

EZCom Thunderbird Radio

Product Guide v0.64 (Preliminary)

Bulletin #1033



For Grayhill Part Numbers:

OEM RF Unit - WM09STDB-0001

CF Card - WM09STDB-0002


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EZCom Thunderbird OEM RF Module	WM09STDB-0001
EZCom Thunderbird CF Card	WM09STDB-0002
Standard Interface Board	WLYY4097-1
AC Power Supply for Interface Board	WL-PWR-9V
Product CD (contains Test File and Product Guide PDF)	WL-WRD
Evaluation Kit - 2 RF Modules, 2 Standard Interface Boards, 2 DB-9 Cables, 2 AC Adapters, 2 Whip Antennas, 1 CD	WLYY4098-1

For antenna options other than a whip antenna, contact Grayhill for the currently available antenna/coax choices.

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EZCom Thunderbird Introduction

Grayhill's EZCom Thunderbird radio is a frequency-hopping wireless module that transfers standard asynchronous¹ serial data streams over-the-air between host devices. The data radio is available in two formats:

- The Thunderbird – for host devices that have an available serial port
- The Thunderbird CF – for Windows CE handheld devices

Small in size and easily integrated into existing hardware, both Thunderbirds operate in the 900 MHz ISM frequency band and offer data rates up to 19200 bps, and ranges up to 24 miles outdoors and 1800 feet indoors. The Thunderbird's Frequency Hopping Spread Spectrum (FHSS) technology achieves exceptionally secure data communication, resistant to noise and interference.

Application Use

Wireless communications solve many otherwise impossible industrial and commercial communications problems. Radio waves can transport data over long distances, through the heat of blast furnaces and the cold temperatures that often prevail at outdoor installations. The standard Thunderbird provides RF communications for fixed needs, such as manufacturing control and security, business, and environmental monitoring. The Thunderbird CF allows mobile personnel and portable equipment to communicate wirelessly.

Note: The standard Thunderbird's functionality is covered in the first part of this manual. Appendix A presents a brief description of the Thunderbird CF, and refers the reader to prior sections when functionality is shared with the standard Thunderbird.

RF Module Features

Receiver Sensitivity: 10^{-6} BER, -105 dBm

Transmit Power: 160 mW (22 ± 2 dBm)

Frequency: 902-928 MHz for the standard module; 902-921 MHz for the anti-pager module²

RF Range: Indoor/Urban – up to 1800 feet; Outdoor Line-Of-Sight – up to 24 miles

Serial Port: The module incorporates a 3.3V CMOS serial port for easy CPU interfacing.

Selectable Serial Data Rates: 2400, 4800, 9600, 19200, 38400, and 57600 bps

Signal Levels: 8 digital I/O with 5V-tolerant 3.3V CMOS signal levels; 3 additional digital I/O that double as 12-bit A/D inputs

The module communicates directly with any UART interfaced host device through its serial port, or with any RS-232 interfaced host device via the optional Grayhill standard interface board.

Note: The RF module can provide simple, built-in I/O functions via its standard 100 mil. pitch interface header, with no separate controller needed. Contact Grayhill for more information.

¹ If a synchronous serial interface is required, please contact the EZCom Thunderbird project manager.

² Upon request, Grayhill can supply an anti-pager RF module with a custom SAW filter designed to suppress the impact of pager and cell phone systems when the Thunderbird is deployed very close to pager or cell transmitters.

Electrical and Mechanical Interfaces

The EZCom Thunderbird uses commonly available connectors and fasteners, and has been otherwise optimized for easy integration into other systems.

Connectors and Pinouts

The Thunderbird RF module incorporates two connectors: the RF connector and the main interface connector, as shown in Figure 1 below.

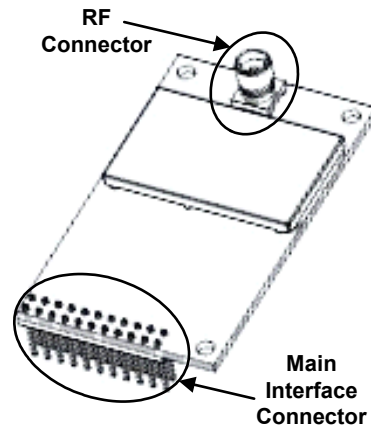


Figure 1. Thunderbird Connectors

Main Interface Connector

The RF module connects to a host device via a 2 x 11, 0.100" pitch male header with 0.025" square posts. The connector supplies power and I/O, and also is the means whereby a UART-interfaced device can connect directly to the module. The header is gold-flashed for lower contact resistance.

The outer row of pins (A1 – A11) on the main interface connector performs basic radio functionality. The inner row of pins (B1 – B11) provides RS-485/422 support; customized versions can provide analog inputs and digital I/O. See Table 1 and Figure 2 on page 7 for more information.

Mating Connectors

For the host device, a female 22-pin connector that uses at least two points of contact per pin is recommended. In high vibration and shock applications, consider using one of the more expensive 22-pin connectors with 4 points of contact, or else solder the header into your PCB. Example female 22-pin connectors with 2 points of contact per pin are listed here:

Female 22-Pin Connectors with 2 Points of Contact

Digi-Key PN 15-44-4111-ND Available at Digi-Key, 800-344-4539 or www.digikey.com
Samtec PN CES-111-01-G-D Available at Samtec, 800-726-8329 or www.samtec.com

Table 1. J2 Pin Signal Descriptions

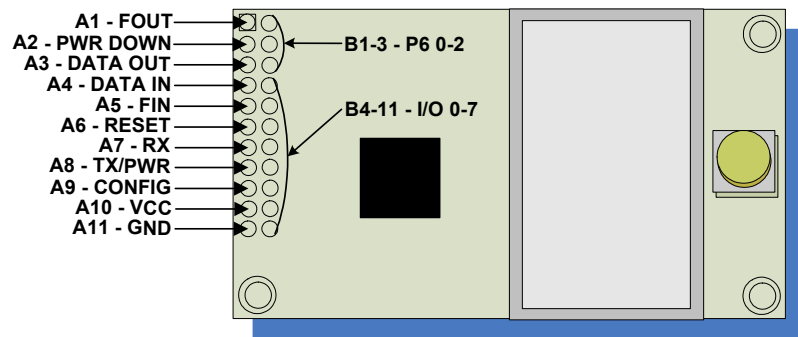
Module Pin	Signal Name	I/O	When Active	Description
A1	FOUT	O*	Low	Flow Control Out
A2	Power Down	I*	High	When driven high, module powers down.
A3	DO (Data Out)	O*	N/A	Serial data leaving Thunderbird module (to host, from over-the-air)
A4	DI (Data In)	I	N/A	Serial data entering Thunderbird module (from host, to over-the-air)
A5	FIN	I**	Low	Flow Control In / Binary Command Mode Control
A6	RESET	I*	Low	Resets module parameters to defaults
A7	RX	O	High	Receive LED pulses high during RF reception.
A8	TX / PWR	O	Low	Transmit LED pulses low during transmission.
			High	At power-up, PWR driven high; remains high
A9	CONFIG	I***	Low	Hold low during reboot to enter AT Command Mode (backup method for command sequence)
A10	VCC	I	-	4.5-15 VDC $\pm$ 5% V regulated
A11	GND	-	-	Ground

* Pin uses a 10K Ω Pull-Up resistor (already installed in the module).

** Pin uses a 10K Ω Pull-Down resistor (already installed in the module).

*** Pin uses a 100K Ω Pull-Up resistor (already installed in the module).

Note: When integrating the Thunderbird with a host PC board, ensure all unused lines are left disconnected (floating).

**Figure 2. Main Interface Connector Pinouts**

RF Connector

Three types of RF connectors are available:

- Soldered $\frac{1}{4}$ wave wire antenna
- Reverse Polarity SMA (RP-SMA)
- MMCX

Note: Though usually installed topside, the RF connector can be installed on the underside of the module. Contact Grayhill to request this installation variation.

Soldered Wire Antenna

If your application is mainly short-range, a soldered wire antenna should be more than sufficient. The integrated antenna will have poorer range performance than larger antennas or antennas with better placement, but it is by far the least expensive antenna solution.

Reverse Polarity SMA Connector

The Reverse Polarity SMA connector is the best choice for remotely mounted antennas such as those placed on equipment boxes. An example of an RP-SMA connection is a Thunderbird radio mounted inside a NEMA enclosure for protection from the elements (see Figure 3 below), with a lightning arrestor used as a bulkhead feed-through connecting to an external coax, which in turn connects to an antenna mounted on a tower.

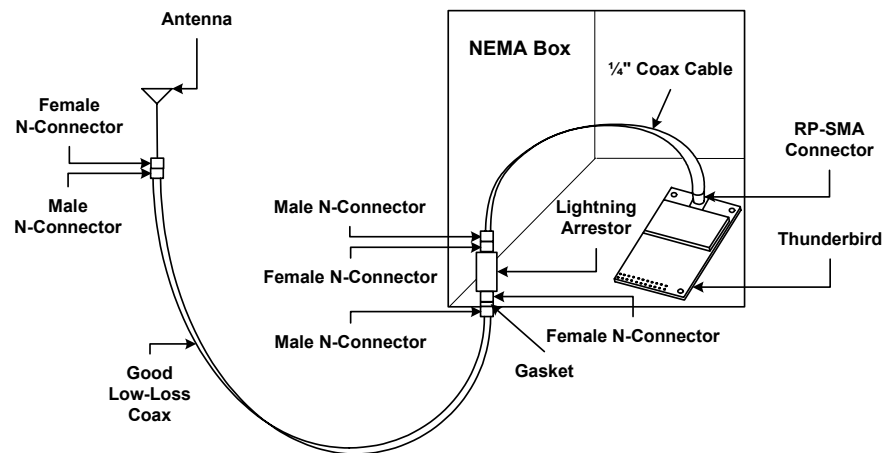


Figure 3. NEMA Box Connection

The connection inside the box is usually accomplished via a high-quality $\frac{1}{4}$ " diameter coaxial cable, like the Times LMR-195 or similar, as these coax choices are easier to route inside a box than the 0.400" or 0.600" diameter coax products commonly used to run up the side of a tower.

For tighter mounting restrictions, an RP-SMA connection can be extended off the PCB with a soldered coax pig-tail. This kind of connection would use an RG-316, 0.140" diameter coaxial cable. The RG-316 has a large attenuation factor, so it should not be more than 12" long.

MMCX Connector

The MMCX connector provides a push-on, snap-action connection designed for a very limited number of insertions. The MMCX connector is best for miniature coaxes most often seen where very tight spaces and short runs are involved. Example uses for MMCX connections are mobile and portable applications. An RP-SMA connector can also be used for those applications where a screw-on connector is required.

Antennas

Several common antennas have been pre-qualified for use with the Thunderbird RF module, including a high-gain patch antenna for directional links and a high-gain, omni-directional antenna for wide-area coverage.

Only Grayhill-approved antennas and cables should be used with this radio. If none of the antennas listed in the RF Module Approved Antenna Lists (below) meet your needs, Grayhill can provide or suggest an antenna solution that will be optimal for your application and will meet FCC requirements.

For optimal antenna operation, it is important that an antenna have an unobstructed line-of-sight. Radios with $\frac{1}{4}$ wave wire antennas soldered to their PCBs and no obstructions in their lines-of-sight work much better than radios with more expensive antennas that have obstructions in their lines-of-sight. An unobstructed line-of-sight means there is no non-gaseous matter with particles larger than 0.020" diameter between the antennas. Fog and smoke should not pose a problem.

Note: Plastic generally does not cause line-of-sight problems unless the carbon content of the plastic is high (carbon is usually added for EMC shielding). Some colorants used in plastic-making can also pose line-of-sight problems. Metal, stone and anything that absorbs water is considered an obstruction.

RF Module Approved Antenna Lists

Table 2. Antennas with 20 cm. Minimum Separation Distance

Antenna Type	Manufacturer	Manufacturer Part Number	Gain (dBd)	Grayhill Part Number
Yagi	Maxrad	BMOY8905	9	WL-ANT-Y9A
Yagi	LM	BYSS-090-09-01	9	WL-ANT-Y9LA
Patch	LM	BPAS85-090-08-11SW	8	WL-ANT-P9LA
Patch	Maxrad	MP8068	8	WLHH1434-1
Omni	Maxrad	MFB9157	7	WL-ANT-MN7A
Omni	Maxrad	MFB9153	3	WLHH1230-1

Table 3. Antennas with Smaller Minimum Separation Distances

Antenna Type	Manufacturer	Manufacturer Part Number	Gain (dBd)	Grayhill Part Number	Min. Separation Distance
PCB Dipole	Centurion	Revie PRO	0	01HH5222-2	N/A
Whip	Maxrad	MEXE902	-0.5	WL-ANT-W9MA	3 cm
$\frac{1}{4}$ Wave Integrated Wire Antenna	Grayhill	Permanent Antenna Wire	-3	WM09STDB-0003	5 cm

Note: To obtain approval of other antennas for use with the EZCom Thunderbird RF module, contact Grayhill. Grayhill can also supply cables to OEM clients.



WARNING: This device has been tested with the antennas listed in Tables 2 and 3 above. When integrated into OEM products, fixed antennas require installation that prevents end users from replacing them with non-approved antennas. Antennas not listed in Tables 2 and 3 must be tested to comply with FCC Section 15.203 (unique antenna connectors) and FCC Section 15.247 (emissions).

Mechanical Interface

The Thunderbird was designed to be bolted to a host PCB and has mounting holes for #6 socket head cap screws for this purpose. You can bolt the radio board itself to a panel or fixture. If you decide to mount the RF module away from the electrical device to which it connects, plug a ribbon cable into the main interface connector to bring the signals out. With the right length of screw standoff, it is possible to capture the ribbon cable connector in such a way that it will not come off unless the screws holding the PCB to the surface on which it is mounted are removed. This method secures the cable against vibration.

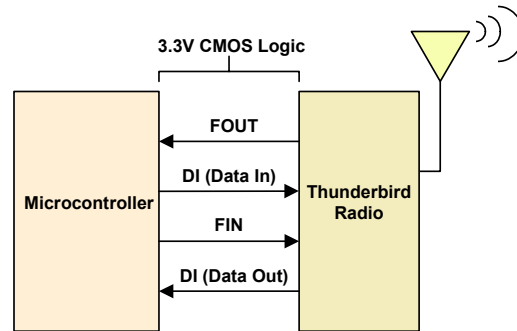


Figure 4. Communications with UART Interfaced Host Devices

Another way to mount the Thunderbird on a host is to connect the module to the Grayhill interface board via the main interface connector, and then bolt the interface board to the host. The interface board's screw holes are larger than those on the Thunderbird PCB, and will accommodate any standard #6 screw. Use of the interface board also allows for I/O signals to be brought out on a separate connector from the serial interface. See the Standard Interface Board section below for more information.

Your RF cabling should be kept as short as practical and secured in such a way that it will not vibrate and wear the insulation off. To have the cabling pass through the side of a box or case, use a bulkhead fitting. For fixed systems, the bulkhead fitting should be a lightning arrestor. Grayhill can provide suitable lightning arrestor kits (Grayhill Part Number WL-ARST-1). The coax connection to any outside enclosure should be in the bottom of the enclosure to allow for a drip-loop on the coax.

RF Module Mechanical Drawings

DXF files supplying mechanical drawings of the EZCom Thunderbird RF module are available at www.grayhill.com. See Figure 15 on page 30 for large-scale mechanical drawings of the standard Thunderbird radio.

RF Module 3-D Models

To more easily integrate the data radio into other systems, 3-D images of the Thunderbird radio are provided in STEP format at www.grayhill.com. A sample 3-D image of the standard interface board appears in Figure 5 below.

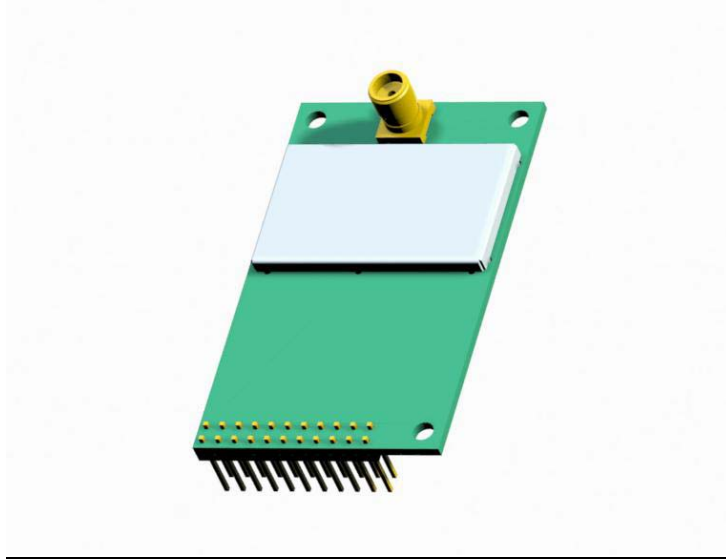


Figure 5. Thunderbird Radio in 3-D

Standard Interface Board

Grayhill offers an optional interface board (Grayhill Part Number WLYY4097-1) that can simplify integration of the Thunderbird radio module with RS-232 level equipment and higher voltage systems. The Grayhill standard interface board provides:

- RS-232 compatible signal levels on a standard female DB-9 connector
- Jumper-selectable DCE or DTE on the serial interface to avoid special cables
- Convenient breakout of the I/O pins to a separate connector for easy I/O usage
- Local voltage regulator capable of up to 19 volt DC input
- TX and RX LEDs for traffic detection
- Hardware reset and command buttons for development use

Setting the J5 Jumper

The jumper at J5 on the standard interface board is factory-set to a DCE configuration (shown on the left in Figure 6 on page 12) to provide a DCE interface for the usual case where a host PC in DTE mode exchanges data with the Thunderbird radio.

Under some circumstances, the standard interface board may need to present a DTE interface – for instance, when the board will be connected to a phone line modem. To have jumper J5 select a DTE interface, shift its 2-pin shunts into vertical positions, as shown on the right in Figure 6.



Figure 6. J5 Configured for DCE – J5 Configured for DTE

Connectors and Pinouts

Power Connector

Each Grayhill interface board has a 2.1 mm wide by 3 mm long female barrel connector for power input. For safety reasons, the polarity of the power connector is positive at the center and the polarity of its outer shell is negative. Power supplied to the board must be greater than 5V at 300 mA with no more than 100 mVp-p noise.

Mating power connectors can be found at Radio Shack or ordered from Digi-Key (Digi-Key Part Number 24857-ND). Grayhill offers an AC switching wall-wart power supply (Grayhill Part Number WL-PWR-9V) to conveniently provide power for this board. Note that the board's 1 amp, 5 volt regulator can be used to power additional small amounts of 5V equipment.

Serial Connector

Each Grayhill standard interface board provides a standard female DB-9 connector, suitable for an RS-232 connection to a computer via a standard male/female 9-pin serial cable.

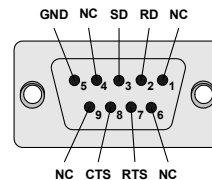


Figure 7. Female DB-9 Connector with RS-232 Signals

I/O Connector

The I/O connector (see the bottom right corner in Figure 8 below) breaks out the 11 available I/O pins, each with a matching ground pin. This allows the I/O to be connectorized with a ribbon or insulation displacement cable.

Interface Board Mechanical Drawings

DXF files containing mechanical drawings of the WLYY4097-1 interface board are available at www.grayhill.com. See Figure 16 on page 31 for large-scale mechanical drawings of the Grayhill standard interface board.

Interface Board 3-D Models

To make it easier to integrate Grayhill WLYY4097-1 interface boards into other systems, images of the board are provided in STEP format at www.grayhill.com. A sample 3-D image of the standard interface board appears in Figure 8 below.

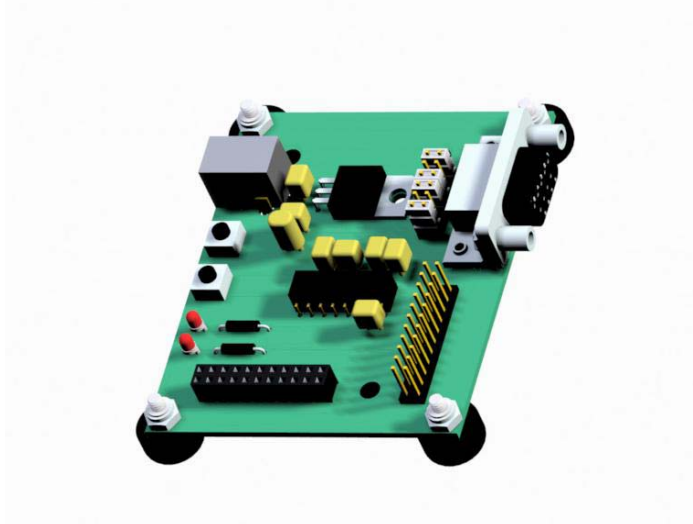


Figure 8. Standard Interface Board in 3-D

Serial Interface

RS-232 is a single-ended, point-to-point interface, which remains the most common serial interface outside the industrial market. Since RS-232 data can only traverse distances of up to 50 feet, RS-232 is used less often in industrial applications than RS-485/422 interfaces.

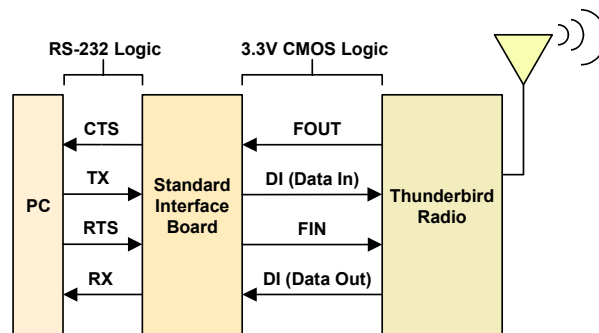


Figure 9. Communications with RS-232 Interfaced Host Devices

The Grayhill standard interface board provides serial interfacing to the standard Thunderbird using the RS-232 protocol. While a default serial data rate of 57600 bps is set at the factory, data rates of 2400, 4800, 9600, 19200, 38400, and 57600 bps are software-selectable.³ See the Configuration section below for more on how to select data rates for the serial interface.

³ On the Thunderbird side, hardware flow control is always on. If a host application such as HyperTerminal is set to *no* flow control, the host application will simply ignore the Thunderbird's flow control signals, possibly causing Thunderbird buffers to overflow and drop data. To prevent buffer overflow and lost data in such a situation, set the serial port to 4800 baud.

Configuration

The advanced addressing and communications settings offered by Thunderbird data radios are configurable using either AT command mode or binary command mode. By default, all data received on the Data In pin (Pin A4) is transmitted on the RF channel. Command modes provide ways to alert a radio that commands – instead of data intended for RF transmission – are incoming, thus allowing the user to modify various operating parameters. Parameter values must be saved to the radio's non-volatile memory (using the ATWR command) or they will be reset to stored values when the radio is next powered on or reset.

AT Commands

AT command mode can be entered by sending a sequence of three identical break characters to the unit via the serial connection. By default, the break character is set to 0x2B (“+”), but it can be changed to a different ASCII character using the ATCC command. All characters that follow the command sequence are interpreted as AT commands and are not sent as data.

In order for the radio to differentiate AT commands from actual data, a number of timeout conditions must be met to enter and remain in AT command mode. Timeout conditions are changed via the commands ATBT, ATAT, and ATCT (or their binary command equivalents). ATBT and ATAT define “silent” times during which no characters can be sent before and after (respectively) sending the AT command sequence, and have initial values of 1 second. ATCT specifies the AT command mode timeout, whose initial value is 20 seconds. For more on these AT commands, see the Configuration Command Table on page 16.

AT commands are sent in the following format:

AT + 2-character command + space (optional) + parameter (optional) + carriage return

AT command characters are ASCII characters, whose alphabetic characters are case-insensitive. Parameters are up to four characters long, and are specified as hexadecimal values. A space is an ASCII character of value 32 decimal (0x20). A carriage return is a character of value 13 decimal (0x0D).

Current parameter settings can be retrieved by sending an AT command without the parameter. The RF module responds to a valid AT command with “OK,” but responds with “ERROR” if an AT command is not recognized or if the AT command string format is incorrect.

Example – to send an AT command to change the radio address to 1A0D (hex), enter:

```
+++  
ATDT 1A0D<CR>  
ATCN<CR>
```

where <CR> represents a carriage return.

The ATCN command allows an immediate exit from AT command mode. Otherwise, the radio automatically returns to data mode when no further valid AT commands have been received within the AT command timeout period (set by ATCT or its equivalent binary command).

Binary Commands

To send a binary command, “flow control in” (FIN), i.e., Pin A5, needs to be set high by the host while the command byte is sent to the module. FIN can be set low while parameter values are sent. If all parameters are received within 0.5 seconds, the command is executed; otherwise, the radio returns to data mode, ignoring the command.

Binary commands have the following format:

Single-byte command (BIN) + two-byte parameter (optional)

Note: If a parameter is two bytes long, the least significant byte needs to be sent first. If the parameter is one byte long, a 0x00 byte needs to be sent after the command byte and before the parameter byte.

Example – to set Sleep Mode to 8 seconds:

Assert FIN to enter binary command mode

Send bytes: 0x01, 0x00, 0x07, 0x08 (ATSM 7 and ATWR as binary commands)

Deassert FIN to exit binary command mode

In binary command mode, the RF module does not respond with a confirmation message unless it receives a query for the current parameter setting. To send a query for a parameter value, FIN is asserted while sending a byte containing the value of the corresponding command number XORed with 0x80. The number of bytes returned to the host is specified in the Configuration Command Table on page 16.

Table 4. Configuration Command Table

Thunderbird data radios expect numerical values in hexadecimal.

Binary Command	AT Command	Description	Parameter Values	# of bytes	Factory Default
00	DT	Radio Address. In order to communicate, radios need to have identical radio addresses.	0000 to FFFF (0 to 65535)	2	0000
01	SM	Sleep Mode	00 - no sleep mode 02 - wake from serial RX 03 - cyclic 0.5 second sleep 04 - cyclic 1.0 second sleep 05 - cyclic 2.0 second sleep 06 - cyclic 4.0 second sleep 07 - cyclic 8.0 second sleep	1	00
02	ST	Time before sleep (valid only in RX and Cyclic Modes)	0001 to FFFF (1 to 65535) in 1/10s of seconds	2	0064
03	HT	Time before beacon (time of inactivity on RX pin before a beacon must be used)	0000 to FFFF (0 to 65535) in 1/10s of seconds A value of 65535 means no long header.	2	FFFF
04	BT	Time before AT command sequence	0001 to FFFF (1 to 65535) in 1/10s of seconds	2	000A
05	AT	Time after AT command sequence	0001 to FFFF (1 to 65535) in 1/10s of seconds	2	000A
06	CT	Timeout from AT command mode	0001 to FFFF (1 to 65535) in 1/10s of seconds	2	00C8
07	FL	Set serial software flow control. Hardware flow control (FOUT) is always on.	0 - Serial software flow control off 1 - Serial software flow control on	1	00
08	WR	Write all configurable parameters to non-volatile memory	None	N/A	N/A
09	CN	Exit from AT command mode immediately	None	N/A	N/A
0A	E0	AT command mode character echo off (default)	None	N/A	N/A
0B	E1	AT command mode character echo on	None	N/A	N/A
0C	LH	Beacon duration	00 to FF (0 to 255) in 1/10s of seconds	1	00
0D	FH	Force beacon on next transmit	None	N/A	N/A
0E	RE	Restore default configuration values	None	N/A	N/A
0F	ER	Receive error count	Number of receive packet errors. Value is reset to 0 on power-up.	2	0000
10	GD	Receive good count	Number of good receive packets. Value is reset to 0 on power-up.	2	0000
11	HP	Hop set, or Radio Group number	00 to 06	1	00
12	MK	Radio Address (RAD) Mask. Only bits set to 1 are used in RAD comparison. Initially set to default global RAD value, RAD Mask is always used as global address.	0000 to FFFF (0 to 65535)	2	FFFF
13	CC	AT command sequence character	20 to 7F (32 to 127)	1	2B
14	VR	Firmware version	0000 to FFFF (0.0 to 255.255)	2	N/A
15	BD	UART baud rate (AT command mode: Issue ATCN command for new baud rate to take effect; Binary command mode: Issue ATWR command and reboot.)	01 - 2400 04 - 19200 02 - 4800 05 - 38400 03 - 9600 06 - 57600	1	06
16	RT	Asserted FIN triggers binary command mode.	0 - binary command mode off 1 - binary command mode on	1	00
17	SY	Synchronization timer. During this time, radios remain in-sync after an initial sync-up.	00 to FF (0 to 255)	1	14
18	SN	Subnet ID - up to 31 subnetworks can be created	00 (default) to 1E	1	00

Operation

The EZCom Thunderbird radio operates in half-duplex mode – either transmitting or receiving data over the air, but not both at the same time. After transmitting RF data, the unit must transition to a standby operation before it can receive any data presented over the air waves; likewise, after receiving RF data, the radio must move to standby before it can transmit any data arriving at its serial port. Table 5 presents radio power mode definitions and current usages.⁴

Table 5. Thunderbird Power Modes

Power Mode	Description	Current
Standby Mode	The radio is fully operational and is currently scanning channels for valid data.	36 mA
Transmit Mode	The radio is fully operational and is currently transmitting data.	168 mA
Receive Mode	The radio is fully operational and is currently receiving data.	40 mA
Serial Receive Low-Power Mode (Standard Thunderbird Only)	The radio configured for this Sleep Mode automatically enters this mode after a user-defined inactivity timeout occurs on both the serial and the RF channel. When the radio is in this mode, any character received on the serial channel causes the radio to transition into Transmit Mode.	18 mA
Cyclic Low-Power Mode (Standard Thunderbird Only)	The radio configured for this Sleep Mode automatically enters this mode after a user-defined inactivity timeout occurs on the RF channel. The radio remains in this mode for the period of time set for Cyclic sleep, after which it moves to Standby Mode and starts scanning the hop channels for data. If no data is detected in one pass through a hop set, the radio goes back to Cyclic sleep.	18 mA, but 36 mA for 160 ms every cycle
Pin Sleep Mode (Standard Thunderbird Only)	When Pin 2 is asserted (high), the radio powers down.	13 mA

Standby Mode

During times of radio activity when the radio is neither transmitting nor receiving, the EZCom Thunderbird radio goes into Standby Mode. From Standby, the unit can move into:

- Transmit Mode, if data is presented on the serial port
- Receive Mode, if data is presented over the air
- Serial Receive Low-Power Mode
- Cyclic Low-Power Mode

The radio moves from Transmit or Receive Mode into Standby Mode when no data comes in on the serial or the RF channel (respectively), or when a receive error is detected. Further inactivity on one or both channels can result in a move from Standby to the assigned low-power mode.

Transmit Mode

When the first byte of data is received on the UART and moved into the unit's RF transmit buffer, the Thunderbird unit moves from Standby to Transmit Mode, taking 2 ms to do so. The radio can buffer up to 254 characters, but deasserts FOUT flow control when approximately 200 characters occupy the transmit buffer, signaling to the host device to stop sending data.

Note: Although software flow control is available for data incoming on the serial line (using the ATFL command), hardware flow control is the preferred method of flow control. Software flow control relies on the host's transmission of the control characters 0x11 and 0x13 (the decimal

⁴ The current usages shown in Table 5 are based on tests using a standard Thunderbird mounted on a standard interface board.

numbers 17 and 19) over the data lines. When serial software flow control is on, if the radio receives any legitimate data byte that has the same value as one of the software flow control characters during the course of regular data transmission from the host to the radio, the radio will assume these are flow control characters, not data bytes, and transmission will stall. When the host is transmitting strictly non-numerical data to the radio, software flow control may work just as well as hardware flow control.

The Thunderbird radio does not use a framed protocol to transmit data, but rather relies on a more transparent-mode functionality. The radio makes decisions to transmit data based on one of two factors – whether its buffer is full, or if it is not full, if there is some data in the buffer and no new data has arrived for a set timeout period.

In Transmit Mode, the radio packetizes the data in its transmit buffer into 35-byte packets. For each packet, the unit computes a 16-bit CRC and attaches it to the end of the packet before transmitting it over the air. Once all packetized data has been transmitted and the RF transmit buffer is empty, the radio returns to Standby Mode.

To reduce average latency time – the time that elapses between the transmitter’s reception of data in its serial port and the receiver’s transmission of data out its serial port – the system integrator can vary the sync timer setting (via the ATSY command or its binary equivalent).

Receive Mode

When a Thunderbird radio in Standby Mode detects data incoming over the RF channel, it transitions to Receive Mode. Once in Receive Mode, the radio processes the received data packets and sends data out its serial port. The radio stays in Receive Mode until it detects no more incoming RF data or it encounters an error in a packet’s CRC – in which case it discards the packet, does not transmit data out its serial port, and moves back to Standby Mode. If serial data was stored in the radio’s RF transmit buffer during the time it was in Receive Mode, once the Thunderbird returns to Standby Mode it detects the data and transmits it.

Depending on network settings, any Thunderbird radio within range of any other Thunderbird radio may receive any transmission that is valid, but may or may not send the received data out its serial port, depending on packet address field values. See the Networking section below for a description of the built-in support for point-to-point and point-to-multipoint networking.

Note: Delivery of data packets is not guaranteed, no notification is sent when packets are dropped, and no retransmission of dropped packets is attempted. It is assumed that retries are handled outside of the Thunderbird radio as in a multi-drop, parallel-wired network.

Low-Power Modes

The EZCom Thunderbird radio functions as a transceiver only when it is completely powered up; when it is in one of its low-power modes, it will neither transmit nor receive data until first returning to Standby Mode.

The low-power (or sleep) modes⁵ described here make it possible to use the radio in low-power or battery-operating environments. The Thunderbird initially has *no* sleep mode enabled, but the system integrator can assign it a Sleep Mode setting by specifying either Serial Receive or Cyclic Low-Power Mode using the ATSM command or its binary equivalent.

When a low-power mode is configured for a radio, the time interval of inactivity before the radio moves into the assigned low-power mode can also be modified using the ATST command or its binary equivalent. The timeout setting specifies a period of time during which the radio receives no data either over the air or at its serial port.

⁵ All low-power modes are applicable only for the standard Thunderbird module.

Serial Receive Low-Power Mode

A Thunderbird radio with Serial Receive Low-Power Mode configured as its Sleep Mode goes to sleep when no data has come in either over the air or over the serial line from its host for the timeout period specified by the ATST command. When a radio so configured sleeps, it will wake up whenever data from its host arrives at its serial port, but not when RF data is incoming over the air waves. Thus, the integrator should assign this low-power mode only to a radio whose primary function is to initiate RF communication. In the following section, such a unit is referred to as the *RF initiator*.

Cyclic Low-Power Mode

When a radio is in Cyclic sleep, it will not listen for data arriving at its serial port. Instead, each time its assigned sleep period ends, the radio wakes up and scans all RF channels for incoming data packets. If no RF data is found, it returns to Cyclic sleep. If RF data is detected, however, the radio stays powered up, transitions into Receive Mode, and operates normally until inactivity causes a transition back to Cyclic sleep.

While a unit is in a Cyclic low-power mode, its FIN pin is deasserted so it cannot receive data over the serial line until it is woken up by a beacon arriving over the air. Thus, the integrator should assign this low-power mode only to a radio whose primary function is to respond to RF communication. This kind of unit is referred to here as the *RF responder*.

An RF initiator with a beacon timeout set to the same value as the ATST value of its responder will go to Beacon Mode at about the same time that the RF responder moves to Cyclic sleep. The next time the initiator sends a packet, it transmits a beacon which must be long enough for it to be detected when the responder next monitors the channel, thus enabling the responder to power up and receive the data packets that follow the beacon.

If an RF initiator is forced to send a beacon – either because an ATFH command was issued or because of an inactivity timeout (set by ATHT or its binary equivalent) – it will do so immediately prior to the data portion. The beacon duration needs to be long enough to successfully wake up the radio(s) in Cyclic sleep. For example, if an RF responder is set to wake up every four seconds and check for a beacon, the initiator must send a beacon at least four seconds long in order to provide enough time for the responder to detect the beacon. To ensure reception of all packets, packet beacon length must be set via ATLN or its binary equivalent to match the cyclic power-up time (which is the time spent in Cyclic sleep).

Pin Sleep Mode

Pin A2 (Power Down) on the Thunderbird's 22-pin connector is high by default due to a 10K Ω pull-up resistor on the Thunderbird PCB. Pin A2 must be tied to ground for the radio to power on. The standard interface board has a fixed pull-down to ensure the radio is powered on when connected to the interface board. When Pin A2 is asserted (high), the onboard voltage regulator turns off, and the radio powers down. Pin Sleep Mode, where the entire radio is powered off, provides the lowest power consumption of all low-power modes. The radio takes 20 ms to move from Pin Sleep Mode to Standby Mode.

Note: In the Cyclic and Pin Sleep Modes, the FOUT pin (Pin A1) is deasserted (high), signaling that the radio is in a low-power mode and that data should not be sent to the radio. The TX/PWR pin (Pin A8) is also deasserted (low) while the radio is in Pin Sleep Mode.

Networking

In its initial, factory-set state, the EZCom Thunderbird radio transmits data that can be received over the air and output on serial channels by other Thunderbird radios in their default states. This default broadcast mode of operation, in which every in-range radio node can successfully

receive and process every transmission, allows the design of a system that provides for all networking tasks – addressing, error checking, acknowledgements and retries – behind the radio link, as if the nodes were attached to a wired, multi-drop bus.

However, the default networking setting do not provide network security. They do not prevent reception of wireless network communications by radios on nearby networks owned by other businesses also using Thunderbird RF technology. Further, using the default settings can result in interference and cross talk, and does not provide the isolation needed for data exchanges by radio pairs or radios in subnetworks operating within close proximity of each other.

To ensure security and isolation, system integrators can use the radio's multiple types of network addresses to establish radio networks, subnetworks, radio groups and point-to-point links.

Thunderbird radios use the following network parameters:

- Vendor Identification (VID) Numbers
- Subnet IDs
- Radio Group Numbers
- Radio Addresses (RADs) and Radio Address (RAD) Masks

Vendor Identification Numbers

In the interests of network security, a system integrator can request a Vendor Identification (VID) number that is programmed into multiple EZCom Thunderbird radios at the factory. Essentially an identifier for the entire network domain of a business, the VID number is stored in permanent memory and can only be modified at the factory. Contact Grayhill sales for a special part number with which to order Thunderbird radios programmed with a unique Vendor ID.

Since only radios with matching VID numbers can intercommunicate, VIDs ensure that radios in one domain will be unable to exchange data with those in another. Note, however, that the assignment of unique VIDs to different radio networks does not guarantee a total absence of interference if other radio networks are operating in the same vicinity.

Subnet IDs

The system integrator can facilitate networking within a VID domain by establishing multiple subdomains using the Subnet ID configuration command. All radios may possess the same VID, but radios assigned one Subnet ID cannot transmit or receive data to or from radios assigned other Subnet IDs. Even though the creation of radio subnetworks⁶ limits communication between radios to those radios on a subnet, it may only somewhat minimize interference.

To create a subnetwork within a VID domain, the integrator configures the same Subnet ID parameter value for all radios connected to host computers required to belong to a subdomain. Up to 31 subnetworks can be established using the ATSN configuration command or its binary command equivalent.

Radio Group Numbers

A radio network or subnetwork can be further broken down into radio groups by assigning the same Radio Group parameter value to all radios in a functional group of data radios. Using the ATRP command or its binary equivalent to set a parameter value for a radio's Radio Group, one of seven possible pseudo-random frequency-hopping sequences is configured for a radio.⁷

Only radios in the same VID, subnet, and radio group can intercommunicate. Thus, when radios share the same VID and subnet but belong to different radio groups, multiple radio pairs can operate in close proximity, causing each other minimal interference in doing so.

⁶ Establishment of subnetworks is optional.

⁷ All Thunderbird radios initially operate using the factory-default hop sequence.

However, even with radios assigned different hop sequences (that is, different Radio Group parameter values), there is still the possibility that channels will overlap. In the event that transmissions from radios in different groups collide on a channel, the collision is resolved by the next hop, since transmissions from radios belonging to different groups follow different hopping sequences and will jump to separate channels.

While it is possible, by establishing 31 subnets and 7 radio groups in each subnet, to subdivide a Thunderbird radio network into 217 different “networks,” this does not mean there are 217 possible hop sequences. A fully specified network (see Figure 10 below) would instead be composed of 31 separate subnetworks, each of which uses the same seven hop sequences.⁸

Radio Addresses

To achieve point-to-point communication, each radio is assigned a 16-bit Radio Address (RAD). When a transmitting radio sends a packet out over the air waves, the transmitting radio’s RAD is encoded into that packet. Every Thunderbird radio comes with a default RAD of zero. Using the ATDT command or its binary equivalent, the system integrator can configure one of 65535 possible hexadecimal RAD values for a radio. Note that, unlike wired networking, Thunderbird network nodes do not require unique network addresses; indeed, the system integrator must think in terms of assigning duplicate addresses to provide for communication between radios.

To provide an example of RAD use in a Thunderbird wireless network, say that a radio group contains, among others, three RF modules that we shall call Radios A, B, and C. Radios A and B are assigned the same RAD, but Radio C is assigned a different RAD. When Radio A transmits data over the air waves, both Radios B and C receive the data, but only Radio B sends data out its serial port. Radio C discards the packets it receives from Radio A, since the RAD specified in the packets does not match its own RAD. Radio C listens to the entire transmission, however, in order to avoid sending a transmission of its own during a transmission of data with a different RAD, and thus helps to maintain overall network synchronization.

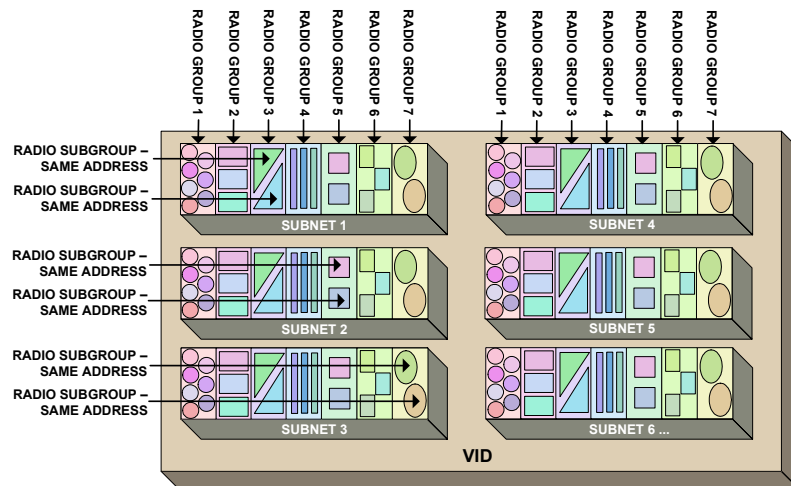


Figure 10. Thunderbird Radio Network Structure

With the addition of the radio address, a system integrator can implement a complete networking hierarchy, enabling communications ranging from broadcasts to all radios in the same VID, subnet and radio group, to highly specific transmissions between the only two radios on the network that share the same VID, subnet ID, radio group number, and radio address.

⁸ Network designers may opt to forego establishing subnets for small networks, and only use radio groups/hop sequences to differentiate between network node functions. In even smaller networks, all radios may exchange data using just one hop sequence, and radio intercommunication may be limited by using different radio addresses.

Radio Address Masks

The Radio Address Mask (RAD mask), set using ATMK or its equivalent binary command, also facilitates networking within a radio group. The RAD mask is a set to the value 0xFFFF at the factory. The RAD mask is the same length as the RAD (16 bits).

During packet reception, any bits set in the RAD mask of the receiver are logically ANDed with the transmitting radio's RAD, which was sent as part of the packet. The result is compared to the receiving radio's RAD, and only when there is a match is the packet received. Modification of the value of the RAD mask to such variations as 0x000F, 0x00F0, 0x0F00, and 0xF000 allows broadcasts to subsets of radios in the same VID, subnet, and radio group.

Using the EZCom Thunderbird Evaluation Kit

The RF communications that can be accomplished using the Evaluation Kit demonstrate how easy it is to operate Thunderbird radios. Simply follow the instructions below to assemble evaluation kit contents, configure two radio connections, and perform over-the-air data transfer tests between the two radios.

Evaluation Kit Contents

- 2 EZCom Thunderbird OEM RF Modules
- 2 Standard Interface Boards
- 2 DB-9 Cables
- 2 AC Adapters
- 2 Whip Antennas
- 1 Product CD containing the TRC.TXT test file and the product guide PDF

Evaluation Test Requirements

To use the evaluation kit to test the data radio using an RS-232 serial interface, you'll need two computers – each with an available comm port, and each running any operating system.

Assembly Instructions

For a finished assembly, refer to the picture in Figure 11 on page 23.

1. Connect each RF module to one of the interface boards by fitting each module's 22-pin connector into each interface board's female headers.
2. Install a whip antenna on each RF module's antenna connector.
3. Insert the male connector on each DB-9 cable into the female connector on each of the interface boards.
4. Attach each DB-9 cable's female connector to an available comm port on each computer.
5. Plug an AC power supply into each of the interface boards, then into a power outlet.
The green LED on each interface board illuminates, indicating the boards are receiving power.

Figure 11. Assembled Evaluation Kit

Configuring the Data Connections

Note: When using a telnet program other than HyperTerminal, the instructions below can still be used as a general guide.

1. Start up HyperTerminal on each computer by selecting *Start | Programs | Accessories | Communications | HyperTerminal*.
2. In each computer's **Connection Description** dialog box, choose a name and an icon for the test connection.
3. In each computer's **Connect To** dialog (see Figure 12), select the comm port to which the radio is connected in the *Connect using* field. (The other fields in the box dim.) Click *OK*.

**Figure 12. Connect To Dialog Box**

4. In the **COM Properties** dialog (see Figure 13), set the following:
 - *Bits per second* – 57600
 - *Data bits* – 8
 - *Parity* – None
 - *Stop bits* – 1
 - *Flow Control* – HardwareClick *OK*.



Figure 13. Com Properties Dialog Box

Radio-computer connections are now configured and ready for the data communications test.

Testing RF Data Communications

1. Select one of the HyperTerminal windows and type a message.
The text you type is immediately transferred over the air and appears only in the remote HyperTerminal window.
2. Select the other HyperTerminal window and type a message.
The text you type appears only in the remote HyperTerminal window.
3. Insert the evaluation kit CD into one computer's CD drive (called *D:* for our purposes) and initiate a file transfer over the air by doing the following:
 - a) Select *Send Text File* on the HyperTerminal *Transfer* menu (or right-click in the HyperTerminal window and select *Send Text File*) to display the **Send Text File** dialog box.
 - b) In the **Send Text File** box, select *Filename: D:\TRC.TXT* and *Protocol: Ymodem*.
 - c) Click *Send*.
4. Set up the other computer to receive the file transfer by doing the following:
 - a) Select *Receive Text File* from the *Transfer* menu (or right-click in the HyperTerminal window and select *Receive Text File*) to display the **Receive Text File** dialog box.
 - b) In the **Receive Text File** box, select a folder in which to place the received file and select *Protocol: Ymodem*.
 - c) Click *Receive*.

The file transfer begins. The text of the TRC.TXT file appears in the other computer's HyperTerminal window.

5. After the completion of this and subsequent file transfers, examine the transferred TRC.TXT text to see if any characters were lost or corrupted.
6. Transfer the file more times. Reverse the direction of the file transfer. Try data transfers with *Xmodem* selected on each computer.
7. Perform range testing by placing the two computers at increasing distances from each other.

Troubleshooting the Evaluation Test

1. Can't find the HyperTerminal program (or other telnet program) on your computer?
 - Search your hard drive for HyperTrm.exe (or the other telnet program you will use).
 - Go to www.hilgraeve.com for a free version of HyperTerminal. For TELIX, see www.mcc.com.au/web/telxdos.htm. For Kermit, see www.columbia.edu/kermit/.
2. Power LED *doesn't* illuminate when the Thunderbird powers on?
 - Remove and reconnect the AC adapter to the interface board.
3. Can't connect to the comm port, or data communications not working?
 - Try choosing another comm port by selecting *Properties* under the *File* menu.
 - If necessary, validate the operation of the two computers' comm ports by using a null modem cable (cross RX and TX).
4. Characters transmitted over the air getting scrambled or lost?
 - Verify that both host computers' comm ports are set to the Thunderbird's serial data transfer rate.

Appendix A. EZCom Thunderbird CF

EZCom Thunderbird data radio functionality is also available in a Compact Flash (CF) card to facilitate networking with handheld personal digital assistants (PDAs).

CF Interface

The Thunderbird CF's Compact Flash interface replaces the standard Thunderbird's 100 mil interface header and is designed to fit standard Compact Flash I/O ports.

RF Connector and Antennas

The MMCX antenna connector at the top of the Thunderbird CF card allows installation of an antenna approved by Grayhill (see Table 6 below). The MMCX connector provides a push-on, snap-action connection designed for a limited number of antenna insertions.

Table 6. Thunderbird CF Approved Antenna List

Antenna Type	Manufacturer	Manufacturer Part Number	Gain (dBd)	Grayhill Part Number	Min. Separation Distance
Whip	Maxrad	MEXE902	-0.5	WL-ANT-W9MA	1 cm

Note: To obtain approval of other antennas for use with the Thunderbird CF, contact Grayhill.

PDA Support

The Thunderbird CF's driver supports Windows CE 3.0 for the Pocket PC. The CF card permits data exchange between its host PDA and other PDAs equipped with Thunderbird CF cards, as well as desktops, laptops, and any other host devices connected to standard Thunderbird radios. Note that receiving host devices may be running any operating system.

The Thunderbird CF is set at the factory to run exclusively at a serial baud rate of 57600 bps. Its serial port assignment defaults to COM2 on the handheld device. The CF card is configurable only for ports COM1-COM4. Should changes to the serial baud rate or COM port assignment be needed, contact Grayhill. The Thunderbird CF has no low-power modes, but powers down when the COM port on the CE device closes. If software is needed to support integration of the Thunderbird CF into a handheld device, contact Grayhill.

Configuring a Terminal Connection

Note: The handheld device's CE driver must be installed before you insert the CF card into the device.

To set up a terminal connection for the EZCom Thunderbird CF:

1. Insert the Thunderbird CF into the PDA's CF slot.
2. On the PDA, select the *Start* menu and then *Settings*.
3. Click the *Connections* tab on the bottom of the *Settings* dialog box.
4. In the *Connections* dialog, select *Modem* and then *New Connection*.
5. In the *Enter a name for the connection* field, enter the connection name, e.g., *Thunderbird*.
6. Choose *Grayhill-TBird* on the *Select a modem* drop-down menu.
7. Select *57600* for the *Baud Rate*. (Or select the custom baud rate you have requested.)
8. Click the *Advanced...* button.

9. Verify that the following *Connection preferences* are set:
 - *Data Bits – 8*
 - *Parity – None*
 - *Stop Bits – 1*
 - *Flow Control – Hardware*
10. On the bottom of the *Advanced* dialog under *Terminal* settings, select the *Use terminal before connecting* and the *Enter dialing commands manually* checkboxes.
11. Click *OK*.
12. In the *Make New Connection* dialog, select *Next*.
13. In the dialog box that follows, deselect the *Cancel call if not connected within* and the *Wait for dial tone* checkboxes.
14. Click *Finish*.

The Thunderbird CF card is now configured for a terminal connection.

Opening a Terminal Connection

To open a terminal connection:

1. On the PDA, select the *Start* menu and then *Programs*.
2. Click *Connections*.
3. In the *Connections* dialog, select the configured connection, e.g., *Thunderbird*.
4. In the next dialog box, click *Connect*.

If the Thunderbird CF card was properly installed, the *Manual Dial Terminal* window appears. The *Manual Dial Terminal* window provides the same functionality that HyperTerminal or another telnet program provides to the standard Thunderbird unit.

Configuring the Thunderbird CF

Use the *Manual Dial Terminal* window to configure the Thunderbird CF. Consult the Configuration section on pages 14-16 for details on using AT or binary command mode to send configuration commands to the Thunderbird CF.

Testing Thunderbird CF Data Transfer

Once the configuration of the Thunderbird CF and its connection is complete, the user can verify its operation and test over-the-air data transfer by inputting a message in the data-mode *Manual Dial Terminal* window on the PDA. The text you enter should appear in the window connected to another Thunderbird or Thunderbird CF unit.

Appendix B. Specifications

Table 7. EZCom Thunderbird Radio Specifications

Specification	Thunderbird RF Module	Thunderbird CF Card
Performance		
Indoor/Urban Range	Up to 1800 feet	Up to 1800 feet
Outdoor LOS Range	Up to 8 miles with dipole antenna Up to 24 miles w/high-gain antenna	Up to 8 miles with dipole antenna
RF Data Rate	Up to 19200 bps	Up to 19200 bps
Transmit Power Output	160 mW (22 ± 2 dBm)	160 mW (22 ± 2 dBm)
Receiver Sensitivity	10 ⁻⁶ BER, -105 dBm	10 ⁻⁶ BER, -105 dBm
General		
Frequency	902-928 MHz, standard; 902-921 MHz, anti-pager model	902-928 MHz
Spread Spectrum	Frequency Hopping, Wideband FM Modulator	Frequency Hopping, Wideband FM Modulator
Channel Capacity	7 hop sequences share 20-27 frequencies.	7 hop sequences share 20-27 frequencies.
Network Topology	Peer-to-Peer, Point-to-Multipoint, Point-to-Point, Multi-Drop	Peer-to-Peer, Point-to-Multipoint, Point-to-Point, Multi-Drop
Subnetwork Capacity	Up to 31 Subnetworks	Up to 31 Subnetworks
Serial Data Interface	RS-232	CF Type 2 Extension
I/O Data Rate	Software selectable from 2400 bps - 57600 bps	Factory-set to 57600 bps; custom baud rate can be requested.
Power Requirements		
Supply Voltage	4.5-15 VDC ± 5% V regulated	3.3 VDC ± 5% V regulated
Transmit Current	160 mA	N/A
Receive Current	30 mA	N/A
Low-Power Current	≤ 10 mA	N/A
Physical Properties		
Dimensions	1.5" x 2.5" x 0.17" (Module only) Height depends on antenna connection method.	N/A
Weight	0.75 oz.	0.70 oz.
Connector	2 x 11, 0.1" pitch male Berg-type header with 0.025" square posts	Compact Flash
Operating Temperature	-40° to 70°	-40° to 70°
Storage Temperature	-40° to 85°	-40° to 85°
Antenna		
Integrated Wire (optional)	¼ wave monopole, 3" length, -3 dBd gain	N/A
Connector (optional)	Reverse Polarity SMA or MMCX	MMCX
Impedance	50 ohms unbalanced	50 ohms unbalanced
Certification		
FCC Part 15.247	NMAWM09STDB0001	NMAWM09STDB0002
Industry Canada (IC)	Pending	Pending

Appendix C. Agency Certification

The EZCom Thunderbird radio complies with Title 47, Part 15, Section 247 of the FCC Rules for radio communication devices.



FCC Approved (USA)

FCC IDs: **Standard Thunderbird** – **NMAWM09STDB0001**
 Thunderbird CF – **NMAWM09STDB0002**

Devices that embed EZCom Thunderbird modules can inherit Grayhill's FCC certification.



**Industry
Canada**

**Industrie
Canada**

Industry Canada Certified #: (Pending)

FCC Notices

Any antenna used with the radio must be greater than 20 cm. away from human exposure to ensure compliance with FCC RF exposure limitations.

This radio has been certified by the FCC for use with other products without any further certification (as per FCC section 2.1091). Changes or modifications not expressly approved by Grayhill could void the user's authority to operate the equipment as well as the warranty.

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications.

However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the transmitter and the receiver.
- Connect the transmitter into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or ask an experienced radio/TV technician for help.

OEM Labeling Requirements

It is an FCC requirement that the FCC ID of this radio device be clearly visible on the outside of any final product in which it is installed. OEM system integrators using this radio module must place the label shown in Figure 14 below on the outside of the final product. A high resolution PDF of this label is available at www.grayhill.com.



Figure 14. Required FCC Label for OEM Products

Appendix D. Mechanical Drawings

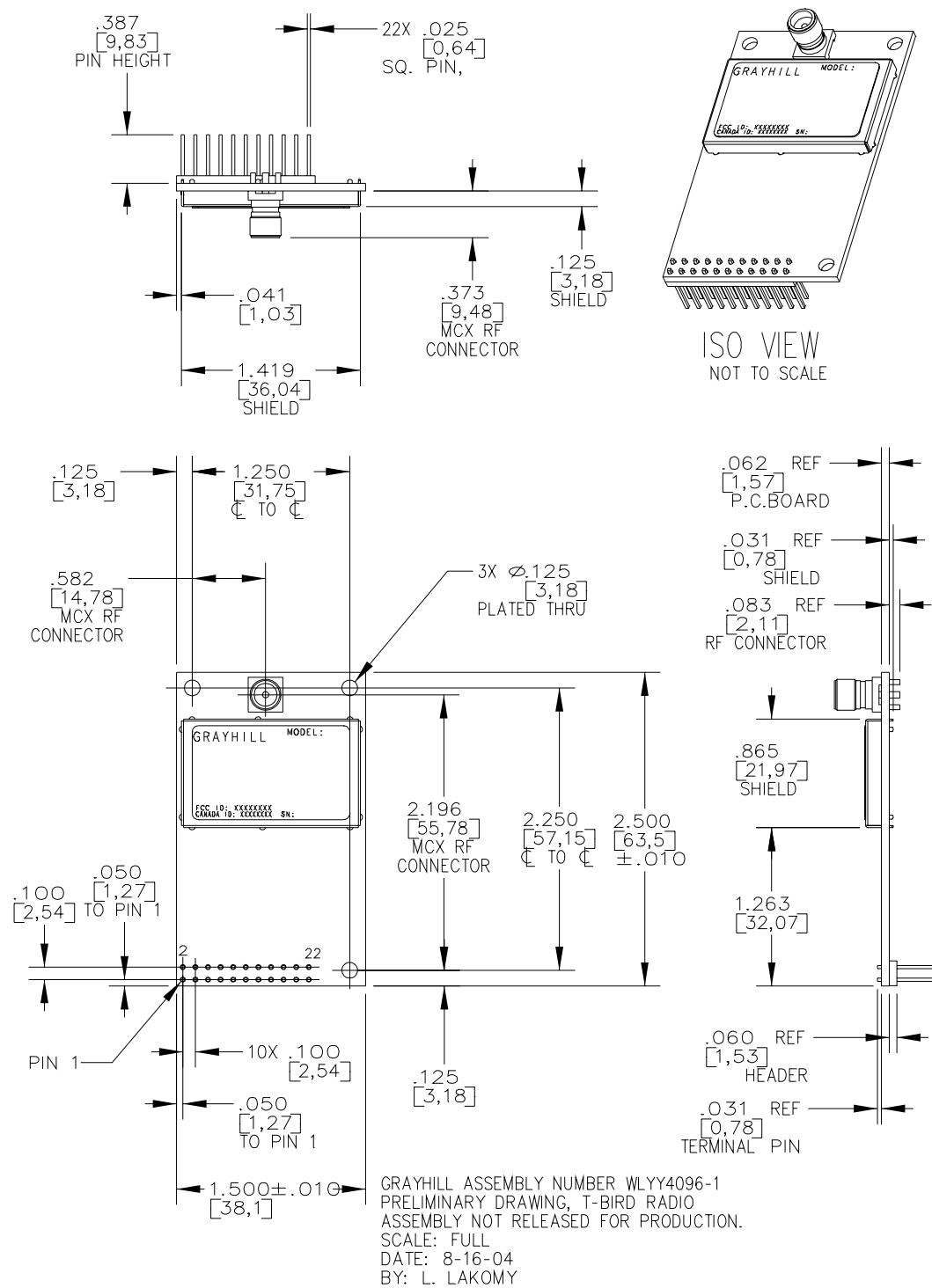


Figure 15. Thunderbird RF Module Mechanical Drawings

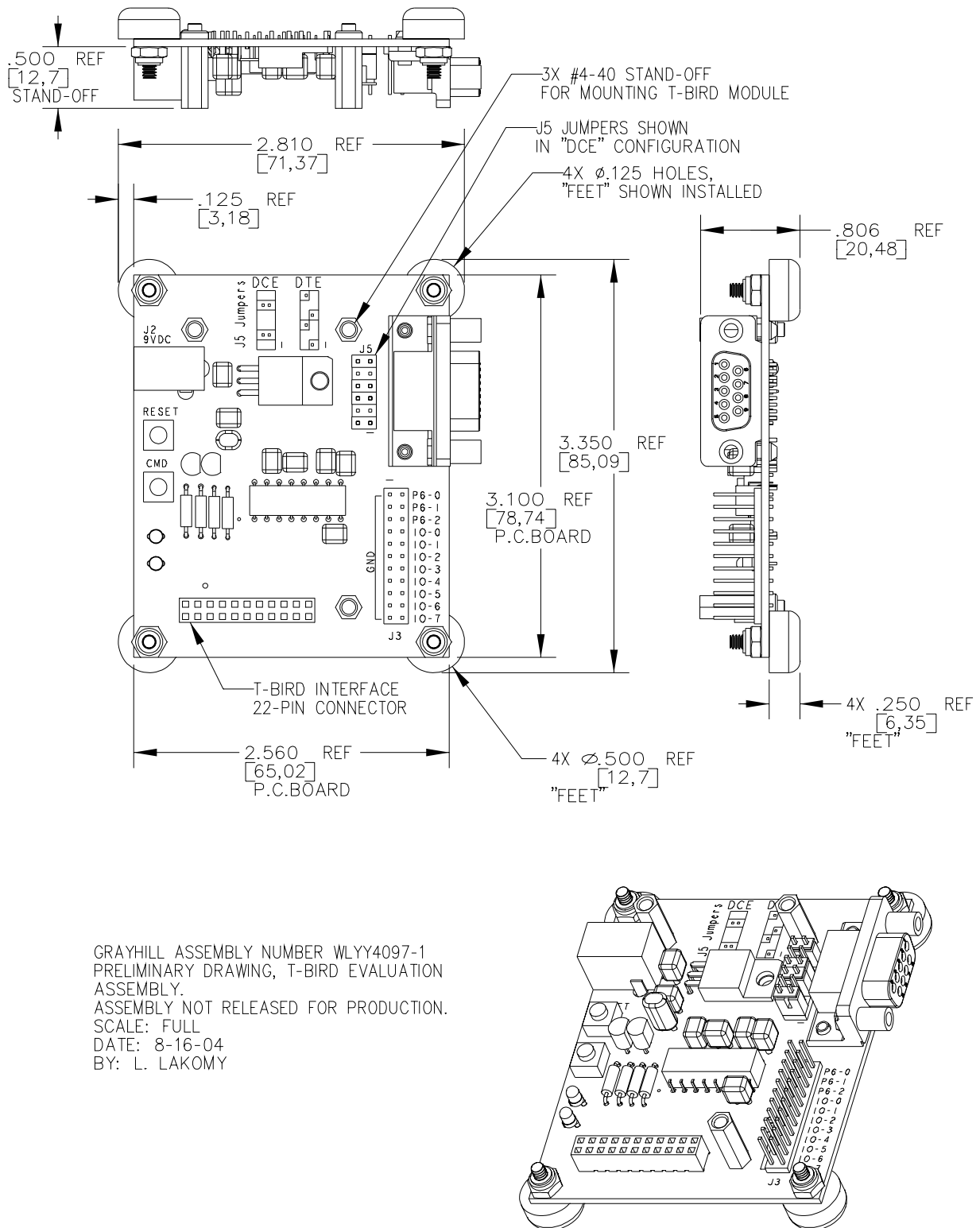


Figure 16. Standard Interface Board Mechanical Drawings

