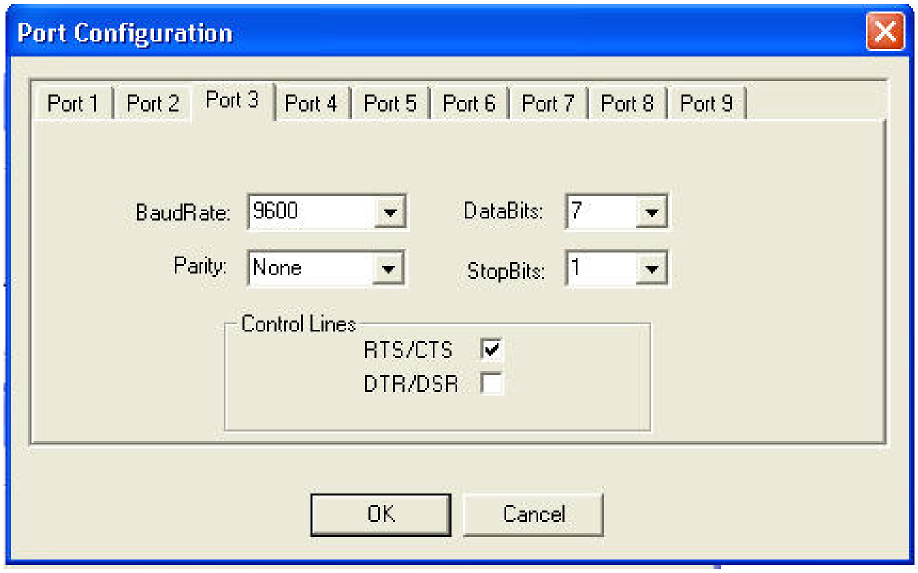


4.4.2 Running two applications across the virtual null modem

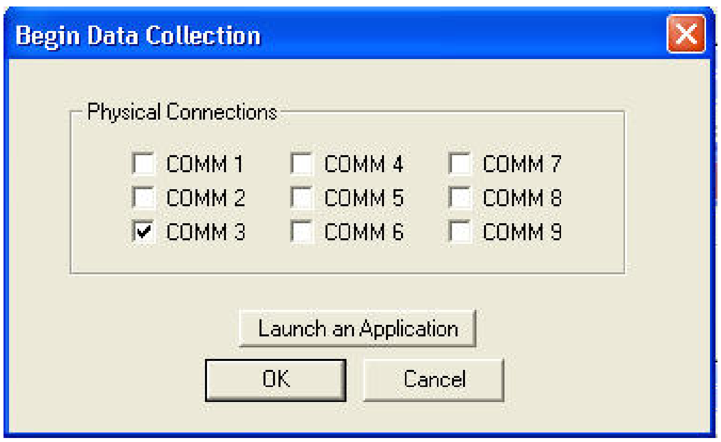
Run Listen32 by clicking on the desktop icon.



Do this again to create a second instance of the program, and position them side by side. Set them up in the same way, but associate them with COM3 and COM4 respectively. The next figure shows the port configuration for one instance. Note the checked RTS/CTS box to enable hardware handshaking.



Also start the data collection on both instances, using COM3 and COM4.



Finally, send data from one instance to the other, and try it in both directions.

Exercise 5: RS-485 basics

5.1 Overview

This exercise will build upon the previous RS-232 exercise, and will introduce the use of RS-485

5.2 Hardware required

- 2x laptops with USB ports
- 2x MOXA UPort 1130
- Voltmeter
- Oscilloscope (if available)
- 2 meters Cat5 twisted pair wire
- Screwdriver, wire stripper

5.3 Software required

It is assumed that the Listen32, PicoScope software and USB-to-serial adapter drivers have been installed.

5.4 Implementation

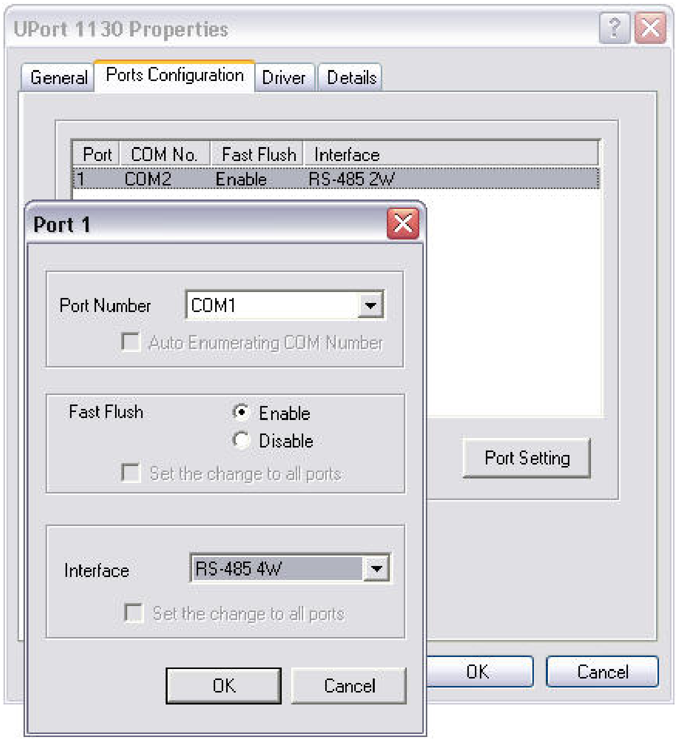
5.4.1 Basic setup

With the exception of its outputs, the UPort 1130 is identical to the UPort 1110.

Plug the UPort 1130 into the USB port in place of the U1110. Check that the red LED lights up. Attach the screw terminal to the DB-9 connector. If the red LED does not light up, update the driver as described in paragraph 2.5.1 of Exercise 2.

The first step is to confirm the device configuration.
As in the case of the UPort 1110, go to the Device manager and locate the ‘Multi-port adapters’

entry. Open it up to show the UPort 1130, then double-click (or right-click->Properties) on the 1130 entry to open the UPort 1130 Properties window.

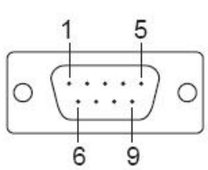


There are three transmission options possible, viz.:

- RS-485 4-wire
- RS-485 2-wire
- RS-422

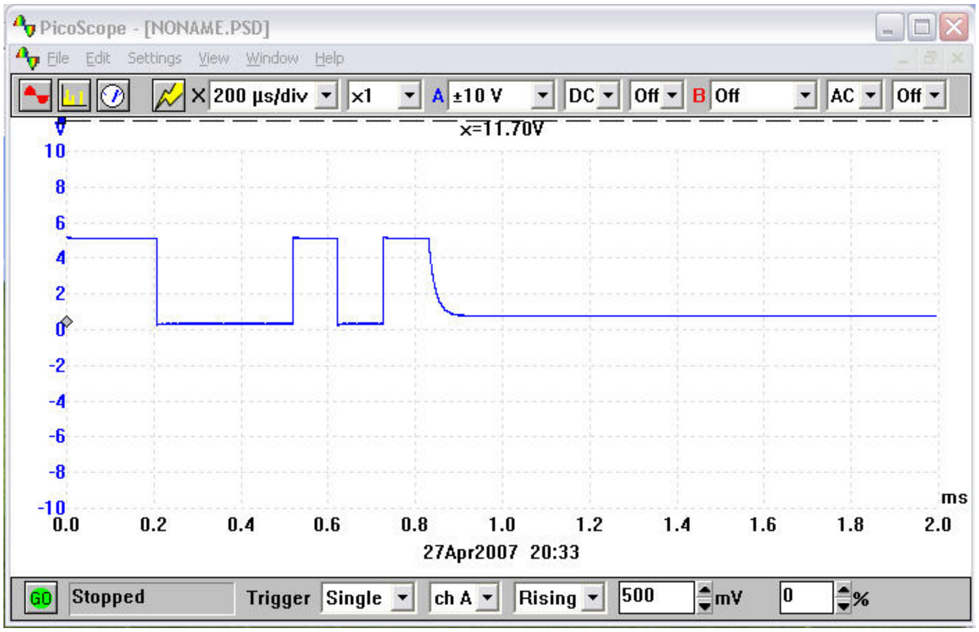
5.4.2 RS-485 4-wire

Check that '4W' mode has been selected (refer to figure above). Interconnect two machines via pins 1, 2, 3 and 4, using 2 pairs of Cat5. Observe the colors so that pin 1 or 'TxD-(A)'(a.k.a. 'A-wire out', shown as 'T+' on the connector- very confusing) on the one machine goes to pin 4 or 'RxD-(A)' (a.k.a 'A wire in', shown as R+ on the connector) on the other machine. In similar fashion, connect pin 2 or 'TxD+(B)'(a.k.a. 'B-wire out', shown as 'T-' on the connector) on the one machine to 'RxD+(B)' (a.k.a 'B wire in', shown as R- on the connector) on the other machine. In plain English, connect T+ and T- on the one terminal strip to the corresponding R+ and R- on the other terminal strip. This, of course, has to be done in both directions.

		UPort 1110	**UPort 1130**	
DB9 (male)	**Pin**	**RS-232**	**RS-422 4-wire RS-485**	**2-wire RS-485**
	1	DCD (in)	TxD-(A)	-
	2	RxD (in)	TxD+(B)	-
	3	TxD (out)	RxD+(B)	Data+(B)
	4	DTR (out)	RxD-(A)	Data-(A)
	5	GND	GND	GND
	6	DSR (in)	-	-
	7	RTS (out)	-	-
	8	CTS (in)	-	-

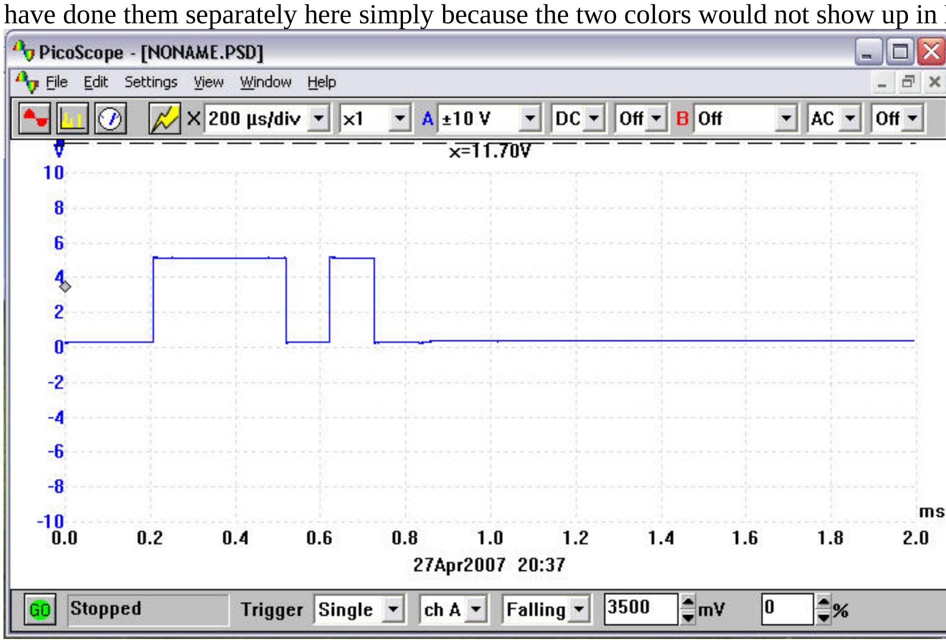
Use Listen32 as in the previous exercises to send characters from one laptop to the other. Observe the results on the display.

Observe the voltage on T+ (i.e. the 'A' wire) on the one machine by means of the PicoScope and send an 'F'. Use the scope settings as shown below for a baud rate of 9600. The trigger level needs to be higher than 200mV as the RS-485 signal does not go right down to 0V (in this case we used 500mV). Remember to click the GO button before sending the 'F'. The transmission starts off with a low-to-high transition that is not evident from this picture, not shown because the actual triggering took place on that transition. Notice how the output at the end of the last bit (at approximately 8.5 mS) is not driven back to 0V but, instead, just decays to a residual level because the driver has gone into a high-impedance state at that point.



Now observe T- (i.e. the 'B' wire) when sending the same character. In this case the transmission begins with a high-to-low transition, on which the triggering takes place.

These scope traces can be obtained simultaneously with two probes (traces showing up in red and blue). We have done them separately here simply because the two colors would not show up in B/W print.



Notice the slight 'step' where the output goes into the high-impedance state.

5.4.3 RS-485 2-wire

Change the adapter configuration from ‘4W’ to ‘2W’. This time we are not cross-connecting the outputs and inputs. Instead, all outputs are connected in parallel, since they are connected to a bus. Data-(A) is connected to Data-(A) (pin 3) and Data+(B) is connected to Data+(B) (pin 4); regardless of the number of laptops used.

Repeat the previous exercise by sending characters across the link.

PART 2: Network communications

Exercise 6: Setting up Ethernet network

6.1 Overview

This exercise illustrates the setup of a very simple 10/100 Mbps Ethernet LAN. This will serve as the basis for our subsequent exercises.

6.2 Hardware required

The hardware required for this practical is as follows:

- Two or more laptops
- 1x Ethernet network interface card (NIC) per computer, unless the Ethernet interface is already built-in
- 1x Cat5 UTP fly-lead per computer
- 1 x hub. Note: the kit contains two small 5 port hubs (SureCom) that can be wired together if necessary.

6.3 Software required

The software required is as follows

- All the computers loaded with Windows 2000/XP
- Driver software for the NICs as provided by the manufacturer.

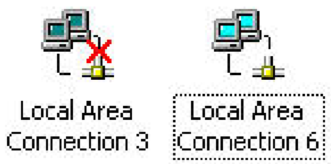
6.4 Implementation

To set up a basic network insert the NICs, if required, into the appropriate slots. Then connect each NIC to the hub with a flylead.

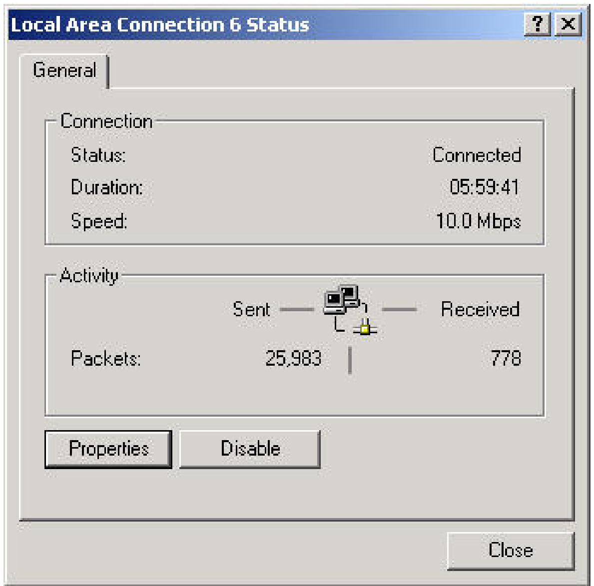
Hub connections

When the computer prompts you to log on, use the user name and password supplied by the instructor. You HAVE to log on if you require access to the LAN.

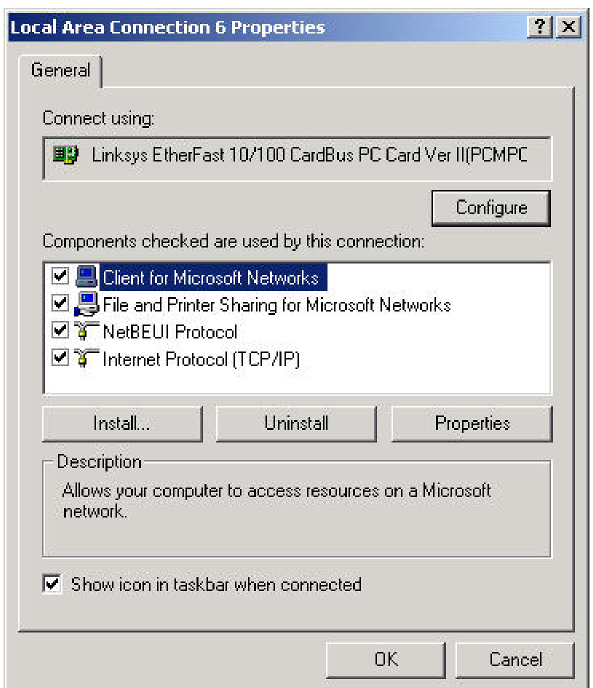
Now click *Start* -> *Settings* -> C*ontrol panel* ->*Network and Dial-up Connections*. The red 'X' indicates that the NIC representing 'local area connection 3' is not currently connected to a hub.



Double-click the local area connection you wish to configure (e.g. local area connection 6 in this example). The following will appear:



Click on *Properties*.



Notice the following:

- The *client* (Client for Microsoft Networks) enables your computer to connect to other computers and access their resources
- 'Connect using…..' refers to the hardware device that physically connects your computer to the network, i.e. the Ethernet NIC in this case. The presence of the 'adapter' icon indicates that the driver for the card has been installed.
- The *protocols* occupying OSI layer 3 and 4 are, in our case, NetBEIU and TCP/IP. All hosts must use the same protocols in order to communicate with each other. Although TCP/IP would have been

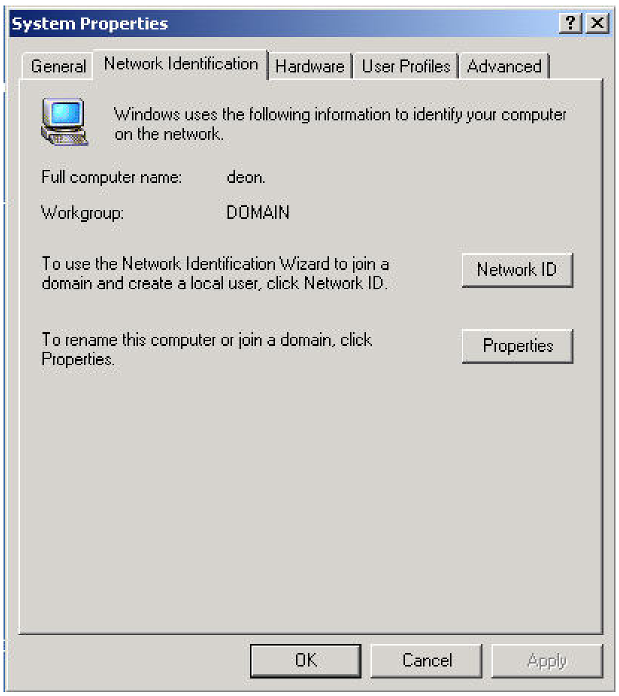
sufficient, NetBEUI had been added to facilitate file sharing between computers using NetBIOS names such as ‘computer1’. It will also allow you to access resources on the other machines in case TCP/IP is not working e.g. because of incorrect IP addresses.

- The *service* (File and Printer Sharing for Microsoft Networks) enables your computer to share its resources such as files, printers and other services with other computers on the network.

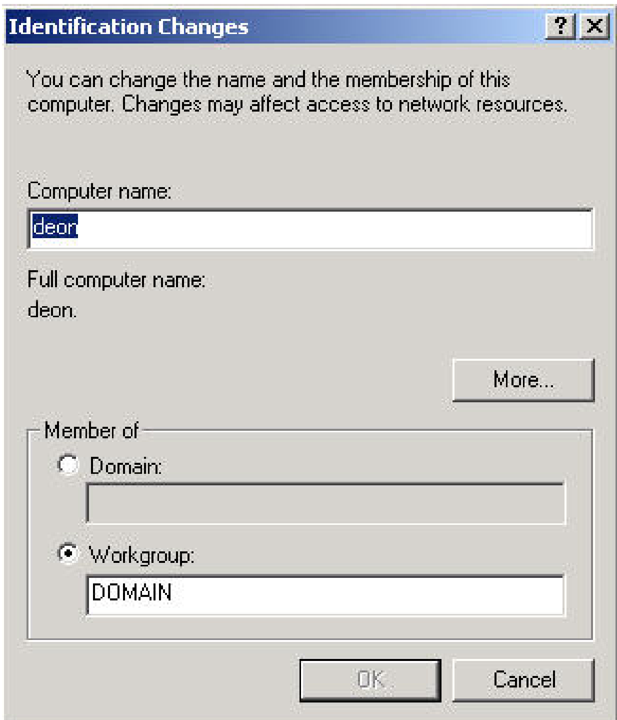
As soon as the NIC is inserted into the computer for the first time, the operating system prompts the user to provide the necessary device drivers. Thus the Client, Service, Adapter and Protocol components are automatically installed. TCP/IP is normally installed by default. If NetBEUI is not installed, you may have a problem seeing all the interconnected machines under ‘My Network Places’. You can add it with the ‘Install’ button just below the list of checked components.

Click *OK* and *Close*.

Now **right** click on *My Computer*, and then click on *Properties* and select *Network Identification.*



Now click on *Properties* and check/edit the computer name as well as the workgroup or domain name.



Computer name is a unique identity for your host computer on the network e.g. 'Computer1' (check with the instructor). This is also referred to as the NetBIOS name.
Workgroup is the name of the workgroup in which the host computer will appear e.g. 'idc' (check with the instructor). In the snag above, the workgroup name is shown as 'domain' but only because that was the name of the workgroup at that given moment in time; it does not refer to an actual domain.

You will be prompted for a user name and a password after rebooting. ALWAYS log on otherwise you will not get access to the network.

The computer should now be suitably configured for networking, and you can explore some troubleshooting of the wiring and hubs.

You will notice that the NIC and associated port on the hub both have their link integrity lights illuminated. Unplug the UTP cable and observe both lights extinguish. The link integrity lights are illuminated only when both devices are operational and correctly wired.

Unplug the UTP cable at both the NIC and hub and replace it with the crossover cable. Note that both sets of lights are extinguished because the wiring is now incorrect. If the hub has a crossover (Uplink) port then plug the crossover cable into this and observe the link integrity lights illuminate as the wiring is once again correct.

Plug the crossover cable directly into another NIC and observe both sets of lights illuminate. This is a useful way of connecting two computers without a hub, for file transfers etc.

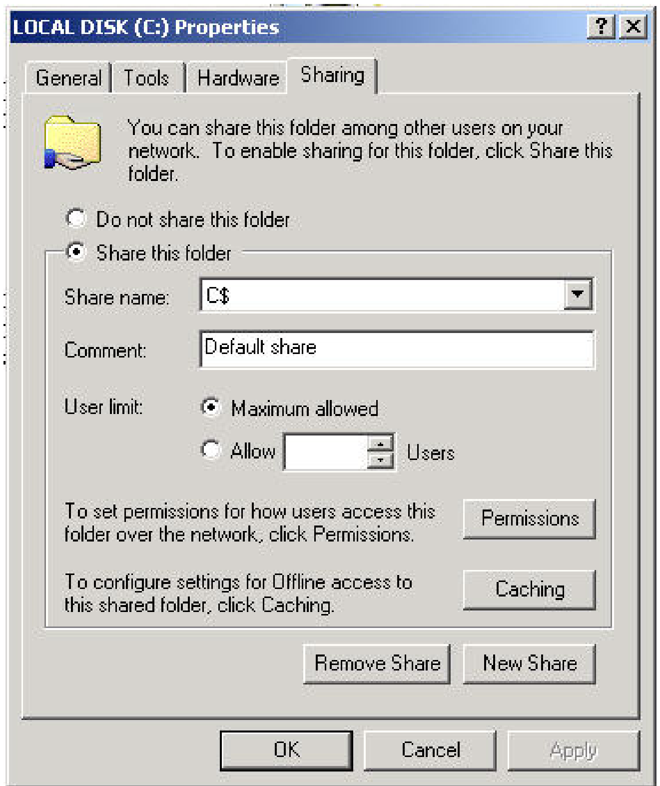
If the link integrity light at the hub is not illuminated simply swap that cable to another working port on the hub to check that the port itself is not faulty.

Whenever data is being sent on the network the network activity lights on ALL ports and NICs will flicker since all messages on an Ethernet network are sent to all users. As other computers are being booted up onto the network activity should be noted. (NB: This is true for a hub, but not for a switch).

Some of the newer devices such as access points we will be using have auto MDIX on all or some ports, meaning that you can use either straight or crossover cable and the port will automatically configure itself.

Invoke Windows (e.g. right click on *Start*, then click *Explore*).

Select the *C drive* and then using the right mouse button right click on the same and select *Sharing*.



Select *Share this folder* and provide a *share name* for this resource. Click on *Permissions* to set access permissions. Click on *Apply* followed by *OK*.

Notice the small hand symbol under the C drive icon indicating that this drive is now shared.

Other resources may similarly be shared.

This concludes the basic network setup of host computers. To verify whether the network setup is OK, double click on *My network places* and *Computers near me* to view the other computers on the network. To see the shared resources available on a specific computer, just click its icon.

You may now browse the network neighborhood and the other computers' shared resources. You may also transfer files back and forth across the network, view a remote file, execute a remote program, etc., all from the comfort of the local host computer.

Notes:

During boot-up, there may be errors displayed stating that there is already another computer on the network with the same name, and all networking services would be disabled. Follow the procedure described above and choose another computer name and restart
Some users may not be able to browse the network neighborhood ('My network places') since they have not logged in with an appropriate username and password at the time of boot-up. Log-off and logon as a valid user.
Others may not be able to either see their own host computer or one or more of the other host computers. This may be a result of not sharing any resources. Follow the procedure described above and share some resource, such as a folder.

Exercise 7: Configuring IP

7.1 Overview

This exercise will review the basic steps in configuring the IP addressing details, and introduces some important troubleshooting utilities.

7.2 Hardware Required

Wired LAN as set up in Exercise 6

Software Required

7.3 Windows-based ping/trace utilities such as TJPingPro and AngryIP

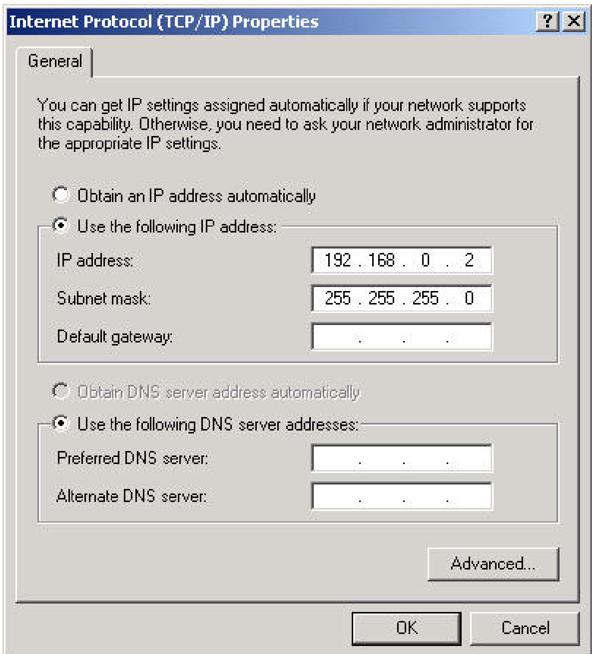
7.4 Implementation

Call up the *Local Area Connection Status* box (as in the previous exercise) and check if TCP/IP is present. In the very unlikely situation of it not being their, install now (Add ->protocol).

Select TCP/IP and click on the *Properties* button.

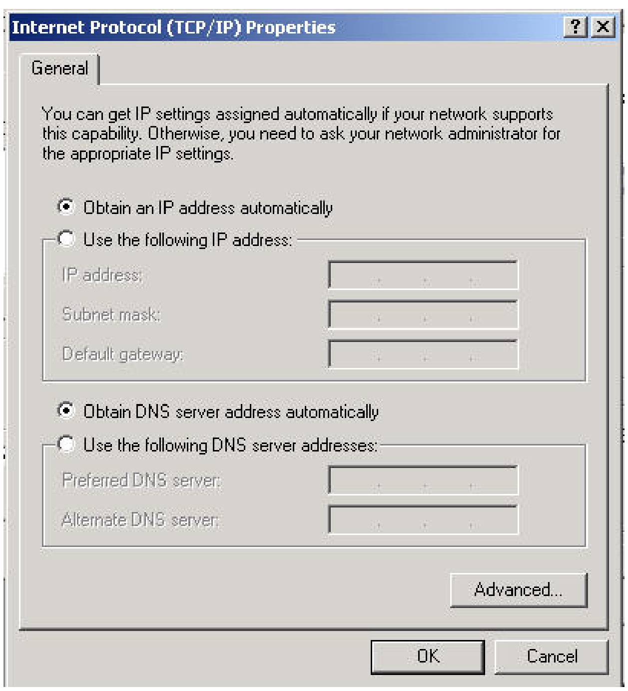
Choose '*Use the following IP address*' and then supply an IP address of the form: W.X.Y.Z (for example 192.168.0.x) where the first three dotted decimals (W.X.Y) represent the network identity (NetID), and the last dotted decimal (Z) represents the host computer identity (HostID) for your machine. Thus we could have IP addresses in the range 192.168.0.1 to 192.168.0.254 inclusive.

Enter the subnet mask of 255.255.255.0 to indicate a default 'class C' network. Click *Apply* ->*OK* -> *Close.*



All other configuration information remains unchanged from the previous exercise. With Windows98 you have to restart at this point, with 2000 and XP it is not necessary.

An alternative is to let a DHCP server allocate an IP address. In this case, select *Obtain an IP address automatically*. The address will be issued when you restart your computer, alternatively you can type *ipconfig /renew* at the DOS prompt.



To verify whether all configuration information has been entered correctly, you can run *wntipcfg.exe*. This can be invoked by clicking on *Start*, selecting *Run*, typing *wntipcfg* in the dialog box, and then clicking *OK*. This utility is not part of 2000/XP but can be downloaded from www.micosoft.com. Alternatively, type *ipconfig /all* at the DOS prompt.

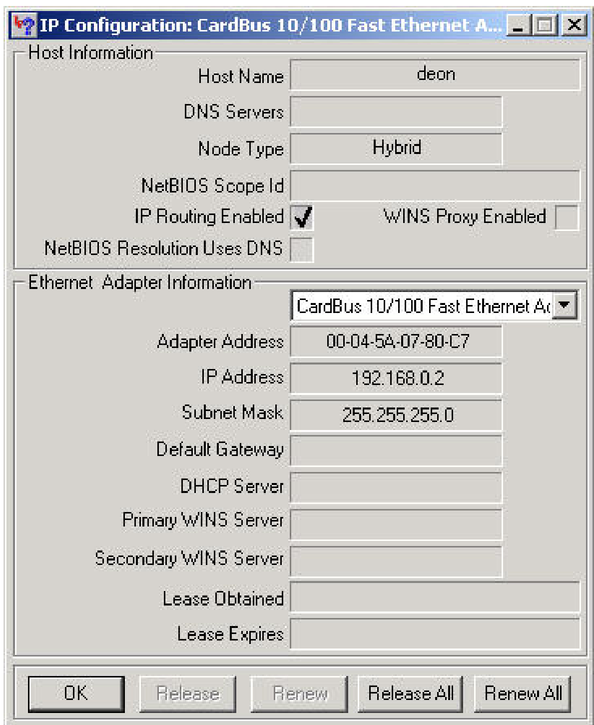
The IP configuration will be displayed along with the Ethernet adapter information. Note the ‘Physical Address’ (MAC address).

The following is the result of *ipconfig /all.*

```
Ethernet adapter Local Area Connection 6:

        Connection-specific DNS Suffix  . :
        Description . . . . . . . . . . . : Linksys EtherFast 10/100 CardBus PC
Card Ver II(PCMPC200 vII) #2
        Physical Address. . . . . . . . . : 00-04-5A-07-80-C7
        DHCP Enabled. . . . . . . . . . . : No
        IP Address. . . . . . . . . . . . : 192.168.0.2
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . :
        DNS Servers . . . . . . . . . . . :
```

A similar result is obtained with *wntipcfg*.



To verify whether this entire configuration is working correctly within the local host computer, type *ping localhost* or *ping 127.0.0.1* in DOS.

If there is a response received from 127.0.0.1 (a universal local loop-back IP address, common to all computers), then it may be assumed that TCP/IP is now correctly configured. Note that the host need not be connected to the network for this command to function.

To verify communication between the local host and remote computers, ping the remote computer’s IP address and/or NetBIOS name. If a reply is received then it is indication that the remote host computer is powered, connected to the network, and the TCP/IP configuration on that remote host computer is correct.

```
C:\>ping 192.168.0.1

Pinging 192.168.0.1 with 32 bytes of data:

Reply from 192.168.0.1: bytes=32 time<10ms TTL=127
Reply from 192.168.0.1: bytes=32 time<10ms TTL=127
Reply from 192.168.0.1: bytes=32 time<10ms TTL=127
Reply from 192.168.0.1: bytes=32 time<10ms TTL=127

Ping statistics for 192.168.0.1:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum =  0ms, Average =  0ms

C:\>_
```

Notes:

During boot-up, there may be an error message stating that there is already another computer on the network with the same IP address, and all networking services will be disabled. Follow the procedure described above, choose another IP address and restart.

Some users may not be able to browse the network neighborhood because they have not logged in with an appropriate username and password. They need to log off and log on again valid users. Others may not be able to either see their own computer or other computers on the network. This is a result of not sharing any resources. Follow the procedure described in exercise 1 and share a resource.

Even though we enter only one ping command, we receive four replies. This is due to the default programmed within the ping.exe executable that sends out 4 sequential ICMP *echo requests*. The echo request message includes 32 bytes of ICMP data and therefore we observe *bytes=32*. The *time=1ms* denotes the total round trip time taken for the ping message to be transmitted and a reply to be received, in milliseconds. *TTL=128* indicates that the replying host is permitting this reply to traverse through a total of 128 routers. Why do we need this?

At the DOS prompt, type '*ping*' (without any options) and it will display a list of the various switches that are available to customize the ping message.

Also type in *arp* –a after pinging, in order to see the arp cache.

If time permits, use third party ping/trace utilities such as AngryIP and TJPingPro. With TJPingPro select *options*, then set a range of IP addresses (e.g.192.168.0.1 to 192.168.0.10) in the top right hand corner. Click OK, followed be 'Sequential Scan '(*Seqscan*).

Exercise 8: Protocol analysis

8.1 Overview

This exercise is a brief introduction to protocol analysis, using a high-quality freeware analyzer.

8.2 Hardware required

Existing network infrastructure

8.3 Software required

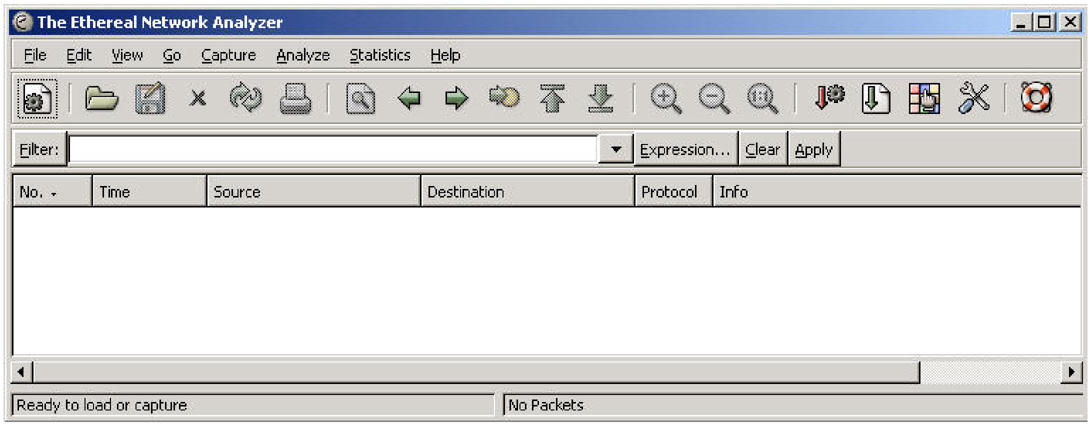
Latest version of 'Ethereal' (know 'Wireshark) plus the capture engine 'winpcap' version 4 or later.

Implementation

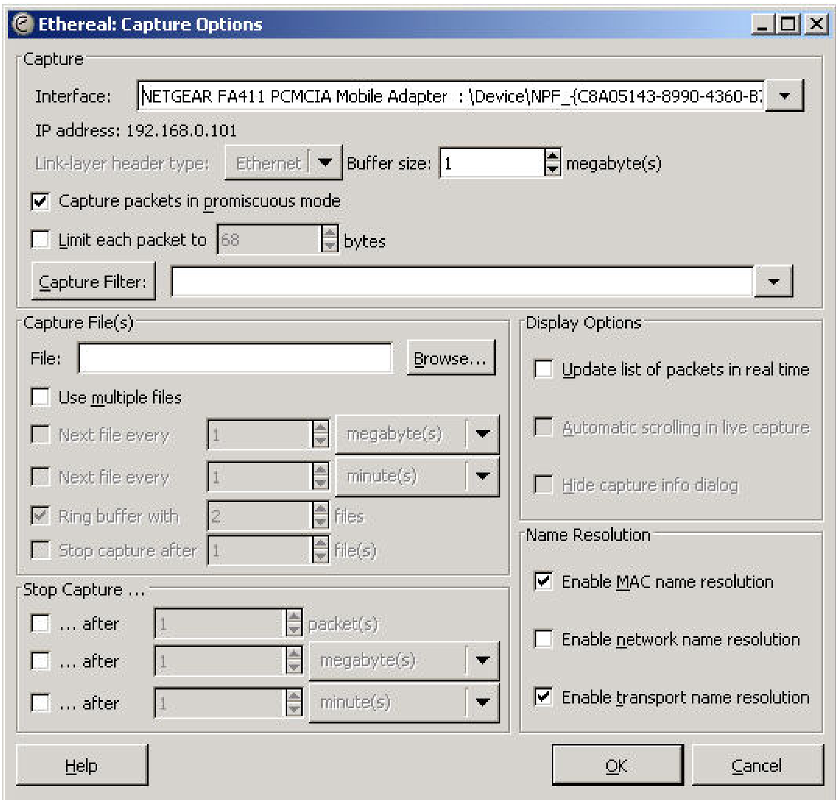
First install winpcap, then install Ethereal. Now set up your machine to ping another machine repetitively, e.g.
`ping 192.168.0.1 –t.`

Click on the Ethereal GUI, or click start->programs->Ethereal

The Ethereal control panel will appear.

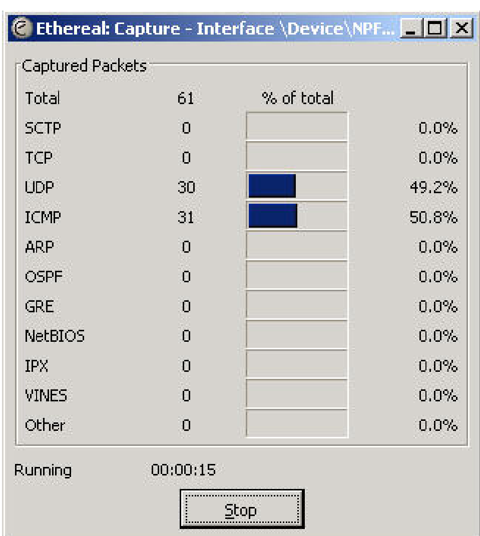


Click *capture->start* and select the appropriate network interface (in this case a Netgear 411 card).

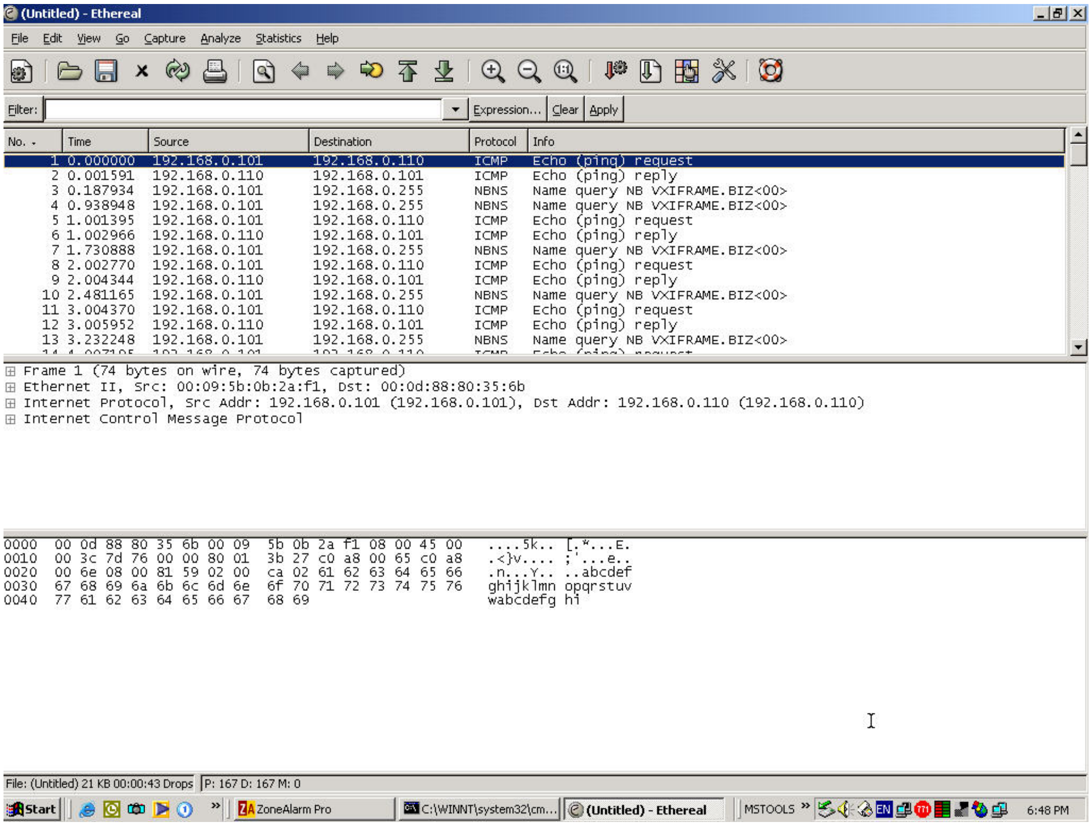


You may experiment with the other default settings, but for now leave them as they are. It is possible to set up rather complex filters to screen out unwanted packets, but in this exercise we will set up the display filters afterwards.

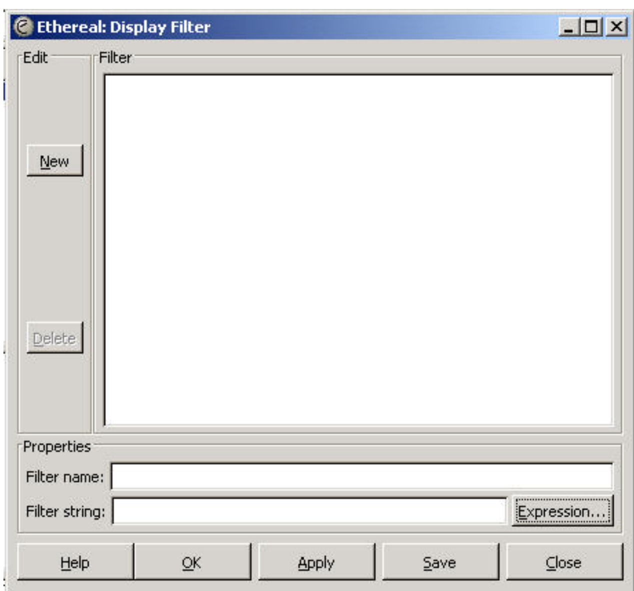
Click *OK*. Capturing will commence and you will be able to observe some statistics regarding the packets being captured.

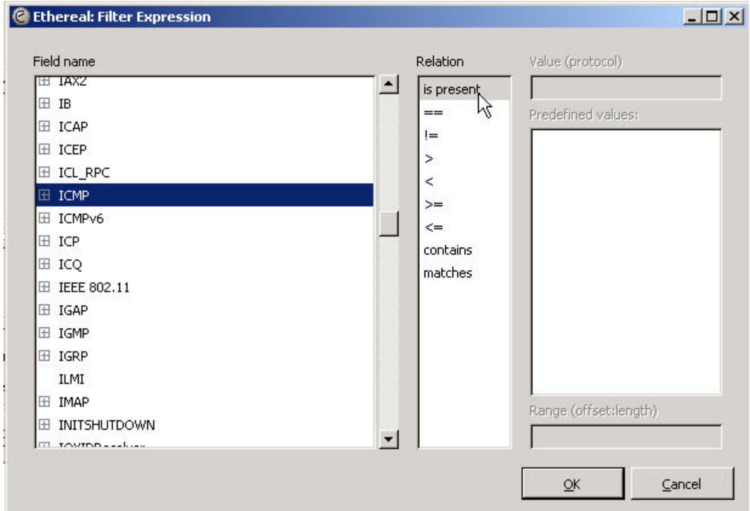


When you have captured a few ICMP packets, click *stop* and the captured packets will be displayed.



Now click *analyze->display filters->expression…*





Select '*+ICMP*' and '*is present*', then click *OK*. Only the ping packets (ICMP) will now be displayed.

No.	Time	Source	Destination	Protocol	Info
1	0.000000	192.168.0.101	192.168.0.110	ICMP	Echo (ping) request
2	0.001591	192.168.0.110	192.168.0.101	ICMP	Echo (ping) reply
5	1.001395	192.168.0.101	192.168.0.110	ICMP	Echo (ping) request
6	1.002966	192.168.0.110	192.168.0.101	ICMP	Echo (ping) reply
8	2.002770	192.168.0.101	192.168.0.110	ICMP	Echo (ping) request
9	2.004344	192.168.0.110	192.168.0.101	ICMP	Echo (ping) reply

Highlight one of the echo request packets, then expand the Ethernet header (click on the '+' next to 'Ethernet') in the middle screen.

```
⊟ Ethernet II, Src: 00:09:5b:0b:2a:f1, Dst: 00:0d:88:80:35:6b
    Destination: 00:0d:88:80:35:6b (D-Link_80:35:6b)
    Source: 00:09:5b:0b:2a:f1 (Netgear_0b:2a:f1)
    Type: IP (0x0800)
```

Note the source and destination MAC addresses, with the first 6 characters decoded to show the manufacturer. In this case the destination is the D-Link DI-624 access point. Now expand the IP header.

```
⊟ Internet Protocol, Src Addr: 192.168.0.101 (192.168.0.101), Dst Addr: 192.168.0.110 (192.168.0.110)
    Version: 4
    Header length: 20 bytes
  ⊞ Differentiated Services Field: 0x00 (DSCP 0x00: Default; ECN: 0x00)
    Total Length: 60
    Identification: 0x7d76 (32118)
  ⊟ Flags: 0x00
      0... = Reserved bit: Not set
      .0.. = Don't fragment: Not set
      ..0. = More fragments: Not set
    Fragment offset: 0
    Time to live: 128
    Protocol: ICMP (0x01)
    Header checksum: 0x3b27 (correct)
    Source: 192.168.0.101 (192.168.0.101)
    Destination: 192.168.0.110 (192.168.0.110)
```

Then the ICMP header.

```
⊟ Internet Control Message Protocol
    Type: 8 (Echo (ping) request)
    Code: 0
    Checksum: 0x8159 (correct)
    Identifier: 0x0200
    Sequence number: 0xca02
    Data (32 bytes)
```

In the bottom section of the screen you can observe the ICMP data (a, b, c, d, f, g, etc) embedded in the message.

```
0020  00 6e 08 00 81 59 02 00  ca 02 61 62 63 64 65 66   .n...Y.. ..abcdef
0030  67 68 69 6a 6b 6c 6d 6e  6f 70 71 72 73 74 75 76   ghijklmn opqrstuv
0040  77 61 62 63 64 65 66 67  68 69                     wabcdefg hi
```

Exercise 9: RTU MOde

6.1 Overview

In this exercise we will run Modbus Serial in RTU mode over an RS-232 link.

6.2 Hardware Required

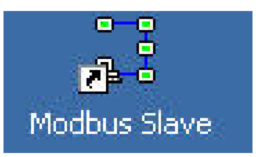
- 2x laptops
- 1x null modem cable with DB-9 connectors
  NB: If a second machine or a null modem cable is not available, then both Modbus Poll and Modbus Slave can be run on the same machine via a virtual null modem.

6.3 Software Required

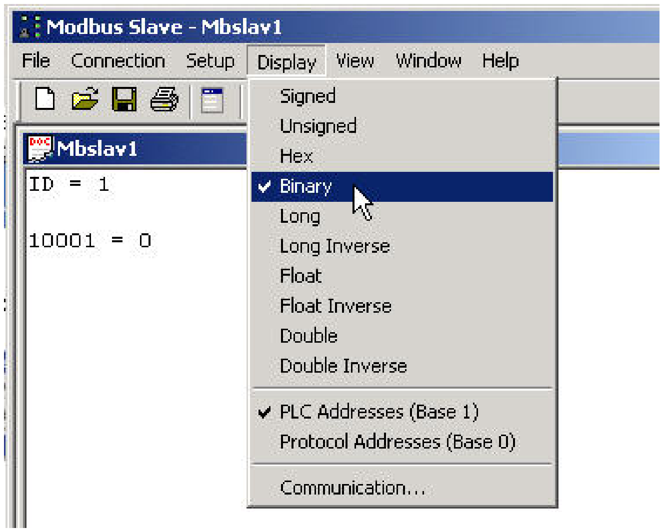
- Modbus Poll v3.60
- Modbus Slave v3.10

6.4 Implementation:

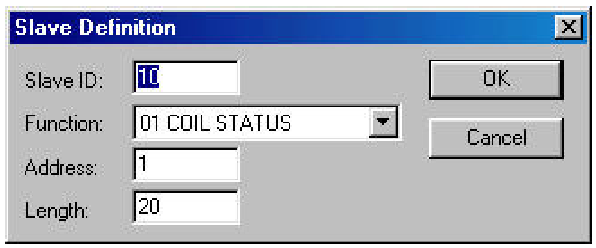
Run Modbus Slave on the remote machine by clicking on the desktop icon.



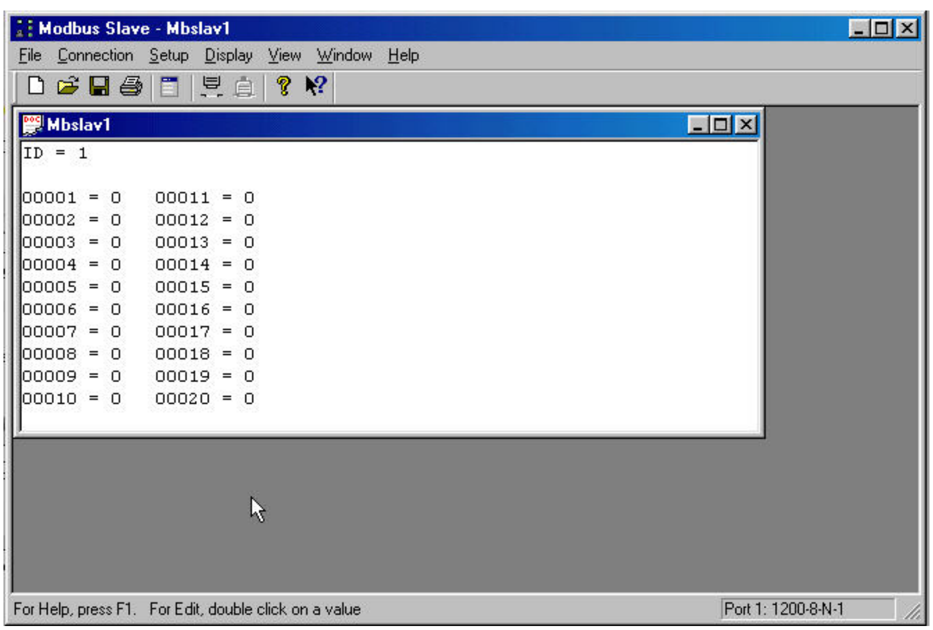
The control panel will open up. Assume that the current setup is as shown.
Click *display*; select *binary* and *PLC addresses (Base 1)*. In this mode we will use the absolute addresses of the registers as opposed to their relative addresses.



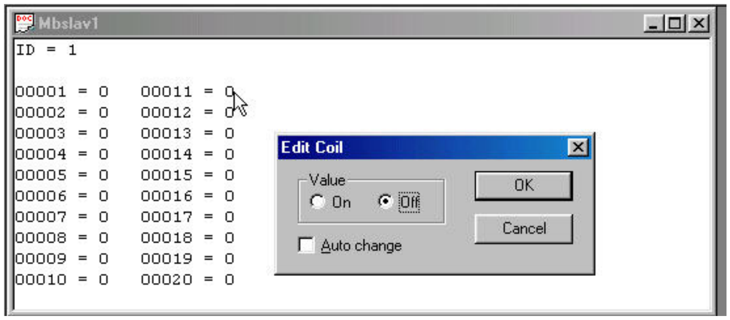
Now hit F2 or click *Setup-> Slave definition*. Set the slave up as follows.



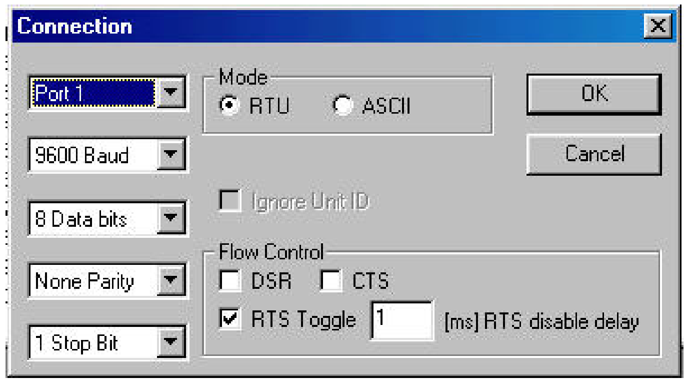
The slave address in this case is 10 (decimal). Function = 01 (read coil status). Address = 1 refers to physical PLC address 00001 (protocol address = offset = 0), and length = 20 means that there are 20 consecutive coils. These will now show up as follows.



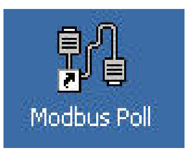
To edit any coil, just double-click on it and toggle between on and off.



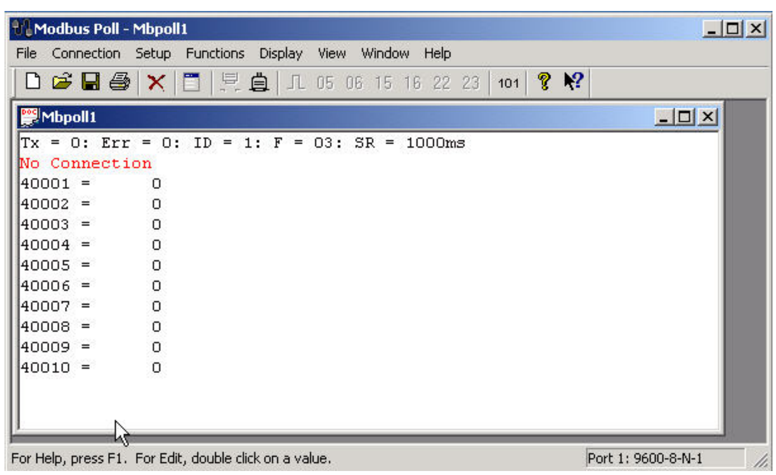
Click *Connection*->*connect* and set up the serial communications parameters as shown. Ensure that RTU mode is selected. Then click OK.



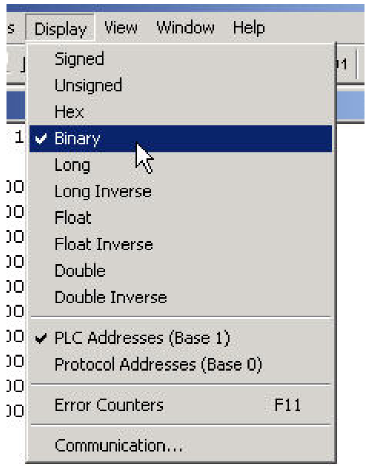
With the slave setup complete, invoke Modbus Poll on the other machine by clicking on the desktop icon.



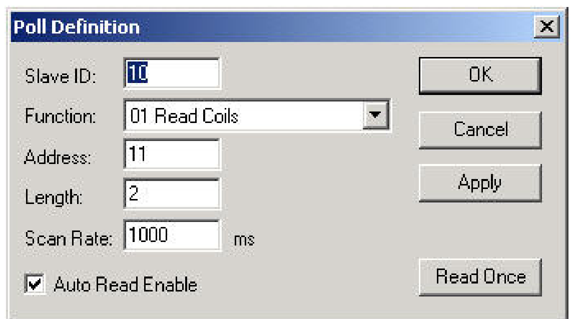
The Modbus Poll control panel will appear.



Click *display* and set it up as follows (the same as for the slave).

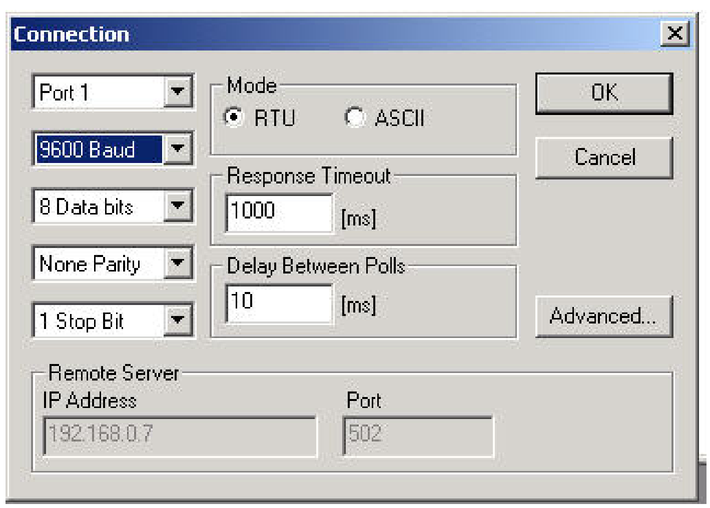


Now hit F2 or click *Setup-> Poll definition.*



In the poll definition above, coils 11 and 12 on slave 10 will be read once every second. Click *OK*.

Hit F3 or click *Connection->connect*. Select COM1 and 9600, 8, N, 1. Ensure that RTU mode is selected.

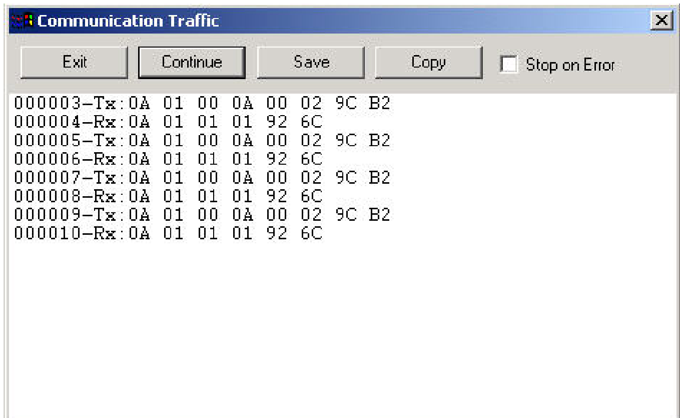


If all goes according to plan, connection will be established. If a red 'timeout' message appears, do the following.

- Click *Disconnect* on both sides
- Check if the poll definitions match (slave addresses and function codes)
- Check that the coils read by the Poll program are a SUBSET of the coils defined by the Slave program, and not the other way around
- Check that the communications parameters are the same for both sides

- Reconnect on both sides

Click *Display->communications* and observe the traffic between master and slave. Remember that it is as seen from the master's perspective; the display on the slave will be the other way around.



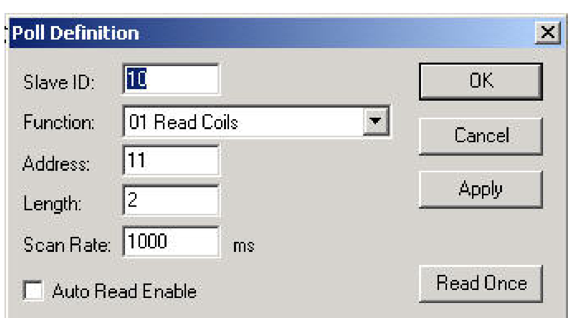
Tx refers to the Modbus request. 0x means Hex.

- Slave = 0x0A (i.e. 10 decimal)
- Function code = 0x01 (1 = Read coil status)
- Initial coil address = 0x000A (i.e. decimal 10 relative or decimal 11 absolute)
- Number of coils = 0x0002
- CRC = 0x9CB2

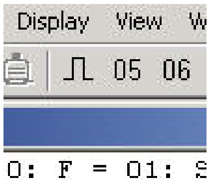
Rx refers to the Modbus Rx response:

- Slave = 0x0A
- Function = 0x01
- Byte count = 0x01
- Coil status = 0x01 = 00000001 Binary, i.e. coil A is set and coil B is cleared.
- CRC = 0x926C

Disconnect on both sides. Terminate the Modbus Slave program and run Listen32 on the slave machine. Set up Listen32 to display data in Hex, and start monitoring the COM port. Set up Modbus Poll to transmit once only (Auto Read Enable un-checked)



Execute the function once by clocking on the 'pulse' sign.



Now stop logging and observe the transmitted Modbus request
Listen32 should display the Modbus ADU, viz. <0A><01><00><0A><00><02><9C><B2.

Appendix C

Cyclic redundancy check (CRC) program listing

```
#include <malloc.h>
#include <stdlib.h>
#include <stdio.h>

#ifndef DAT                // to avoid multiple definitions due to order
#define DAT                // of #includes
struct dat    // this is a data structure used for passing between objects
       {
       int    addr,                    // address of device
              fcn,                     // number of function
              dcount,                  // number of elements in data
              crc;                     // crc check code
       char   *data;                   // pointer to data
       };
#endif

static unsigned CRC16=0xA001; // Polynomial used for CRC-16 checksum

union doub {                                    // union for CRC check
       unsigned i;                     // as an unsigned word
       char c[2];                      // as two characters
       struct bits{                    // as a bitfield
```

```
        unsigned msb:1;            // most significant bit
        unsigned:14;
        unsigned lsb:1;            // least significant bit
        } b;
    };

void whatcrc(struct dat *d, int mode)   // calculate a CRC given a dat structure
    {
    char *msg;                 // buffer to message
    int i,j,len;        // counters and length of message
    union doub sck,byt;

    len=(mode?2:0)+2+(d->dcount); // calculate length (data is the only field
without fixed length)
    msg = (char *)malloc(len);  // allocate space for message buffer
    if (!msg)                  // didn't happen? Say so and quit.

        {
        printf("Sorry, but I couldn't allocate memory\n");
        exit(1);
        }

    // Load the msg buffer
    msg[0]=d->addr;            // load the addr field as byte 1
    msg[1]=d->fcn;             // load the fcn field as byte 2

    for (i=0;i<d->dcount;++i)
        msg[i+2]=d->data[i];

    if (mode)
        {
        msg[i+2]=(d->crc&0xFF00)>>8;
        msg[i+3]=d->crc&0x00FF;
        }


    // CRC check algorithm live!

    sck.i=0xFFFF;                      // set initial remainder
    for (i=0;i<len;++i)                // for each byte in buffer
```

```
        {
        byt.c[0]=msg[i];    // put the current character at end of working byt
        byt.c[1]=0;                // set start of byt to 0
        sck.i^=byt.i;              // set sck to sck XOR byt (MOD-2 maths)
        for (j=0;j<8;++j)                // for each bit
                {
                if (sck.b.msb)
                        {
                        sck.i>>=1;           // shift the remainder right 1 bit
                                                (divide by 2)
                        sck.b.lsb=0;         // and set the MSB to 0
                        sck.i^=CRC16;        // set remainder = sck XOR the CRC16
                                                polynomial
                        }
                else
                        {
                        sck.i>>=1;           //  shift  the  remainder  right  1  bit
(divide by 2)
                        sck.b.lsb=0;         // and set the MSB to 0
                        }
                }
        }
    d->crc = (sck.i)<<8;   // update the CRC in the data structure
    d->crc |= (sck.i&0xFF00)>>8;
    free (msg);                // free the temporary storage area
    }
```

Appendix D

Serial link design

C.1 Strategies in writing protocol software

Bearing in mind the complexity of implementing a protocol program, the anecdotal stories of cost over-runs in writing protocols are not surprising. This section will examine the software implementation of a protocol.

Protocol software has to support bi-directional communications between two devices. This requires the appropriate data (of interest to the user) being packaged in a 'system level envelope' by the transmitter, and decoded by the receiver. The system level is usually of fixed length and describes fully how the protocol works. The data level, on the other hand, can often be of a variable length.

The process of writing a protocol involves various levels of sophistication and the following factors have to be considered in implementing an appropriate protocol:

Cost	The budget size has to be carefully assessed against the required level of protocol implementation.
Level of performance	If you only require a low level of performance there is no point in implementing the full protocol at an increased cost.
Future requirements	Future requirements may encourage the programmer to include additional features now, which may only be used in the future.
Risk and security	Where possible failure of the serial link has the potential for catastrophic results, it may be prudent to put significant effort into protocol development.
Access to information, technical support	Many vendors are very reluctant to release all the information about their particular protocol for fear of compromising their market position, or do not have the local organization to provide adequate technical support.

The three levels of writing protocol software are:

- Simple one-way asynchronous
- Simple one-way synchronous
- Bi-directional asynchronous

Simple one-way asynchronous

This allows the programmer to drive the software development with a protocol that constructs a message and transmits it from device A to device B. The response from device B would then be crudely received and displayed by device A. Any messages generated independently by device B (without initiation from device A) would not be read by device A.

This would apply to both read and write type messages from device A. In the case of read messages, the user can verify that the correct data status was received in the return string. In the case of write messages, the user can confirm that the address specified in the request message has been updated correctly by the response message.

Simple one-way synchronous

This implementation would be to extend the first option to make the program in device A respond to synchronous messages from device B. By synchronous we mean that the program in device A would enter a mode where it would wait for a command to be issued from device B and respond accordingly. During this time device A would not be able to send a command to device B.

Bi-directional asynchronous

This option would provide asynchronous bi-directional communications between the two devices. That is, device A could send commands to device B, and simultaneously service any requests received from device A.

This option would require an interrupt service routine to initiate the response to a device ‘A’ command, as it arrives. This is important because the speed of response is also a constraint imposed by the protocol. A response that is too slow may have to be ignored.

The disadvantages of this option are the complexity of the protocol software required. In addition, the device used for such a task would have to be sufficiently fast to allow the interrupts to be serviced, and to handle its own processing requirements.

C.2 A typical program structure

A block diagram of a typical program structure is given in Figure C.1. The structure has been used successfully in implementing a number of different protocol structures, but is included here only as a guide.

Typically, most industrial protocols are involved in the following operations:

- Read digital data
- Read analog data
- Write digital data
- Write analog data

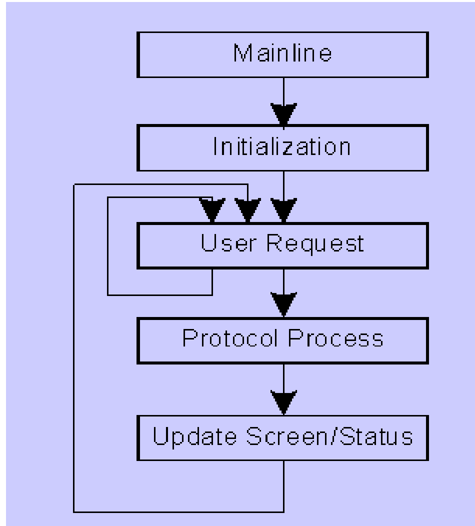


Figure C.1
Block diagram of typical protocol program structure

The following describes each part of the typical protocol program structure.

Initialization

This routine runs at the start of the program only and comprises a number of routines (or tasks).

Variable initialization

The program should declare adequate storage for the data area, to be used for transfer of the data points, across the serial link by the protocol. The data areas used in each communicating device do not necessarily have to be identical in size or even structure. The easiest way to use storage is to define an array of variables representing a block of addresses. All data should be initialized before the other program steps are commenced.

Device status and display initialization

The display and status variables should be initialized. This includes putting the display into the correct video mode and writing all static text to the screen. The communication port should also be initialized.

User request

This function processes incoming commands from the user. The use of interrupts here would be ideal.

C.3 Protocol process

This is the main body of the program; the steps are as follows:

- Get any input required from the user and write to or read from the other device.
- Compute any parts of the protocol that require calculation, e.g. CRC check word, byte count etc.

- Send a command message and wait for the response.
- Update the display showing the response message, system and data fields.
- Read any input data from the other device and decode as per the protocol structure.
- Identify, define any error messages that occur and pass onto the next step.

Update device status

This is where any clean-up operations are performed. This includes such items as communications port status, or a message indicating the success or failure of the preceding operation. The ‘protocol process’ routine could return an error code to the main part of the program.

C.4 Typical problems encountered in protocol software

Some typical practical problems, which a programmer may encounter when implementing protocol software, are listed below. A lot of these may sound like commonsense but it is surprising how many times they are ignored.

Typical problems are:

- The list of data points transferred over the communications link is normally dynamic. Appropriate data structures to handle the variation in the points transferred (and their addresses) are not implemented.
- Speed of transfer of data across the communications link is too slow because of the quantity of points transferred across. A prioritized or exception reporting scheme of transfer of data points can solve this problem.
- Buffer size of receiver is inadequate. This causes loss of data or delays in transferring information across the link.
- Receiving station, CPU cannot react fast enough to service data coming in, because of overload generated by other activities.
- Physical disruption to communications channel (by a link breakage) causes a catastrophic collapse in re-establishing transfer of the latest data because of inadequate error handling and the build up of old messages.
- The use of interrupt handling of messages is avoided because of the complexity associated with this feature. This results in a significant degradation in performance because of the overload of the CPU.
- Scaling of data at transmitter and receiver is often not done correctly.

C.5 Fragments of protocol programs written in BASIC

A program is included at the end of this chapter, which demonstrates the use of a protocol with a PC (refer to section C.11). This is to illustrate the basics of constructing a protocol and the various functions used.

Microsoft QuickBASIC has been chosen for illustrating the basics of protocol construction, for the following reasons:

- It is a simple and straightforward computer language to use.
- It is relatively powerful and efficient (especially in the later versions).
- Many people are familiar with it.
- It can be compiled (instead of merely interpreted).
- It is low cost and freely available.

It should be emphasized that QuickBASIC is not the most efficient computer language for this sort of work. Most programmers elect to use C language because of its portability, power and efficiency. C is, however, a fairly cryptic language, difficult to remember, and learning it is time-consuming. Hence, it has not been used for this example.

Microsoft QuickBASIC is a programming environment that includes all the tools needed for writing, editing, running, and de-bugging programs. A full help facility is available online to assist in writing the programs. The software has to run on an IBM PC or IBM PC compatible, which uses MS-DOS.

BASIC program implementation

A few elementary 'housekeeping' rules are necessary when using QuickBASIC language. Comments have been added to all QuickBASIC statements, used in the example program, to help you understand the programming process.

The following points should be remembered when writing a program. Although obviously directly related to QuickBASIC, the concepts will be applicable to implementations in other languages.

In this discussion, COM1 and COM2 refer to the two serial ports on the IBM or compatible PC. The following opening statement, which makes BASIC as tolerant as possible of hardware-related problems, should always be used when uncertain of the hardware and software configuration:

OPEN 'COM1:300,N,8,1,BIN,CD0,CS0,DS0,OP0,RS,TB2048, RB2048' AS #1

(This OPEN is FOR RANDOM access). The following is an explanation of each recommended parameter used in the OPEN statement:

- The higher the baud rate, the greater the chances of problems; thus, 300 baud is unlikely to give any problems. 56 K baud is the highest speed possible over most telephone lines, due to their limited high-frequency capability. 19 200 baud, which requires a direct wire connection, is most likely to cause problems. (Possible baud rates for QuickBASIC are: 75, 110, 150, 300, 600, 1200, 1800, 2400, 4800, 9600 and 19 200).
- Parity usually does not help significantly. Because of this, no parity (*N*) is recommended. As discussed in an earlier chapter, parity error detection is not a very efficient way of identifying errors.

For those devices that require parity, the parity enable (PE) option should be used in the OPEN COM statement, which is required to turn on parity checking. When the PE option turns on parity checking, a 'Device I/O error' occurs if the two communication programs have two different parities (parity can be Even, Odd, None, Space or Mark). For example, a 'Device I/O error' occurs when two programs try to talk to each other across a serial line using the following two different OPEN COM statements.

OPEN 'COM,1200,O,7,2,PE'FOR RANDOM AS #1

and

OPEN "COM2:1200,E,7,2,PE"FOR RANDOM AS#2

If the PE option is removed from the OPEN COM statements above, no error message is displayed.

- The above example uses 8 data bits and 1 stop bit. 8 data bits requires no parity (*N*), because of the size limit for BASIC's communications data frame (10 bits).
- The BIN (binary mode) is the default. Note: The ASC option does NOT support XON/XOFF protocol, and the XON and XOFF characters are passed without special handling.
- Ignoring hardware handshaking often corrects many problems. Thus, if the application does not require handshaking, try turning off the following hardware line-checking:
  - CD0 Turns off time out for data carrier detect (DCD) line
  - CS0 Turns off time out for clear to send (CTS) line
  - DS0 Turns off time out for data set ready (DSR) line
  - OP0 Turns off time out for a successful OPEN
- RS suppresses detection of request to send (RTS).
- For buffer-related problems, increase the transmit and receiver buffer sizes above the 512-byte default:
  - TB2048 = Increases the transmit buffer size to 2048 bytes
  - RB2048 = Increases the receive buffer size to 2048 bytes

A large receive buffer can work around BASIC delays caused by statements, like the graphics function, PAINT, which use the processor intensively.

The following are additional important hints for troubleshooting communications problems:

- Use the INPUT$(x) function in conjunction with the LOC (n) function to receive all input from the communications device (where 'x' is the number of characters returned by LOC(n)), which is the number of characters in the input queue waiting to be read. 'n' is the file number that is OPENed for 'COM1:' or 'COM2:'.
- Avoid using the INPUT#n statement to input from the communications port because INPUT#n waits for a carriage return (ASCII 13) character.
- Avoid using the GET#n statement for communications because GET#n waits for the buffer to fill (and buffer overrun could then occur).
- Avoid using the PUT#n statement for communications and use the PRINT#n statement instead. For example, in QuickBASIC 4.00b and 4.50, in BASIC Compiler 6.00 and 6.00b, and in BASIC PDS 7.00 and 7.10 using the PUT#n,,x$ syntax for sending a variable length string variable as the third argument of the PUT#n statement sends an extra 2 bytes containing the string length before the actual string. These 2 length bytes sent to the communications port may confuse the receiving program, if it is not designed to handle them. No length bytes are sent with PUT#n,,x$ in QuickBASIC 4.00 (QuickBASIC versions earlier than 4.00 don't offer the feature to use a variable as the third argument of the PUT#n statement).
- Many communications problems can only be shown on certain hardware configurations and are difficult to resolve or duplicate on other computers. Experimenting with a direct connection (with a short null modem cable) is recommended instead of with a phone/modem link, between sender and receiver, to isolate problems on a given configuration.

- The wiring scheme for cables varies widely. Check the pin wiring on the cable connectors. For direct cable connections, a long or high-resistance cable is more likely to give problems than a short, low-resistance one.
- If both 'COM1:' and 'COM 2:' are open, 'COM2:' will be serviced first. At high baud rates, 'COM1:' can lose characters when competing for processor time with 'COM2:'.
- Using the ON COM GOSUB statement, instead of polling the LOC(n) function to detect communications input, can sometimes work around timing or buffering problems caused by delays in BASIC. Delays in BASIC can be caused by string space garbage collection, PAINT statements, or other operations that heavily use the processor.

C.6 Management of data points over the serial link

Although possibly considered a trivial subject by most engineers who are more concerned with the development and commissioning of the data communications system, the management of the data coming over the link can be a challenging issue.

The main reasons why this requires attention are:

- Data can vary from a few points to a few thousand.
- Data points coming across a serial link can vary in terms of addressing as the design proceeds.
- Update times of serial data points can vary from point to point.
- Tag names of serial points can vary as the design and implementation proceeds.

Typical parameters that need to be recorded (preferably in a database program such as dBase to allow easy manipulation of the data) are:

- Tag name of the data point
- Description of the data point
- Address of point (e.g. Modbus address)
- Update time for point
- Scaling factor
- Maximum and minimum and ranges (including the possibility of the data becoming negative)
- Data format (maximum number of digits)
- Type of data for point (e.g. ASCII, integer, floating point)
- Destination of point
- Source of point

An area, which always causes problems, is scaling of the data on the link. For example, if the protocol restricts the range of values over the link to 0 to 4095 (i.e. a 12 bit quantity) and the actual engineering (or 'real world' quantities) are –10 kPa to 20 000 kPa, some delicate footwork has to be done. This is to ensure that there are no problems with the scaling at the transmitting end, transfer of the data across the link and rescaling at the receiving end. In addition, there should be a careful analysis of the loss in resolution caused by scaling.

C.7 Suggested testing philosophy for a communications system

Data communication is a strategic part of a control system. Failure of a communications link could be the cause of information loss from thousands of data points. It is imperative, therefore, that a communications system is thoroughly tested within the framework of a rigorous standard.

There are numerous reasons for the test requirements to be more demanding than those for a standard control system; some of the main reasons are:

- Information losses resulting from a failure of a communications link can be catastrophic.
- Loading factors of a data communications system can vary considerably and may lead to failure if the system is pushed to the limit.
- The communications interface can be complex consisting of hardware/firmware and software components.
- The communication link normally serves as an interface between two dissimilar systems (sometimes consisting of different design personnel, different hardware), which raises the level of technical risk and the need for common understanding of the overall requirements of the system.

A good framework in which to do the testing is ANSI/IEEE standard 829-1983 for software test documentation. While some engineers may be less than enthusiastic about formal testing procedures of this nature, the investment in time and effort is worthwhile in creating a high quality final product, engineered with proven standards of performance. The authors can testify from bitter experience that this approach pays off.

A typical test procedure (or master test plan) for the link between a PC and the Modbus port of a new PLC is sketched out below.

C.8 Typical test procedure example

The test specification procedures and recording practices have been prepared in accordance with ANSI/IEEE Std 829-1983. All software written or modified for this installation will be tested according to these guidelines.

This test is to confirm that the link from the PC to the Modbus port of the new PLC operates correctly as per the specifications.

Features to be tested

The functions to be tested will be derived from the serial link requirements specification PC-MOD1 and functional specification PC-MOD2. These functions will be grouped under the following headings:

- Hardware/firmware checks
- Interface protocol
- Interface I/O points (and addresses)
- Control strategy
- Program structure

Test environment

A PC/AT (the monitor) will interface via a second PC/AT (or protocol analyzer) to the Modbus port of the serial hardware being tested. Serial port (COM 1) of the second

PC/AT will connect to the PC/AT monitor. Serial port (COM 2) will connect to the Modbus port of the serial hardware being tested.

The relevant ‘C’ language compiled software modules for the serial link will be downloaded into the monitor PC/AT.

The appropriate EPROM (Revision C, 10 Nov.’91) for the PLC will be inserted into the PLC communication board. Test data will be downloaded into the monitor PC controller and the proprietary unit control system.

Testing approach

There are no risks and contingencies at the initial phase of testing, as this is performed offline and merely tests the serial interface system. The second stage of testing is envisaged to directly interface with the operational hardware, but will be done in a manual mode at the specific construction yard. The third phase of testing will be the commissioning phase and will be carried out at the plant.

The second and third phases of the testing which do have risks will not form part of this test procedure, but will be incorporated into an overall test program covering all aspects of testing.

General strategy

The test hardware will be connected to the proprietary hardware under test. The appropriate version of compiled C code and data will be downloaded to the monitor PC. The vendor will download certain specified data structures in the unit controller. Each item of data will be transferred between the two nodes of the link in the appropriate form.

Specifically the following characteristics will be checked:

- Accuracy of data transfer
- Average speed of data transfer
- Loopback and diagnostic tests where applicable
- Loading of link with high traffic loads
- Interaction of multiple nodes on link (e.g. multiplexers, dual controllers)
- Transmission of incorrect function requests
- Interface between ‘C’ code and the EPROM on the proprietary hardware
- Interface ‘C’ code and the user software in PLC
- Interface between ‘C’ code and the serial port hardware/firmware
- Handling of failure of:
  - Serial link
  - Proprietary hardware/firmware/software
- Monitor hardware/firmware/software (with reference to fallback strategies, recovery times, diagnostics, error messages)
- High levels of electrostatic/electromagnetic noise on the link
- Adequacy of earthing systems for each mode of line (including earth potential rise)
- Performance of error checking features of the link (e.g. using CRC-16)

Note: A PC-based protocol analyzer will be used to confirm that the data structures being transmitted down the link and the appropriate responses are correct. This will be in addition to the diagnostic messages generated by both the monitor PC and the PLC serial hardware being tested.

Acceptance tests on the various portions of the system will occur at different stages of the testing. Tests will be jointly performed by the client and the contractor. No modified software will be available for use by the client until it has been fully tested and accepted by the client.

Associated test documentation

Full test documentation should be filled out correctly and stored in a central safe location.

C.9 An example serial data communication link

This section contains an example of a serial data communication link for the control of a variable speed drive using the EIA-485 interface and ANSI-X3.28 protocol.

'Smart' instrumentation and other digital sensors and actuators are increasingly being used in factory automation and industrial process control systems. A 'sensor' is a general term that refers to instruments, monitors, etc. that measure field variables such as temperature, pressure, levels, flow and power in a process control system. An 'actuator' is a general term that refers to devices located in the field, such as valves, variable speed drives, positioners, servos, etc., that implement instructions from the control system.

Making effective use of these devices depends on their ability to transfer data reliably and quickly to and from other controlling devices, such as computers, PLCs, DCSs, etc. via a common data communications network. Data communications at this level is usually referred to as the 'field level' communications and the type of networks used are often called the 'field bus'.

Data communications at the field level is usually reliable when all the equipment comes from one manufacturer. When several different types of equipment from various manufacturers are required to communicate on the same network, difficulties always seem to appear. One major reason is that no clear and universally acceptable data communication network standard has yet emerged for systems for the field level.

The process of developing and implementing acceptable international standards is a painfully slow process and a solution to this problem is still a long way off. In the meantime, manufacturers have created their own standards or have used a combination of available standards that may have been developed for other similar applications.

Therefore, the practical problem of controlling a field actuator device, such as a variable speed drive (VSD), from an intelligent control device, such as a PLC or a PC, needs to be addressed on an application by application basis. This section describes the process of designing and implementing a simple data communications system for transferring data between an IBM compatible PC and an AC VSD to achieve the following:

- To read data from the list of parameter registers in the VSD, transfer them to the PC and display variables such as speed, current etc., on the PC monitor.
- To write data to the VSD parameter registers for starting, stopping, changing settings (e.g. speed reference), or adjusting any other variable in the VSD, as would be required in an industrial application.

Most modern VSDs have some form of communications capability, usually based on a well known physical standard, such as EIA-232 or EIA-485. The transfer of data can be controlled by a suitable program (written by the user) based on one of the ASCII character protocols. The program should be able to address multiple VSDs on the network without having a problem with data collision on the network. Typically, the programs use the poll/response method with one 'master' (PC or PLC) in control of the network and several ‘slaves’ (VSDs). The slaves respond only when they are polled by the master. Although this approach works quite well, it has some limitations that affect the overall performance of the system:

- This type of system is slow because it uses low baud rates, with inefficient ASCII coding. The master also needs to address each slave individually. This type of data communications solution is not suitable for controlling several drives in applications with fast speed and torque dynamics.
- There is no available software standardization, so a special program has to be written for each application.

The physical interface

The physical connections between the PC and VSDs are according to the EIA-232 and EIA-485 interface standards, both of which are covered in detail in Chapter 3 The standard PC is fitted with an EIA-232 port. The standard VSD port is EIA-485, suitable for multidropping up to 32 units.

From Chapter 3, it is clear that EIA-232 and EIA-485 are not directly compatible and the two devices cannot be directly connected and expected to work.

This apparent mismatch at the physical level can be overcome by one of the following methods:

- Interface Converter – an EIA-232/EIA-485 interface converter can be connected between the two devices to convert the voltage levels and the connection configuration from one to the other (unbalanced to differential). An interface converter should be physically located close to the EIA-232 port (i.e. at the PC end) to take advantage of the better performance characteristics of the EIA-485 interface for the longer distance to the VSD in the field. The interface between the PC and the interface converter is one-to-one, while the EIA-485 side may have several drives (up to 32) connected in a multidrop configuration. The internal connection details, of an EIA-232/EIA-485 converter, are shown in figure below.

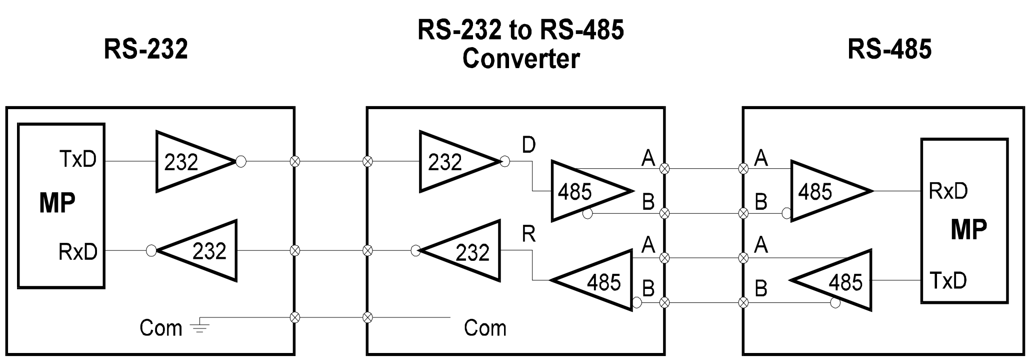


Figure C.2
Block diagram of an EIA-232/EIA-485 converter

- EIA-485 PC interface card – plug-in EIA-485 interface cards are available for IBM compatible PCs for mounting directly onto the motherboard. Similar cards are also available for PLCs. This card must be configured as a separate port in the PC. The PC can then be connected directly to the EIA-485 network.

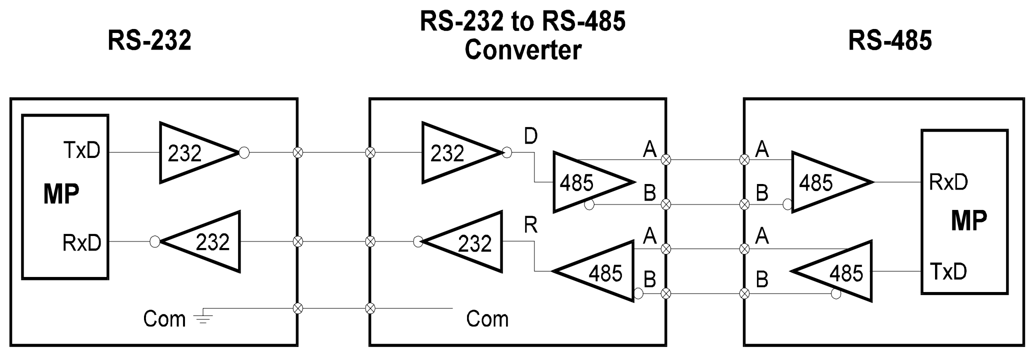


Figure C.3
Block diagram of an EIA-232/EIA-485 converter

The software interface

Once the physical interface problems have been solved, the flow of data between the PC and the VSD must be controlled by software located in the master device. In our example, the program is based on ANSI-X3.28-2.5-A4, which is an ASCII based protocol that defines the format, order, and syntax of the characters. There is no standard format, or content, for this type of program and it is usually written by the user to suit the application. The program below is an example of a simple program written in QuickBASIC for demonstration purposes only.

In accordance with ANSI-X3.28, the 10 bit character format is as follows:

- 1 Start Bit : Logic 0
- 7 Data Bits : ASCII Code for each character
- 1 Parity Bit : Even or None
- 1 Stop Bit : Logic 1

There are two styles of message order and syntax:

- Read message
- Write message

The read message comprises of a maximum 9 characters in the order shown in the following flow chart. The read message is used to transfer data from the VSDs to the master. This data is usually the field data, such as speed, current, etc. or the VSD’s setting parameters.

The block checksum character (BCC) is a single character generated from all the data in the message and is used to detect errors in the transmitted data.

The write message comprises of a maximum 17 characters in the order shown in the following flowchart. The write message is used to transfer data from the master to the VSDs. This data is used to issue commands to the field device or change parameters (e.g. start, stop, change speed).

The baud rate can be set to any one of the 'standard' values between 300 to 19,200 bps.

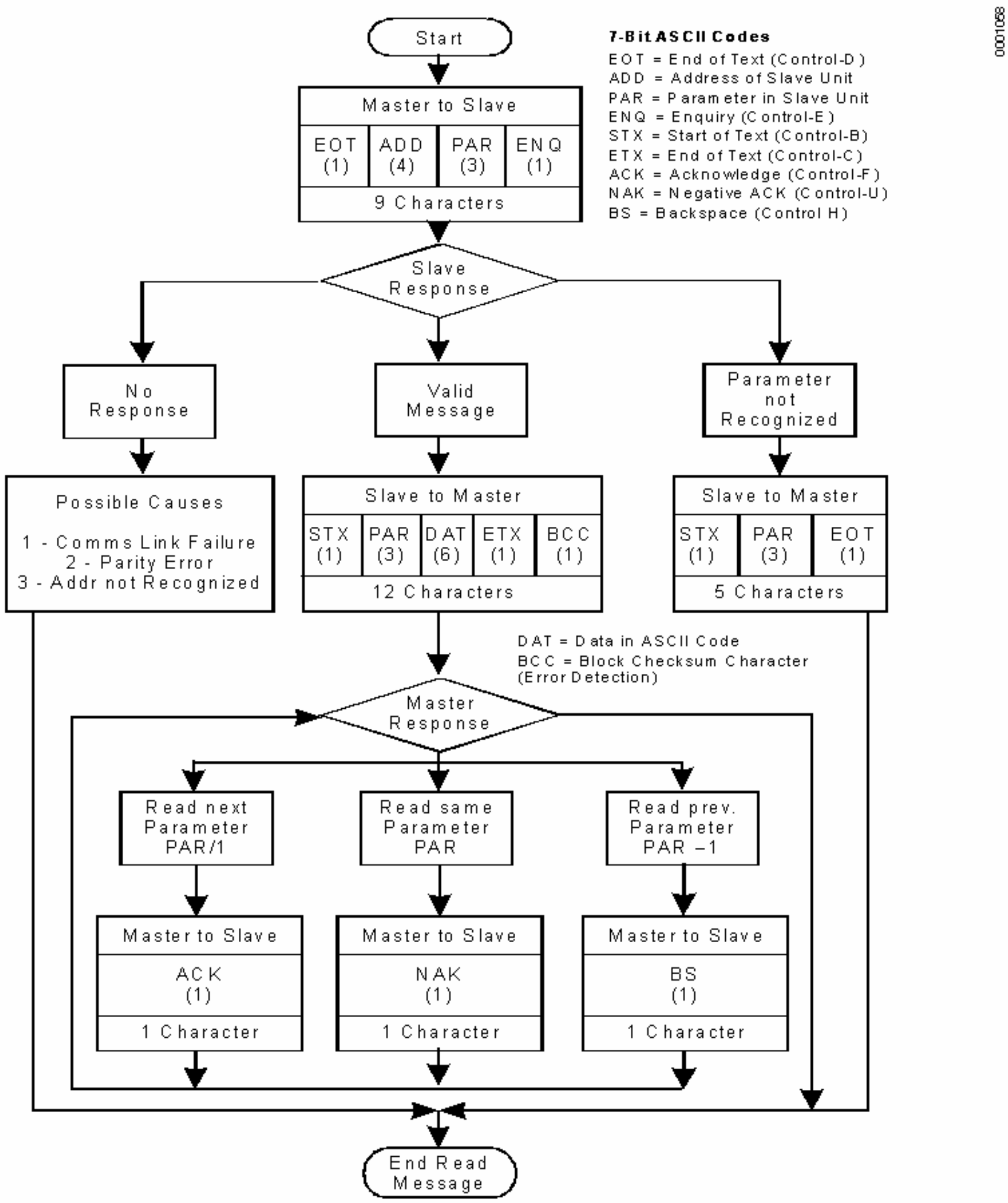


Figure C.4
Flow chart showing the order and syntax of the read message

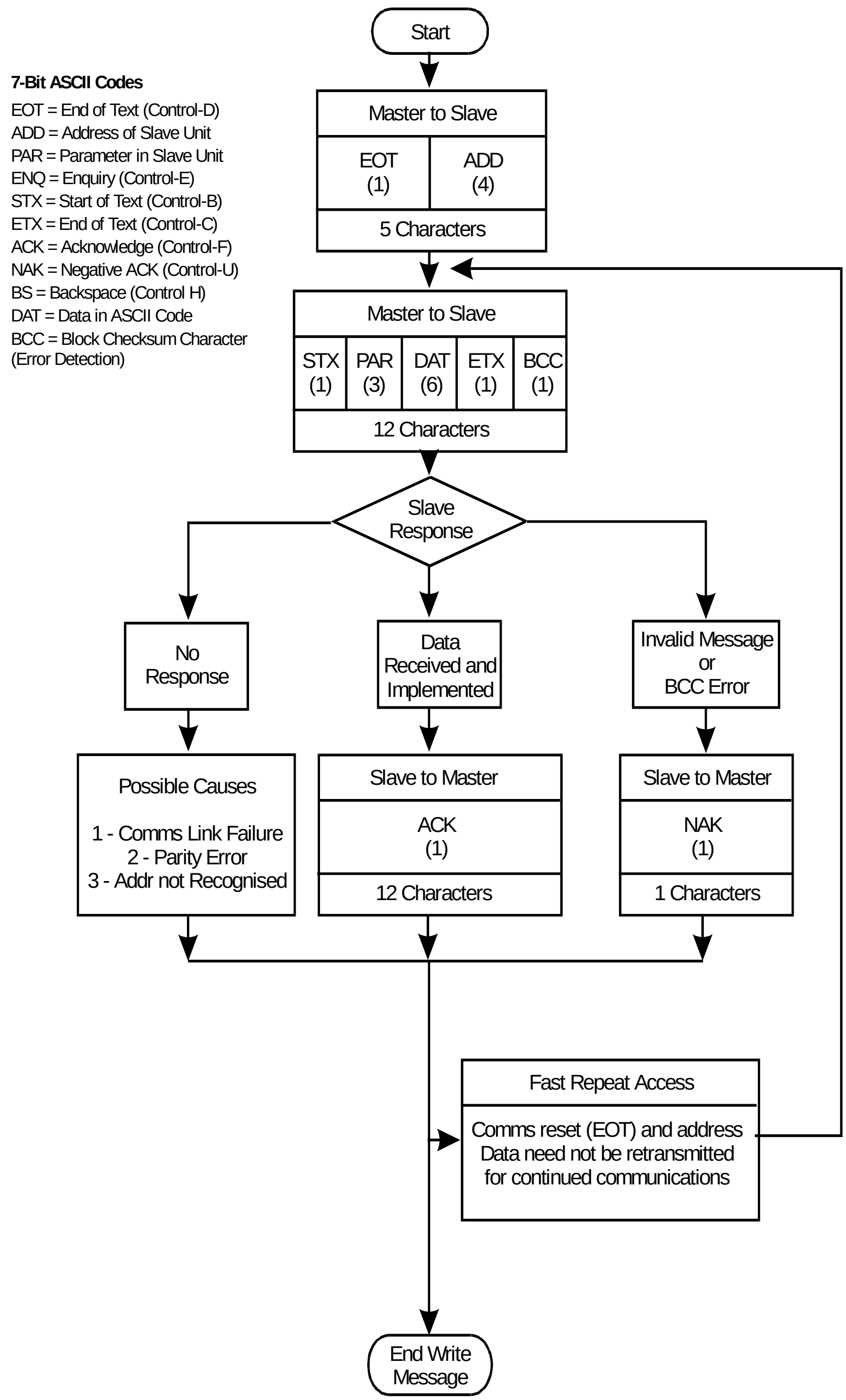


Figure C.5
Flow chart showing the order and syntax for the write message

C.10 Typical list of VSD parameters

Table C.1 shows a shortened list of typical parameters for a ontrol Techniques 'Vector' drive. The parameter registers in the range 00 to 99 contain analog (numerical) values, while those from 100 to 199 contain binary digital values. The read command can be used to transfer data from the VSD parameter registers to the PC over the serial data communications link.

The write command can be used to transfer data to the VSD parameter registers from the PC.

Parameter no.	Analog/ bits	Description	Default Value
00	A	Digital speed reference, run	100
01	A	Digital speed reference, inch	– 100
02	A	Analog speed reference offset	0
03	A	Minimum speed limit	– 1500
04	A	Maximum speed limit	+ 1500
05	A	Analog reference input filter	32
06	A	Torque limit – motoring	150
07	A	Torque limit – generating	150
08	A	Internal torque reference	0
09	A	Forward acceleration limit	0.01
10	A	Reverse acceleration limit	0.01
11	A	Forward deceleration limit	0.01
12	A	Reverse deceleration limit	0.01
13	A	Speed loop proportional gain	1.5
14	A	Speed loop internal gain	1.5
15	A	Speed loop derivative gain	0
16	A	Analog output scaling	1.67
17	A	Speed reference select	3
18	A	Analog speed input scaling	600
22	A	Serial link – drive address	01
23	A	Serial link – baud rate	9600
25	A	Security key	0
40	A	Drive model number	n/a
41	A	Motor full load current	n/a
42	A	Motor magnetizing current	n/a
43	A	Motor base frequency	n/a
70	A	Motor speed	n/a
71	A	Motor frequency	n/a
75	A	Active current	n/a
78	A	DC bus voltage	n/a
82	A	Motor line current	n/a
100	B	Security key enable	n/a
101	B	Miscellaneous trip	1
102	B	Drive enable	1
103	B	Drive reset	n/a
104	B	Zero torque demand	1
105	B	Torque/speed control mode	1

106	B	Torque reference select	1
120	B	Serial link – parity enable	1
121	B	Serial link – block checksum enable	1
133	B	Drive healthy	n/a

Table C.1
Example list of VSD parameters

C.11 Example

```
'*  INSTRUMENT DATA COMMUNICATIONS
'*
'*  Example of PC program written in Microsoft QuickBASIC Version 4.5
'*  for IBM compatible PC to a Control Techniques CD Variable Speed Drive.
'*
'*  Creation date : 02-12-91
'*
'*
'*  SERIAL INTERFACE CONNECTION
'*  This program provides for communication to a Commander CD Variable
'*  Speed Drive through one of the PC's EIA-232 serial interface ports.
'*  An EIA-485 interface would be preferable because of its noise immunity.
'*
'*
'*  THE PROTOCOL
'*  The protocol implemented is ANSI-X3.28-2.5-A4. It defines the
'*  format and order of characters and the syntax of the commands.
'*  A character consists 10 bits, comprising 1 start bit (logic-0),
'*  followed by 7 data bits (ASCII Code), 1 parity bit (even or none)
'*  and the final bit is 1 stop bit (logic-1).
'*
'*  There are two styles of commands.
'*  The READ command allows reading of all the drives parameters.
'*  The WRITE command allows the read/write to be changed.
ON ERROR GOTO FAULT    'Activate error trapping
CLS                    'Clears the screen

OPEN "COM1:9600,E,7,1,CD0,CS0,DS0,OP0,RS" FOR RANDOM AS #1
'*  Opens the PC's serial port 1 for serial bit-by-bit communication
'*  with the peripheral device.  (The OPEN is FOR RANDOM access)
'*  An explanation of each parameter used in the OPEN statement follows:

'*  1. 9600 specifies the Baud Rate (bits transmitted each second). The
'*     baud rate setting for the drive and the host (PC) must be set
'*     equal to allow communication to take place.

'*  2. E sets the parity of the drive to EVEN.  With even parity selected,
'*     the parity bit is set to logic 1 when the data segment of the
'*     character consists of an odd number of logic 1's.
```

```
'*  3. 7 bits in each byte of data transmitted or received constitute
'*     actual data.
'*  4. Since this application does not require handshaking, setting CD,
'*     CS, DS and OP to 0 tells the hardware to ignore handshaking
'*         CD0 = Turns off time-out for Data Carrier Detect (DCD) line
'*         CS0 = Turns off time-out for Clear To Send (CTS) line
'*         DS0 = Turns off time-out for Data Set Ready (DSR) line
'*         OP0 = Turns off time-out for a successful OPEN
'*  5. RS suppresses detection of Request To Send (RTS)

MENU: VIEW PRINT 1 TO 24     'set text viewport
CLS
LOCATE 4, 5: PRINT "VECTOR Drive communications program"
LOCATE 5, 5: PRINT "~~~~~~~~~~~~~~~~~~~"
LOCATE 7, 5: PRINT " 1.  List Parameter Values"
LOCATE 8, 5: PRINT " 2.  Get a specific particular parameter from VECTOR"
LOCATE 9, 5: PRINT " 3.  Write data to VECTOR"
LOCATE 10, 5: PRINT " 4.  Quit"
LOCATE 12, 5: PRINT " Select an option (1-4)"

OPT: '* Wait for key to be pressed
    KY$ = INKEY$: IF KY$ = "" THEN GOTO OPT
    A = VAL(KY$)
    IF A >= 4 THEN GOSUB QUIT
    ON A GOSUB PARAMVALUES, GETPARAM, WRITEDATA
    GOTO MENU

QUIT: CLOSE #1   ' end communication with the Flux Vector Drive
     END       ' end the basic program

'****************************************************************

' Read all the drive parameters
' ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
' The message format is:   <EOT>    ADD      PAR      <ENQ>
'                          1 char   4 chars  3 chars  1 char

' When the ASCII control character <EOT> is sent it initializes the drive
' connected to the serial link.   (<EOT> - ASCII code 04 HEX, CONTROL D)

' ADD represents the drive address. The drive address identifies which
' device connected to the serial link is to be communicated with. For
' data integrity the digits are sent twice. For example if addressing
' drive 31 send 3311.

' PAR - this is the parameter which is required to be read. It is a maximum
' of 3 characters. e.g. For the Minimum Speed Limit, Pr-3 : just the number
' 003 is sent

' The message is terminated by the ASCII control character <ENQ>.
```

```
' (<ENQ> - ASCII CODE 05 HEX, CONTROL E)
'****************************************************************

' Response from the drive:  <STX>      PAR      DATA     <ETX>     BCC
' ~~~~~~~~~~~~~~~~~~~~~~~~   1 char   3 chars   6 chars   1 char   1 char

' <STX> is an ASCII control character. This indicates to the host the start
'  of the reply.                    (<STX> - ASCII code 02 HEX, CONTROL B)

' PAR - The drive parameter. (See above for description)

' DATA - This symbol represents a parameter's numerical value. It is 1-6
' numeric characters in length, with optional decimal point and sign
' character, and is accurate to 1 decimal point.
' <ETX> is an ASCII control character. It indicates to the host that the
' data is finished.
' BCC, Block checksum - The final character is generated by the drive to
' allow the host which is receiving data to perform an error check on the
' data received. This character is not sent if the drive is set for BCC
' disabled, bit parameter b-21. BCC is the exclusive-OR of all the characters
' after the <STX> character up to and including the <ETX> character.
' If the BCC is disabled the ASCII control character <CR> is sent.
' NOTE: The same parameter can be re-read simply by sending the ASCII
' control character <NAK> (ASCII code 15 HEX, CONTROL U).
' Alternatively it is possible to step forward or backwards through the
' parameters sequentially by sending the ASCII control characters <ACK>
' (ASCII code 6 HEX, CONTROL F) OR <BS> (ASCII code 8 HEX, CONTROL H)
'****************************************************************

PARAMVALUES:
 CLS
 txd$ = CHR$(4) + "0011000" + CHR$(5)       'String transmitted
                                            '<EOT> - CHR$(4)
                                            '<ENQ> - CHR$(5)
 rxd$ = ""
 LOCATE 1, 5: PRINT "STRING TRANSMITTED IS :- "; txd$
 LOCATE 3, 1: PRINT "PARAMETER"
 LOCATE 3, 14: PRINT "VALUE"
 LOCATE 3, 40: PRINT "PARAMETER"
 LOCATE 3, 54: PRINT "VALUE"
 VIEW PRINT 4 TO 25         'set text viewport
 x = 4                      'x-coord cursor position
 i = 0                      'variable to keep track of y-coord position
 parameter$ = "00"
 PRINT #1, txd$             'Writes data to Coms port 1
 GOSUB delay

DO UNTIL parameter$ = "83"        'display up to parameter 83
   rxd$ = INPUT$(LOC(1), #1)       'receive input from the comms device
   STXloc = INSTR(rxd$, CHR$(2))   'find position of control character
```

```
                                '<STX> to obtain start of message

    rxd$ = MID$(rxd$, STXloc, 11)   'remove unwanted noise from response OR
                                'obtain required info from response.
                                'Ignore BCC - ie BCC disabled
    parameter$ = MID$(rxd$, 2, 3)
    IF VAL(parameter$) > 83 THEN RETURN
    parameter$ = MID$(rxd$, 3, 2)   'extract parameter from response
    dat$ = MID$(rxd$, 5, 6)         'extract data from driver's response
    GOSUB CURSORPOSI
    LOCATE y, x
    PRINT parameter$; "       "; dat$
    IF VAL(parameter$) >= 83 THEN GOSUB MENURETURN
    prevrxd$ = rxd$             'keep record of the previous received
                               'message from the drive in case of error
    PRINT #1, CHR$(6)           'Send <ACK> to the drive to step forward
                               'through the parameters sequentially
    GOSUB delay
   LOOP
   RETURN
  GETPARAM: '******************************
        'Get a specific parameter from VECTOR
        CLS
        LOCATE 3, 3: PRINT "1.   Minimum Speed Limit"
        LOCATE 4, 3: PRINT "2.   Maximum Speed Limit"
        LOCATE 5, 3: PRINT "3.   Drive Address"
        LOCATE 6, 3: PRINT "4.   Baud Rate"
        LOCATE 7, 3: PRINT "5.   Motor Speed"
        LOCATE 8, 3: PRINT "6.   Motor Frequency"
        LOCATE 9, 3: PRINT "7.   Active Current"
        LOCATE 10, 3: PRINT "8.   Drive Status"
        LOCATE 11, 3: PRINT "9.   Parity Status"
        LOCATE 12, 3: PRINT "10.  Block CheckSum Status "
        LOCATE 13, 3: PRINT "11.  Hardware Status"
        LOCATE 14, 3: PRINT "12.  Return to main menu"
        LOCATE 16, 1: PRINT "Choose a parameter and press 'return':"
        INPUT PR$
        IF LEN(PR$) = 0 OR LEN(PR$) > 2 OR PR$ = "12" THEN RETURN
        IF PR$ = "1" THEN GOSUB GP1
        IF PR$ = "2" THEN GOSUB GP2
        IF PR$ = "3" THEN GOSUB GP3
        IF PR$ = "4" THEN GOSUB GP4
        IF PR$ = "5" THEN GOSUB GP5
        IF PR$ = "6" THEN GOSUB GP6
        IF PR$ = "7" THEN GOSUB GP7
        IF PR$ = "8" THEN GOSUB GP8
        IF PR$ = "9" THEN GOSUB GP9
        IF PR$ = "10" THEN GOSUB GP10
        IF PR$ = "11" THEN GOSUB GP11
```

```
TRANSMIT: txd$ = CHR$(4) + "0011" + DP$ + CHR$(5)
        rxd$ = ""
        PRINT #1, txd$
        GOSUB delay

        rxd$ = INPUT$(LOC(1), #1)
        IF rxd$ = "" THEN GOTO TRANSMIT
        STXloc = INSTR(rxd$, CHR$(2))  'Filter out any noise if it exists
        rxd$ = MID$(rxd$, STXloc, 11)
        IF MID$(rxd$, 2, 3) <> DP$ THEN GOTO TRANSMIT
        dat$ = MID$(rxd$, 5, 6)
        LOCATE 18, 4: PRINT MSG$; " "; dat$; " "; UNIT$
        LOCATE 20, 1: PRINT "Would you like to read another parameter (Y/N)"

RAGAIN: KY$ = INKEY$: IF KY$ = "" THEN GOTO RAGAIN
     IF KY$ = "y" OR KY$ = "Y" THEN GOTO GETPARAM
     RETURN

GP1: DP$ = "003"
    MSG$ = "The minimum speed limit is: "
    UNIT$ = "r.p.m."
    RETURN
GP2: DP$ = "004"
    MSG$ = "The maximum speed limit is: "
    UNIT$ = "r.p.m."
    RETURN
GP3: DP$ = "022"
    MSG$ = "The drive address is:"
    UNIT$ = ""
    RETURN
GP4: DP$ = "023"
    MSG$ = "The baud rate is:"
    UNIT$ = "baud"
    RETURN
GP5: DP$ = "070"
    MSG$ = "The motor speed is:"
    UNIT$ = "r.p.m."
    RETURN
GP6: DP$ = "071"
    MSG$ = "The motor frequency is:"
    UNIT$ = "Hz"
    RETURN
GP7: DP$ = "075"
    MSG$ = "The active current is:"
    UNIT$ = "%"
    RETURN
GP8: DP$ = "102"
    MSG$ = "The drive is:"
    UNIT$ = "  0-drive enabled   1-drive disabled"
    RETURN
```

```
GP9: DP$ = "120"
     MSG$ = "The parity is:"
     UNIT$ = "  0-parity disabled   1-parity enabled"
     RETURN
GP10: DP$ = "121"
      MSG$ = "The block checksum is:"
      UNIT$ = "  0-BCC disabled   1-BCC enabled"
      RETURN
GP11: DP$ = "190"
      MSG$ = "The hardware status is:"
      UNIT$ = "  0-Inactive   1-Active"
      RETURN
'*****************************************************************
********
'The Write Command.  The message sent to the drive is :-

'   <EOT>    ADD    <STX>     PAR     DATA    <ETX>     BCC
'    1 char  4 chars   1 char   3 chars   6 chars   1 char   1 char

' If the drive parameter, data or the BCC is in error then the control
' character <NAK> is sent.
' If it is required to write further data to the drive, it is not necessary
' to re-send the initialization character or the drive address. The drive
' parameter characters are the first characters sent.
'*****************************************************************
*********
WRITEDATA: '* Send data to VECTOR
        CLS
        COUNT = 0
        LOCATE 3, 3: PRINT "1.   Minimum Speed Limit"
        LOCATE 4, 3: PRINT "2.   Maximum Speed Limit"
        LOCATE 5, 3: PRINT "3.   Drive Status"
        LOCATE 6, 3: PRINT "4.   Return to main menu"
        LOCATE 8, 1: PRINT "Choose a parameter: (1,2,3 or 4)";

WDMENU: KY$ = INKEY$: IF KY$ = "" THEN GOTO WDMENU
      A = VAL(KY$)
      IF A >= 4 THEN GOSUB MENU
      ON A GOSUB WD1, WD2, WD3
      COUNT = COUNT + 1

WDSEND: IF COUNT <= 1 THEN
        txd$ = CHR$(4) + "0011" + CHR$(2) + DP$ + DATA$ + CHR$(3) + " "
      ELSEIF COUNT > 1 THEN
        txd$ = DP$ + DATA$ + CHR$(3) + " "
      END IF
      rxd$ = ""
      PRINT #1, txd$
      FOR j = 1 TO 3
        GOSUB delay
```

```
        NEXT
        rxd$ = INPUT$(LOC(1), #1)
        IF rxd$ = "" THEN GOTO WDSEND
        '************ First locate the beginning of the received string
        FOR k = 1 TO LEN(rxd$)
         ch$ = MID$(rxd$, k, 1)
         IF ch$ = CHR$(6) OR ch$ = CHR$(15) THEN messageposi = k
        NEXT

        rxd$ = MID$(rxd$, messageposi, 1)

        IF rxd$ = CHR$(15) THEN
         PRINT " I/O error"; rxd$
        ELSEIF rxd$ = CHR$(6) THEN
         PRINT "successful write"; rxd$
        ELSEIF rxd$ <> CHR$(15) OR rxd$ <> CHR$(6) THEN
         GOTO WDSEND
        END IF
        LOCATE 20, 1: PRINT "Would you like to write to another parameter (Y/N)"

    WAGAIN: KY$ = INKEY$: IF KY$ = "" THEN GOTO WAGAIN
        IF KY$ = "y" OR KY$ = "Y" THEN GOTO WRITEDATA
        RETURN

    WD1: DP$ = "003"
       GOSUB INPUTDATA
       RETURN
    WD2: DP$ = "004"
       GOSUB INPUTDATA
       RETURN
    WD3: DP$ = "102"
       LOCATE 15, 1: INPUT "Do you wish to (E)nable or (D)isable the drive"; ABLE$
       IF ABLE$ = "E" THEN
        DATA$ = " 0000."
       ELSEIF ABLE$ = "D" THEN
        DATA$ = " 0001."
       ELSEIF ABLE$ <> "E" OR ABLE$ <> "D" THEN
        GOTO WD3
       END IF
       RETURN

    '*****************************************************************
  *********
    'Error handling routine

    ' This is the first statement the program branches to after an error.
    ' The error handler is placed where it cannot be executed during the normal
    ' flow of program execution.
    '*****************************************************************
  **********
```

```
FAULT: LOCATE 23, 1
       PRINT "ERL="; ERL, "ERR="; ERR;
       GOSUB PAUSE
       rxd$ = prevrxd$
       RESUME NEXT

PAUSE: LOCATE 24, 1: PRINT "Press any key to continue ... ";
KEYPRESSED: KY$ = INKEY$
            IF KY$ = "" THEN GOTO KEYPRESSED
            LOCATE 23, 1: PRINT "                              "
            LOCATE 24, 1: PRINT "                              "
            RETURN

NEXTSCR: LOCATE 24, 1: PRINT "Press any key for next screen of Parameters  ... ";
KYPRESSED: KY$ = INKEY$
           IF KY$ = "" THEN GOTO KYPRESSED
           RETURN
MENURETURN: LOCATE 24, 1: PRINT "Press any key to return to the main menu
..."
KPRESSED: KY$ = INKEY$
          IF KY$ = "" THEN GOTO KYPRESSED
          RETURN

CURSORPOSI:
    i = i + 1
    IF i <= 19 THEN
      y = i + 3
      x = 4
    ELSEIF i > 19 AND i <= 38 THEN
      y = i - 16
      x = 44
    ELSEIF i > 38 AND i <= 57 THEN
      y = i - 35
      x = 4
    ELSEIF i > 57 THEN
      y = i - 54
      x = 44
    END IF
    IF i = 39 THEN GOSUB NEXTSCR: CLS
    RETURN
delay: 'Delay
  FOR k = 1 TO 10
  z = SIN(z * 3.4) + COS(z * 3.45)
  NEXT k
  RETURN

INPUTDATA:
     DECPOSI = 0
```

```
LOCATE 12, 1: INPUT "Enter data to be sent (-1500 to 1500)  (No decimals) ",
dat$
IF ABS(VAL(dat$)) > 1500 OR LEN(dat$) > 5 THEN GOTO WD1

FOR CNT = 1 TO LEN(dat$)
  DUM$ = MID$(dat$, CNT, 1)
  IF DUM$ = "." THEN DECPOSI = CNT
NEXT

IF LEFT$(dat$, 1) = "-" THEN
  IF DECPOSI = 0 THEN    'No decimal
    IF LEN(dat$) = 3 THEN dat$ = "-" + "00" + RIGHT$(dat$, 2) + "."
    IF LEN(dat$) = 4 THEN dat$ = "-" + "0" + RIGHT$(dat$, 3) + "."
    IF LEN(dat$) = 5 THEN dat$ = dat$ + "."
  ELSEIF DECPOSI <> 0 THEN
    LOCATE 15, 1: INPUT "Please enter a whole number:"; b
    GOTO WD1
  END IF
ELSEIF LEFT$(dat$, 1) <> "-" THEN
  IF DECPOSI = 0 THEN    'No decimal
    IF LEN(dat$) = 2 THEN dat$ = " " + "00" + RIGHT$(dat$, 2) + "."
    IF LEN(dat$) = 3 THEN dat$ = " " + "0" + RIGHT$(dat$, 3) + "."
    IF LEN(dat$) = 4 THEN dat$ = " " + RIGHT$(dat$, 4) + "."
    IF LEN(dat$) = 5 THEN dat$ = dat$ + "."
  ELSEIF DECPOSI <> 0 THEN
    LOCATE 15, 1: INPUT "Please enter a whole number:"; b
    GOTO WD1
  END IF
END IF
DATA$ = dat$
RETURN
```

Appendix E

Glossary

A

ABM	Asynchronous balanced mode
ACE	Association control element
ACE	Asynchronous communications element. Similar to UART
ACK	Acknowledge (ASCII - control F)
Active filter	Active circuit devices (usually amplifiers), with passive circuit elements (resistors and capacitors) and which have characteristics that more closely match ideal filters than do passive filters.
Active passive device	Device capable of supplying the current for the loop (active) or one that must draw its power from connected equipment (passive).
ADCCP	Advanced data communication control procedure
ADDR	Address field
Address	A normally unique designator for location of data or the identity of a peripheral device that allows each device on a single communications line to respond to its own message.
Algorithm	Normally used as a basis for writing a computer program. This is a set of rules with a finite number of steps for solving a problem.
Alias frequency	A false lower frequency component that appears in data reconstructed from original data acquired at an insufficient sampling rate (which is less than two (2) times the maximum frequency of the original data).
ALU	Arithmetic logic unit

Amplitude flatness	A measure of how close to constant the gain of a circuit remains over a range of frequencies.
Amplitude modulation	A modulation technique (also referred to as AM or ASK) used to allow data to be transmitted across an analog network, such as a switched telephone network. The amplitude of a single (carrier) frequency is varied or modulated between two levels – one for binary 0 and one for binary 1.
Analog	A continuous real time phenomena where the information values are represented in a variable and continuous waveform.
ANSI	American National Standards Institute – the principal standards development body in the USA.
APM	Alternating pulse modulation
Appletalk	A proprietary computer networking standard initiated by the Apple Computer for use in connecting the Macintosh range of computers and peripherals (including laser writer printers). This standard operates at 230 kbps.
Application layer	The highest layer of the seven layer ISO/OSI reference model structure, which contains all user or application programs.
Arithmetic logic unit	The element(s) in a processing system that perform(s) the mathematical functions such as addition, subtraction, multiplication, division, inversion, AND, OR, NAND and NOR.
ARP	Address resolution protocol A transmission control protocol/ Internet protocol (TCP/IP) process that maps an IP address to Ethernet address, required by TCP/IP for use with Ethernet.
ARQ	Automatic request for transmission A request by the receiver for the transmitter to retransmit a block or frame because of errors detected in the originally received message.
AS	Australian standard
ASCII	American standard code for information interchange. A universal standard for encoding alphanumeric characters into 7 or 8 binary bits. Drawn up by ANSI to ensure compatibility between different computer systems.
AS-i	Actuator sensor interface
ASIC	Application specific integrated circuit
ASK	Amplitude shift keying – see Amplitude modulation

ASN.1 Abstract syntax notation 1 – an abstract syntax used to define the structure of the protocol data units associated with a particular protocol entity.

Asynchronous Communications where characters can be transmitted at an arbitrary unsynchronized point in time and where the time intervals between transmitted characters may be of varying lengths. Communication is controlled by start and stop bits at the beginning and end of each character.

Attenuation The decrease in the magnitude of strength (or power) of a signal. In cables, generally expressed in dB per unit length.

AWG American wire gauge

B

Balanced circuit A circuit so arranged that the impressed voltages on each conductor of the pair are equal in magnitude but opposite in polarity with respect to ground.

Bandpass filter A filter that allows only a fixed range of frequencies to pass through. All other frequencies outside this range (or band) are sharply reduced in magnitude.

Bandwidth The range of frequencies available expressed as the difference between the highest and lowest frequencies is expressed in Hertz (or cycles per second).

Base address A memory address that serves as the reference point. All other points are located by offsetting in relation to the base address.

Baseband Baseband operation is the direct transmission of data over a transmission medium without the prior modulation on a high frequency carrier band.

Baud Unit of signaling speed derived from the number of events per second (normally bits per second). However if each event has more than one bit associated with it the baud rate and bits per second are not equal.

Baudot Data transmission code in which five bits represent one character. 64 alphanumeric characters can be represented. This code is used in many teleprinter systems with one start bit and 1.42 stop bits added.

BCC Block check calculation

BCC Block check character – error checking scheme with one check character; a good example being block sum check.

BCD Binary coded decimal
A code used for representing decimal digits in a binary code.

BEL Bell (ASCII for control-G)

Bell 212 An AT&T specification of full duplex, asynchronous or synchronous 1200 baud data transmission for use on the public telephone networks.

BER Bit error rate

BERT/BLERT	Bit error rate/block error rate testing – an error checking technique that compares a received data pattern with a known transmitted data pattern to determine transmission line quality.
BIN	Binary digits
BIOS	Basic input/output system
Bipolar	A signal range that includes both positive and negative values.
BISYNC	Binary synchronous communications protocol
Bit	Derived from "**BI**nary Digi**T**", a one or zero condition in the binary system.
Bit stuffing with zero bit insertion	A technique used to allow pure binary data to be transmitted on a synchronous transmission line. Each message block (frame) is encapsulated between two flags that are special bit sequences. Then if the message data contains a possibly similar sequence, an additional (zero) bit is inserted into the data stream by the sender, and is subsequently removed by the receiving device. The transmission method is then said to be data transparent.
Bits per second (bps)	Unit of data transmission rate.
Block sum check	This is used for the detection of errors when data is being transmitted. It comprises a set of binary digits (bits) which are the modulo 2 sum of the individual characters or octets in a frame (block) or message.
Bridge	A device to connect similar subnetworks without its own network address. Used mostly to reduce the network load.
Broadband	A communications channel that has greater bandwidth than a voice grade line and is potentially capable of greater transmission rates. Opposite of baseband. In wideband operation the data to be transmitted are first modulated on a high frequency carrier signal. They can then be simultaneously transmitted with other data modulated on a different carrier signal on the same transmission medium.
Broadcast	A message on a bus intended for all devices that requires no reply.
BS	Backspace (ASCII Control-H)
BS	British standard
BSC	Bisynchronous transmission A byte or character oriented communication protocol that has become the industry standard (created by IBM). It uses a defined set of control characters for synchronized transmission of binary coded data between stations in a data communications system.
BSP	Binary synchronous protocol

Buffer An intermediate temporary storage device used to compensate for a difference in data rate and data flow between two devices (also called a spooler for interfacing a computer and a printer).

Burst mode A high-speed data transfer in which the address of the data is sent followed by back to back data words while a physical signal is asserted.

Bus A data path shared by many devices with one or more conductors for transmitting signals, data or power.

Byte A term referring to eight associated bits of information; sometimes called a ‘character’.

C

CAN Controller area network

Capacitance Storage of electrically separated charges between two plates having different potentials. The value is proportional to the surface area of the plates and inversely proportional to the distance between them.

Capacitance (mutual) The capacitance between two conductors with all other conductors, including shield, short-circuited to the ground.

CATV Community Antenna Television

CCITT See ITU

Cellular polyethylene Expanded or ‘foam’ polyethylene consisting of individual closed cells suspended in a polyethylene medium.

Character Letter, numeral, punctuation, control figure or any other symbol contained in a message.

Characteristic impedance The impedance that, when connected to the output terminals of a transmission line of any length, makes the line appear infinitely long. The ratio of voltage to current at every point along a transmission line on which there are no standing waves.

CIC Controller in charge

Clock The source(s) of timing signals for sequencing electronic events e.g. synchronous data transfer.

CMD Command byte

CMR Common mode rejection

CMRR Common mode rejection ratio

CMV Common mode voltage

Common carrier A private data communications utility company that furnishes communications services to the general public.

Composite link	The line or circuit connecting a pair of multiplexers or concentrators; the circuit carrying multiplexed data.
Contention	The facility provided by the dial network or a data PABX which allows multiple terminals to compete on a first come, first served basis for a smaller number of computer posts.
CPU	Central processing unit
CR	Carriage return (ASCII control-M)
CRC	Cyclic redundancy check – an error-checking mechanism using a polynomial algorithm based on the content of a message frame at the transmitter and included in a field appended to the frame. At the receiver, it is then compared with the result of the calculation that is performed by the receiver. Also referred to as CRC-16.
CRL	Communication relationship list
Cross talk	A situation where a signal from a communications channel interferes with an associated channel's signals.
Crossed planning	Wiring configuration that allows two DTE or DCE devices to communicate. Essentially it involves connecting pin 2 to pin 3 of the two devices.
Crossover	In communications, a conductor that runs through the cable and connects to a different pin number at each end.
CSMA/CD	Carrier sense multiple access/collision detection – when two senders transmit at the same time on a local area network; they both cease transmission and signal that a collision has occurred. Each then tries again after waiting for a predetermined time period.
CTS	Clear to send
Current Loop	Communication method that allows data to be transmitted over a longer distance with a higher noise immunity level than with the standard EIS-232-C voltage method. A mark (a binary 1) is represented by current of 20 mA and a space (or binary 0) is represented by the absence of current.

D

DAQ	Data acquisition
Data integrity	A performance measure based on the rate of undetected errors.
Data link layer	This corresponds to layer 2 of the ISO reference model for open systems interconnection. It is concerned with the reliable transfer of data (no residual transmission errors) across the data link being used.
Data reduction	The process of analyzing large quantities of data in order to extract some statistical summary of the underlying parameters.

Datagram	A type of service offered on a packet-switched data network. A datagram is a self contained packet of information that is sent through the network with minimum protocol overheads.
DCD	Data carrier detect
DCE	Data communications equipment or data circuit-terminating equipment – devices that provide the functions required to establish, maintain, and terminate a data transmission connection. Normally it refers to a modem.
DCS	Distributed control systems
Decibel (dB)	A logarithmic measure of the ratio of two signal levels where dB = $20\log_{10} V1/V2$ or where dB = $10\log_{10} P1/P2$ and where V refers to voltage or P refers to power. Note that it has no units of measurement.
Default	A value or setup condition assigned, which is automatically assumed for the system unless otherwise explicitly specified.
Delay distortion	Distortion of a signal caused by the frequency components making up the signal having different propagation velocities across a transmission medium.
DES	Data encryption standard
DFM	Direct frequency modulation
Dielectric constant (E)	The ratio of the capacitance using the material in question as the dielectric, to the capacitance resulting when the material is replaced by air.
Digital	A signal which has definite states (normally two).
DIN	Deutsches Institut Fur Normierung
DIP	Dual in line package, referring to integrated circuits and switches.
Direct memory access	A technique of transferring data between the computer memory and a device on the computer bus without the intervention of the microprocessor. Also abbreviated to DMA.
DISC	Disconnect
DLE	Data link escape (ASCII character)
DNA	Distributed network architecture
DPI	Dots per inch
DPLL	Digital phase locked loop
DR	Dynamic range The ratio of the full-scale range (FSR) of a data converter to the smallest difference it can resolve. DR = 2n where n is the resolution in bits.

Driver software	A program that acts as the interface between a higher-level coding structure and the lower level hardware/firmware component of a computer.
DSP	Digital signal processing
DSR	Data set ready or DCE ready in EIA-232D/E – A EIA-232 modem interface control signal which indicates that the terminal is ready for transmission.
DTE	Data terminal equipment – devices acting as data source or data sink, or both.
DTR	Data terminal ready or DTE ready in EIA-232D/E
Duplex	The ability to send and receive data simultaneously over the same communications line.

E

EBCDIC	Extended binary coded decimal interchange code An eight bit character code used primarily in IBM equipment. The code allows for 256 different bit patterns.
EDAC	Error detection and correction
EFTPOS	Electronic funds transfer at the point of sale
EIA	Electronic Industries Association – a standards organization in the USA specializing in the electrical and functional characteristics of interface equipment.
EISA	Enhanced industry standard architecture
EMI/RFI	Electromagnetic interference/radio frequency interference 'background noise' that could modify or destroy data transmission.
EMS	Expanded memory specification
Emulation	The imitation of a computer system performed by a combination of hardware and software that allows programs to run between incompatible systems.
ENQ	Enquiry (ASCII Control-E)
EOT	End of transmission (ASCII Control-D)
EPA	Enhanced performance architecture
EPR	Earth potential rise
EPROM	Erasable programmable read only memory – non-volatile semiconductor memory that is erasable in an ultra violet light and reprogrammable.
Error rate	The ratio of the average number of bits that will be corrupted to the total number of bits that are transmitted for a data link or system.
ESC	Escape (ASCII character)
ESD	Electrostatic discharge
ETB	End of transmission block

Ethernet	Name of a widely used LAN, based on the CSMA/CD bus access method (IEEE 802.3). Ethernet is the basis of the TOP bus topology.
ETX	End of text (ASCII control-C)
Even parity	A data verification method normally implemented in hardware in which each character must have an even number of 'ON' bits.

F

Farad	Unit of capacitance whereby a charge of one coulomb produces a one volt potential difference.
FAS	Fieldbus access sublayer
FCC	Federal communications commission
FCS	Frame check sequence – a general term given to the additional bits appended to a transmitted frame or message by the source to enable the receiver to detect possible transmission errors.
FDM	Frequency division multiplexer – a device that divides the available transmission frequency range in narrower bands, each of which is used for a separate channel.
FIB	Factory information bus
FIFO	First in, first out
Filled cable	A telephone cable construction in which the cable core is filled with a material that will prevent moisture from entering or passing along the cable.
FIP	Factory instrumentation protocol
Firmware	A computer program or software stored permanently in PROM or ROM or semi-permanently in EPROM.
Flame retardancy	The ability of a material not to propagate flame once the flame source is removed.
Flow control	The procedure for regulating the flow of data between two devices preventing the loss of data once a device's buffer has reached its capacity.
FMS	Fieldbus message specification
FNC	Function byte
Frame	The unit of information transferred across a data link. Typically, there are control frames for link management and information frames for the transfer of message data.
Frequency modulation	A modulation technique (abbreviated to FM) used to allow data to be transmitted across an analog network where the frequency is varied between two levels – one for binary '0'

	and one for binary '1'. Also known as frequency shift keying (or FSK).
Frequency	Refers to the number of cycles per second.
FRMR	Frame reject
FSK	Frequency shift keying, see frequency modulation
Full duplex	Simultaneous two-way independent transmission in both directions (4 wire). See Duplex.

G

G	Giga (metric system prefix – 10^9)
Gateway	A device to connect two different networks which translates the different protocols.
GMSK	Gaussian minimum shift keying
GPIB	General purpose interface bus – an interface standard used for parallel data communication, usually used for controlling electronic instruments from a computer. Also known as IEEE 488 standard.
Ground	An electrically neutral circuit that has the same potential as the earth. A reference point for an electrical system also intended for safety purposes.

H

Half duplex	Transmissions in either direction, but not simultaneously.
Hamming	
Distance	A measure of the effectiveness of error checking. The higher the Hamming distance (HD) index, the safer is the data transmission.
Handshaking	Exchange of predetermined signals between two devices establishing a connection.
Hardware	Refers to the physical components of a device, such as a computer, sensor, controller or data communications system. These are the physical items that one can see.
HART	Highway addressable remote transducers
HDLC	High level data link control The international standard communication protocol defined by ISO to control the exchange of data across either a point-to-point data link or a multidrop data link.
Hertz (Hz)	A term replacing cycles per second as a unit of frequency.
Hex	Hexadecimal
HF	High frequency
Host	This is normally a computer belonging to a user that contains (hosts) the communication hardware and software necessary to connect the computer to a data communications network.

HSE	High speed Ethernet

I

I/O address	A method that allows the CPU to distinguish between different boards in a system. All boards must have different addresses.
IA5	International alphabet number 5
IC	Integrated circuit
ICS	Instrumentation and control system
IDF	Intermediate distribution frame
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers – an American based international professional society that issues its own standards and is a member of ANSI and ISO.
IEEE	Institute of Electrical and Electronic Engineers
IFC	International Fieldbus Consortium
ILD	Injection laser diode
Impedance	The total opposition that a circuit offers to the flow of alternating current or any other varying current at a particular frequency. It is a combination of resistance R and reactance X, measured in Ohms.
Inductance	The property of a circuit or circuit element that opposes a change in current flow, thus causing current changes to lag behind voltage changes. It is measured in henrys.
Insulation resistance (IR)	That resistance offered by insulation to an impressed dc voltage, tending to produce a leakage current though the insulation.
Interface	A shared boundary defined by common physical interconnection characteristics, signal characteristics and measurement of interchanged signals.
Interrupt handler	The section of the program that performs the necessary operation to service an interrupt when it occurs.
Interrupt	An external event indicating that the CPU should suspend its current task to service a designated activity.
IP	Internet protocol
IRQ	Interrupt request line
ISA	Industry Standard Architecture (for IBM Personal Computers)
ISB	Intrinsically safe barrier
ISDN	Integrated services digital network – the new generation of worldwide telecommunications network that utilizes digital

	techniques for both transmission and switching. It supports both voice and data communications.
ISO	International Standards Organization
ISP	Interoperable systems project
ISR	Interrupt service routine, see interrupt handler
ITB	End of intermediate block
ITS	Interface terminal strip
ITU	International Telecommunications Union – formerly CCITT (Consultative Committee International Telegraph and Telephone). An international association that sets worldwide standards (e.g. V.21, V.22, V.22bis).

J

Jumper	A wire connecting one or more pins on the one end of a cable only.

K

k (kilo)	This is 2^{10} or 1024 in computer terminology, e.g. 1 kB = 1024 bytes.

L

LAN	Local area network – a data communications system confined to a limited geographic area typically about 10 km with moderate to high data rates (100 kbps to 50 Mbps). Some type of switching technology is used, but common carrier circuits are not used.
LAN	Local area network. See Local area network.
LAP-M	Link access protocol modem
LAS	Link active scheduler
LCD	Liquid crystal display – a low-power display system used on many laptops and other digital equipment.
LDM	Limited distance modem – a signal converter which conditions and boosts a digital signal so that it may be transmitted further than a standard EIA-232 signal.
Leased (or Private) line	A private telephone line without inter-exchange switching arrangements.
LED	Light emitting diode A semiconductor light source that emits visible light or infra red radiation.
LF	Line feed (ASCII Control-J)
Line driver	A signal converter that conditions a signal to ensure reliable transmission over an extended distance.

Line turnaround	The reversing of transmission direction from transmitter to receiver or vice versa when a half duplex circuit is used.
Linearity	A relationship where the output is directly proportional to the input.
Link layer	Layer 2 of the ISO/OSI reference model. Also known as the data link layer.
Listener	A device on the GPIB bus that receives information from the bus.
LLC	Logical link control (IEEE 802)
LLI	Lower layer interface
Loaded line	A telephone line equipped with loading coils to add inductance in order to minimize amplitude distortion.
Loop resistance	The measured resistance of two conductors forming a circuit.
Loopback	Type of diagnostic test in which the transmitted signal is returned on the sending device after passing through all, or a portion of, a data communication link or network. A loopback test permits the comparison of a returned signal with the transmitted signal.
LRC	Longitudinal redundancy check
LSB	Least significant bits – the digits on the right hand side of the written HEX or BIN codes.
LSD	Least significant digit

M

M	Mega. Metric system prefix for 10^6.
m	Meter. Metric system unit for length.
MAC	Media Access Control (IEEE 802).
MAN	Metropolitan Area Network
Manchester	
encoding	Digital technique (specified for the IEEE 802.3 Ethernet baseband network standard) in which each bit period is divided into two complementary halves; a negative to positive voltage transition in the middle of the bit period designates a binary ‘1’, whilst a positive to negative transition represents a ‘0’. The encoding technique also allows the receiving device to recover the transmitted clock from the incoming data stream (self clocking).
MAP 3.0	Standard profile for manufacturing developed by MAP.
MAP	Manufacturing automation protocol – a suite of network protocols originated by General Motors, which follow the seven layers of the OSI model. A reduced implementation is referred to as a mini-MAP.
Mark	This is equivalent to a binary 1.

Master/slave Bus access method whereby the right to transmit is assigned to one device only, the **master,** and all the other devices, the **slaves** may only transmit when requested.

MDF Main distribution frame

MIPS Million instructions per second

MMI Man-machine-interface

MMS Manufacturing message services – a protocol entity forming part of the application layer. It is intended for use specifically in the manufacturing or process control industry. It enables a supervisory computer to control the operation of a distributed community of computer-based devices.

MNP Microcom networking protocol

Modem eliminator A device used to connect a local terminal and a computer port in lieu of the pair of modems to which they would ordinarily connect, allow DTE to DTE data and control signal connections otherwise not easily achieved by standard cables or connections.

Modem MODulator/DEModulator – a device used to convert serial digital data from a transmitting terminal to a signal suitable for transmission over a telephone channel or to reconvert the transmitted signal to serial digital data for the receiving terminal.

MOS Metal oxide semiconductor

MOV Metal oxide varistor

MSB Most significant bits – the digits on the left hand side of the written HEX or BIN codes.

MSD Most significant digit

MTBF Mean time between failures

MTTR Mean time to repair

Multidrop A single communication line or bus used to connect three or more points.

Multiplexer (MUX) A device used for division of a communication link into two or more channels either by using frequency division or time division.

N

NAK Negative acknowledge (ASCII Control-U)

Network architecture A set of design principles including the organization of functions and the description of data formats and procedures used as the basis for the design and implementation of a network (ISO).

Network layer Layer 3 in the ISO/OSI reference model, the logical network entity that services the transport layer responsible for ensuring that data passed to it from the transport layer is routed and delivered throughout the network.

Network topology
The physical and logical relationship of nodes in a network; the schematic arrangement of the links and nodes of a network typically in the form of a star, ring, tree or bus topology.

Network An interconnected group of nodes or stations.

NMRR Normal mode rejection ratio

Node A point of interconnection to a network.

Noise A name given to the extraneous electrical signals that may be generated or picked up in a transmission line. If the noise signal is large compared with the data carrying signal, the latter may be corrupted resulting in transmission errors.

NOS Network operating system

NRM Unbalanced normal response mode

NRZ Non return to zero – pulses in alternating directions for successive 1 bits but no change from existing signal voltage for 0 bits.

NRZI Non return to zero inverted

Null modem A device that connects two DTE devices directly by emulating the physical connections of a DCE device.

Nyquist sampling theorem In order to recover all the information about a specified signal it must be sampled at least at twice the maximum frequency component of the specified signal.

O

OD Object dictionary

Ohm (Ω) Unit of resistance such that a constant current of one ampere produces a potential difference of one Volt across a conductor.

Optical isolation Two networks with no electrical continuity in their connection because an optoelectronic transmitter and receiver have been used.

OSI Open systems interconnection

P

Packet A group of bits (including data and call control signals) transmitted as a whole on a packet switching network. Usually smaller than a transmission block.

PAD Packet access device – an interface between a terminal or computer and a packet switching network.

Parallel transmission The transmission model where a number of bits is sent simultaneously over separate parallel lines. Usually unidirectional such as the Centronics interface for a printer.

Parity bit A bit that is set to a ‘0’ or ‘1’ to ensure that the total number of 1 bits in the data field is even or odd.

Parity check The addition of non-information bits that make up a transmission block to ensure that the total number of bits is always even (even parity) or odd (odd parity). Used to detect transmission errors but rapidly losing popularity because of its weakness in detecting errors.

Passive filter A circuit using only passive electronic components such as resistors, capacitors and inductors.

PBX Private branch exchange

PCIP Personal computer instrument products

PDU Protocol data unit

Peripherals The input/output and data storage devices attached to a computer e.g. disk drives, printers, keyboards, display, communication boards, etc.

Phase modulation The sine wave or carrier changes phase in accordance with the information to be transmitted.

Phase shift keying A modulation technique (also referred to as PSK) used to convert binary data into an analog form comprising a single sinusoidal frequency signal whose phase varies according to the data being transmitted.

Physical layer Layer 1 of the ISO/OSI reference model, concerned with the electrical and mechanical specifications of the network termination equipment.

PID Proportional integral derivative – a form of closed loop control.

PLC Programmable logic controller

Point to point A connection between only two items of equipment.

Polling A means of controlling devices on a multipoint line. A controller queries devices for a response.

Polyethylene A family of insulators derived from the polymerization of ethylene gas and characterized by outstanding electrical properties, including high IR, low dielectric constant, and low dielectric loss across the frequency spectrum.

Polyvinyl chloride (PVC) A general-purpose family of insulations whose basic constituent is polyvinyl chloride or its copolymer with vinyl acetate. Plasticizers, stabilisers, pigments and fillers are

	added to improve mechanical and/or electrical properties of this material.
Port	A place of access to a device or network, used for input/output of digital and analog signals.
Presentation layer	Layer 6 of the ISO/OSI reference model, concerned with negotiating suitable transfer syntax for use during an application. If this is different from the local syntax, the translation to/from this syntax.
Profibus	Process field bus developed by a consortium of mainly German companies with the aim of standardization.
Protocol entity	The code that controls the operation of a protocol layer.
Protocol	A formal set of conventions governing the formatting, control procedures and relative timing of message exchange between two communicating systems.
PSDN	Public switched data network Any switching data communications system, such as telex and public telephone networks, which provides circuit switching to many customers.
PSK	See Phase shift keying
PSTN	Public switched telephone network – this is the term used to describe the (analog) public telephone network.
PTT	Post, Telephone and Telecommunications Authority or: push to talk signal
PV	Primary variable

Q

QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying

R

R/W	Read/write
RAM	Random access memory – semiconductor read/write volatile memory. Data is lost if the power is turned off.
Reactance	The opposition offered to the flow of alternating current by inductance or capacitance of a component or circuit.
REJ	Reject
Repeater	An amplifier that regenerates the signal and thus expands the network.
Resistance	The ratio of voltage to electrical current for a given circuit measured in Ohms.
Response time	The elapsed time between the generation of the last character of a message at a terminal and the receipt of the first character of the reply. It includes terminal delay and network delay.

RF	Radio frequency
RFI	Radio frequency interference
Ring	Network topology commonly used for interconnection of communities of digital devices distributed over a localized area, e.g. a factory or office block. Each device is connected to its nearest neighbors until all the devices are connected in a closed loop or ring. Data is transmitted in one direction only. As each message circulates around the ring, it is read by each device connected in the ring.
RMS	Root mean square
RNR	Receiver not ready
ROM	Read only memory – computer memory in which data can be routinely read but written to only once using special means when the ROM is manufactured. A ROM is used for storing data or programs on a permanent basis.
Router	A linking device between network segments which may differ in layers 1, 2a and 2b of the ISO/OSI reference model.
RR	Receiver ready
RS	Recommended standard (e.g. RS-232C) – newer designations use the prefix EIA (e.g. EIA-RS-232C or just EIA-232C).
RS-232-C	Interface between DTE and DCE, employing serial binary data exchange. Typical maximum specifications are 15 m (50 feet) at 19200 Baud.
RS-422	Interface between DTE and DCE employing the electrical characteristics of balanced voltage interface circuits.
RS-423	Interface between DTE and DCE, employing the electrical characteristics of unbalanced voltage digital interface circuits.
RS-449	General purpose 37 pin and 9 pin interface for DCE and DTE employing serial binary interchange.
RS-485	The recommended standard of the EIA that specifies the electrical characteristics of drivers and receivers for use in balanced digital multipoint systems.
RSSI	Receiver signal strength indicator
RTS	Request to send
RTU	Remote terminal unit – terminal unit situated remotely from the main control system.
RxRDY	Receiver ready

S

S/N	Signal to noise (ratio)
SAA	Standards Association of Australia
SAP	Service access point

SDLC	Synchronous data link control – IBM standard protocol superseding the bisynchronous standard.
SDM	Space division multiplexing
SDS	Smart distributed system
Serial transmission	The most common transmission mode in which information bits are sent sequentially on a single data channel.
Session layer	Layer 5 of the ISO/OSI reference model, concerned with the establishment of a logical connection between two application entities and with controlling the dialogue (message exchange) between them.
SFD	The start of frame delimiter
Short haul modem	A signal converter that conditions a digital signal for transmission over dc continuous private line metallic circuits, without interfering with adjacent pairs of wires in the same telephone cables.
Signal to noise ratio	The ratio of signal strength to the level of noise.
Simplex transmissions	Data transmission in one direction only.
Slew rate	This is defined as the rate at which the voltage changes from one value to another.
SNA	Subnetwork access, or systems network architecture
SNDC	Subnetwork dependent convergence
SNIC	Subnetwork independent convergence
SNR	Signal to noise ratio
Software	Refers to the programs that are written by a user to control the actions of a microprocessor or a computer. These may be written in one of many different programming languages and may be changed by the user from time to time.
SOH	Start of header (ASCII Control-A)
Space	Absence of signal. This is equivalent to a binary 0.
Spark test	A test designed to locate imperfections (usually pinholes) in the insulation of a wire or cable by application of a voltage for a very short period of time while the wire is being drawn through the electrode field.
SRC	Source node of a message
SREJ	Selective reject
Star	A type of network topology in which there is a central node that performs all switching (and hence routing) functions.
Statistical multiplexer	A device used to enable a number of lower bit rate devices, normally situated in the same location, to share a single,

higher bit rate transmission line. The devices usually have human operators and hence data is transmitted on the shared line on a statistical basis rather than, as is the case with a basic multiplexer, on a pre-allocated basis. It endeavors to exploit the fact that each device operates at a much lower mean rate than its maximum rate.

STP Shielded twisted pair

Straight through pinning RS-232 and RS-422 configuration that match DTE to DCE, pin for pin (pin 1 with pin 1, pin 2 with pin 2, etc.).

STX Start of text (ASCII Control-B).

Switched line A communication link for which the physical path may vary with each usage, such as the public telephone network.

SYN Synchronous Idle

Synchronization The coordination of the activities of several circuit elements.

Synchronous transmission Transmission in which data bits are sent at a fixed rate, with the transmitter and receiver synchronized. Synchronized transmission eliminates the need for start and stop bits.

T

Talker A device on the GPIB bus that simply sends information on to the bus without actually controlling the bus.

TCP Transmission control protocol

TCU Trunk coupling unit

TDM Time division multiplexer
A device that accepts multiple channels on a single transmission line by connecting terminals, one at a time, at regular intervals, interleaving bits (bit TDM) or characters (character TDM) from each terminal.

Telegram In general a data block which is transmitted on the network. Usually comprises address, information and check characters.

Temperature rating the maximum and minimum temperature at which an insulating material may be used in continuous operation without loss of its basic properties.

TIA Telecommunications Industry Association

Time sharing A method of computer operation that allows several interactive terminals to use one computer.

TNS Transaction bytes

Token ring Collision free, deterministic bus access method as per IEEE 802.2 ring topology.

TOP Technical Office Protocol – a user association in USA which is primarily concerned with open communications in offices.

Topology	Physical configuration of network nodes, e.g. bus, ring, star, tree.
Transceiver	Transmitter/receiver – network access point for IEEE 803.2 networks.
Transient	An abrupt change in voltage of short duration.
Transport layer	Layer 4 of the ISO/OSI reference model, concerned with providing a network independent reliable message interchange service to the application oriented layers (Layers 5 through 7).
Trunk	A single circuit between two points, both of which are switching centers or individual distribution points. A trunk usually handles many channels simultaneously.
TTL	Transistor-transistor logic
Twisted pair	A data transmission medium, consisting of two insulated copper wires twisted together. This improves its immunity to interference from nearby electrical sources that may corrupt the transmitted signal.

U

UART	Universal asynchronous receiver/transmitter – an electronic circuit that translates the data format between a parallel representation, within a computer, and the serial method of transmitting data over a communications line.
UHF	Ultra high frequency
Unbalanced circuit	A transmission line in which voltages on the two conductors are unequal with respect to ground e.g. a coaxial cable.
Unloaded line	A line with no loaded coils that reduce line loss at audio frequencies.
UP	Unnumbered poll
USB	Universal serial bus
USRT	Universal synchronous receiver/transmitter. See UART.
UTP	Unshielded twisted pair

V

V.35	ITU standard governing the transmission at 48 kbps over 60 to 108 kHz group band circuits.
Velocity of propagation	The speed of an electrical signal down a length of cable compared to speed in free space expressed as a percentage.
VFD	Virtual field device – a software image of a field device describing the objects supplied by it e.g. measured data, events, status etc. which can be accessed by another network.
VHF	Very high frequency

VLAN	Virtual LAN
Volatile memory	An electronic storage medium that loses all data when power is removed.
Voltage rating	The highest voltage that may be continuously applied to a wire in conformance with standards of specifications.
VRC	Vertical redundancy check
VSD	Variable speed drive
VT	Virtual terminal

W

WAN	Wide area network
Word	The standard number of bits that a processor or memory manipulates at one time. Typically, a word has 16 bits.

X

X.21	ITU standard governing interface between DTE and DCE devices for synchronous operation on public data networks.
X.25	ITU standard governing interface between DTE and DCE device for terminals operating in the packet mode on public data networks.
X.25 Pad	A device that permits communication between non X.25 devices and the devices in an X.25 network.
X.3/X.28/X.29	A set of internationally agreed standard protocols defined to allow a character oriented device, such as a visual display terminal, to be connected to a packet switched data network.
X-ON/X-OFF	Transmitter on/transmitter off – control characters used for flow control, instructing a terminal to start transmission (X-ON or control-S) and end transmission (X-OFF or control-Q).
XOR	Exclusive-OR