Operating Manual

MHX-2400

2.4 GHz Spread Spectrum OEM Transceiver

Revision 1.11, December 1, 2000

MHX-2400

2.4 GHz
Spread-Spectrum
Embedded Modem

WARNING

In order to comply with the FCC/IC adopted RF exposure requirements, this transmitter system will be installed by the manufacturer's reseller professional. Installation of all antennas must be performed in a manner that will provide at least 20 cm clearance from the front radiating aperture, to any user or member of the public.

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1. Introduction

1.0 Product Overview

Congratulations on choosing the MHX-2400 wireless transceiver! Your new MHX-2400 modem is a state-of-the-art, 2.4 GHz frequency-hopping spread-spectrum communications module.   When the MHX-2400 module is incorporated into the design of new or existing equipment, terminal devices (DTEs) up to 30 km (or more)[1] apart will be capable of establishing high-speed[2] communications wirelessly.

MHX-2400 modules provide a practical and reliable alternative to using traditional analog phone-line modems or "permanent wire" serial cable (RS-232) connections for data communications between asynchronous serial equipment. Moreover, wireless data communications using the MHX-2400 module means you will benefit from:

- greater flexibility and freedom to relocate terminal equipment,
- eliminated requirement for access to wire-based transfer media such as telephone lines,
- the ability to communicate through walls, floors, and many other obstacles.

While the MHX-2400 module is compact in its design, it delivers power and convenience and offers quality and dependability. The MHX-2400 module's versatility makes it the ideal solution for applications ranging from office-productivity to industrial data control and acquisition.

While a pair of MHX-2400 modules can link two terminal devices ("point-to-point" operation), multiple MHX-2400 modules can be used together to create a network of various topologies, including "point-to-multipoint" and "repeater" operation. Multiple independent networks can operate concurrently, so it is possible for unrelated communications operations to take place in the same or a nearby area without sacrificing privacy, functionality, or reliability.

1.1 Features

Key features of the MHX-2400 module include:

- transmission within a public, license-exempt band of the radio spectrum[3] – this means that it can be used without access fees (such as those incurred by cellular airtime);
- a serial I/O data port (TTL levels) with handshaking and hardware flow control, allowing the MHX-2400 module to interface directly to any microprocessor with an asynchronous serial interface.

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[1] Ideal conditions with clear line-of-sight communications, using high-gain antennas.
[2] Up to 115,200 bits per second (bps).
[3] 902-928 MHz, which is license-free within North America; may need to be factory-configured differently for some countries.

- 49 sets of user-selectable pseudo-random hopping patterns, intelligently designed to offer the possibility of separately operating multiple networks while providing security, reliability and high tolerance to interference;

- encryption key with 65536 user-selectable values to maximize security and privacy of communications;

- built-in CRC-16 error detection and auto re-transmit to provide 100% accuracy and reliability of data;

- ease of installation and use – the MHX-2400 module uses a subset of standard AT style commands, very similar to those used by traditional telephone line modems.

While the typical application for the MHX-2400 is to provide a short- to mid-range wireless communications link between DTEs, it can be adapted to almost any situation where an asynchronous serial interface is used and data intercommunication is required.

1.2 About this Manual

This manual has been provided as a guide and reference for installing and using MHX-2400 wireless modem modules. The manual contains instructions, suggestions, and information which will help you set up and achieve optimal performance from your equipment using the MHX-2400 module.

It is assumed that users of the MHX-2400 module have either system integration or system design experience. Chapter 2 details the requirements and connections of the MHX-2400 module. Chapter 3 describes the AT command register setup and configuration. The Appendices, including the Glossary of Terms, are provided as informational references which you may find useful throughout the use of this manual as well as during the operation of the wireless modem.

Throughout the manual, you will encounter not only illustrations that further elaborate on the accompanying text, but also several symbols which you should be attentive to:

Caution or Warning: Usually advises against some action which could result in undesired or detrimental consequences.

Point to Remember: Highlights a key feature, point, or step which is worth noting, Keeping these in mind will make using the MHX-2400 more useful or easier to use.

Tip: An idea or suggestion is provided to improve efficiency or to make something more useful.

With that in mind, enjoy extending the boundaries of your communications with the MHX-2400 module.

2. Initial Setup and Configuration

2.0 Unpacking and Inspection

The following items should be found in the shipping carton. Inspect the contents for any shipping damage. Report damages or shortages to the distributor from which the unit was purchased. Keep all packing materials in the event that transportation is required in the future.

Package contents (normal distribution):

        ①   MHX-2400 Wireless Modem module   1

        ②   Operating Manual (this document)   1

2.1 Additional Requirements

Since the MHX-2400 module is a unique product in a class of its own, it will communicate only with another MHX-2400 module which has been compatibly configured. Thus, at least two MHX-2400 modules will be required to establish a wireless communications link.

Additionally, the following requirements should be taken into consideration when preparing to incorporate the MHX-2400 module in new or existing designs.

- Small footprint for the MHX-2400 module (*e.g.,* 2.1" W x 3.5" L x 0.8" H) on the OEM PCB.
- Serial port and control signals from the host microprocessor. See sample application schematics in Appendix C.
- +5 Vdc supply from the host OEM electronics.
- An external antenna (customer supplied).

2.2 Connectors and Indicators

The MHX-2400 module connects to the host equipment by two single row header strips on the underside of the unit. This enables the MHX-2400 module to be directly soldered or socketed onto the host equipment manufacturer's PCB. The pinout for the module is given in Figure 1.
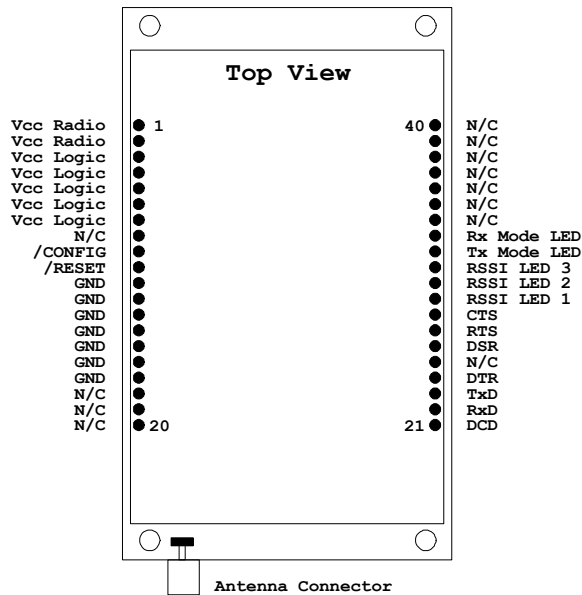
```
                          ┌─────────────────────────┐
                          │   ○                 ○    │
                          │  ┌───────────────────┐   │
                          │  │     Top View      │   │
                          │  │                   │   │
            Vcc Radio ────┼──┤● 1           40 ● ├───┼──── N/C
            Vcc Radio ────┼──┤●               ● ├───┼──── N/C
            Vcc Logic ────┼──┤●               ● ├───┼──── N/C
            Vcc Logic ────┼──┤●               ● ├───┼──── N/C
            Vcc Logic ────┼──┤●               ● ├───┼──── N/C
            Vcc Logic ────┼──┤●               ● ├───┼──── N/C
            Vcc Logic ────┼──┤●               ● ├───┼──── N/C
                  N/C ────┼──┤●               ● ├───┼──── Rx Mode LED
              /CONFIG ────┼──┤●               ● ├───┼──── Tx Mode LED
               /RESET ────┼──┤●               ● ├───┼──── RSSI LED 3
                  GND ────┼──┤●               ● ├───┼──── RSSI LED 2
                  GND ────┼──┤●               ● ├───┼──── RSSI LED 1
                  GND ────┼──┤●               ● ├───┼──── CTS
                  GND ────┼──┤●               ● ├───┼──── RTS
                  GND ────┼──┤●               ● ├───┼──── DSR
                  GND ────┼──┤●               ● ├───┼──── N/C
                  GND ────┼──┤●               ● ├───┼──── DTR
                  N/C ────┼──┤●               ● ├───┼──── TxD
                  N/C ────┼──┤●               ● ├───┼──── RxD
                  N/C ────┼──┤● 20          21 ● ├───┼──── DCD
                          │  └───────────────────┘   │
                          │                          │
                          │   ○                 ○    │
                          └───────────┬──────────────┘
                                   ┌──┴──┐
                                   └─────┘  Antenna Connector
```

Figure 1 - Pinout Diagram

The interface connectors and indicator lights are summarized below:

Vcc Radio - These pins supply power for the MHX-2400's radio circuitry. Best performance is achieved by providing linearly regulated voltage to these pins. It is essential to keep this supply rail as clean as possible - preferrably by not directly feeding a switching power supply into Vcc Radio. In addition, it is recommended that Vcc Radio be regulated as close to 5.5V as possible (without exceeding 5.5V). Running from a 5V regulator will decrease the transmitted power by roughly 1dB. The linear regulator must be rated for at least 800 mA

Vcc Logic - These pins supply power for the MHX-2400's digital circuitry. It is recommended you use a linear regulator to feed Vcc Logic. Current consumption in the logic circuitry is typically 100 mA. The regulator should be rated for at least 200 mA. To simplify the OEM design, the Radio Vcc can be connected to the Logic Vcc.

GND - Ground return pins for both Radio and Logic circuitry

/RESET - This momentary active low input signal (100 ms typical) resets the MHX-2400.

/CONFIG - Leave this pin unconnected. Do NOT ground.

Receive Signal Strength Indicator (RSSI) - These active high TTL outputs are designed to drive LED's. As the signal strength increases, the number of active RSSI lines increases, starting with RSSI1. When configured as a Repeater, the module does not indicate RSSI. The LED's perform a "scanning" function, blinking on and off in sequence when a Slave or Repeater modem is searching for synchronization. The current sourcing capability of these lines is 20 mA.

IMPORTANT:
For best performance, it is strongly recommended to use a separate, linearly regulated supply for Vcc Radio. Do not directly feed a switching power supply into Vcc Radio.

For OEM design simplicity, connect both the radio and logic Vcc connections together.

Caution: Using any other power supply which does not provide the proper voltage or current could damage the MHX-2400 module.

Data Port (DCE) - Pins 21 through 28 inclusive. This port is used to interface the MHX-2400 module to a DTE device and operates at 2400 to 115,200 bps.   The levels are active low 5V logic levels, and include (See Appendix B for a complete description):

Pin No.	Name	Description	I/O
21	DCD	Data Carrier Detect	O
22	RxD	Receive Data	O
23	TxD	Transmit Data	I
24	DTR	Data Terminal Ready	I
25	NC	No Connect	
26	DSR	Data Set Ready	O
27	RTS	Request to Send	I
28	CTS	Clear to Send	O

RX Indicator - This active high output indicates the modem is receiving data packets with correct CRC, and is designed to drive a LED. When the unit is configured as a Slave, this LED will typically be on solid under good operating conditions.

TX Indicator - This active high output is designed to drive a LED, and indicates the modem is transmitting.

Antenna Connector - The MHX-2400 uses an end launch SMA RF connector. Microhard Systems can provide the cabling from the module to the appropriate antenna connector. A suitable antenna must be used to ensure adequate performance of the MHX-2400 module.

N/C - These pins are reserved for future use. Do not connect to these pins.
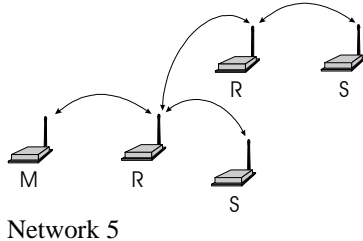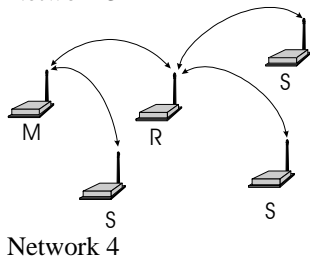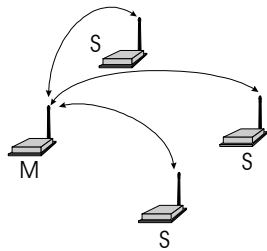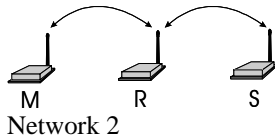
Network 1

Network 2
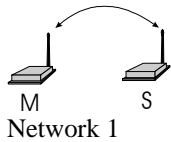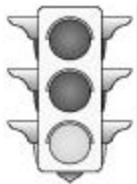

Network 3

Network 4

Network 5

Figure 2 - Sample Network Topologies. Virtually any Combination of Slaves and Repeaters May be Used.

2.3 Configuration

Prior to establishing a wireless link, each MHX-2400 module participating in the link must be correctly configured for compatibility and for the desired mode of operation.

Network topologies consisting of a single *Master* and virtually any combination of *Slaves* and *Repeaters* may be deployed. The functionality of any particular MHX-2400 can be configured as follows:

- ■ **Master Point-to-Point**: The module is configured to communicate with a single *Slave*, either directly, or through one or more *Repeaters*.

- ■ **Master Point-to-Multipoint**: The module is configured to communicate with one or more *Slaves* and/or *Repeaters*.

- ■ **Slave**: The module is configured to communicate with one particular *Repeater* or *Master.*

- ■ **Repeater**: The module is configured to pass information from either a *Master* or another *Repeater* onto subsequent *Repeaters* and/or *Slaves* and vice versa. The *Repeater* also acts as a *Slave* in the sense that, like a *Slave*, it passes information to/from its serial port.

All units within a *network* must be assigned a common Network Address; thus enabling multiple networks to co-exist in the same vicinity without unwanted crosstalk between modules.   Examples of different network topologies are shown in Figure 2.   Network 1 shows Point-to-Point communication between a Master and Slave. Network 2 makes use of a Repeater to communicate with the Slave. Network 3 illustrates a simple Point-to-Multipoint network with no Repeaters. Networks 4 and 5 gives examples of Point-to-Multipoint networks consisting of both Repeaters and Slaves. There is effectively no restriction to the number of Repeaters and Slaves that can be added to a network. As seen in Network 4, a Master can communicate directly with both Slaves and Repeaters. The MHX-2400 has been designed to allow for additional Repeaters and Slaves to be added to an existing network without having to reconfigure any units already in the network. This saves a tremendous amount of time when deploying additional units in the field.

2.3.1 Quick Start Approach

The MHX-2400 is equipped with four standard factory default settings. Instead of manually configuring each individual operating parameter, a global command may be used to quickly configure the modem for a particular type of operation. For example, to quickly implement Network 1, Factory default 1 would be applied to the Master, and Factory default 2 would be applied to the Slave. To quickly set up Network 2, apply Factory 1 to the Master, Factory 3 to the Repeater, and Factory 4 to the Slave. *These defaults will get you started and only ensure that a link can be established, but do not necessarily provide the best performance.*   Optimization of the communications link is discussed in later sections.

How to Set Up A Simple Network

The MHX-2400 will always be in one of two states:

- **Data Mode** – When in this state, the modem is listening and talking to other modems in the network (the modem is online).

- **Command Mode** – When in this state, the modem is awaiting "AT Commands" from the serial port. These commands are used to configure all operating parameters of the modem. When in this state, the modem is "offline".

To implement the very basic network illustrated in Figure 2, Network 1,

- Plug the modem into the development board and connect a straight-through serial cable between the development board and the terminal (e.g., your PC)

- Connect an antenna cable and antenna to the module.

- Configure the unit to Factory Setting 1 by typing AT&F1 <return>. This puts the unit into Master Point-to-Multipoint mode.

- Store these settings to memory by typing AT&W <return>.

- Put the modem into Data Mode by typing ATA <return>. There are other ways to enter Data Mode, which are discussed in Chapter 3.

- Perform the above steps for the second unit, using the command AT&F2 instead of AT&F1. This will configure the second unit as a Slave.

The units should now be communicating. Remember, the parameters defined by AT&F1 and AT&F2 will likely not be the most ideal for your application, but will quickly allow you to test the units. A complete summary of the settings defined by AT&F1,2,3 and 4 can be found in Appendix D. Factory Default Settings.

Settings are not immediately stored in non-volatile memory, therefore, the command &W is issued to store the current configuration into non-volatile memory. Settings are retained even after powering down. All user selectable parameters for the MHX-2400 are described in detail in Chapter 3: Configuration Options.

Warning: Using an antenna that is inappropriate for use with the MHX-2400 module could result in undesired performance, and may damage the unit. It is the user's responsibility to ensure the antenna has adequate lightning protection.

2.4 Checking the Link

To check if the units are communicating, observe the LED indicators on the development board. If the link is good, up to three RSSI outputs on the Slave modem should be active; and if the link is absent (due to a fault at one end or another, such as misconfiguration), the outputs will be in either "scanning mode" or inactive.

Characters typed at the Master terminal should appear at the Slave's terminal, and vice versa. Also, verify that the RX LED blinks as packets of data are received at the Master modem. As data is sent from Slave to Master, the RX indicator should blink on as correct packets of data are received. It is recommended that if MHX-2400 modules will be deployed in a field where large distances separate the units, the modems should be configured and tested in close proximity (*e.g.*, in the same room) first to ensure a good link can be established and settings are correct. This will facilitate troubleshooting, should problems arise.

3. Configuration Options

3.0 Command Line Interface

The MHX-2400 modem can be easily configured to meet a wide range of needs and applications. You can have your modem perform a variety of functions by sending it instructions (in the form of commands). Sending a command overrides the modem's operating characteristics.

Your modem must be in Command Mode for it to execute a command. If you send characters when the modem is in Data Mode, the modem transmits the characters over the air.

Depending on its settings, the modem will either power up in Command Mode or Data Mode. Normally, when first received from the factory, the unit will power up in Command Mode.

You can place the modem into Data Mode either by

1. Issuing the answer command

2. Issuing the online command

You can place the modem into Command Mode either by

1. Sending the escape sequence

2. Toggling the DTR line (depending on the &D parameter see pg 11).

The escape sequence will not be accepted unless both the MHX-2400 and the terminal are set to the same baud rate

To enter a command line and have your modem execute it, use the following procedure:

1. With your modem in the Command Mode, type AT. These characters, known as the attention characters, must be typed at the beginning of each command line.

2. Type the command(s). Include any parameters required by the command. To make the command line more readable, you can insert as many spaces as desired. The command line holds up to 16 characters, not including the AT prefix.

Refer to Appendix A (page 19) for a summary of the modem commands

3. Press the ENTER key. Your modem executes the command line and sends you a word response (usually OK).

Configuration options are not stored in non-volatile memory until the WRITE command (&W) is executed

For example, to set the Operating Mode S101 register to Master Point-to-Multipoint mode, enter the following command line; AT S101 = 1 <return>.

To display what a register is currently set to, enter the following command line; AT Sxxx? <return>. The modem will output the value of the register.

Note: If you want to send more than one command line, wait for a response before entering the AT prefix at the start of the next command line.

To re-execute the previous command, enter A/. The modem will execute the previous command line.

When in Command Mode, the modem "autobauds", meaning that it will automatically adjust to the baud rate of the terminal. You may change the terminal baud rate while in Command Mode without losing communication with the modem.

For the AT command protocol, an escape sequence consists of three consecutive escape codes preceded and followed by at least 1 second of inactivity. Typically, the '+' character is used as the escape code.

> +++   preceded and followed by 1 second of inactivity

Note that the terminal must be configured to the same baud rate as the modem in order for the mode to recognize the escape sequence. The modem is unable to "autobaud" while in Data Mode.

3.1 AT Commands

Several AT Commands are supported by the MHX-2400 module. The following is a short description of all available commands. '*' denotes standard factory settings. All of the following commands must be preceded by "AT"

A   Answer

The A command causes the modem to attempt to connect with another remote modem (Type ATA <return>).

E   Command Echo

Your modem is preset to return (or echo) commands to the host microprocessor when in Command Mode.

> **E0**   No Command Echo
> ***E1**   Command Echo

I   Identification

The I command returns various modem information settings.

> **I1**   Product Code (MHX-2400)
> **I2**   Issue ROM Check (OK or ERROR)
> **I3**   Product Identification (Firmware Version)
> **I4**   Firmware Date
> **I5**   Firmware Copyright
> **I6**   Firmware Time
> **I7**   Serial Number

O   On-line Mode

The O command attempts to put the modem online and communicate with a remote modem.

Q   Quiet Mode

Your modem is preset to send responses when it executes commands, and there after to keep the host informed of its status.

        *Q0   Enable modem responses
        Q1   Disable modem responses

V   Result Codes display

Your modem can either display result codes as words or numbers.

        V0   Display Result Codes as numbers
        ***V1**   Display Result Codes as words

W   Connection Result

The W command returns your modem to the Data Mode from the Command Mode

        *W0   Reports computer (DTE) baud rate as CONNECT xxxx
        W1   Reports computer (DTE) rate and wireless rate between
                   modems as CARRIER xxxx.
        W2   Reports modem (DCE) baud rate as CONNECT xxxx

Z   Reset and load stored configuration

The Z command resets the modem and loads the stored configuration.

&C   DCD (Data Carrier Detect)

The &C command controls the modem's DCD output signal to the host microprocessor. This command determines when the DCD is active.

        &C0   DCD is always ON
        *&C1**   DCD on when modems are synchronized. DCD is always
                   on when unit is configured as Master.
        &C2   DCD used for output data framing and Modbus mode.
                   See page 25 for details.

&D   DTR (Data Terminal Ready)

The &D command controls what action the modem performs when the DTR input line is toggled. The DTR input is controlled by the host microprocessor.

        *&D0   DTR line is ignored
        &D1   Not Supported
        &D2   DTR disconnects and switches to Command Mode
        &D3   DTR disconnects and resets modem. Modem will remain
                   in this state until DTR again goes active.
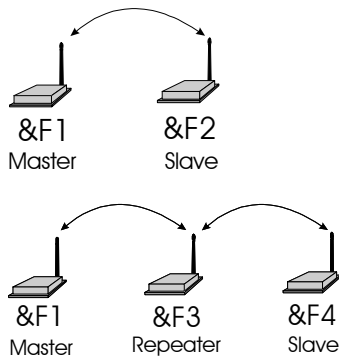
&F   Load Factory Default Configuration

The &F command resets the modem and loads the default factory configuration.

&F1   Master Point-to-Multipoint. Designed to communicate with modems configured as &F2 or &F3.

&F2   Slave. Designed to communicate with another modem configured as &F1.

&F3   Repeater. Designed to communicate with modems configured as &F1 and &F4.

&F4   Slave working with factory default Repeater and factory default Master. Communicates directly with Repeater configured as &F3.

&K   Handshaking

The &K command controls the handshaking between the modem and host microprocessor.

&K0   Disable handshaking
&K2   RTS/CTS input data framing. See page 25 for details.
*&K3   Enable hardware handshaking (RTS/CTS)

&S   DSR (Data Set Ready)

The &S command controls the DSR line for the modem, and determines when it is active

&S0   DSR is always ON
*&S1   DSR is ON in Data Mode, OFF in Command Mode

&V   View Configuration

The &V command displays the current (DTE) baud rate, and all setable modem parameters including S register values.

&E   Framing Error Check

This command enables or disables Framing Error Check. When enabled, the modem looks for the stop bit. If the stop bit is absent, the byte is thrown out. When enabled, the modem also does a parity check. Note that the data format (number of data bits, parity type, and number of stop bits) is defined by S register 110.

*&E0   Disable Framing Error Check
&E1   Enable Framing Error Check

&W   Write Configuration to Memory

The &W command stores the active configuration into the modem's non-volatile memory.

Sxxx?   Read S register value

This command causes the modem to display the current setting of S register xxx.

Sxxx=yyy   Set S register value (see section 3.3 S-Registers)

This command sets the specified S register to a value specified by yyy.

3.2 Command Result Codes

The MHX-2400 module can either display the results of a command as either text strings or numerical data. The following chart shows resulting text string and corresponding numeric result.

0	OK
3	NO CARRIER
4	ERROR
7	CONNECT 2400
8	CONNECT 3600
9	CONNECT 4800
10	CONNECT 7200
12	CONNECT 9600
13	CONNECT 14400
14	CONNECT 19200
15	CONNECT 28800
17	CONNECT 38400
18	CONNECT 57600
33	CONNECT 115200
62	CARRIER 45000
64	CARRIER 20000

3.3 S Registers

S Register 0 - Auto Answer

If this register is set to zero, the modem will power up in command mode. If this register is non-zero, the modem will power up in data mode.

S Registers 2 through 5 cannot be stored to non-volatile memory.

S Register 2 - Escape Code

This register contains the ASCII value of the escape character.

The default value (decimal 43) is equivalent to the ASCII character '+'. Values greater than 127 disable the escape feature and prevent you from returning to the Command Mode. This register cannot be stored to non-volatile memory. If the modem is reset, or powered down, the default value is restored.

Default is '+' (decimal 43).

S Register 3 - CR Control Code

This register contains the ASCII value of the carriage return character.

This is the character that is used to end the command line and is also the character that appears after the modem sends a response. This register cannot be stored to non-volatile memory. If the modem is reset, or powered down, the default value is restored.

Default is 'CR' (decimal 13).

S Register 4 - Linefeed Control Code

Register S4 sets the ASCII value of the linefeed character.

The modem sends the linefeed character after sending a carriage return character when sending text responses. This register cannot be stored to non-volatile memory. If the modem is reset, or powered down, the default value is restored.

Default is 'LF' (decimal 10).

S Register 5 - Backspace Control Code

Register S5 sets the ASCII value of the backspace character.

This character is both the character created by entering BACKSPACE and the character echoed to move the cursor to the left. This register cannot be stored to non-volatile memory. If the modem is reset, or powered down, the default value is restored.

Default is 'BS' (decimal 8).

S Register 101 - Operating Mode

The Operating Mode (register S101) partly defines the "personality" of the MHX-2400 module. Allowable settings for this register are 1 through 4 as follows:.

- S101=1   Master Point to Multipoint
- S101=2   Master Point to Point
- S101=3   Slave
- S101=4   Repeater

The default for this register depends on which factory default is selected as shown below:

- Default for Factory Setting &F1 is 1 (Master Point-to-Multipoint)
- Default for Factory Setting &F2 is 3 (Slave)
- Default for Factory Setting &F3 is 4 (Repeater)
- Default for Factory Setting &F4 is 3 (Slave)

Only one Master can exist for each network.

1)Master - Point to Multipoint. In any given network, there is always only one Master. All other units should be configured as either Slaves or Repeaters. When defined as a Point-to-Multipoint Master, the modem broadcasts data to all Slaves and Repeaters in the network, and is also the ultimate destination for data transmitted by all Slaves and Repeaters. In addition, the Master defines the following network parameters to be utilized by all other modems in the network (See the appropriate sections for a complete description of these parameters):

- Maximum Packet Size (S112)
- Minimum Packet Size (S111)
- Wireless Link Rate (S103)
- Hop Interval (S109)

2)Master - Point to Point. This mode of operation is identical to Master Point-to-Multipoint, with the exception that the Master only broadcasts to one particular Slave or Repeater. The modem with which communication occurs is defined by the Unit Address (S105). For example, if a Slave has been assigned Unit Address 100, and the Master wishes to communicate with that Slave, the Master must also be assigned a Unit Address of 100. If there are Repeaters in the network, they will pass the packet through to the Slave, and vice versa. Because Repeaters also have Slave functionality (i.e., a Repeater can be connected to a terminal), the Master can choose to communicate solely with a Repeater. This would be accomplished by assigning the same Unit Address to both the Master and the Repeater.

3)Slave. Up to 65534 Slaves may exist in a network, all of which communicate with the common Master (either directly or via Repeater(s)). Slaves cannot directly communicate with other Slaves, nor can they acknowledge packets of data sent by the Master. Clearly this would cause conflicts when there are multiple Slaves. The Master does, however, send acknowledgements to all messages it receives from Slaves. The Master initiates communications by sending a broadcast message to all Slaves. All Slaves are free to respond in a "Slotted ALOHA" fashion, meaning that each Slave can choose one of several windows in which to transmit. If there happens to be two Slaves attempting to talk at the same time, the Master may not receive the data, and the Slaves therefore would not get an acknowledgement. At this point, the Slaves would attempt to get the information through at random time intervals, thus attempting to avoid any more conflicts. Special parameters which control the Slave's response characteristics can be modified with S Registers S115 and S213.
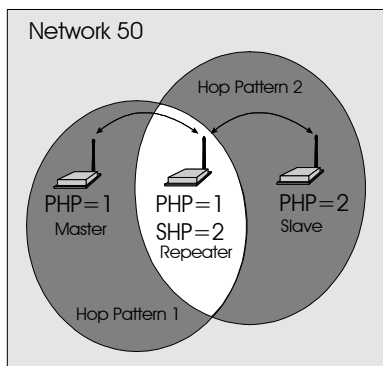

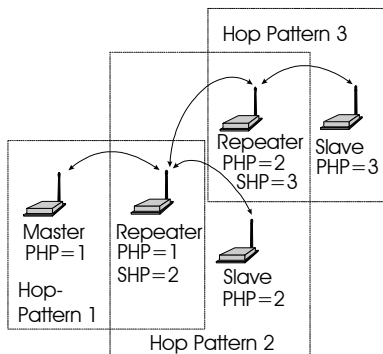**Figure 3 – Repeater Operation**

Figure 4 – A Network Utilizing Three Hopping Patterns

If there is no DTE connected to the Repeater, turn off handshaking (&K0) and set the baud rate to 115K.

4) Repeater. A more precise title would be Repeater/Slave, because a Repeater also has much of the same functionality as a Slave. A terminal can be connected at the Repeater location and communicate with the Master terminal. There is no restriction to the number of Repeaters in a network, allowing for communication over virtually limitless distances. The presence of one Repeater in a network automatically degrades system throughput by half. Additional Repeaters, regardless of the quantity, do not diminish system throughput any further. To understand Repeater operation, consider the module as belonging to two hopping patterns at the same time: The Primary Hopping Pattern and the Secondary Hopping Pattern. In Figure 3, the Master belongs to Hopping Pattern 1, and communicates with the Repeater on this hopping pattern. The Slave belongs to Hopping Pattern 2, and communicates with the Repeater on this hopping pattern. The whole system belongs to Network 50 (i.e., all units must be assigned the same Network Address (S104), which in this case was selected to be 50. Note that Slaves and Master only communicate on their respective Primary Hopping Pattern. Repeaters communicate on the Primary Hopping Pattern when communicating with the Master (or with another Repeater between itself and the Master). Repeaters communicate on their Secondary Hopping Pattern when communicating with Slaves (or with another Repeater between itself and the Slaves). Figure 4 shows another example.

If the Repeater is not also being used as a Slave (there is no DTE connected to the serial port), it is recommended that the Repeater's baud rate be set to 115K, and that handshaking be disabled (&K0). This will help ensure a smooth flow of data through the network.

S Register 102 - Serial Baud Rate

The Serial Baud Rate is the current speed that the modem is using to communicate with the DTE. When the AT command prefix is issued, the modem performs an 'autobaud' operation and determines what the current DTE baud rate is set to. The S register value returns the current setting of the DTE baud rate.

The possible values are:

* 1	**115200**
2	57600
3	38400
4	28800
5	19200
6	14400
7	9600
8	7200
9	4800
10	3600
11	2400

It is generally advisable to choose the highest rate that your terminal equipment will handle to maximize performance, unless a limitation on the available bandwidth is desired. If the DTE is a personal computer, the port can usually be used reliably at 115200. It is not possible to write values to this register, since the instant another AT command is issued, the register will revert to the current baud rate. Therefore, it is advisable to operate in Command Mode at the desired baud rate for Data Mode.

S Register 103 - Wireless Link Rate

The Master determines the Wireless Link Rate. This setting on all other modems is ignored..

The Wireless Link Rate is the speed and optimization method for which modems will communicate over the RF link. It is only necessary to set this parameter on the Master unit. Units configured as Repeaters and Slaves will ignore this setting, and adjust automatically to the rate of the Master.

The allowable settings are:

2	Fast without Forward Error Correction
*4	**Fast with Forward Error Correction**

Depending on the application requirements, each mode will provide different throughput and performance. Appendix E. Performance Tables give some indication of the performance to be expected in each mode.

In general, Forward Error Correction (FEC) reduces throughput, but in some environments will actually increase throughput. FEC can reduce the number of bad data packets, and hence reduce the need to retransmit.

S Register 104 - Network Address

The Network Address defines the membership to which individual units can be a part of. By establishing a network under a common Network Address, the network can be isolated from any other concurrently operating network. As well, the Network Address provides a measure of privacy and security. Only those units which are members of the network will participate in the communications interchange. Valid values for the Network Address range from 0 to 65535, inclusive.

To enhance privacy and reliability of communications where multiple networks may operate concurrently in close proximity, it is suggested that an atypical value be chosen – perhaps something meaningful yet not easily selected by chance or coincidence.

Default is 1.

S Register 105 - Unit Address

In point-to-point operation, the Unit Address on both the Master and Slave (or Repeater) units must be the same. In a multipoint system, the Unit Address uniquely identifies each Slave and Repeater from one another. Each unit in a multipoint system must have a unique Unit Address ranging from 1 to 65535. Do not use 0 as a Unit Address, and do not use a Unit Address more than once within the same Network. This is required because the Master must be able to acknowledge each unit individually, based on the Unit Address.

S Register 106 - Primary Hopping Pattern
S Register 206 - Secondary Hopping Pattern

Since the MHX-2400 is a frequency-hopping modem, the carrier frequency changes periodically according to one of 49 pseudo-random patterns, defined by the Primary and Secondary Hopping Patterns. Valid entries for each are 0 through 50.

The concept of Primary and Secondary Hopping Patterns was introduced in the discussion of S Register 101 (Operating Mode).

Using the designations M[a,] Rx[a,b] and Sx[a] where:
- *M* indicates Master;
- *R* indicates Repeater;
- *S* indicates Slave;
- *x* is the Unit Address;
- *a* is the primary hopping pattern; and,
- *b* is the secondary hopping pattern;

the following diagrams illustrate the methodology for deploying simple to complicated networks:

M[1]	←→	S1[1]					
M[1]	←→	R1[1,2]	←→	S2[2]			
M[1]	←→	R1[1,2]	←→	R2[2,3]	←→	S3[3]	
M[1]	←→	R1[1,2]	←→	R2[2,3]	←→	R3[3,4]	←→ S4[4]
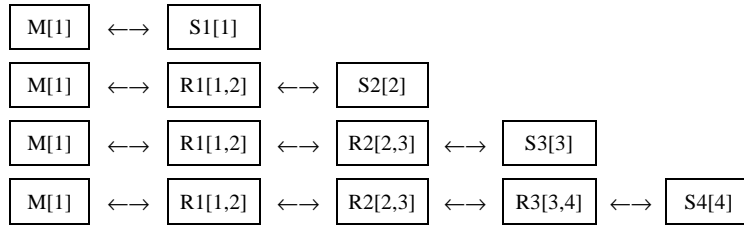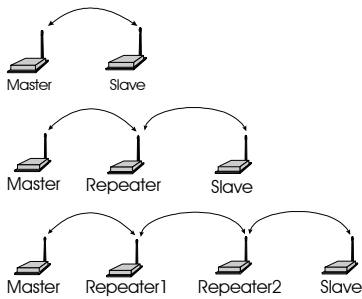
It is reasonable to consider a Repeater as being both a Slave and a Master, alternating between Primary and Secondary Hopping Patterns as the unit changes channel. Consider R1 in the illustration below. When communicating with the Master, R1 is acting like a Slave on Primary Hopping Pattern 1. When communicating with R2 and S4, R1 is acting like a Master on Secondary Hopping Pattern 2. If multiple Repeaters are used, they should have different Secondary Hopping Patterns:

```
                ←→  R1[1,2]  ←→  R2[2,5]  ←→  S3[5]
                               ←→  S4[2]
M[1]
                ←→  R5[1,3]  ←→  R6[3,6]  ←→  S7[6]
                ←→  R8[1,4]  ←→  S9[4]
```

Note that all units have a unique Unit Address.

Networks of any complexity can be created by linking multiple Repeaters and Slaves:

```
                ←→  R1[1,2]  ←→  S2[2]
                               ←→  S3[2]
                ←→            ←→  R5[3,6]  ←→  S6[6]
M[1]               R4[1,3]                 ←→  S7[6]
                               ←→  R8[3,7] ←→  R9[7,8] ←→ S10[8]
                ←→  S11[1]
                ←→  S12[1]
```
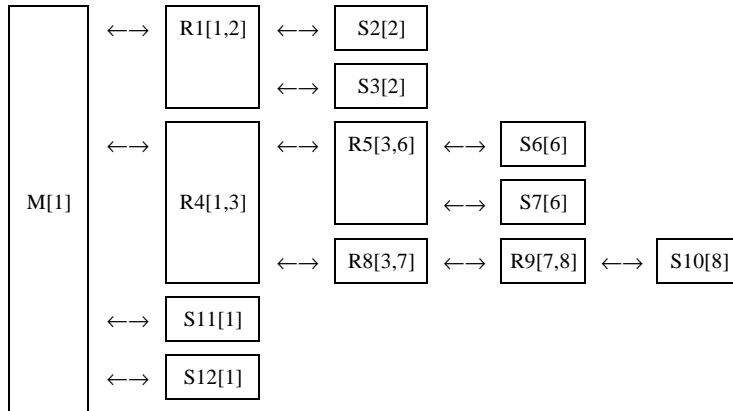
With a limitation of 51 hopping patterns, one might suspect that there is a limitation to the number of repeaters in a system. However, if the units are far enough away from one another, hopping patterns may be reused in different sections of the network, without causing interference.

Master   Slave

Master   Repeater   Slave

Master   Repeater1   Repeater2   Slave

Slaves and Masters do not use Secondary Hopping Patterns

Remember to assign a unique Unit Address (1 to 65535) to each unit in the system

S Register 107 - Encryption Key

All units within a network must use the same encryption key.

The Encryption Key provides a measure of security and privacy of communications by rendering the transmitted data useless without the correct key on the receiver. Valid Encryption Keys range from 0 to 65535.

Keep in mind that all units within the network must use the same key for communications to succeed.

S Register 108 - Output Power Level

The Output Power Level determines at what power the MHX-2400 transmits. The super-sensitive MHX-2400 can operate with very low power levels, so it is recommended that the lowest power necessary is used; using excessive power contributes to unnecessary "RF pollution".

The allowable settings are:

0	10 mW		4	500 mW
1	50 mW		5	750 mW
*2	**100 mW**	6	1 W	
3	250 mW			

Ideally, you should test the communications performance between units starting from a low power level and working upward until the RSSI is sufficiently high and a reliable link is established. Although the conditions will vary widely between applications, typical uses for some of the settings are described below:

Power	Use
10 mW	For in-building use, typically provides a link up to 300 feet on the same floor or up/down a level. Outdoors, distances of 10 km can be achieved if high-gain (directional) antennas are placed high above ground level and are in direct line-of-sight.
50 mW	200-500 ft indoors, 8-15 km* outdoors.
100 mW	400-800 ft indoors, 15-25 km* outdoors.
1000 mW (1 W)	Typically provides communications up to a distance of 1000 feet or more in-building on the same floor or up/down a few levels, depending on building construction (wood, concrete, steel, etc.). In ideal line-of-sight conditions, up to 30 km* or more can be achieved. Note that only an antenna with a gain of no more than 6 dBi may be used. Any higher is a violation of FCC rules. See IMPORTANT warning below.

* These outdoor distances assume antennas are mounted at least 100 ft above ground level

IMPORTANT:

FCC Regulations allow up to 36 dBi effective radiated power (ERP). Therefore, the sum of the transmitted power (in dBm), the cabling loss and the antenna gain cannot exceed 36 dBi.

1 mW = 0 dBm

10 mW = 10 dBm

100 mW = 20 dBm

1000 mW = 30 dBm

For example, when transmitting 1 Watt (30 dBm), with cabling losses of 2 dB, the antenna gain cannot exceed 36 - 30 + 2 = 8 dBi. If an antenna with a gain higher than 8 dBi were to be used, the power setting must be adjusted appropriately. Violation of FCC regulations can result in severe fines.

The hopping interval is controlled by the master. The slave and repeater units will use the hopping interval setting from the master.

S Register 109 - Hopping Interval

This option determines the frequency at which the modems change channel. Note that the Master controls this parameter for the entire network. This setting is ignored in units configured as Slaves or Repeaters.

The allowable settings are:

1	8 msec
2	12 msec
3	16 msec
4	20 msec
5	30 msec
6	45 msec
7	80 msec
*8	120 msec

See Appendix E for optimal Hopping Interval settings in relation to packet size and link rate.

S Register 110 - Data Format

This register determines the format of the data on the serial port. Allowable settings are:

***1**	**8 bits, No Parity, 1 Stop**
2	8 bits, No Parity, 2 Stop
3	8 bits, Even Parity, 1 Stop
4	8 bits, Odd Parity, 1 Stop
5	7 bits, No Parity, 1 Stop
6	7 bits, No Parity, 2 Stop
7	7 bits, Even Parity, 1 Stop
8	7 bits, Odd Parity, 1 Stop
9	7 bits, Even Parity, 2 Stop
10	7 bits, Odd Parity, 2 Stop
11	9 bits, No Parity, 1 Stop

S Register 111 - Packet Minimum Size
S Register 112 - Packet Maximum Size
S Register 116 - Packet Character Timeout

These settings determine the conditions under which the modem will transmit accumulated data over the air.

S Register 111 - Minimum Size

Valid entries for this register are 1 to 255 bytes, which defines the minimum number of bytes to receive from the DTE before encapsulating them in a packet and transmitting over the air.

Note that the minimum packet size for all modems in the network is determined by the Master only. This setting is ignored in all Slave and Repeater modems. The default is 1 byte.

The Minimum and Maximum Packet Size is controlled by the Master. The Slave and Repeater units will use the Minimum and Maximum Packet Size setting from the Master.

S Register 112 - Maximum Size

This setting has a range of 2 to 255, and defines the maximum number of bytes from the DTE which should be encapsulated in a packet. This value should be greater than the minimum packet size, but not smaller than is necessary for reliable communications. If the wireless link is consistently good and solid, a maximum size of 255 will yield the best throughput (depending on the higher level protocols of the connected equipment). However, if the link is poor (*e.g.*, experiencing excessive interference) and data is frequently retransmitted, the maximum packet size should be reduced. This decreases the probability of errors within packets, and reduces the amount of traffic in the event that retransmissions are required.

Note that the maximum packet size for all modems in the network is determined by the Master only. This setting is ignored in all Slave and Repeater modems. The default is 255 bytes.

S Register 116 - Packet Character Timeout

This register has valid entries of 0 to 254 milliseconds. The Packet Character Timeout timer looks for gaps in the data being received from the DTE. The timer is only activated after the Minimum Packet Size has been accumulated in the modem. After which, if the timer detects a gap in the data exceeding the Packet Character Timeout value, the modem will transmit the data.

The MHX-2400 will accumulate data in its buffers from the DTE until one of the following requirements is met (whichever occurs first):

- The Maximum Packet Size (in bytes) has been accumulated;

- The Minimum Packet Size has been accumulated AND the Packet Character Timeout interval has elapsed.

The default for the Packet Character Timeout is 9 ms. If set to 0 ms, the unit will buffer exactly the minimum packet size before transmitting.

S Register 113 - Packet Retransmissions

This register applies to both Master and Repeater operation. It does not apply to Slave operation. The Master will retransmit each data packet exactly the number of times defined by the Packet Retransmissions parameter. The Master retransmits once at the beginning of each hopping interval until the limit is reached. This parameter is not necessary in Slave units since all Slaves receive acknowledgement from the Master. As discussed previously, the Repeater effectively behaves as both a Master and a Slave. When the Repeater is tuned to its Secondary Hopping Pattern (acting as a Master), the Packet Retransmissions Parameter comes into play. The Repeater will re-send packets of data on to Slaves or other Repeaters exactly the number of times defined by the Packet Retransmissions parameter.

Recipients of the packet will discard any duplicates The valid settings for this parameter are 0 to 255 retransmissions. The default is 2.

S Register 213 - Packet Retry Limit

Packet Retry Limit is analogous to Packet Retransmissions, but specifically applies to Slaves and Repeaters. This parameter is not used by the Master. Because the Slave has the advantage of receiving acknowledgements from the Master, it is not necessary to blindly retransmit each packet. If the Slave does not get an acknowledgement on the next hop, it will retransmit its packet. This will continue until the Packet Retry Limit is reached or an acknowledgement is received. If the limit is reached, the modem will give up and discard the data. Valid settings are 0 to 255 retries. The default value is 2.

The Repeater makes use of this parameter when it is tuned to its Primary Hopping Pattern and is acting like a Slave.

S Register 115 - Packet Repeat Interval

A parameter that is specific to Slaves and Repeaters is the Packet Repeat Interval.

The allowable settings are 1 through 255. The default is 1.

This parameter defines a range of random numbers that the Slave will use as the next slot in which it will attempt to send the packet. For example, if this register is set to 7, the Slave will choose a number between one and seven as the next slot in which to transmit. Suppose the random number generator picks 5, then the Slave will transmit in the fifth time slot. A Slave will transmit a maximum of once per hopping interval, however, depending on the duration of the hopping interval and the maximum packet size, more than one slot per hop is potentially available. The Slave will transmit more frequently when a Repeat Interval with a smaller range is selected. Choose 1 to have the Slave transmit in the first available slot. Choose higher intervals for less frequent transmission, or to avoid collisions between many Slaves in the system.

S Register 117 - Modbus Mode

Modbus Mode allows for the MHX-2400 to be fully Modbus compatible. Please contact Microhard Systems for assistance when configuring the unit for Modbus operation. Optimal Modbus settings rely on several other S Register parameters.

The allowable settings for this register are:

*0	**Disabled**
1	Enabled

S Register 120 - RTS/DCD Framing
S Register 121 - DCD Timeout

The MHX-2400 supports two special types of data framing:

- Input (or RTS/CTS) Data Framing; and,
- Output (or DCD) Data Framing

Input Data Framing is enabled by configuring the Handshaking Parameter as &K2. This type of framing makes use of the S120 parameter as illustrated in Figure 5. Parameter S120 can be set to any value between 0 and 254 ms.
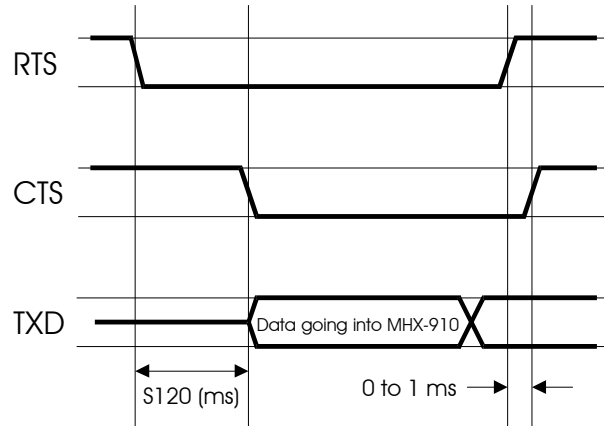
Figure 5 - Input Data Framing

To enable output (DCD) data framing, set the Data Carrier Detect parameter as &C2. This type of framing uses both S120 and S121 registers as shown in Figure 6. Valid ranges for each parameter are 0 to 254 ms.
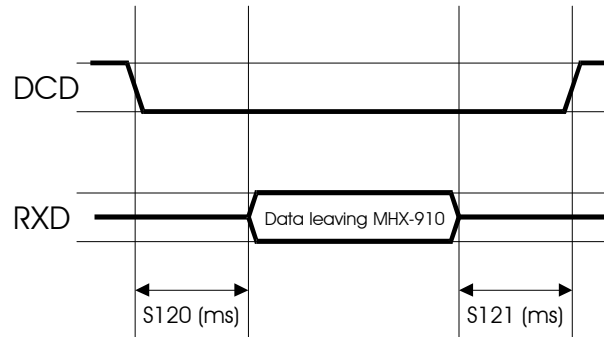
Figure 6 - Output Data Framing

S Register 123 - RSSI Reading

This register displays the average signal strength in dBm over the previous four hop intervals. Valid RSSI readings apply only to units configured as Slave or Repeater.

A. Modem Command Summary

The following provides a command summary for the MHX-2400 module. Factory settings are denoted with a '*'.

AT Commands

|	
A	Answer
E	Command Echo
	E0 No Echo
	* E1 Command Echo
I	Identification
	I0 Product Code
	I2 ROM Checksum test
	I3 Firmware Version
	I4 Firmware Date
	I5 Copyright
	I6 Firmware Time
O	On-line Mode
Q	Quiet Mode
	* Q0 Enables Result Codes
	Q1 Disables Result Codes
V	Result Codes Display
	V0 Display as Numbers
	* V1 Display as Words
W	Connection Result
	* W0 Reports DTE as CONNECT xxxx
	W1 Reports computer (DTE) rate and wireless rate between modems as CARRIER xxxx.
	W2 Reports DCE as CONNECT xxxx
Z	Reset and load stored configuration
&C	DCD (Data Carrier Detect)
	&C0 DCD is always on
	* &C1 DCD is on when modems are synchronized
	&C2 DCD used for output data framing
&D	DTR (Data Terminal Ready)
	&D0 DTR ignored
	* &D2 DTR disconnects and switches to command
	&D3 DTR disconnects and resets modem
&F	Load Factory Default
	&F1 Master
	&F2 Slave
	&F3 Repeater
	&F4 Slave through Repeater
&K	Handshaking
	&K0 Disable Handshaking
	&K2 RTS/CTS Input Framing
	* &K3 Enable Handshaking
&S	DSR (Data Set Ready)
	&S0 DSR is always on
	* &S1 DSR on in data, off in command mode
&V	View Configuration
&W	Write configuration to memory
Sxx?	Read S register value
Sxx=yy	Set S register value

Result Codes

0	OK	12	CONNECT 9600
3	NO CARRIER	13	CONNECT 14400
4	ERROR	14	CONNECT 19200
7	CONNECT 2400	15	CONNECT 28800
8	CONNECT 3600	17	CONNECT 38400
9	CONNECT 4800	18	CONNECT 57600
10	CONNECT 7200	33	CONNECT 115200
64	CARRIER 20000	62	CARRIER 45000

S Registers

S0	Auto Answer [0...255]
	0 = power up in Command Mode,
	non-zero = power up in Data Mode
S2	Escape code [0...255] default '+'
S3	CR character [0...255] default <cr>
S4	Line Feed [0...255] default <lf>
S5	Backspace [0...255] default <bs>
S101	Operating Mode
	1 - Master Point to Multipoint
	2 - Master Point to Point
	3 - Slave
	4 - Repeater
S102	Serial Baud Rate
	*1 = 115200, 2 = 57600, 3 = 38400
	4 = 28800, 5 = 19200, 6 = 14400
	7 = 9600, 8 = 7200, 9 = 4800,
	10 = 3600, 11 = 2400
S103	Wireless Link Rate
	2 = Fast w/o FEC
	*4 = Fast with FEC
S104	Network Address [0...65535]
S105	Unit Address [1...65535]
S106	Primary Hopping Pattern [0...50]
S206	Secondary Hopping Pattern [0...50]
S107	Encryption Key [0...65535]
S108	Output Power Level
	0 = 10 mW, 1 = 50 mW, *2 = 100 mW, 3 = 250 mW
	4 = 500 mW, 5 = 750 mW, 6 = 1W
S109	Hopping Interval
	1 = 8 msec, 2 = 12 msec, 3 = 16 msec,
	4 = 20 msec, 5 = 30 msec, 6 = 45 msec,
	7 = 80 msec, *8 = 120 msec
S110	Data Format
	* 1 = 8N1, 2 = 8N2, 3 = 8E1, 4 = 8O1
	5 = 7N1, 6 = 7N2, 7 = 7E1, 8 = 7O1
	9 = 7E2, 10 = 7O2, 11 = 9N1
S111	Packet Minimum Size [1...Maximum Size]
S112	Packet Maximum Size [2...255]
S113	Packet Retransmissions [0...255]
S213	Packet Retry Limit [0...255]
S115	Packet Repeat Interval [1..255]
	Default = 1
S116	Packet Character Timeout [0...254 ms]
S117	Modbus Mode
	*0 = Disabled, 1 = Enabled
S120	RTS/DCD Framing Interval [0...254 ms]
S121	DCD Timeout [0...254 ms]

B. Serial Interface

The MHX-2400 module uses 8 pins on the header connector for asynchronous serial I/O. The interface conforms to standard RS-232 signals without level shifting, so direct connection to a host microprocessor is possible.

The signals in the asynchronous serial interface are described below:

DCD *Data Carrier Detect* - **Output from Modem** - When asserted (TTL low), DCD informs the DTE that a communications link has been established with another MHX-2400.

RX *Receive Data* - **Output from Modem** - Signals transferred from the MHX-2400 are received by the DTE via RX.

TX *Transmit Data* - **Input to Modem** - Signals are transmitted from the DTE via TX to the MHX-2400.

DTR *Data Terminal Ready* - **Input to Modem** - Asserted (TTL low) by the DTE to inform the modem that it is alive and ready for communications.

SG *Signal Ground* - Provides a ground reference for all signals transmitted by both DTE and DCE.

DSR *Data Set Ready* - **Output from Modem** - Asserted (TTL low) by the DCE to inform the DTE that it is alive and ready for communications. DSR is the modem's equivalent of the DTR signal.

RTS *Request to Send* - **Input to Modem** - A "handshaking" signal which is asserted by the DTE (TTL low) when it is ready. When hardware handshaking is used, the RTS signal indicates to the DCE that the host can receive data.

CTS *Clear to Send* - **Output from Modem** - A "handshaking" signal which is asserted by the DCE (TTL low) when it has enabled communications and transmission from the DTE can commence. When hardware handshaking is used, the CTS signal indicates to the host that the DCE can receive data.

Modem   Host
(DCE)   Microprocessor
        Signal   **(DTE)**

1 ——— DCD ———→ IN
2 ——— RX ———→ IN
3 ←—— TX ——— OUT
4 ←—— DTR ——— OUT
5 ——— SG ———→ IN
6 ——— DSR ———→ IN
7 ←—— RTS ——— OUT
8 ——— CTS ———→ IN

Arrows denote the direction that signals are asserted (*e.g.*, DCD originates at the DCE and tells the DTE that a carrier is present).

Notes: It is typical to refer to RX and TX from the perspective of the DTE. This should be kept in mind when looking at signals relative to the modem (DCE); the modem *transmits* data on the RX line, and *receives* on TX.

"DCE" and "modem" are often synonymous since a modem is typically a DCE device.

"DTE" is, in most applications, a device such as a host microprocessor.

C. Sample Schematic Diagram

The following is a sample microprocessor implementation with a MICROCHIP PIC 16C74 and the MHX-2400. The MHX-2400 performs no level shifting on the serial port, so direct connection to the host microprocessor is possible.

DO NOT CONNECT THE MHX-2400 TO RS 232 DRIVER OUTPUTS. DAMAGE TO THE UNIT MAY RESULT.

On this implementation, the onboard SCI of the PIC 16C74 is directly connected pins 2 and 3 of the MHX-2400. The bi-directional Port D is used for asserting or monitoring control signals from the MHX-2400.

The RESET and CONFIG signals are momentary active low signals asserted by the host microprocessor.

RESET initializes the MHX-2400 and places the system in a known state. This signal should be set high after the host microprocessor has been reset.

The CONFIG line is reserved for factory use. This signal should be set high.

PIC16C74   MHX-900

PIC16C74	Signal	MHX-900
RC7	RXD	2
RC6	TXD	3
RD0	DCD	1
RD1	DTR	4
RD2	DSR	6
RD3	RTS	7
RD4	CTS	8
RD5	CONFIG	32
RD6	RESET	31

Power Connections not shown
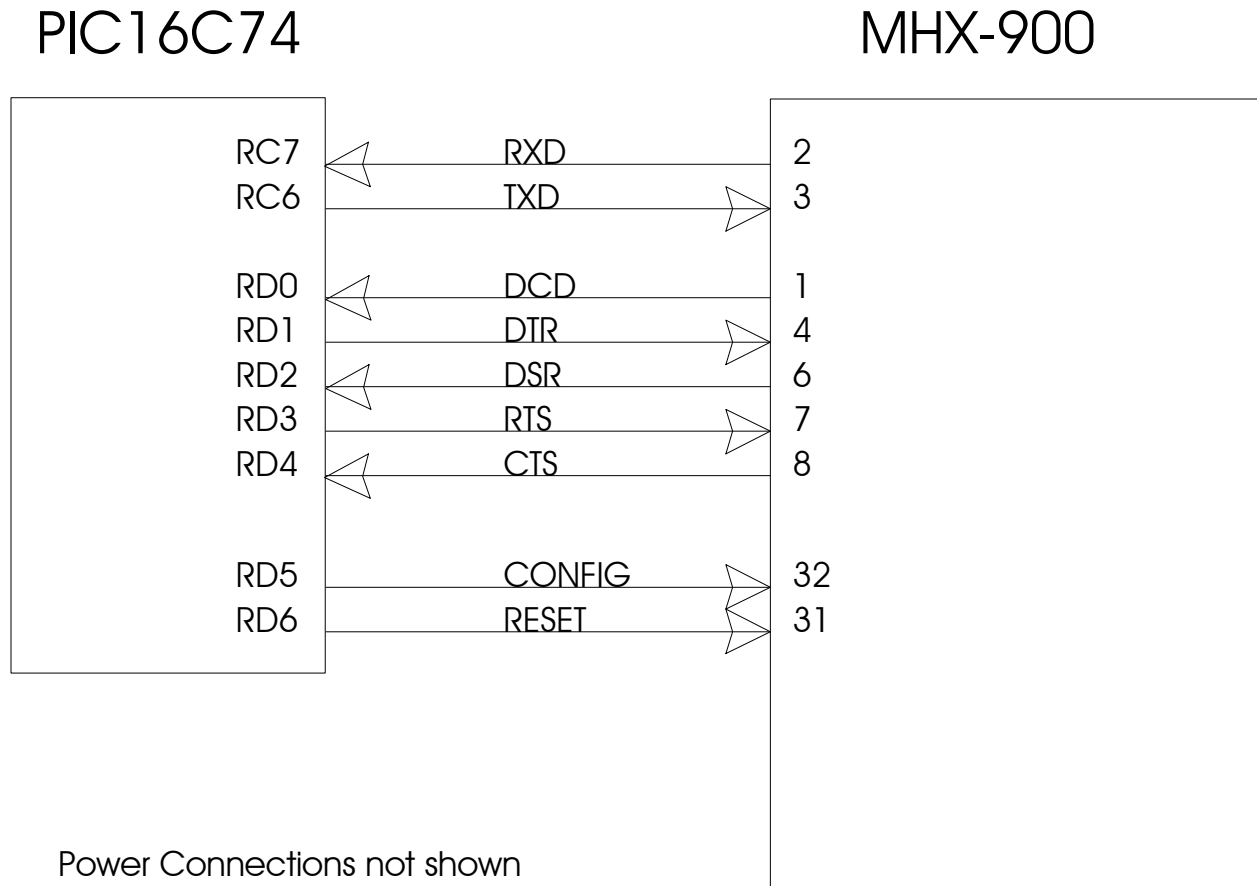
D. Factory Default Settings

AT&F1 - Master Default Settings

E1, Q0, V1, W0, S0=0, S2=43, S3=13, S4=10, S5=8

DCD	&C1 (On)
DTR	&D0 (DTR is ignored)
Framing	&E0 (Disabled)
Handshaking	&K3 (Enabled)
DSR	&S1 (On in Data, Off in Command)
Operating Mode	S101=1 (Master P-MP)
Serial Baud Rate	S102=1 (115kbaud)
Wireless Link Rate	S103=4 (Fast, FEC)
Network Address	S104=1
Unit Address	S105=1
Primary Hop Pattern	S106=0
Encryption Key	S107=1
Output Power	S108=2 (100mW)
Hop Interval	S109=8
Data Format	S110=1 (8N1)
Packet Minimum Size	S111=1
Packet Maximum Size	S112=255
Packet Retransmissions	S113=2
Packet Repeat Interval	S115=1 (Don't Care)
Character Timeout (ms)	S116=8
Modbus Mode	S117=0
RTS/DCD Framing (ms)	S120=0
DCD Timeout (ms)	S121=0
Secondary Hop Pattern	S206=2 (Don't Care)
Packet Retry Limit	S213=2 (Don't Care)

AT&F2 - Slave Default Settings

E1, Q0, V1, W0, S0=1, S2=43, S3=13, S4=10, S5=8

DCD	&C1 (On when modems are synced)
DTR	&D0 (DTR is ignored)
Framing	&E0 (Disabled)
Handshaking	&K3 (Enabled)
DSR	&S1 (On in Data, Off in Command)
Operating Mode	S101=3 (Slave)
Serial Baud Rate	S102=1 (115kbaud)
Wireless Link Rate	S103=4 (Fast, FEC) (Set by Master)
Network Address	S104=1
Unit Address	S105=2
Primary Hop Pattern	S106=0
Encryption Key	S107=1
Output Power	S108=2 (100mW)
Hop Interval	S109=8 (Set by Master)
Data Format	S110=1 (8N1)
Packet Minimum Size	S111=1 (Set by Master)
Packet Maximum Size	S112=255 (Set by Master)
Packet Retransmissions	S113=2 (Don't Care)
Packet Repeat Interval	S115=1
Character Timeout (ms)	S116=9
Modbus Mode	S117=0
RTS/DCD Framing (ms)	S120=0
DCD Timeout (ms)	S121=0
Secondary Hop Pattern	S206=2 (Don't Care)
Packet Retry Limit	S213=2

AT&F3 - Repeater Default Settings

E1, Q0, V1, W0, S0=1, S2=43, S3=13, S4=10, S5=8

DCD	&C1 (On when modems are synced)
DTR	&D0 (DTR is ignored)
Framing	&E0 (Disabled)
Handshaking	&K3 (Enabled)
DSR	&S1 (On in Data, Off in Command)
Operating Mode	S101=4 (Repeater)
Serial Baud Rate	S102=1 (115kbaud)
Wireless Link Rate	S103=4 (Fast, FEC) (Set by Master)
Network Address	S104=1
Unit Address	S105=3
Primary Hop Pattern	S106=0
Encryption Key	S107=1
Output Power	S108=2 (100mW)
Hop Interval	S109=8 (Set by Master)
Data Format	S110=1 (8N1)
Packet Minimum Size	S111=1 (Set by Master)
Packet Maximum Size	S112=255 (Set by Master)
Packet Retransmissions	S113=2
Packet Repeat Interval	S115=1
Character Timeout (ms)	S116=8
Modbus Mode	S117=0
RTS/DCD Framing (ms)	S120=0
DCD Timeout (ms)	S121=0
Secondary Hop Pattern	S206=2
Packet Retry Limit	S213=2

AT&F4 -Slave Through Repeater Default Settings

E1, Q0, V1, W0, S0=1, S2=43, S3=13, S4=10, S5=8

DCD	&C1 (On when modems are synced)
DTR	&D0 (DTR is ignored)
Framing	&E0 (Disabled)
Handshaking	&K3 (Enabled)
DSR	&S1 (On in Data, Off in Command)
Operating Mode	S101=3 (Slave)
Serial Baud Rate	S102=1 (115kbaud)
Wireless Link Rate	S103=4 (Fast, FEC) (Set by Master)
Network Address	S104=1
Unit Address	S105=4
Primary Hop Pattern	S106=2
Encryption Key	S107=1
Output Power	S108=2 (100mW)
Hop Interval	S109=8 (Set by Master)
Data Format	S110=1 (8N1)
Packet Minimum Size	S111=1 (Set by Master)
Packet Maximum Size	S112=255 (Set by Master)
Packet Retransmissions	S113=2 (Don't Care)
Packet Repeat Interval	S115=1
Character Timeout (ms)	S116=8
Modbus Mode	S117=0
RTS/DCD Framing (ms)	S120=0
DCD Timeout (ms)	S121=0
Secondary Hop Pattern	S206=2 (Don't Care)
Packet Retry Limit	S213=2

E. Performance Tables

The scope of this appendix is to find the best possible performance and maximum packet size at different modes of operation. The setup assumes a baud rate of 115k, no retries and no retransmissions..

	Hop Interval	Optimal Packet Size (bytes)	Throughput (kbps)*
Slave to Master Communication. (No Repeater) **Link Rate = Fast NO FEC**	1 (8 ms)	14	20
	2 (12 ms)	66	52
	3 (16 ms)	110	66
	4 (20 ms)	154	74
	5 (30 ms)	255	83
	6 (45 ms)	255	56
	7 (80 ms)	255	31
	8 (120 ms)	255	21
Slave to Master Communication. (No Repeater) **Link Rate = Fast WITH FEC**	1 (8 ms)	5	4
	2 (12 ms)	34	22
	3 (16 ms)	54	28
	4 (20 ms)	76	32
	5 (30 ms)	130	38
	6 (45 ms)	210	43
	7 (80 ms)	255	30
	8 (120 ms)	255	20
Repeater to Master Direct Communication. **Link Rate = Fast NO FEC**	1 (8 ms)	N/A	N/A
	2 (12 ms)	3	1
	3 (16 ms)	22	13
	4 (20 ms)	44	21
	5 (30 ms)	101	32
	6 (45 ms)	178	39
	7 (80 ms)	255	31
	8 (120 ms)	255	21
Repeater to Master Direct Communication. **Link Rate = Fast WITH FEC**	1 (8 ms)	N/A	N/A
	2 (12 ms)	N/A	N/A
	3 (16 ms)	5	2
	4 (20 ms)	16	6
	5 (30 ms)	43	12
	6 (45 ms)	80	16
	7 (80 ms)	174	20
	8 (120 ms)	255	20
Slave to Master Through One or More Repeaters. **Link Rate = Fast NO FEC**	1 (8 ms)	N/A	N/A
	2 (12 ms)	3	1
	3 (16 ms)	22	13
	4 (20 ms)	43	21
	5 (30 ms)	93	31
	6 (45 ms)	174	38
	7 (80 ms)	255	31
	8 (120 ms)	255	21
Slave to Master Through One or More Repeaters. **Link Rate = Fast WITH FEC**	1 (8 ms)	N/A	N/A
	2 (12 ms)	N/A	N/A
	3 (16 ms)	N/A	N/A
	4 (20 ms)	14	6
	5 (30 ms)	40	12
	6 (45 ms)	80	16
	7 (80 ms)	174	19
	8 (120 ms)	255	20

F. Hopping Patterns

This Appendix provides a guide for selecting appropriate hopping patterns (S106,S206). There are 49 hopping patterns: Patterns have been designed to notch out certain segments of the ISM band.

Pattern Number	Spectrum Used
0 - 7	2.4012 - 2.4824 GHz
8 - 10	2.4012 - 2.4312 GHz
11 - 13	2.4052 - 2.4352 GHz
14 - 16	2.4092 - 2.4392 GHz
17 - 19	2.4132 - 2.4432 GHz
20 - 22	2.4172 - 2.4472 GHz
23 - 25	2.4212 - 2.4512 GHz
26 - 28	2.4252 - 2.4552 GHz
29 - 31	2.4292 - 2.4592 GHz
32 - 34	2.4332 - 2.4632 GHz
35 - 37	2.4372 - 2.4672 GHz
38 - 40	2.4412 - 2.4712 GHz
41 - 43	2.4452 - 2.4752 GHz
44 - 46	2.4492 - 2.4792 GHz
47 - 48	2.4520 - 2.4820 GHz

Patterns 44 to 48 may be manually edited by entering AT&H at the Command Line. Each pattern must use a channel only once, and must consist of exactly 76 channels. There are 202 channels available ranging from Channel 1 at 2.4016 GHz up to Channel 202 at 2.4820 GHz

G. Technical Specifications

Electrical/Physical

Data Interface	Asynchronous Serial Port, TTL Levels
Signals	Sig. Gnd, TX, RX, DCD, DSR, DTR, RTS, CTS
Bandwidth / Data Rate	2,400 - 115,200 bps, uncompressed half-duplex, Approx. 100 kbps sustained in intelligent asymmetrical full-duplex transmission mode
Communications Range[1]	30 kilometres (19 miles)
Power Requirements	5 VDC, 1.0 Amp
Power Consumption	700 mA max, 450 mA typical at 1W transmit; 200 mA receive
Operating Frequency	2.4000 GHz to 2.4835 GHz
System Gain	135 dB
Sensitivity	-105 dBm
Output Power	10, 50, 100, 250, 500, 750, 1000mW (user-selectable)
Spreading Code	Frequency Hopping
Hopping Patterns	20 pseudo-random, user-selectable
Error Detection	CRC-16 with auto re-transmit
Error Correction	User-selectable Forward Error Correction (FEC)
Dimensions (LxWxH)	Encl: 3.5" x 2.1" x 1." (90 mm x 53 mm x 25 mm)
Weight	75 grams
Operating Environment	Temperature: -40 to +70°C Humidity: 5 to 95%, non-condensing
Storage Temperature	-40 to 90°C

1. Clear line-of-sight, elevated high-gain antennas.

H. Glossary

Terminology Used in the MHX-2400 Operating Manual

Asynchronous communications A method of telecommunications in which units of single bytes of data are sent separately and at an arbitrary time (not periodically or referenced to a clock). Bytes are "padded" with start and stop bits to distinguish each as a unit for the receiving end, which need not be synchronized with the sending terminal.

Attenuation The loss of signal power through equipment, lines/cables, or other transmission devices. Measured in decibels (dB).

Bandwidth The information-carrying capacity of a data transmission medium or device, usually expressed in bits/second (bps).

Baud Unit of signaling speed equivalent to the number of discrete conditions or events per second. If each signal event represents only one bit condition, then baud rate equals bits per second (bps) – this is generally true of the serial data port, so *baud* and *bps* have been used interchangeably in this manual when referring to the serial port; this is not always the case during the DCE-to-DCE communications, where a number of modulation techniques are used to increase the bps rate over the baud rate.

Bit The smallest unit of information in a binary system, represented by either a 1 or 0. Abbreviated "b".

Bits per second (b/s or bps) A measure of data transmission rate in serial communications. Also see *baud*.

Byte A group of bits, generally 8 bits in length. A byte typically represents a character of data. Abbreviated "B".

Characters per second (cps) A measure of data transmission rate for common exchanges of data. A character is usually represented by 10 bits: an 8-bit byte plus two additional bits for marking the start and stop. Thus, in most cases (but not always), *cps* is related to *bits per second (bps)* by a 1:10 ratio.

CRC (Cyclic Redundancy Check) An error-detection scheme for transmitted data. Performed by using a polynomial algorithm on data, and appending a checksum to the end of the packet. At the receiving end, a similar algorithm is performed and checked against the transmitted checksum.

Crossover cable (Also known as rollover, null-modem, or modem-eliminator cable) A cable which allows direct DTE-to-DTE connection without intermediate DCEs typically used to bridge the two communicating devices. Can also be used to make cabled DCE-to-DCE connections. The name is derived from "crossing" or "rolling" several lines, including the TX and RX lines so that transmitted data from one DTE is received on the RX pin of the other DTE and vice-versa.

Data Communications Equipment (DCE, also referred to as Data Circuit-Terminating Equipment, Data Set) A device which facilitates a communications connection between *Data Terminal Equipment* (DTEs). Often, two or more compatible DCE devices are used to "bridge" DTEs which need to exchange data. A DCE performs signal encoding, decoding, and conversion of data sent/received by the DTE, and transmits/receives data with another DCE. Common example is a modem.

Data Terminal Equipment (DTE) An end-device which sends/receives data to/from a DCE, often providing a user-interface for information exchange. Common examples are computers, terminals, and printers.

dBm Stands for "Decibels referenced to one milliwatt (1 mW)". A standard unit of power level commonly used in RF and communications work. n dBm is equal to $10^{(n/10)}$ milliwatt, so 0dBm = 1mW, -10dBm = 0.1mW, -20dBm = 0.01mW, etc.

DCE See *Data Communications Equipment*.

DTE See *Data Terminal Equipment*.

Flow Control A method of moderating the transmission of data so that all devices within the communications link (DTEs and DCEs) transmit and receive only as much data as they can handle at once. This prevents devices from sending data which cannot be received at the other end due to conditions such as a full buffer or hardware not in a ready state. This is ideally handled by hardware using flow-control and handshaking signals, but

can be controlled also by software using X-ON/X-OFF (transmitter on/off) commands.

Frequency-hopping A type of *spread spectrum* communication whereby the carrier frequency used between transmitter and receiver changes repeatedly in a synchronized fashion according to a specified algorithm or table. This minimizes unauthorized jamming (interference) and interception of telecommunications.

Full-duplex Where data can be transmitted, simultaneously and independently, bi-directionally.

Half duplex Exists when the communications medium supports bi-directional transmission, but data can only travel in one direction at the same time.

Handshaking A flow-control procedure for establishing data communications whereby devices indicate that data is to be sent and await appropriate signals that allow them to proceed.

Line-of-sight Condition in which a transmitted signal can reach its destination by travelling a straight path, without being absorbed and/or bounced by objects in its path.

Master The station which controls and/or polls one or more Slave stations in a point-to-point or point-to-multipoint network. Often functions as a server or hub for the network.

Non-volatile memory Memory which retains information which is written to it.

Null modem cable See *Crossover cable*.

Point-to-point A simple communications network in which only two DTEs are participants.

Point-to-multipoint A communications network in which a *Master* DTE communicates with two or more *Slave* DTEs.

Repeater A device which automatically amplifies or restores signals to compensate for distortion and/or attenuation prior to retransmission. A repeater is typically used to extend the distance for which data can be reliably transmitted using a particular medium or communications device.

RS-232 (Recommended Standard 232; more accurately, RS-232C or EIA/TIA-232E) Defined by the EIA, a widely known standard electrical and physical interface for linking DCEs and DTEs for serial data communications. Traditionally specifies a 25-pin D-sub connector, although many newer devices use a compact 9-pin connector with only the essential signaling lines used in asynchronous serial communications. Lines have two possible states: "high" (on, active, asserted, carrying +3 to +25 V) or "low" (off, inactive, disasserted, carrying -3 to -25 V).

RTU (Remote Terminal Unit) A common term describing a DTE device which is part of a wide-area network. Often a RTU performs data I/O and transmits the data to a centralized station.

Serial communications A common mode of data transmission whereby character bits are sent sequentially, one at a time, using the same signaling line. Contrast with parallel communications where all bits of a byte are transmitted at once, usually requiring a signal line for each bit.

Shielded cable Interface medium which is internally shrouded by a protective sheath to minimize external electromagnetic interference ("noise").

Slave A station which is controlled and/or polled by the Master station for communications. Typically represents one end of a point-to-point connection, or one of the terminal nodes in a point-to-multipoint network. Often a RTU is linked by a Slave DCE.

Spread spectrum A method of transmitting a signal over a wider bandwidth (using several frequencies) than the minimum necessary for the originally narrowband signal. A number of techniques are used to achieve spread spectrum telecommunications, including *frequency hopping*. Spread spectrum provides the possibility of sharing the same band amongst many users while increasing the tolerance to interference and noise, and enhancing privacy of communications.

Throughput A measure of the rate of data transmission passing through a data communication system, often expressed as bits or characters per second (bps or cps).