Spread Spectrum Radio System User's Manual

3289 East Hemisphere Loop
Tucson, AZ 85706-5028 U.S.A.
520 746-9127 [tel]
520 889-5790 [fax]
http://www.mmsi.com

March 2001

Note: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area ia likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Changes or modifications not expressly approved by Modular Mining Systems could void the user's authority to operate this equipment.

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MODULAR™
Mining Systems

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Spread Spectrum Radio System

About This Manual

This manual contains a description of the spread spectrum radio (SSR) system designed by Modular Mining Systems (MMS). Its use is intended for MMS personnel and clients who may be responsible for the system's operation. Detailed installation and checkout procedures are provided in a separate installation guide. Detailed user interface information is also provided separately. The definitions of acronyms used in this manual are given in Appendix A. The radio module specifications are provided in Appendix B.

System Description

The MMS-designed SSR system is based on direct sequence spread spectrum (DSSS) technology, which provides a substantial improvement in signal-to-noise performance over conventional modulation techniques. Operating in the ISM 2.4- to 2.4835-GHz frequency band, the transmitted signal is spread within the frequency domain by using an 11-bit Barker sequence chipping code to obtain a transmission bandwidth of 22 MHz and data rates of 1 and 2 Mb/s. The received signal is strengthened by a processing gain of 10.4 dB, thereby increasing the signal's resistance to interference.

The improved radio performance and increased bandwidth, as compared with a 9600-b/s narrow-band system, reduces congestion in mines with large equipment fleets. Intensive graphic images, such as updates for the Color Graphics Console (CGC) screen, and large amounts of diagnostic data can be efficiently transmitted.

The SSR system comprises two major subsystems: the mobile equipment system and the repeater system. The primary hardware includes Hubs, radio modules, and mobile repeater stations. Rather than one or two conventional narrow-band repeaters, the SSR system uses several small repeaters, as shown in the following simplified diagram:

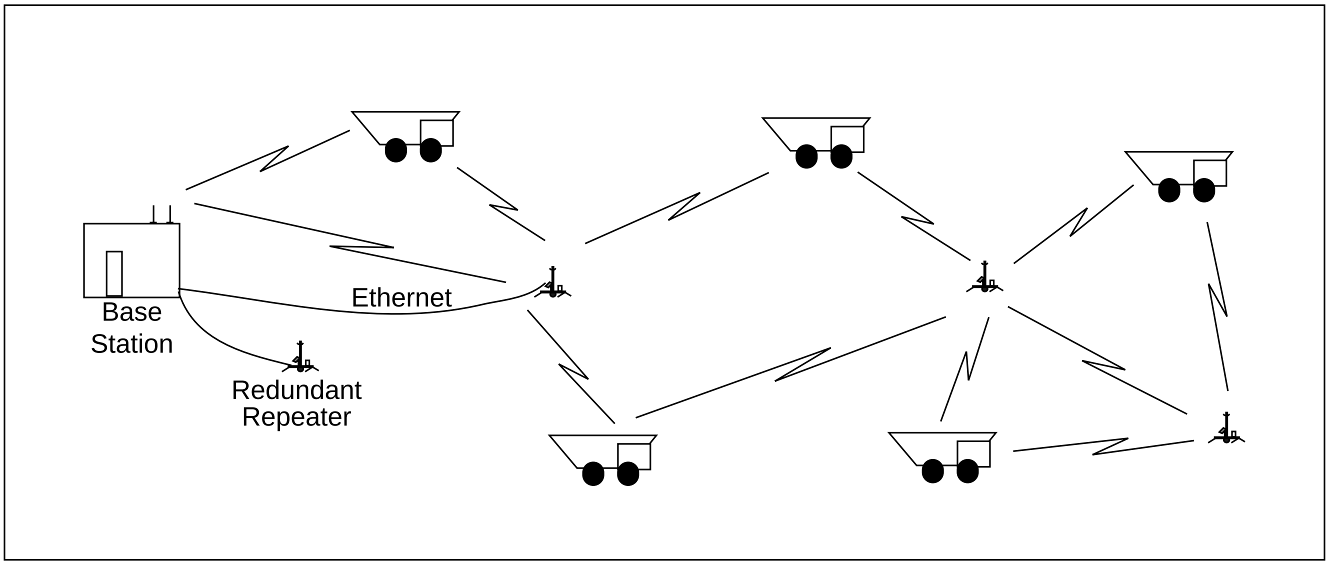


Figure 1 SSR System Configuration, Simplified

Each repeater extends the base station's area of coverage and communicates with the base station by way of other repeaters or directly by way of a fiber optic cable.

The base station uses redundant radios to ensure continued operation in case a radio fails. Likewise, primary routing paths between repeaters incorporate alternative routing paths in case a repeater fails. The mine can optionally add repeaters to provide redundancy to whatever extent is desired.

Initial installation is expedient in part because the ISM frequency band is license free, and there are no delays associated with license applications. Nor are there licensing fees. The system's inherent architecture makes adding repeaters to an installed system practically effortless, and mobile repeaters are easily deployed to cover new work areas as the mine's topography changes.

The mobile equipment system and the repeater system are described in the following sections.

Mobile Equipment System

Each truck, shovel, dozer, drill, or other mine equipment in the network requires the following major components:

- two 2.4-GHz radios
- a Hub

Although not integral to the SSR system, a CAN-based CGC and a GPS antenna are also essential units of *DISPATCH* hardware required on mine equipment.

Radio Module

Two radios are needed per mine vehicle or machine so that 360-degree coverage is obtained without having an antenna mounted above the equipment. On a haul truck, the radios are typically mounted on the front left and right deck or handrails.

Each radio module (Figure 2) consists of a molded plastic case containing the radio electronics and antenna on the same circuit board. An internal EMI shield protects the electronics.

Figure 2 Radio Module, External View

The overall dimensions of the unit are 22 by 16.5 by 34.3 centimeters (8.7 by 6.5 by 13.5 inches) and it weighs only 1.6 kilograms (3.5 pounds).

Each radio connects to the onboard Hub by way of a cable carrying power and data signals. The cable connects to a single 6-pin connector on the back of the radio module. The signals are identified in the following table:

Table 1 Radio Module External Connector

Pin	Signal	Description
A	DATA OUT +	LVDS driven from radio +
B	DATA OUT –	LVDS driven from radio –
C	DATA IN –	LVDS received from Hub –
D	DATA IN +	LVDS received from Hub +
E	PWR IN	24 V dc received from Hub*
F	PWR GND	Power ground connected to Hub

*Acceptable input range is 8 to 38 volts.

Shielded connections inside the radio encapsulate the LVDS lines so that radiation is minimized.

Hub The Hub controls the high-speed LVDS links to the radios by way of FPGAs inside the Hub and the radio modules. The Hub supplies protected power to the radios as well as protected power to all other *DISPATCH* hardware on the mine equipment, such as the CGC and external Generic Serial Processor (GSP). This eliminates the need for an external power supply and reduces the amount of input protection circuitry the non-Hub devices require.

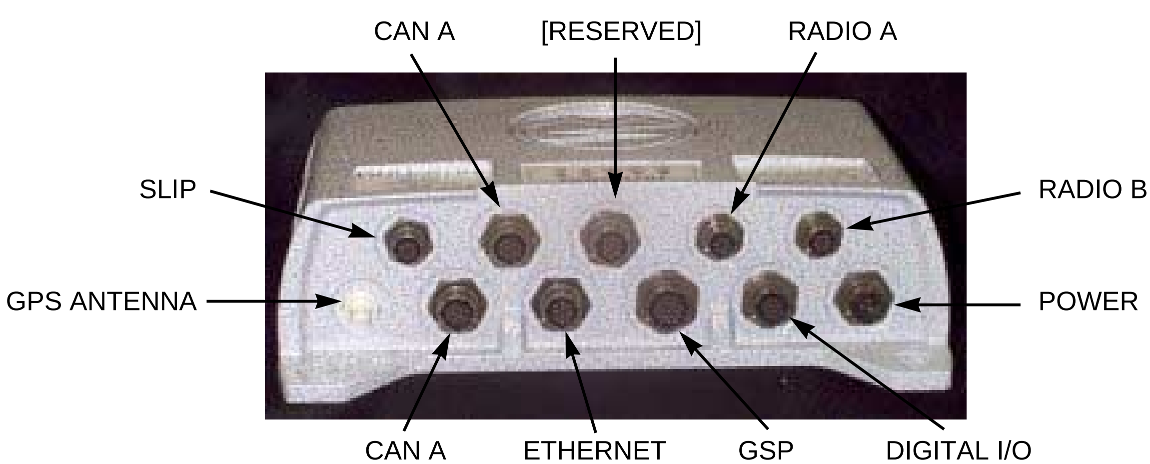


Figure 3 Mobile Equipment Hub

The Hub is installed inside the equipment's cab usually mounted to the wall or on an upright bracket attached to the floor or rear dash. It consists of a rugged case and base plate made of cast aluminum, which has been anodized and enameled to provide maximum protection from harsh environments. Its physical dimensions are approximately 35.4 by 26.2 by 9.4 centimeters (14 by 10.3 by 3.7 inches), and it weighs 4.3 kilograms (9.5 pounds).

Major Circuit Boards

The mobile equipment Hub houses the following major components:

- processor board

  This board has an Intel SA1100 processor, DRAM, ROM, flash memory, FPGA, Ethernet controller (10Base-T), CAN controller, and other primary components. All transceivers and isolation components are on the isolation interface board, thereby making the processor board relatively stable. This board is also small enough to allow full-size high-precision GPS receivers to be mounted next to it inside the Hub cover.

- power board

  This board distributes protected, isolated, and regulated power to the system components. The input power source is nominally 12 or 24 V dc. The optional 12-V Hub has an operational range of 10 to 19 volts; the optional 24-V Hub has an operational range of 18 to 35 volts.

- connector board

  This board provides the internal connections between the power and isolation interface boards, and all connections to external devices.

- isolation interface board

  This board provides electrical protection and isolation to signals coming from outside the Hub to the processor.

- location system (GPS) adapter board

  This board provides the interface between the processor board and the GPS receiver.

Over and Undervoltage Protection

The Hub power board has built-in protection from damage to the electronics during a constant steady-state over or undervoltage condition. When either condition occurs, the Hub shuts off by disconnecting itself from the power source, and remains off as long as the accessory switch is open. When the condition no longer exists, and the accessory switch closes, the Hub turns itself back on.

When the accessory switch opens during normal operation, a soft shutdown occurs, which permits the software to save data, complete pending radio communications, and shut down in an orderly fashion.

Connectors and Indicators

There are 11 external connectors on the front of the Hub. A decal affixed to the top of the Hub indicates the type of connection at each. One of these connectors is reserved for future use. The other 10 are briefly described in the following table:

Table 2 Equipment Hub Connectors

Connector	Description
GPS ANTENNA	type TNC coaxial cable connector for GPS antenna
SLIP	RS-232 service port for laptop during system startup, update, and troubleshooting
CAN A (2 connectors)	provides power output to and data communications with standard CAN devices including CGC and external GSP units; software configurable to support SAE standard devices
RADIO A	provides power and data link to radio A*
RADIO B	provides power and data link to radio B*
POWER	receives source power
DIGITAL I/O	provides two digital inputs for contact-closure-type devices such as foot switches
GSP	provides 15-V isolated power to and two communications ports (A and B) for serial devices. The A port can be RS-232 or RS-485; the B port is RS-232.
ETHERNET	standard 10Base-T network connection

* The radios are configured A or B during software installation.

The five status lights on top of the Hub convey important information to the user. The purpose of each is listed in the following table:

Table 3 Equipment Hub Status Indicators

Status Light	Indication
PWR	Hub is receiving power from source.
GPS	Link with GPS is operating.
RADIO A	Link with radio A is operating.
RADIO B	Link with radio B is operating.
COMM	Link with mine network is operating.

Mobile Equipment Options

The options available with each mobile equipment system include the following:

- The Hub power system can be either 12 or 24 V dc.
- External multi-protocol CAN-based GSPs can be added to support more than the two third-party serial devices that the internal GSP on the Hub processor board satisfies.
- Future enhancements include an external unit that can provide an analog/digital interface to third-party monitoring equipment such as oil pressure systems.

Repeater System

Several repeater units are required to provide coverage in the work area. The actual quantity is determined by the user and largely based on MMS-conducted site surveys. The desired level of redundancy also impacts the quantity used.

Each repeater unit consists of the following standard components:

- an environmental enclosure containing a Hub with a 1-W, DSSS, 2.4-GHz radio
- an omnidirectional antenna with a 12-, 18-, or 24-foot mast
- a lightning diverter

Optionally, the user may select

- a steel mounting base
- a wheel option

- a solar power system with backup batteries and surge protection
- an ac-to-dc power system with surge protection
- GPS capability

A repeater with optional solar panel and wheels is configured similarly to the following example:

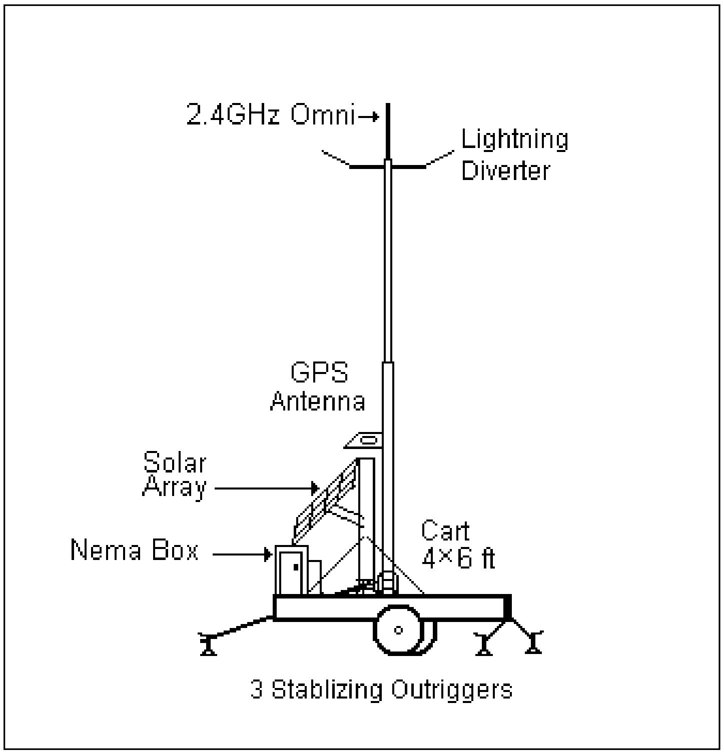


Figure 4 Example Mobile Repeater

Hub Like the Hub on the mobile equipment, the repeater Hub is made of cast aluminum that has been anodized and enameled. It is also the same size as the mobile equipment Hub but is mounted inside an environmental enclosure that is 50.8 by 40.6 by 20.3 centimeters (20 by 16 by 8 inches) and made of powder-coated 14-gage steel.

An access door is provided on the front of this NEMA enclosure, and holes for the antenna coaxial cables and power are provided in the rear. The enclosure also contains surge suppressors—on the incoming coaxial cables—and the ac-to-dc converter with power line protection if power is obtained from an ac source rather than the solar panel.

Closed Opened

Figure 5 Repeater Hub Environmental Enclosure

A repeater equipped with a solar panel also has backup battery power. The batteries are installed in a large environmental enclosure. Power line protection from the solar panel to the Hub in its enclosure is provided by surge suppressors inside a third enclosure attached to the enclosure containing the batteries.

Major Circuit Boards

The repeater Hub houses the following major components:

- radio board

  The electronics on this board are identical to those on the mobile system's radio module. However, this board does not have an integrated antenna.

- processor board

  This is the identical board used in the mobile equipment system.

- connector board

  This board provides the connections between the internal components and external devices.

- location system (GPS) adapter board

  This board is present only if the repeater is equipped with the GPS option. It provides the interface between the processor board and the GPS receiver.

Connectors and Indicators

There are six external connectors on the front of the Hub. A decal affixed to the top of the Hub indicates the type of connection at each.

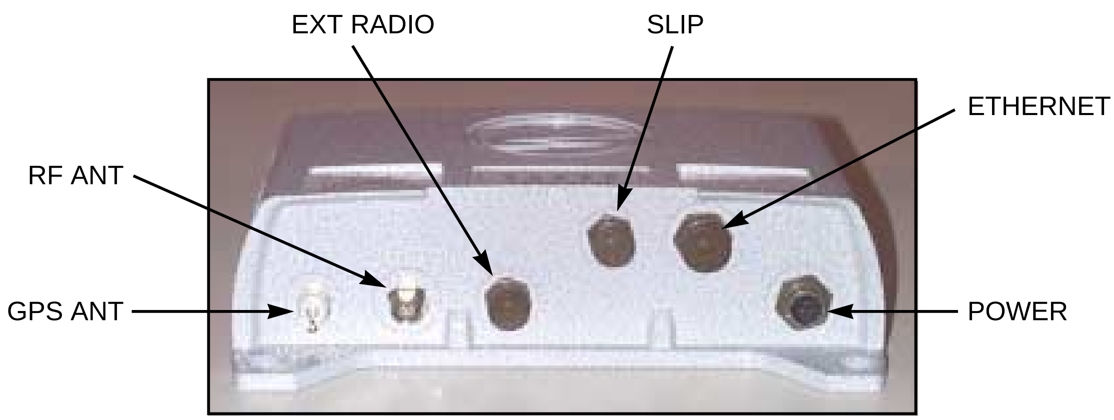


Figure 6 Repeater Hub

The following table provides a brief description of each of the connectors:

Table 4 Repeater Hub Connectors

Connector	Description
GPS ANT	type TNC coaxial cable connector for GPS antenna
RF ANT	type N coaxial cable connector for 2.4-GHz radio antenna
EXT RADIO	provides connection to an external SSR if an internal radio is not used. This connector is normally not used.
SLIP	RS-232 service port for laptop connection during system startup, update, and troubleshooting

Table 4 Repeater Hub Connectors *(Continued)*

Connector	Description
ETHERNET	fiber optic 10Base-T Ethernet connection from/to base station
POWER	receives 24-V dc operating power either from solar panels or ac source through ac-to-dc converter

The purpose of each status light on top of the Hub is listed in the following table:

Table 5 Repeater Hub Status Indicators

Status Light	Indication
PWR	Hub is receiving power from source.
GPS	GPS is operating and LED is blinking the number of satellites currently being tracked.
LINK	The 10Base-T Ethernet link is operating.
LAN	The 10Base-T Ethernet LAN is operating.
COMM	Link with data radio communications network in mine is operating.

Repeater System Options

The options available with each repeater are as follows:

- A steel base with three stabilizing outriggers and a support for the antenna mast provides a means for mounting the electronics, antenna mast, and solar-power system if applicable. Each outrigger has a jack stand that can be manually adjusted to suit the level of the terrain.
- A steel frame with two 15-inch wheels and a standard trailer hitch converts the fixed configuration to a mobile configuration. This frame mounts below the fixed base to which the electronics, mast, and solar system are attached. In this configuration, the repeater can be easily towed and relocated by pickup or automobile.

- Solar power can be provided by way of panels, which are available in 150-, 200-, and 300-W power ratings. The required power rating is determined by the repeater's geographic location.
- Power can be provided by way of an ac-to-dc converter. When this option is selected, the converter and surge protection are physically located in the NEMA enclosure with the Hub. Both 50 and 60 Hz are supported as well as 100- to 120-V ac and 200- to 240-V ac ranges, which are jumper selectable. The converter requires 1.3 amps at 100 V ac.
- GPS capability to enable *DISPATCH* to track a relocated repeater.

Base Station

The repeater Hub is also used as the base station. In this case, the environmental enclosure is not used because the base station is normally inside a building, and the antennas are mounted outside. The power source is hard wired to the Hub through an ac-to-dc converter. A fiber optic Ethernet connection is used to isolate the base station computers from the base station Hub, radio, and antennas.

System Installation and Checkout

Installation of the hardware on mine equipment consists of installing mounting brackets in predesignated locations, and then mounting the radios and Hubs to the brackets. Cables are then routed and the connections are made and checked. Neither the Hub nor radios require being opened.

The repeater base and trailer require some assembly; then the antenna mast and brackets are installed. After all hardware is mounted, cable connections are made and checked.

The batteries in the 24-V solar-powered repeater system are charged by the panels until they reach 28.2 to 29.0 V, and must be charged to 25.4 to 26.6 V dc before the load may be applied. When the batteries discharge to 22.4 to 23.6 V, the load disconnects. On a fully charged set of batteries, the repeater can continue operation without sunlight for several days.

As each mobile equipment system and repeater system is installed, operating and application software is downloaded from a laptop through the Hub SLIP port. Then the RF links to the base station or another communications node are checked to verify throughput is acceptable.

Details on installation and checkout procedures are provided in a separate manual.

User Interface

The status of any and all repeaters in the system configuration can be monitored from the *DISPATCH* central computer.

A

Acronyms

The acronyms listed in the following table are used in this manual:

Table A.1 Acronyms Used in This Manual

Acronym	Definition
CAN	Controller Area Network
CGC	Color Graphics Console
DRAM	dynamic random access memory
DSSS	direct sequence spread spectrum
EMI	electromagnetic interference
FPGA	field-programmable gate array
GPS	Global Positioning System
GSP	Generic Serial Processor
ID	identification
ISM	Industrial, Scientific, and Medical
LVDS	low-voltage differential signal
MMS	Modular Mining Systems
NEMA	National Electrical Manufacturers Association
PCB	printed circuit board
ROM	read-only memory
SAE	Society of Automotive Engineers
SSR	spread spectrum radio
VSMS	Vital Signs Monitoring System

B

Radio Module Specifications

General Description

The 2.4-GHz DSSS spread spectrum radio is based on the Intersil PRISM I chipset (Intersil was formally Harris). The Intersil PRISM I information can be found at the following Web site:

www.intersil.com/prism/ (Select PRISM I * 2 Mb/s product link.)

Because MMS used the Intersil design for the radio, most of the specifications in this appendix are directly from Intersil documentation. However, two major areas differ and are reflected in these specifications

- MMS replaced the Intersil PA/switch chip with a new amplifier design and a separate antenna switch.
- The radio has no MAC (Media Access Controller) chip and, instead, is controlled through a custom link with the Hub (MMS computer).

MMS replaced the Intersil PA/switch chip to achieve 1 watt of output power (the maximum permitted by the FCC) instead of just 18 dBm. The additional power provides an increased range so that the radios can be used in an open-pit mine with line-of-sight being approximately 8 miles node to node. As required by the FCC for radios with over 20 dBm (100 mW) of power, the power setting is adjustable.

The controlling link is a 22-Mb/s LVDS digital link between the radio and the Hub. The radio must be connected to the Hub, and the radio board has a built-in antenna. As an option, MMS would like to cut the antenna off the board and use an omnidirectional antenna.

MMS plans to sell approximately 2100 of the PRISM I radio design before exploring the PRISM II design from Intersil.

Functional Specifications

The radio operates in the license-free 2.400- to 2.4835-GHz ISM (Industrial, Scientific, Medical) frequency band and is capable of two data rates

- DBPSK Differential Binary Phase Shift Keying 1 Mb/s
- DQPSK Differential Quadrature Phase Shift Keying 2 Mb/s

Tables B.1 through B.4 list the radio module specifications:

Table B.1 Radio Supply Power

Specification	Typical	Unit
Power Voltage Input Range (acceptable)	9–38	volts DC
Radio Module Input Voltage from Hub (controlled via Hub)	24	volts DC
Radio Module Power (receive mode only)	1.43	watts
Radio Module Power (full 98% TX duty cycle)	4.7	watts
Radio Module Power (typical 20% duty cycle)[a]	2.1	watts

a. Power = 1.43 + (3.4 ∗ duty cycle) watts

Table B.2 Radio RF Performance and Operation

Specification	Typical	Unit
Output Power Range	2–30	dBm
Output Power Resolution (8-bit DAC)	256	steps
TX Distance Range (based on 2–30 dBm)	0.3–8.0	miles
B.E.R.	1×10^{-6}	bits
Processing Gain (per 11-bit chipping code)	10.4	dB
Image Rejection	80	dB
Adjacent Channel Rejection	>35	dB
Receiver Noise Figure	7	dB
Channel Noise (N=kTB where B=2 MHz despread)	–110.97	dBm
Signal-to-Noise Ratio (SNR-$E_b/N_o * R/B_T$)	11.1	dBm
Receiver Sensitivity (= noise floor + SNR)	–92.87	dBm

Table B.2 Radio RF Performance and Operation *(Continued)*

Specification	Typical	Unit
Dynamic Range (TX power – receiver sensitivity)	122.87	dB
Transmit Spectral Mask (at 1st side-lobe)	–30	dBr
TX & RX Data Rates Using DBPSK	1	Mb/s
TX & RX Data Rates Using DQPSK[a]	2	Mb/s
Chipping Code (currently is a 802.11 compatible Barker)	11	chips
Key-up (synchronization – must be at DBPSK data rate)	128	bits (& µs)
Maximum Packet Size[b]	1024	bytes
Output Power Resolution (8-bit DAC)	128	steps
Channels	12	—
Channel Separation[c]	5	MHz
IF Frequency	280	MHz
LO VCO Frequency (= 2 × IF)	560	MHz

a. Default operation will be DQPSK.
b. The 128-bit synchronization header is not counted.
c. Channels start at 2412 MHz and increment in 5-MHz steps (802.11 style).

Table B.3 Radio Physical Specifications

Specification	Typical	Unit
Overall Module Size (L × W × H)	8.7 × 6.5 × 13.5	inches
Overall Weight	3.5	pounds
Backplate (structural foam using Valox FV649)	0.75	pounds
Cover (Valox 357)	1.53	pounds
PCB Dimensions (W × H)	6.5 X 9.6	inches
PCB Construction – 0.093" FR4	6 layer	—
Operational Temperature Range	–30 to +60	Celsius

Table B.4 Radio Antenna Performance

Specification	Typical	Unit
Antenna Type = Integrated Quad Vivaldi on FR4	—	—
AZ 3-dB Beam width	190	degrees
EL 3-dB Beam width	28	degrees
Gain	6	dB
Feed Structure Losses (0.3 dB per inch on 0.030" FR4)	1.5	dB

FCC Items

To pass FCC regulations, the radio must pass a stringent set of standards set forth in the following document:

FCC Title 47 part 15, in particular the following sections:

- section 203 – antenna requirement
- section 209 – radiated emissions outside of band (general)
- section 247 – operation within band (all aspects)
- section 249 – operation within band (field strength)

The following table presents several key test parameters that have been verified:

Table B.5 Verified FCC Test Parameters

Parameter	Typical	Unit
Spectral Sideband Suppression	30	dBr
Max Antenna Gain	6	dB
Max Transmit Power	30	dBm
Outside of Frequency Band Emissions Attenuation	≥50	dB

Channel Definitions

The channel selection is identical to the 802.11 standard, which is as follows:

Table B.6 Channel Definitions

Channel[a]	Onboard RF VCO[b]	Transmit Frequency
1	2132 MHz	2412 MHz
2	2137 MHz	2417 MHz
3	2142 MHz	2422 MHz
4	2147 MHz	2427 MHz
5	2152 MHz	2432 MHz
6	2157 MHz	2437 MHz
7	2162 MHz	2442 MHz
8	2167 MHz	2447 MHz
9	2172 MHz	2452 MHz
10	2177 MHz	2457 MHz
11	2182 MHz	2462 MHz
Japan	2204 MHz	2484 MHz

a. Each channel has a 17-MHz bandwidth.
b. The onboard RF VCO output is always the Transmit Freq – IF Freq (280 MHz).

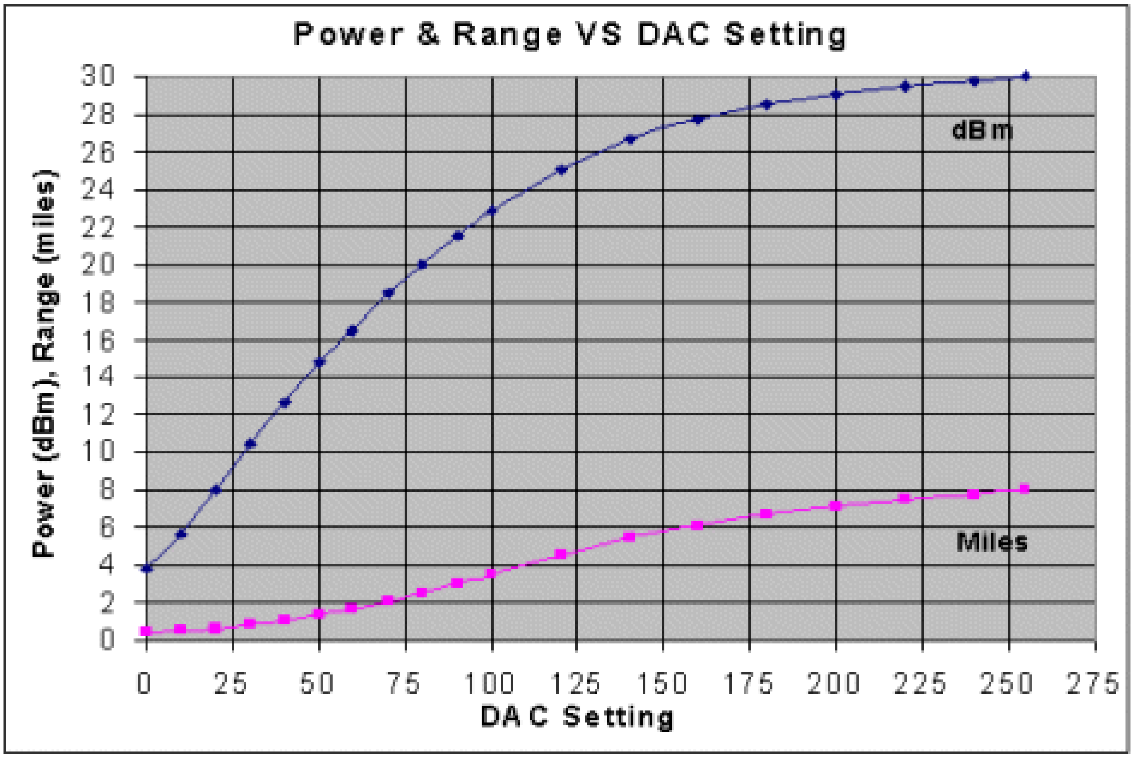
See the “DSSS Channels and Regulations” section for detail.

Power and Distance

The following table and diagram show data pertaining to the power output versus gain control input:

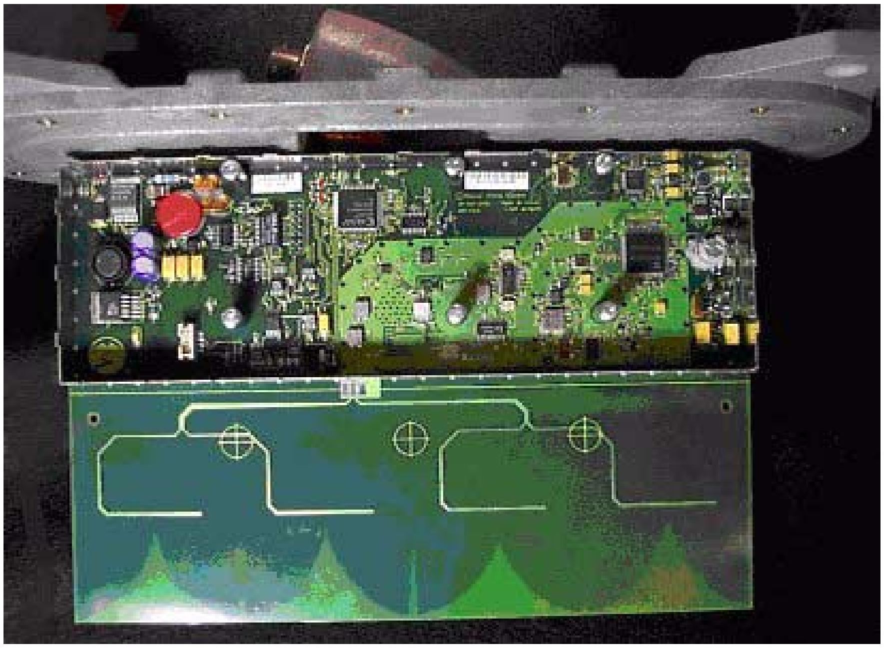
Table B.7 Power vs. Range

Setting DAC	Power dBm	Power mW	Range Miles	Range km
0	3.85	2.43	0.39	0.63
10	5.70	3.72	0.49	0.78
20	8.01	6.32	0.64	1.02
30	10.49	11.19	0.85	1.36
40	12.67	18.50	1.09	1.75
50	14.81	30.29	1.39	2.24
60	16.47	44.38	1.69	2.71
70	18.45	70.01	2.12	3.41
80	19.99	99.81	2.53	4.07
90	21.53	142.12	3.02	4.85
100	22.84	192.16	3.51	5.64
120	25.06	320.63	4.53	7.29
140	26.68	465.94	5.46	8.79
160	27.71	590.43	6.15	9.89
180	28.48	705.23	6.72	10.81
200	29.04	801.99	7.16	11.53
220	29.47	884.78	7.52	12.11
240	29.78	950.97	7.80	12.55
255	30.00	1000.00	8.00	12.87


Power & Range VS DAC Setting
Power (dBm), Range (miles)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
dBm
Miles
0 25 50 75 100 125 150 175 200 225 250 275
DAC Setting

Photographs

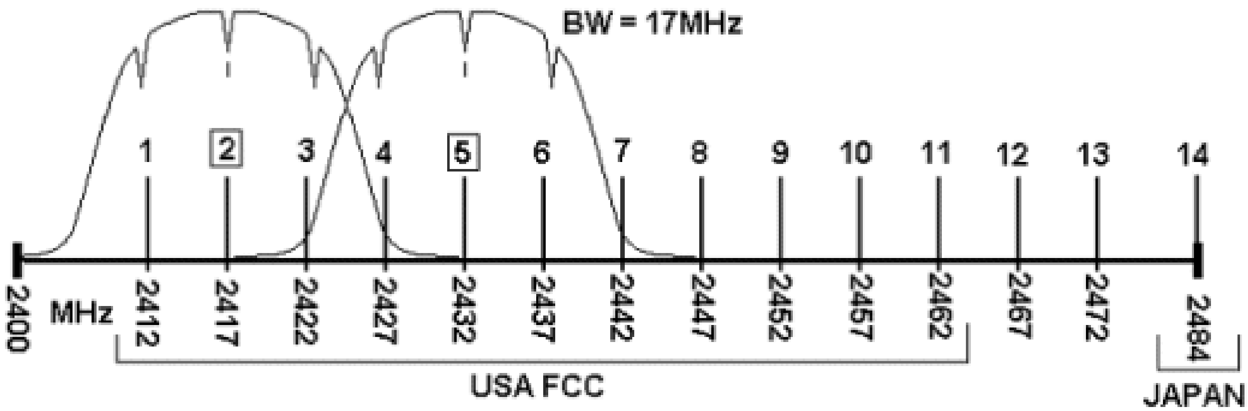
As shown in the following photograph, the radio is basically a PRISM I chipset with a 1-watt amplifier and a power supply. The FPGA controls the radio by way of the digital serial link from the Hub computer.



The following photograph shows the radio with its plastic cover on.

DSSS Channels and Regulations

The following diagram and table show frequency band allocation:



USA:	ISM Band	2400-2483.5 MHz (Same for Europe – ETSI)
	Power	1 watt maximum (30 dBm)
	Directivity	6 dB antenna gain maximum
JAPAN:	ISM Band	2471 – 2497 MHz
	Power	10 mW / MHz

Note: The microwave oven operates at 2.43 GHz. Also, the two other ISM bands in the U.S.A. are 902–928 MHz and 5725–5850 MHz.

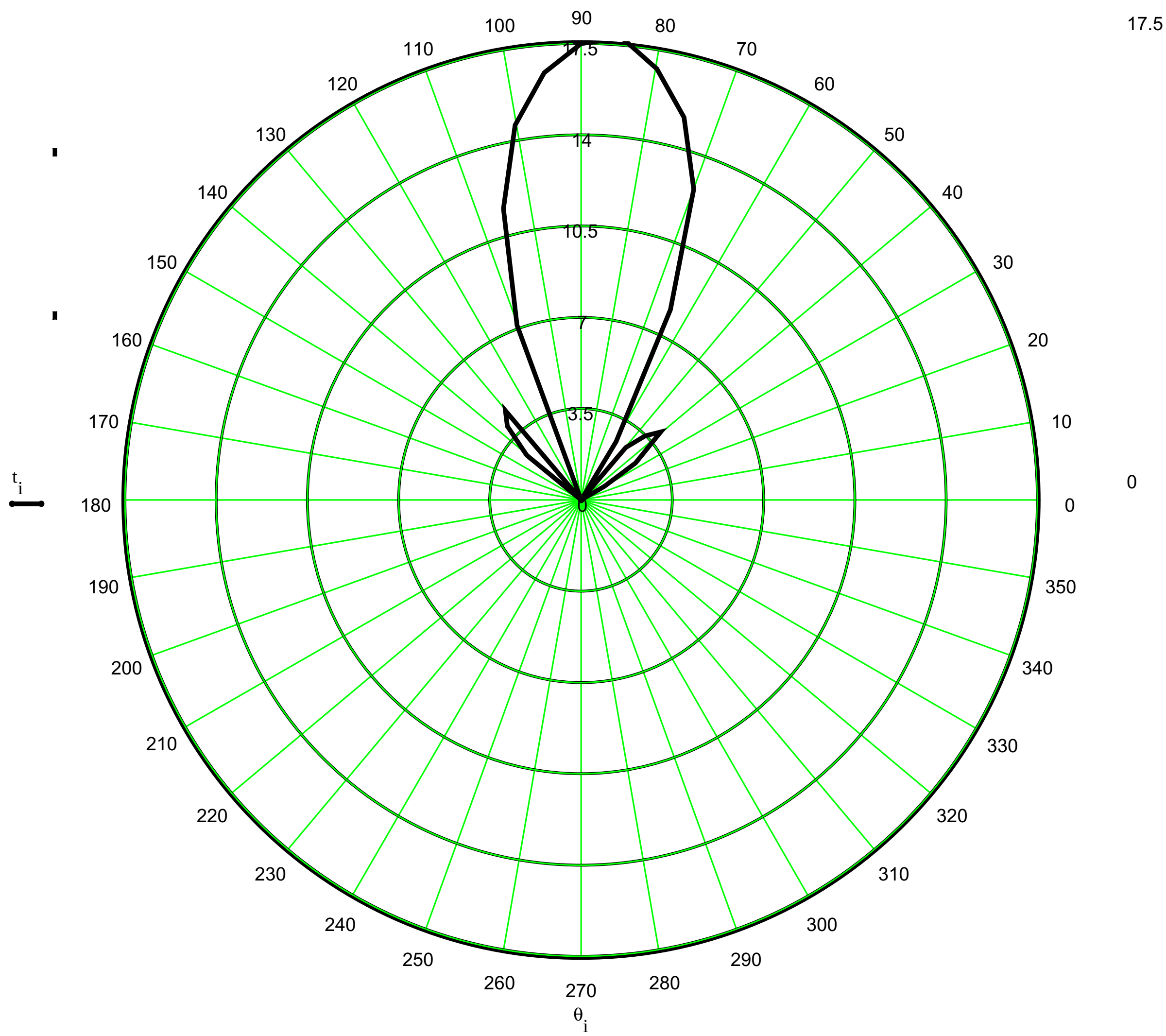
Table B.8 Frequency Band Allocation

Channel ID	Frequency (MHz)	Regulatory Domains					
		X'10' FCC	X'20' IC	X'30' ETSI	X'31' Spain	X'32' France	X'40' MKK
1	2412	X	X	X	-	-	-
2	2417	X	X	X	-	-	-
3	2422	X	X	X	-	-	-
4	2427	X	X	X	-	-	-
5	2432	X	X	X	-	-	-
6	2437	X	X	X	-	-	-

Table B.8 Frequency Band Allocation *(Continued)*

Channel ID	Frequency (MHz)	Regulatory Domains					
		X'10' FCC	X'20' IC	X'30' ETSI	X'31' Spain	X'32' France	X'40' MKK
7	2442	X	X	X	-	-	-
8	2447	X	X	X	-	-	-
9	2452	X	X	X	-	-	-
10	2457	X	X	X	X	X	-
11	2562	X	X	X	X	X	-
12	2467	-	-	X	-	X	-
13	2472	-	-	X	-	X	-
14	2484	-	-	-	-	-	X

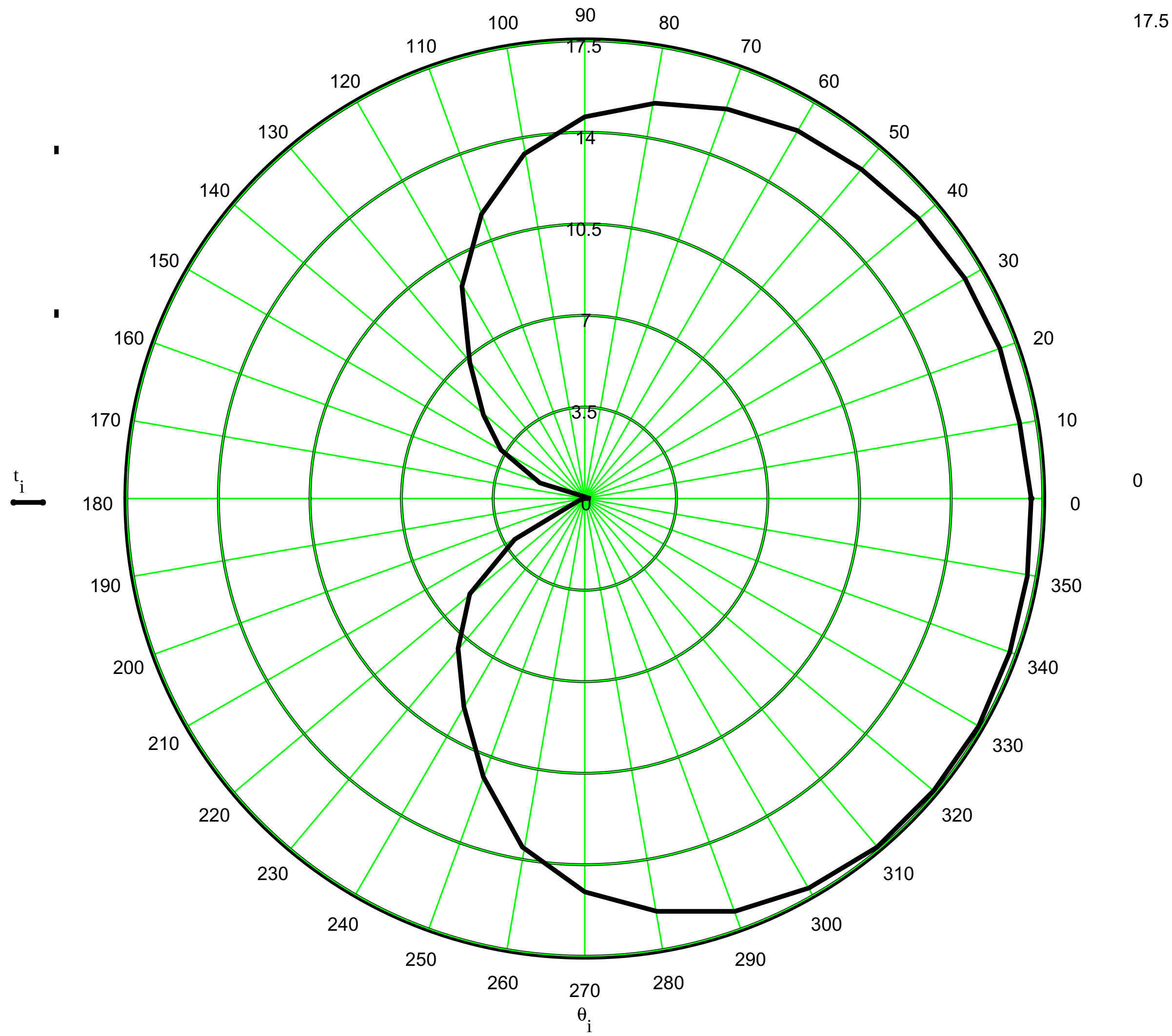
EL Antenna Pattern



Antenna Parameters:

Plot File	polar_data_74E_5ea.MCD
Title	Quad Element Vivaldi
Radius	1.45"
Separation	2.400" per element (1/2 λ)
Element Gap	0.100"
Element	2.300"

AZ Antenna Pattern



Antenna Parameters:

Plot File	polar_data_74H.MCD
Title	Quad Element Vivaldi
Radius	1.45"
Separation	2.400" per element (1/2 λ)
Element Gap	0.100"
Element	2.300"

Revision History

Revision	Date	Comments
—	March 2001	First issue