INSTRUCTION MANUAL

RF407-Series Spread Spectrum Radios

3/16

Limited Warranty

Assistance

Products may not be returned without prior authorization. The following contact information is for US and international customers residing in countries served by Campbell Scientific, Inc. directly. Affiliate companies handle repairs for customers within their territories. Please visit *www.campbellsci.com* to determine which Campbell Scientific company serves your country.

To obtain a Returned Materials Authorization (RMA), contact CAMPBELL SCIENTIFIC, INC., phone (435) 227-9000. After an application engineer determines the nature of the problem, an RMA number will be issued. Please write this number clearly on the outside of the shipping container. Campbell Scientific's shipping address is:

CAMPBELL SCIENTIFIC, INC.
RMA#_____
815 West 1800 North
Logan, Utah 84321-1784

For all returns, the customer must fill out a "Statement of Product Cleanliness and Decontamination" form and comply with the requirements specified in it. The form is available from our website at *www.campbellsci.com/repair*. A completed form must be either emailed to *repair@campbellsci.com* or faxed to (435) 227-9106. Campbell Scientific is unable to process any returns until we receive this form. If the form is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer's expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC**. FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.com or by telephoning (435) 227-9000 (USA). You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations, such as those of the FAA in the USA.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical
- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 20 feet, or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather
- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance
- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

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CRBasic Example

RF407-Series Spread Spectrum Radio

1. Introduction

This manual discusses the configuration, operation, and maintenance of the Campbell Scientific RF407 series frequency-hopping spread-spectrum (FHSS) radios. This manual will refer to these devices collectively as either "radio," "RF407 series," or "RF407-series radio" unless otherwise noted.

The RF407-series radios are designed for license-free use in several countries:

- The RF407 has a 902 to 928 MHz operating-frequency range appropriate for use in the United States and Canada. (FCC / IC compliant)

- The RF412 has a 915 to 928 MHz operating-frequency range appropriate for use in Australia and New Zealand. (ACMA compliant)

- The RF422 has an 863 to 873 MHz operating-frequency range appropriate for use in the European Union (ETSI compliant)

2. Precautions

- 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. See Appendix A, *Part 15 FCC Compliance Warning (p. A-1)*, for more information.

- Ensure maximum protection against surges. Use coaxial (antenna) surge protection. Keep RS-232, CS I/O, and USB connections short or use protective isolation and surge protection when appropriate.

- Where an AC adapter is used, Campbell Scientific recommends pn 15966. Any other AC adapter used must have a DC output not exceeding 16 volts measured without a load to avoid damage to the radio. Over-voltage damage is not covered by factory warranty.

- Line-of-sight obstructions and RF interference will affect the transmission distance. See Appendix B, *Distance vs. Antenna Gain, Terrain, and Other Factors (p. B-1)*, for a discussion of antenna gain and other factors affecting distance.

3. Initial Inspection

- The RF407-series radios ship with an SC12 serial cable, a USB A to USB B Cable, 2 grommets, and 2 screws.

- Upon receipt of the RF407-series radio, inspect the packaging and contents for damage. File damage claims with the shipping company. Contact Campbell Scientific to facilitate repair or replacement.

- Immediately check package contents against shipping documentation. Thoroughly check all packaging material for product that may be trapped.

Contact Campbell Scientific immediately about any discrepancies. Model numbers are found on each product. On cables, the model number is often found at the connection end of the cable.

4.   QuickStart

Out of the box, the radio is configured for use with a datalogger connecting via CS I/O and using CS I/O SDC address 7.

4.1   Remote Station Radio

Using the supplied SC12 serial cable, connect the radio's **CS I/O** port to the **CS I/O** port of the datalogger.

4.2   Base Station Radio

You will need to connect the radio to your PC and use *Device Configuration Utility* (*DevConfig*) to change the radio's **Active Interface** to **USB**. To learn more about connecting with *DevConfig* see Section 8.1, *DevConfig (p. 9)*. Using *DevConfig*, set the radio's **Active Interface** setting to **USB**. The **Power Mode** setting should match that of the device you are connecting to. **Apply** the change(s), close *DevConfig*, and leave the radio connected to the PC via USB.

4.3   *LoggerNet* Setup

The next step is to run *LoggerNet* and configure it to connect to the datalogger via the radio link.

1.   From the EZ View of the *LoggerNet Setup* screen, press **Add**, select your datalogger type, enter a name for your datalogger, and press **Next**.

2.   Under **Connection Type**, select **Direct Connect**. Press **Next**.

3.   Under **COM Port Selection**, select the port designated as **RF407-Series**.

4.   Under **Datalogger Settings**, select a **Baud Rate** of **115200**, enter the **PakBus Address** of the datalogger, and set **Extra Response Time** to **1 second**. Press **Next**.

5.   Under **Datalogger Settings – Security**, enter any security codes that have been previously configured in the datalogger. Press **Next**.

6.   Review the **Communication Setup Summary** and verify that all settings are correct. Press **Next**.

7.   On the **Communication Test** screen, select **Yes** and press **Next** to verify communication with the datalogger. If unable to communicate, press the **Previous** button and review your settings. Once you have successfully communicated with your datalogger, press the **Finish** button.

8.   You are now ready to connect to your datalogger using the *LoggerNet Connect* screen.

5. Overview

Spread-spectrum radios spread the normally narrowband information signal over a relatively wide band of frequencies. This allows the communications to be more immune to noise and interference from RF sources such as pagers, cellular phones, and multipath. The RF407-series radios reduce susceptibility to RF interference from other spread-spectrum devices by providing user-selectable frequency-hopping patterns.

The RF407-series radios can provide up to three miles transmission range with an inexpensive whip antenna. The radios can provide greater than 16 mile transmission range when using a higher gain directional antenna at ideal conditions. Compatible antennas are described in Section 7.7.1, *Compatible Antennas (p. 8)*.

6. Specifications

General

> Dimensions: 11.1 x 6.9 x 2.7 cm (4.4 x 2.7 x 1.1 in)
> Weight: 136 g (4.8 oz)
> Two-piece aluminum case, black anodized

Radio

> Frequency-Hopping Spread-Spectrum (FHSS) Radio Transceiver
> Frequency:
>> RF407: 902 to 928 MHz
>> RF412: 915 to 928 MHz
>> RF422: 863 to 873 MHz
> Transmit Power Output (RF407, RF412): 5 to 250 mW, software selectable
> Transmit Power Output (RF422): 2 to 25 mW, software selectable
> Receiver Sensitivity (RF407, RF412): –101 dBm
> Receiver Sensitivity (RF422): –106 dBm
> Channel Capacity: 7 hop sequences share 25 frequencies
> (RF422 implements Listen Before Talk (LBT) and Automatic Frequency Agility (AFA))
> RF Data Rate (RF407, RF412): 200 kb/s
> RF Data Rate (RF422): 10 kb/s
> RF Connector: Reverse Polarity SMA (RPSMA) jack, 50 Ohm unbalanced

Power

> Powered over CS I/O or 2.5 mm DC power jack
> Input Voltage: 9 to 16 Vdc
> Average Current Drain @ 12V
>> Transmit: < 80 mA (250 mW TX Power)
>> Receive: 15 mA
>> Standby: < 0.5 mA (depending on power saving mode)

Connections

> USB:
>> USB Type B jack
>> Can draw enough power for normal operation from standard USB host
> RS-232:
>> DB9, Female
>> 1200, 4800, 9600, 19200, 38400, 57600, and 115200 baud rate supported

CS I/O:
> DB9, Male
> Provides power connection from datalogger for normal operation
> Supports SDC (7|8|10|11) and Modem Enable (ME) Master communication modes
> Does not support ME Peripheral mode

Diagnostics
> LEDs: TX/PWR, RX
> Received Signal Strength Indicator (RSSI) for Last Packet

Operating Temperature
> Standard: –25 to 50 °C
> Extended: –40 to 85 °C

Configuration
> *Device Configuration Utility* via USB

Compliance
> United States FCC Part 15.247: MCQ-XB900HP
> Industry Canada (IC): 1846A-XB900HP

7. Product Description

7.1 Mounting

The mounting holes are designed to align with a one-inch-on-center hole pattern and provide for ridged mounting of the radio in either a vertical or horizontal orientation. #6-32 x 0.375-inch stainless steel Phillips head screws (pn 505) and nylon grommets (pn 6044) are supplied for securing the radio to the backplate of a Campbell Scientific enclosure.

7.2 Power

There are three ways the radio may be powered for operation. The radio may be powered via CS I/O, USB, or the 2.5 mm DC power jack labeled as Power.

The power connector is most commonly used to supply power to the radio when the radio is used as a standalone PakBus® router / RF repeater or when the **RS-232** port is used for interconnect with another device. The Field Power Cable (pn 14291) or AC to DC power adapter (pn 15966) are used for supplying 12 Vdc to the power connector.

The power connector of the radio uses the inner conductor for positive (+) voltage and the outer / sleeve conductor for ground (–).

CAUTION	There are many AC adapters available with barrel connectors that will fit the RF407 series. Damage that occurs from the use of an AC adapter that is not the 15966 AC to DC power adapter will not be covered by warranty. If using a different AC adapter, be sure that the adapter's "no load" voltage is below the 16 Vdc; measure the output with a DC voltmeter while the AC adapter is plugged into the outlet but not powering anything.

7.3   USB

The radio has a USB Type B jack that can be connected to your PC using the supplied 17648 USB cable. The connection is used for power, configuration, and data.

NOTE	INSTALL the DEVICE DRIVER BEFORE connecting the radio to your PC via USB for the first time. You will need the device driver properly installed before you can connect to the radio via USB. To install the device driver, download the latest version of *DevConfig* from our website. Under **Device Type**, select **Radio | RF407 Series**. Click the **Install the USB device driver** link and follow the prompts.

Most host USB ports will supply a sufficient amount of voltage and current for all normal operations. When used as a base radio, an external power supply is generally not required. When sourcing operational power from the PC's USB port, connect the radio directly to the PC or to an externally powered USB hub.

When the radio is connected to the PC, a virtual COM port will be added to the list of available ports (COM and LPT) devices. It will be descriptively labeled, for example "RF407 Series (COM10)", where COM10 denotes the COM port enumerated by the Windows® operating system.

The **USB** port is always available for configuration purposes. Independent of the Active Interface radio setting, USB can always be used for connecting with *DevConfig* for radio configuration.

The USB interface is only available for operational, network communication when the radio **Active Interface** setting is set as **USB**.

TABLE 7-1. USB Pinout (USB Type B Jack)	
Pin	**Function**
1	5V
2	Data–
3	Data+
4	GND

7.4   CS I/O

The **CS I/O** port is a 9-pin male D-Sub connector that is typically connected to a Campbell Scientific datalogger using the supplied SC12 cable. This connection is used for power and data.

The **CS I/O** port is not a typical RS-232 connection and is specific to Campbell Scientific products. CS I/O cannot be used for radio configuration using *DevConfig*.

For a typical remote radio site, the radio need only be connected to the datalogger **CS I/O** port using the supplied SC12 cable. This connection will supply operational power to the radio and serve as the data connection between the radio the datalogger. The **Active Interface** setting must be set to **CS I/O SDC**.

An alternative, but much less common, use of CS I/O is connection to another communication peripheral through an A100 CS I/O null modem adapter (pn 17366). This is typically only used when creating a "phone to RF base" configuration. The radio's **Active Interface** setting must be set to **CS I/O ME Master** and the other device (for example COM220) must be capable of being configured as a modem enabled (ME) peripheral.

TABLE 7-2. CS I/O Pinout (9-PIN D-SUB MALE)			
Pin	**Function**	**I/O**	**Description**
1	5V	I	Sources 5 Vdc to power peripherals
2	GND		GND for pin 1 and signals
3	Ring	O	Raised by modem to put datalogger into telecommunications mode
4	RX	O	Serial data receive line
5	Modem Enable	I	Raised when datalogger determines that associated modem raised the ring line
6	Synchronous Device Enable	I	Used by datalogger to address synchronous devices; can be used as a printer enable
7	CLK/Handshake	I/O	Used by datalogger with SDE and TX lines to transfer data to synchronous devices
8	12V supplied by datalogger	PWR	Sources 12 Vdc to power peripherals
9	TX	I	Serial data transmit line
I = Signal into the RF407 series, O = Signal out of the RF407 series			

7.5   RS-232

The **RS-232** port is a DCE, 9-pin female D-Sub connector used to for connecting the radio to the **RS-232** port of a datalogger, computer, or another RS-232 device. This connection is most commonly used when connecting the

radio to a device without a **CS I/O** port or when linking two communication peripherals, for example directly connecting the radio to an Ethernet serial server.

The **RS-232** port can be connected to a DTE device, like a computer or NL201, using the pn 10873, 9-Pin female to 9-Pin male serial cable. The **RS-232** port can be connected to another DCE device, like a datalogger RS-232 or MD485 or cellular modem, using the 18663, 9-pin male-to-male null modem serial cable.

When using RS-232, 12 Vdc power should be supplied to the power connector using a field power connector or AC power adapter. The **Active Interface** setting must be set to **RS-232**, and the **RS-232** port configuration, like baud rate, should match the device the radio is connected to.

RS-232 cannot be used for radio configuration using *DevConfig*.

TABLE 7-3. RS-232 Pinout (9-PIN D-SUB FEMALE)		
Pin	**I/O**	**Description**
1		
2	O	TX
3	I	RX
4		
5		GND
6		
7		
8	O	CTS
9		
I = Signal into the RF407 series, O = Signal out of the RF407 series		

7.6   LEDs

The radios have a red LED labeled **TX/PWR** and a green LED labeled **RX**. When 12V power is applied, Both LEDs light for about one second.

The red LED lights to indicate when the receiver is actively listening. When the radio is transmitting, the red LED will pulse (it will not be on solid).

Green LED activity indicates that there is an RF signal being received

7.7   Antenna

The radio has a reverse polarity SMA (RPSMA) jack antenna connection. It is important to note the distinction between RPSMA and SMA connectors when selecting a mating antenna or antenna cable.

7.7.1 Compatible Antennas

Campbell Scientific offers antennas to satisfy the needs for various base station and remote station requirements. All antennas (or antenna cables) that attach directly to the radio have an RPSMA plug connector. The use of an unauthorized antenna could cause transmitted field strengths in excess of FCC rules, interfere with licensed services, and result in FCC sanctions against the user. One of the following antennas listed below must be used.

CAUTION	An FCC authorized antenna is a required component. You must pick one of the antennas below.

CAUTION	In order to comply with the FCC RF exposure requirements, the RF407 series may be used only with approved antennas that have been tested with these radios and a minimum separation distance of 20 cm must be maintained from the antenna to any nearby persons.

Approved Antennas	
Campbell Scientific Part Number	**Description**
14201	900 MHz 9 dBd Yagi Antenna with Type N Female and Mounting Hardware
14204	900 MHz 0 dBd Omnidirectional 1/2 Wave Whip Antenna with Right Angle and RPSMA Male
14205	900 MHz 6 dBd Yagi Antenna with Type N Female and Mounting Hardware
14221	900 MHz 3 dBd Omnidirectional Antenna with Type N Female and Mounting Hardware
14310	900 MHz 0 dBd Omnidirectional 1/4 Wave Whip Antenna, Straight 3 inches Tall with RPSMA Male
15730	900 MHz 0 dBd Omnidirectional 1/4 Wave Whip Antenna with Right Angle and RPSMA Male
15731	900 MHz 0 dBd Omnidirectional 1/4 Wave Whip Antenna, Straight 2 inches Tall with RPSMA Male
15970	900 MHz 1 dBd Dipole Antenna with Adhesive Mount and RPSMA Female 79 in. Cable

7.7.2 Electrostatic Issues and Surge Protection

Many radio installations are outdoors and therefore susceptible to lightning damage, especially via the antenna system. Also, depending on climate and location, electrostatically-charged wind can damage sensitive electronics, if sufficient electric charge is allowed to accumulate on the antenna and cable.

To protect against electrostatic damage, the antenna connector of the radio is connected to the radio case which can be tied to a good earth ground for discharge of electrostatic build up.

Also to protect against electrostatic damage, Campbell Scientific offers pn 31314, Antenna Surge Protection Kit. The surge protection kit includes a PolyPhaser® surge protector, a coax jumper for connecting the RF407-series radio to the PolyPhaser, ground wire lead, and mounting hardware. The PolyPhaser has Type N jack connectors on both ends; one for connection to a COAXNTN-L cable and the other for connection to the 18-inch length of COAXRPSMA cable included in the kit. To have the surge protection kit pre-installed by Campbell Scientific (bulkhead-mounted through the enclosure wall), see pn 31312.

7.7.3 Antenna Cables

Some antennas require an additional antenna cable to connect to the radio directly or to an interconnected surge protector.

COAXRPSMA-L is a LMR195 coaxial cable terminated with a Type N plug on one end and a RPSMA plug on the other. The COAXRPSMA-L can be used to connect antennas with a Type N jack connector directly to the RF407-series radios. Such antennas include the 14201, 14205, and 14221.

COAXNTN-L is a RG8/U coax cable terminated with a Type N plug on both ends. The COAXNTN-L is typically used to connect antennas with a Type N jack connector to an inline surge protector, or to a bulk head Type N jack.

8. Configuring the RF407 Series

8.1 *DevConfig*

DevConfig is the primary tool for configuring the radio. *DevConfig* version 2.11 or later is required. *DevConfig* can be downloaded free of charge from *www.campbellsci.com/downloads*.

NOTE	INSTALL the DEVICE DRIVER BEFORE plugging the radio into your PC for the first time. You will need the device driver properly installed before you can connect to the radio via USB. To install the device driver using *DevConfig*, select **Radio	RF407 Series** under **Device Type**. Click the **Install the USB device driver** link and follow the prompts.

1. Open *DevConfig*.

2. Under **Device Type**, select **Radio | RF407 Series**.

3. Carefully review the Connect Instructions text provided on the right.

4. With the USB device driver installation complete, connect the supplied USB cable between the USB port on your computer and the **USB** port on the radio.

5. Click the **Browse** button next to **Communication Port**.

6. Select the port labeled **RF407-Series**.

7. Click **OK**.

8. Click **Connect**.

9. Configure the radio as needed for your application. See Section 11, *Operation (p. 15)*.

10. Click **Apply** to save your changes.

You will be prompted to save your configuration. Doing so will allow you to easily recall the configuration later or apply this same configuration to other devices.

9. *LoggerNet* Setup

9.1 Basic Setup

Start *LoggerNet* and open the *Setup* screen from the **Main** category of the toolbar. Start the configuration by clicking on the **Add Root** button. From the **Add** submenu make the following selections:

- ComPort
- PakBusPort
- Your datalogger

Finally, click the **Close** button on the **Add** submenu. Your setup tree should appear as shown below:
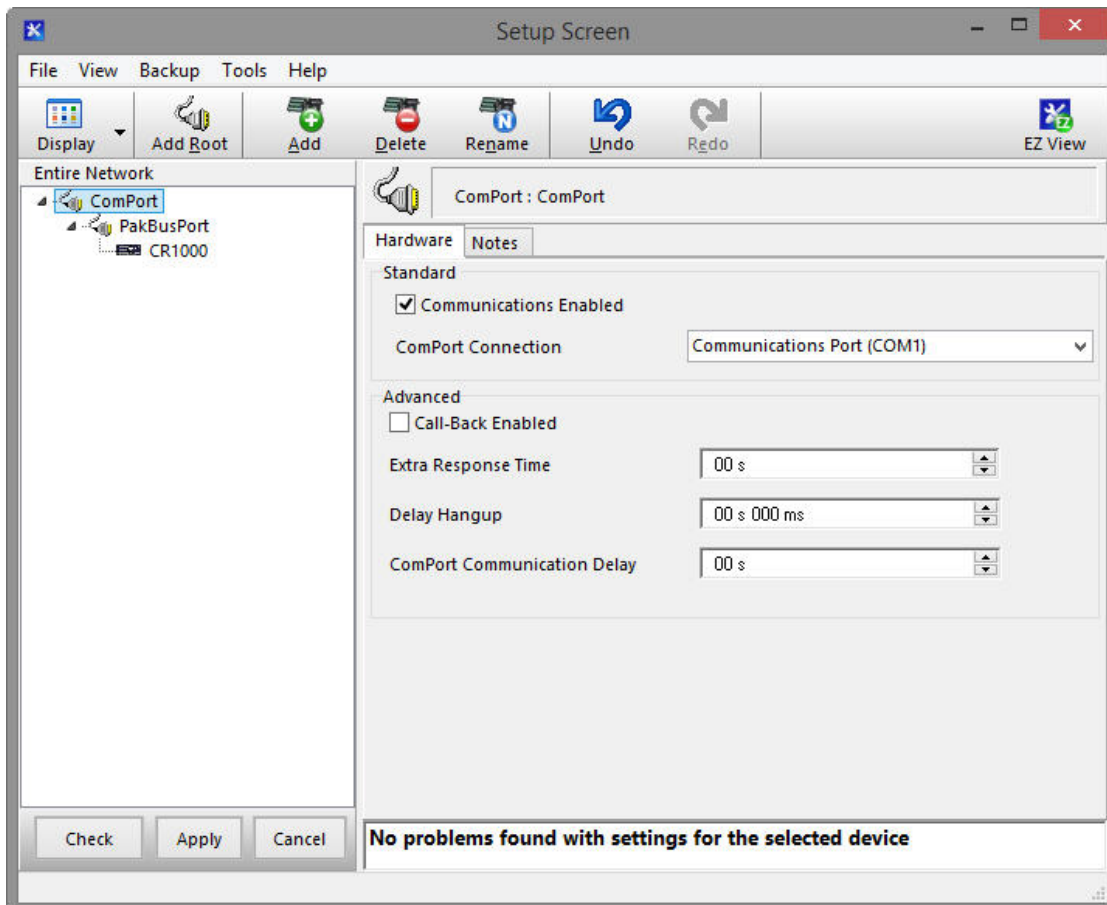
With the setup tree entered, you will now need to complete the configuration of each element. Start with selecting the **ComPort** element at the root of the tree. Under **ComPort Connection**, select port labeled **RF407-Series**.
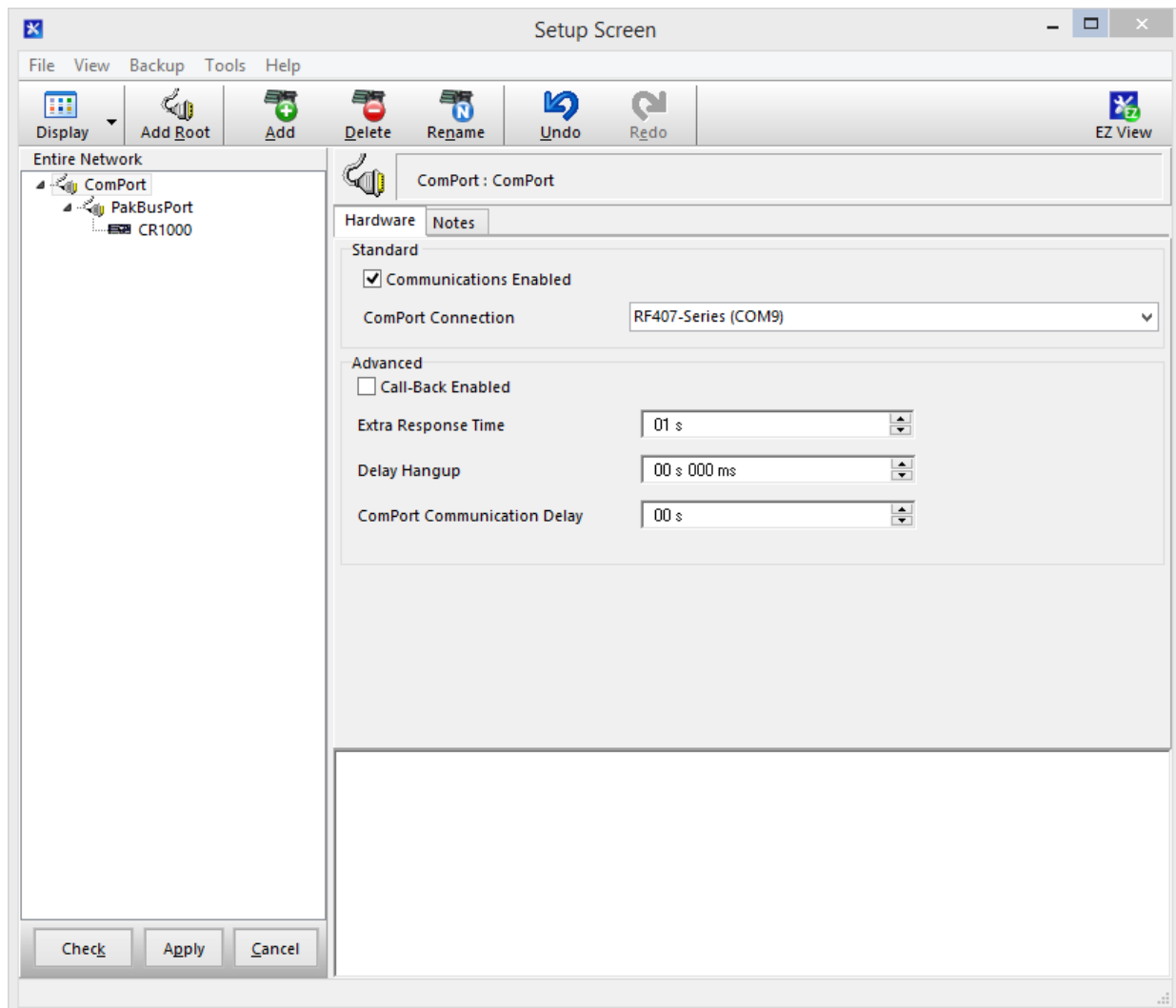
Select the **PakBusPort** element in the tree, and select the **PakBus Port Always Open** checkbox. Set the **Maximum Baud Rate** to **115200**.
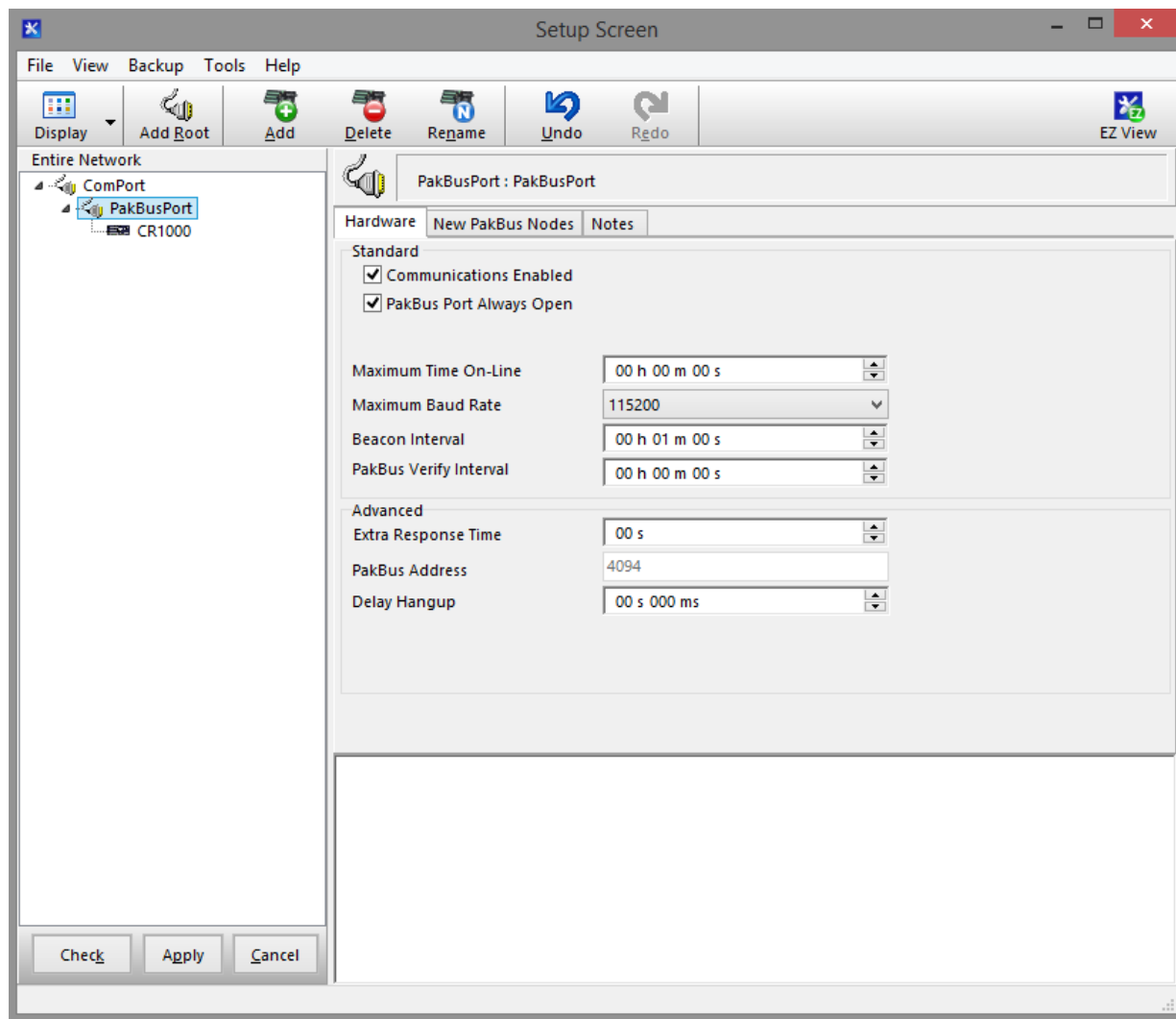
Finally, select your datalogger in the tree. Set the **PakBus Address** field to the PakBus® address of your datalogger. Enter the **Security Code**, if security has been set up in your datalogger.
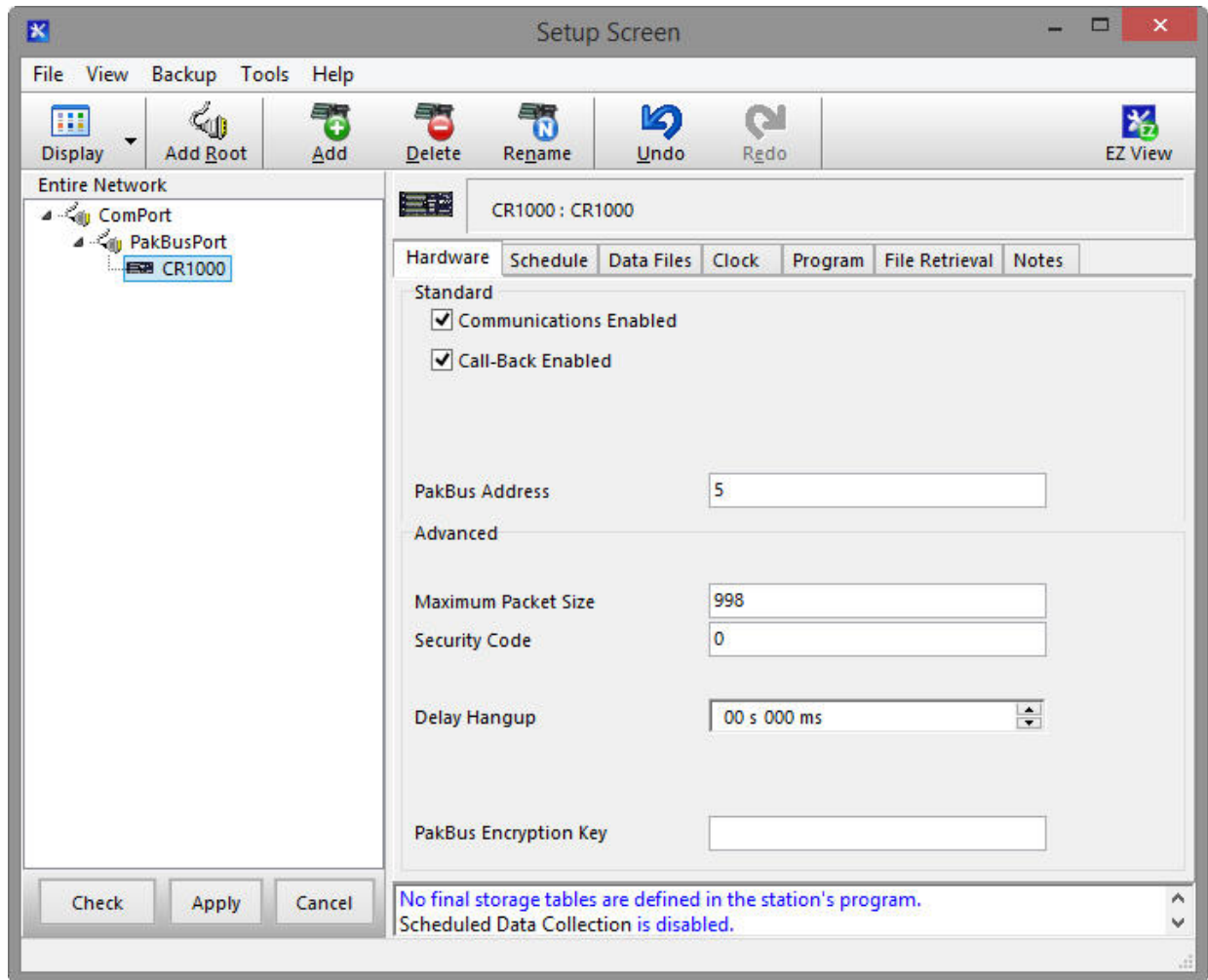
Press the **Apply** button to save your changes. You are now ready to connect to your datalogger using the *LoggerNet Connect* screen.

9.2 Using a Repeater

When using an RF407-series radio as a repeater in your network, it can be entered into the *LoggerNet Setup* screen using the **pbRouter** device and entering the PakBus® address of the RF407 series in the **PakBus Address** field. If the repeater is the first hop from *LoggerNet*, it should always be shown in the network map. This will force routes to go through the repeater. If the repeater is further down the network, it may still be helpful to display it in the network map. However, it does not force routes to go through the repeater.
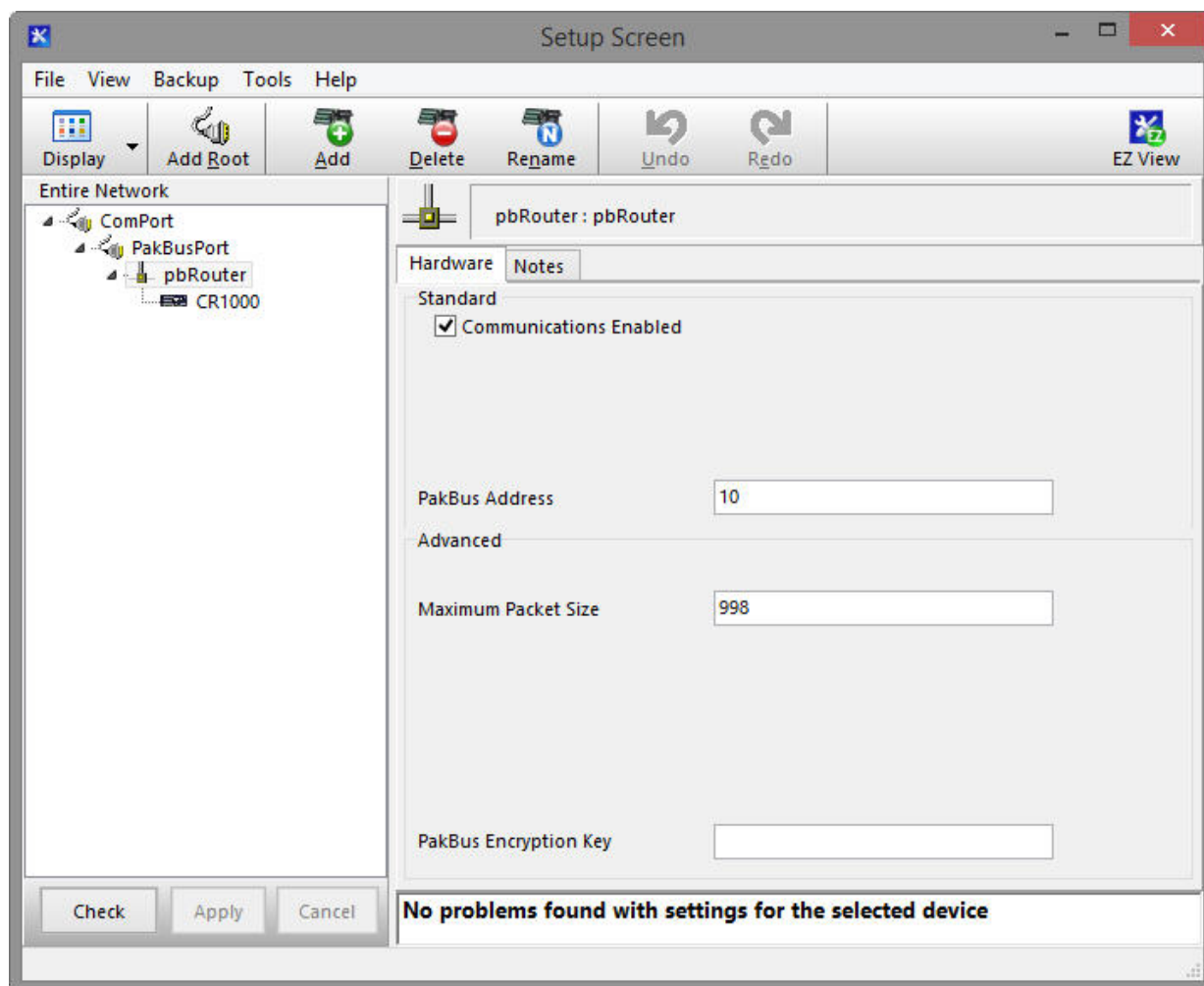
10. Installation Best Practices

10.1 Avoiding Interference

In-band interference within "view" of either radio in a link can significantly degrade communications. Attempt to avoid locating radios and antennas near other transmitters or transmitting through commercial communication tower locations. Additionally, a powerful signal of almost any frequency at very close range can simply overwhelm a receiver. Test such a site with a representative setup before committing to it. Relocating an antenna by a few feet vertically or horizontally or constraining the radiation pattern with a directional antenna may make a significant difference. Keep in mind that commercial tower sites

and urban areas tend to evolve over time meaning new sources of interference may develop over time.

10.2 Antenna Selection, Placement, and Mounting

Antenna selection and placement can play a large role in system performance. Often directional antennas are preferred over omnidirectional antennas when possible as RF energy can be more selectively directed and received and higher gains can be realized without the consumption of additional power. Additionally, a good rule of thumb is to place antennas as high as possible. Giving an antenna a higher elevation often increases the amount of area and distance it can "see" and cover with "line of sight". Sometimes performance can be improved by even slightly changing the horizontal or vertical position of the antenna.

10.3 Antenna Cables

- Routing

  - Route all conductors and cables in a neat, orderly fashion. Avoid routing directly over or across system components.

  - Avoid routing conductors carrying low level analog signals in close proximity and parallel to conductors carrying digital signals or switched voltage levels.

- Bend Radius

  - The RF cable used to interconnect the radio and antenna has a specified minimum bend radius. Exceeding it will lead to a degradation of system performance: extra losses, high VSWR, etc.

- Strain Relief

  - Avoid cable chaffing and connector fatigue by strain relieving all conductors and cables that span a distance of more than 12 inches or have a potential for relative motion due to vibration or wind.

- Connectors

  - All exposed RF connectors should be weatherproofed. A good method is to apply overlapping wraps of a good quality mastic tape, extending several inches beyond either side of the connection, then cover the mastic tape with tight, overlapping wraps of a good quality vinyl tape.

  - Maintain electrical connectors in a clean, corrosion-free condition by means of a periodic application of a good quality aerosol-based contact cleaner.

11. Operation

The following settings are available for the RF407-series radios. Configure them as appropriate for your application.

11.1 Main

11.1.1 Active Interface

The radio provides three physical ports for interfacing to a computer, datalogger, or other device. They are USB, RS-232, and CS I/O. The **CS I/O** port has two operational modes, SDC and ME Master. Additionally, there is PakBus Router which is a software defined interface that disables normal operation of all of the physical ports. Only one interface can be selected as active at any given time. Note that despite the value of this setting, the **USB** port will always be available for configuration.

Interface	Description
CS I/O SDC	Use this setting when the **CS I/O** port is connected to a Campbell Scientific datalogger **CS I/O** port. The devices will use the concurrent synchronous device for communication protocol. Also, see the setting **SDC Address** *(p. 17)* and make sure that multiple SDC devices connected to a single **CS I/O** port use unique SDC addresses.
RS-232	Use this setting when the **RS-232** port is connected to the **RS-232** port of a datalogger, computer, or another RS-232 device. This setting is most commonly used when connecting the radio to a device without a **CS I/O** port or when linking two communication peripherals, for example directly connecting the radio to an Ethernet serial server. Also, see **RS-232 Baud Rate** *(p. 17)* and the advanced settings **RS-232 Parity** *(p. 23)*, **Stop Bits** *(p. 23)*, **Character Length** *(p. 23)*, and **Auto Power Down** *(p. 23)*.
USB	Use this setting when connecting the radio to a computer. This setting is the most common when the device is used as a "base radio" for a network. A computer's USB port can simultaneously be used for powering and communicating with the device.
PakBus Router	Use this setting when a standalone PakBus® router is required to repeat messages through a network. In this mode, the **CS I/O**, **RS-232**, and **USB** ports are NOT available for connecting other devices for normal network operations. Note that despite the value of this setting, the **USB** port will always be available for configuration. The **Protocol** setting must be set as **PakBus Node**. Also ensure that **PakBus Address** is unique within the PakBus network.
CS I/O ME Master	Use this setting only under special circumstances where the **CS I/O** port is connected to another Campbell Scientific peripheral configured for Modem Enable (ME) through an A100 Null Modem Adapter. The A100 will swap TX / RX and ME / RING and supply power to the devices. The **ME Baud Rate** of both devices must match. An example includes connecting this device to a COM2xx phone modem. Also see Section 11.3.8, *ME Baud Rate (p. 23)*.

11.1.2 SDC Address

Specifies the **CS I/O** port SDC address when **Active Interface** is set as **CS I/O SDC**.

11.1.3 RS-232 Baud Rate

Specifies the baud rate that will be used on the **RS-232** port when **Active Interface** is set as **RS-232**. Other related advanced settings include **RS-232 Parity**, **Stop Bits**, **Character Length**, and **Auto Power Down**.

11.1.4 Protocol

Protocol	Description
Transparent	Provides a transparent link with no interpretation of the data packet. This mode is most commonly used with array based dataloggers. This mode is also used for non PakBus® protocols like Modbus. When used this way, **Retry Level** must be set to **None**.
PakBus Aware	This is the most commonly used protocol setting for PakBus® networks. The radio will automatically inherit an RF identifier equal to the PakBus address of the device it is serially attached to. In this mode, the radio will be capable of performing RF level retries and acknowledgements and provide a more reliable link than Transparent mode used for broadcast messaging. You do not need to manually set a unique RF radio address or a unique PakBus address. This device will not appear in *PakBus Graph*.
PakBus Node	This mode is similar to PakBus Aware, but it requires the device to have a unique PakBus address specified. Because the radio is PakBus addressable, status information, such as received signal strength indicator (RSSI), can be queried through a get variables transaction. Additionally, if the radio is connected to a PakBus router, it will also be viewable in *PakBus Graph* and accessible by other remote PakBus devices. If attached to a PakBus router, network overhead will increase due to the increase in number of PakBus nodes in the network. If **Active Interface** is also set to **PakBus Router**, this mode will allow the device to function as a standalone RF repeater. This setting must be used if **Active Interface** is set as **PakBus Router**. This setting is most commonly used when a user wants to a) use the device as a standalone PakBus repeater, b) make the device available remotely for viewing and editing settings, or c) attach more than one radio to a single datalogger.

11.1.5 RF Hop Sequence

Specifies the radio channel hop sequence. This setting must match in all radios in the same RF network. This setting can also be used to prevent radios in one RF network from listening to transmissions of another.

11.1.6 Network ID

Specifies the RF network. This setting must match in all radios in the same RF network. Valid entries are 0 to 32767.

11.1.7 Power Mode

Power Mode governs the duty cycle that the radio will use for powering its receiver. As such, it governs the amortized current drain for the radio. Note that choosing a low power mode that requires a long transmission header for a network with frequent communications can actually cause a higher average power draw; a large percentage of the communication interval is spent in high power transmission.

Power Mode	Typical Avg. Current Draw @12V	Description
Always on	< 12 mA	The radio receiver is always on. Additional wakeup header is never transmitted. Use this setting in a network with very frequent communications or when network latency needs to be minimized.
0.5 Second	< 2 mA	The radio receiver is turned on every 0.5 seconds for 100 milliseconds to look for RF activity. The radio transmits a 700 millisecond wakeup header with the first transmission occurring after a period of RF inactivity. This is one of the most common setting in networks that do not contain CR200(X)-series dataloggers.
1 Second	< 1 mA	The radio receiver is turned on every 1 second for 100 milliseconds to look for RF activity. The radio transmits a 1.2 second wakeup header with the first transmission occurring after a period of RF inactivity. This is one of the most common setting in networks that contain CR200(X)-series dataloggers.
4 Second	< 0.6 mA	The radio receiver is turned on every 4 seconds for 100 milliseconds to look for RF activity. The radio transmits an 4.2 second wakeup header with the first transmission occurring after a period of RF inactivity. Only use this setting in networks where time between communications is long (hours) and saving on average an additional 1 to 1.5 mA is essential.

11.1.8 Retry Level

An advantage of using one of the PakBus® protocol modes is that the radios will retry packet delivery at the RF level. This setting specifies the level to which the radio should retry to deliver an unacknowledged RF packet transmission. When an RF packet fails to be acknowledged by the destination,

the radio will delay a random amount of time before resending the packet again. A receiving radio responds to the sending radio with an ACK packet for every radio packet it receives addressed to it with a valid CRC.

Retry Level	Retry Count
None	0
Low	3
Medium	5
High	7

NOTE　　If the Retry Level is increased in a network with poor reception and many nodes, latency will greatly increase, sometimes to the point of non-operation if inundated with traffic.

11.1.9 Radio TX Power Level

This setting specifies the power level at which the RF module transmits. Levels are approximate. The maximum TX power for the RF407 and RF412 is 250 mW (+24 dBm); for the RF422 it is 25 mW (14 dBm).

TX Power Level, dBm	TX Power Level, mW
7	5
15	32
18	63
21	125
24	250

It is very important that the TX power level selected and the gain of the attached antenna do not exceed the maximum allowed ERP permitted by local laws. These rules vary from region to region. For example, in much of the United States, FCC part 15 rules limit the 900 MHz, ISM band transmission from this radio to a maximum effective radiated power of +36 dBm. If the radio is set to transmit at +24 dBm (250 mW), the maximum gain antenna that may be attached is 11 dBi (~8.5 dBd).

11.2 PakBus®

11.2.1 PakBus Address

This setting specifies the PakBus® address for this device. The value for this setting must be chosen such that the address of the device will be unique in the scope of the PakBus network. Duplication of PakBus addresses in two or more devices can lead to failures and unpredictable behavior in the PakBus network. Valid range is 1 to 4094. However, values greater than 3999 are generally reserved for software products.

11.2.2 PakBus Beacon Interval

This setting, in units of seconds, governs the rate at which beacons will be broadcast over the **Active Interface** for the purpose of discovering PakBus

neighbors. When **Active Interface** is **PakBus Router**, beacons will be sent over RF; otherwise, beacons will be sent over the serial port selected as the **Active Interface**. Set to zero to disable beaconing.

If **PakBus Verify Interval** is set to zero, a verify interval of 2.5 times the **PakBus Beacon Interval** will be assumed by the device.

11.2.3 PakBus Verify Interval

This setting specifies the interval, in units of seconds, which will be reported as the link verification interval in the PakBus hello transaction message. It will indirectly govern the rate at which the device will attempt to start a hello transaction with a neighbor if no other communication has taken place within the negotiated PakBus link verification interval. When **Active Interface** is **PakBus Router**, hello transactions will occur over RF; otherwise, they will be sent over the serial port selected as the **Active Interface**.

If **PakBus Verify Interval** is set to zero, a verify interval of 2.5 times the **PakBus Beacon Interval** will be reported by the device.

NOTE	It is advised that **PakBus Verify Interval** be set to an interval several times larger than your expected general communication interval, for example, data collection interval.

11.2.4 Central Router

Specifies the PakBus address of another device that the RF407 series will use as a **Central Router**. A valid setting is a single address between 1 and 4094. When set, the RF407 series will act as a branch router. Specifying a central router address can reduce the amount of PakBus RF traffic by eliminating the exchange of neighbor lists with routers beyond the central router. This is especially true when the network contains many transient or intermittent PakBus routers. If the RF407 series does not know how to explicitly route a packet, it will be handed off to the **Central Router** specified by this setting.

11.2.5 Neighbors Allowed

This setting specifies an explicit list of nodes the RF407 series will accept as neighbors when acting in the capacity of a PakBus RF repeater / router. If the list is empty (default), any node will be accepted as a neighbor. This setting will not affect the acceptance of a neighbor if that node's address is greater than 3999. The formal syntax for this setting is:

neighbor := { "(" range-begin "," range-end ")" }.
range-begin := pakbus-address. ;
range-end := pakbus-address.
pakbus-address := number. ; 0 < number < 4000

Example: (129,129) (1084, 1084)

In the example above, nodes 129 and 1084 are assigned as neighbors to the RF407 series.

11.3 Advanced

11.3.1 Radio MAC Address

The radio MAC Address.

11.3.2 Available Frequencies

This read-only setting shows a bit field of the frequencies that are available in the modules' region of operation. Each bit corresponds to a physical channel. For the RF407 and RF412, channels are spaced 400 kHz apart. For the RF422, channels are spaced 200 kHz apart.

RF407 and RF412	RF422
Bit 0 – 902.400 MHz Bit 1 – 902.800 MHz . . . Bit 31 – 914.800 MHz . . . Bit 63 – 927.600 MHz	Bit 0 – 863.15 MHz Bit 1 – 863.35 MHz . . . Bit 14 – 865.95 MHz . . . Bit 29 – 869.85 MHz

11.3.3 Radio Channel Mask

The **Radio Channel Mask** allows channels to be selectively enabled or disabled. This is useful to avoid using frequencies that experience unacceptable levels of RF interference.

This setting is a bit field. Each bit in the bit field corresponds to a frequency as defined in the **Available Frequencies** setting above. When a bit in the **Radio Channel Mask** and the corresponding bit in the **Available Frequencies** are both set to 1, that physical channel may be chosen by the module as an active channel for communication.

A minimum of 25 channels must be made available for the module to communicate on. The module will choose the 25 lowest enabled frequencies as its active channels if more than 25 are enabled.

All modules in a network must use an identical set of active channels. Separate networks which are in physical range of each other should use different **Network IDs** to avoid receiving data from the other network.

Note that channel 19 (910.000 MHz) is disabled by default. This channel has approximately 2 dBm worse receiver sensitivity than other channels. It is suggested that this channel not be used.

11.3.4 Operating System Version

Device operating system version

11.3.5 Radio Firmware Version

Radio firmware version

11.3.6 Received Signal Strength

Indicates the signal strength of the last packet received by this radio, and the PakBus address that it came from. The units of the RSSI are –dBm. Because the received signal strength can vary due to multipath, interference, or other environmental effects, it may not give a true indication of communication performance or range. However, received signal strength can be useful for activities such as:

- determining the optimal direction to aim a Yagi antenna
- determining the effects of antenna height and location
- trying alternate (reflective) paths
- seeing the effect of vegetation and weather over time

Accessing the Received Signal Strength Indicator

- Direct connection –
  Using a direct connection from the PC to the RF407-series **USB** port, *DevConfig* can be used to view the **Received Signal Strength**. Once a connection is established using *DevConfig,* the **Received Signal Strength** can be located under the **Advanced** tab.

- Datalogger query –
  The RF407 series must be configured as a PakBus node using *DevConfig*. Under the **Main** tab, set the **Protocol** to **PakBus Node**. This setting makes the RF407 an independent device in the network. The RF407 series must also be given a unique **PakBus Address** under the **PakBus** tab. This will prevent communication errors with other devices in the network and provide an address for a datalogger to query. The datalogger uses the **GetVariables()** instruction in the program to request the RSSI information, which includes the PakBus address of the device the RF407 series last received communication from. A datalogger can request the RSSI information from any RF407-series node in the network as long as there is a known communication route. Once the datalogger has received the RSSI, it can be displayed in the **Public** table or stored to a data table.

CRBasic Example 11-1. Retrieving RSSI Information

```
'Example Program
Const RFPBA = 401      'Set PakBus address of the RF407-series Node
Const Neigh = -1       'Set neighbor address, -1 = Auto Discover, or 0 = No neighbor

Public Result, RFstatus(2)

Alias RFstatus(1) = RSSI    'Received signal strength indicator
Alias RFstatus(2) = PBA     'Address of the last received communication

BeginProg
  Scan (5,Sec,0,0)

    GetVariables(Result,ComSDC7,Neigh,RFPBA,0000,0,"Public","RFSignalLevel",RFstatus(),2)

  NextScan
EndProg
```

- *PakBus Graph –*
  The RF407 series must be configured as a PakBus node using *DevConfig*. Under the **Main** tab, set the **Protocol** to **PakBus Node**. This setting makes the RF407 an independent device in the network. The RF407 series must also be given a unique **PakBus Address** under the **PakBus** tab. The RSSI and radio settings can be remotely accessed for any RF407 node displayed in *PakBus Graph*. Right-click on a device and a floating menu will be presented. Click on the **Edit Settings** option to display a list of settings. The RSSI is located under the **Advanced** tab in the **Received Signal Strength** field. The RSSI and the PakBus address of the device the RF407 last received communication from will both be displayed in the same field.

11.3.7 Battery Voltage

Specifies the battery voltage in volts at the radio.

11.3.8 ME Baud Rate

Specifies the baud rate that will be used on the **CS I/O** port when configured for ME Master.

11.3.9 RS-232 Parity

Specifies the parity that will be used on the **RS-232** port.

11.3.10 RS-232 Stop Bits

Specifies the number of stop bits used on the **RS-232** port.

11.3.11 RS-232 Character Length

Specifies the length in bits of character frames on the **RS-232** port.

11.3.12 RS-232 Auto Power Down

Specifies whether to always power the RS-232 device or that the RS-232 TX automatically powers down when there is no activity for 30 seconds.

12. Attributions

PakBus is a registered trademark of Campbell Scientific, Inc.

PolyPhaser is a registered trademark of Transtector Systems, Inc.

Windows is a registered trademark of Microsoft.

Appendix A. Part 15 FCC Compliance Warning

Changes or modifications to the RF407-series radio systems not expressly approved by Campbell Scientific, Inc. could void the user's authority to operate this product.

Note: 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 equipment and receiver.

- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.

- Consult the dealer or an experienced radio/TV technician for help.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

1) This device may not cause harmful interference, and

2) This device must accept any interference received, including interference that may cause undesired operation.

Appendix B. Distance vs. Antenna Gain, Terrain, and Other Factors

B.1 Introduction

The communication distance you can expect to obtain using the RF407 series depends on many factors including line of sight, antenna height, and antenna gain. Examples of distance achieved using different antennas and line of sight are shown in TABLE B-1.

<table>
<tr><td colspan="3" align="center">TABLE B-1. RF Path Examples</td></tr>
<tr>
<th>Distance Achieved (miles)</th>
<th>Antennas</th>
<th>Path Between Radios</th>
</tr>
<tr>
<td>2</td>
<td>14204 Omnidirectional ½ Wave 0 dBd[1] Whip
to
14204 Omnidirectional ½ Wave 0 dBd Whip</td>
<td>Virtual line of sight on valley floor with wetland foliage.</td>
</tr>
<tr>
<td>10</td>
<td>14204 Omnidirectional ½ Wave 0 dBd Whip
to
14204 Omnidirectional ½ Wave 0 dBd Whip</td>
<td>Line of sight across a valley (on foothills approximately 300 feet above the valley floor on each end).</td>
</tr>
<tr>
<td>35</td>
<td>14204 Omnidirectional ½ Wave 0 dBd Whip
to
14201 9 dBd Yagi</td>
<td>Line of sight across a valley (on foothills approximately 300 feet above the valley floor on each end).</td>
</tr>
<tr><td colspan="3">[1] dBd = decibel level compared to a simple dipole antenna</td></tr>
</table>

LINE OF SIGHT

You should arrange for a line-of-sight signal path between radios. At 900 MHz, there is little signal bending, however, there is reflection from hills, water, and conductive objects. Sometimes reflections provide a helpful path around an obstacle. There can be some trees and bushes in the signal path (with reduction in signal strength), but a hill will block the signal effectively. Thick trees can limit range to as little as 800 feet. Where possible, avoid buildings and other man-made structures in the signal path as they absorb or reflect some of the direct wave, possibly below the level needed for communications.

ANTENNA HEIGHT

In situations where the radio antennas are situated virtually line of sight, the elevation of antennas (by choice of site or by installing a tower or mast) can substantially increase signal strengths. The amount of increase depends on factors in the propagation path between the radios including terrain, foliage, and man-made structures. Elevating one or both of the antennas essentially raises the signal path allowing the direct wave to better avoid absorption or reflection which can sometimes be more helpful than adding higher gain antennas.

GAIN ANTENNAS

Increasing antenna gains improves signal strength and distance. For example, the substitution of a 9 dBd Yagi antenna where a 0 dBd omnidirectional existed theoretically extends the attainable distance by a factor of 2.8. Adding 9 dBd Yagi antennas on both ends in place of 0 dBd whip antennas theoretically extends the distance by a factor of 7.9. The higher the Yagi's gain, the narrower the beam width and the more critical it is that it be aimed right on target.

B.2 How Far Can You Go?

Estimating Distance for Spread-Spectrum Radios

B.2.1 Overview

There is a great deal of interest in estimating the distance you can expect to achieve with the RF407-series radios. Also of interest are the effects of cable length, antenna gain, and terrain. Some of these items are easy to quantify (cable loss, for instance); others are difficult to quantify (such as the effect of ground reflections). They are all important, though, and affect how well the RF system performs.

Probably the best approach to take in making range estimates is to do a site survey that considers the topography, location of antennas and radios, and cable lengths, make some assumptions about the path losses, and see if there is still some net gain. If there is, or if it is close, the next course is to actually try it out.

B.2.2 Link Analysis

In an RF system, there are gains (transmitter power, antenna gains, and receiver sensitivity "gain") and losses (cable loss and path loss). If the gains exceed the losses, you have a connection; any excess is the "link margin."

EXAMPLE GAINS		EXAMPLE LOSSES	
Transmitter Power	24	Transmitter Cable	3
Transmitter Antenna	6	Free Space	120
Receiver Antenna	6	Receiver Cable	3
Receiver Sensitivity "gain"	109		
TOTAL GAINS =	145 dB	TOTAL LOSSES =	126 dB

Link Margin = (Total Gains) – (Total Losses) = 145 – 126 = 19 dB

A minimum of 6 dB of link margin is recommended.

Here is a block diagram of the various components of gain/loss:

Radio Transmitter		Cable Loss		Antenna Gain		Free Space Loss		Antenna Gain		Cable Loss		Radio Receiver
Pt	-	Lt	+	Gt	-	Lp	+	Gr	-	Lr	=	Pr
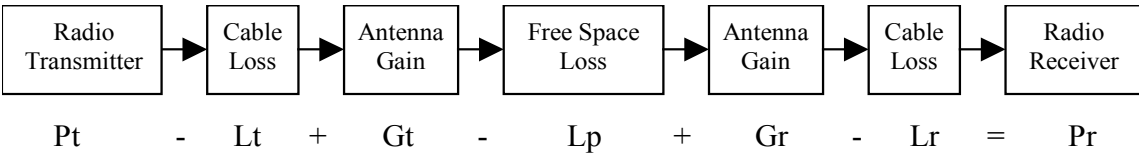
Where:
Pt =>   transmitter output power, in dBm (24 dBm in the case of the RF407
        series at maximum transmitter power)
Lt =>   cable loss between transmitter and antenna in dB (see Cable Loss section)
Gt =>   transmit antenna gain in dBi (dBi = dBd + 2.15)
Lp =>   path loss between isotropic antennas in dB (see TABLE B-7, TABLE
        B-8)
Gr =>   receive antenna gain in dBi
Lr =>   cable loss between antenna and receiver in dB
Pr =>   signal power at the radio receiver in dBm

The signal power at the receiver (Pr) must exceed the receiver sensitivity
(−101 dBm) by a minimum of 6 dB for an effective link. The amount that Pr
exceeds the receiver sensitivity is the link margin.

All of these elements are known, or are easily determined, with the exception
of Lp. Unfortunately, signal path loss can make the difference between a
marginal link 1/2 mile apart, and a reliable link 10 miles apart!

B.2.3 Transmitter Power

Transmitter output power is often expressed in dBm, which is a decibel power
rating relative to 1 milliWatt. The formula is: dBm = 10 log (Pt) with Pt
expressed in milliWatts.

TABLE B-2. Transmitter Power	
Transmitter Power (Pt) (milliWatts)	**dBm**
1	0
5 (RF407 series minimum)	7
10	10
50	17
100	20
250 (RF407 series maximum)	24
1000	30
5000	37

B.2.4 Cable Loss

Cable loss is a function of cable type, length, and frequency and is usually
specified as attenuation (dB) per 100 ft. of cable. Using a low loss cable
becomes very important as the cable run distances increase. Here are some
typical cable types and their properties:

B-3

TABLE B-3. Cable Loss		
Cable Type	**Outside Diameter**	**Loss (dB/100 ft) @ 900 MHz**
RG-58A/U	0.195 in	21.1
COAXRPSMA-L	0.195 in	11.1
RG-8	0.405 in	6.9
COAXNTN-L	0.405 in	4.5
LMR-400	0.405 in	3.9
*Campbell Scientific stocked antenna cables are shaded.		

Campbell Scientific's "COAXRPSMA-L" uses LMR-195 antenna cable.
Cable loss is proportional to length as the following table illustrates.

TABLE B-4. LMR-195 Cable Loss vs. Length @ 900 MHz	
Length (ft.)	**Loss (dB)**
100	11.1
50	5.6
25	2.8
10	1.1
6	0.7

B.2.5 Antenna Gain

Antenna gain is specified either in dBi (decibels of gain relative to an isotropic
radiator) or in dBd (decibels of gain relative to a dipole). The relationship is:

$$dBi = dBd + 2.15$$

Some antennas that are FCC approved for use with the RF407 series are:

TABLE B-5. Antenna Gain of Recommended Antennas							
Mfg.	**Antenna Type**	**Band**	**Model**	**Part Number**	**dBd Gain**	**dBi Gain**	**Size**
Astron	Omni (1/2 wave)	900 MHz	AXH900 RP SMA R	14204	0	2.15	6.75 in
Antenex	Collinear	900 MHz	FG9023	14221	3	5.15	24 in
MaxRad	Yagi	900 MHz	BMOY8905	14201	9	11.15	21.4 in

B.2.6 Receiver Sensitivity

Receiver sensitivity is usually specified in dBm for a specific bit error rate
(BER). The transceiver module used in the RF407 series is specified at –101
dBm at 200 kb/s.

If the received signal strength is greater than the receiver sensitivity, a link can be established. Any excess signal strength above the receiver sensitivity is "link margin," and is a very good thing; a minimum of 6 dB of link margin should be sought.

B.2.7 Path Loss

We have combined in this section the normal "free space" path loss (only seen in mountaintop to mountaintop scenarios) with no loss due to ground reflections, diffraction, leaf/forest absorption, etc. It is all loss!

A starting point is the "free space" path loss. Here are two equations for this:

Lp (dB) = 32.4 + 20 • log(f) + 20 • log (d) dB   (f in MHz, d in km)
Lp (dB) = 36.6 + 20 • log(f) + 20 • log (d) dB   (f in MHz, d in miles)

Here is a table showing the free space path loss (in dB). Note the effect of frequency.

TABLE B-6. Free Space Path Loss									
Frequency	**Distance**								
	1 mi.	2 mi.	4 mi.	8 mi.	10 mi.	16 mi.	22 mi.	26 mi.	30 mi.
400 MHz	89	95	101	107	109	113	115	117	118
915 MHz	96	102	108	114	116	120	123	124	125
2.4 GHz	104	110	116	122	124	128	131	133	134

Notice the relationship between path loss and distance: each time you double the distance, you lose 6 dB of signal under free space conditions. Or, put another way, if you add 6 dB of gain (for example with 6 dB of additional antenna gain, or 6 dB *less* cable loss), you can double the distance for free space conditions.

As mentioned before, free space conditions are the ideal, but seldom actually seen. The higher the antenna height relative to the terrain in the line-of-sight path, the closer to free space conditions. Antenna height is everything!

Here are some additional propagation effects that increase the path losses:

Diffraction

This is caused by objects close to the line-of-sight path. Real world examples of this would be hills, buildings, or trees. The object may not be in the direct line of sight, but if it is close enough, it will cause the RF to diffract around the object, giving additional path loss. "Close enough" is a function of frequency, path length, and position of the obstacle along the path.

An example at 900 MHz: a 10 mile path length with an obstacle halfway along the path will see diffraction "losses" from an obstacle within ~70 ft. of line-of sight. The amount of loss would be from 6 dB to 20 dB, depending on the obstacle surface. A sharp edge (like a rock cliff) would give the minimum loss (6 dB), while a rounded hill would give the maximum loss (20 dB).

Ground Reflections

These are caused by the RF signal being reflected from the ground (or water), and undergoing a phase shift so that it destructively interferes with the line-of-sight signal. The conditions that cause this the most are propagation over water, or over a low-lying fogbank. The reflected signal suffers little attenuation, gets out of phase, and interferes with the main signal. If antennas need to be sited near water, they should be positioned away from the water's edge so that the ground vegetation attenuates the reflected RF.

The result of the reflection and interference (worst case) is that the path loss increases as the 4th power of the distance, instead of the 2nd power. This changes the distance term in the path loss equation to: $40 \cdot \log (d)$ dB. Then, with each doubling of distance, the path loss increases by 12 dB, instead of 6 dB.

Vegetation

Losses due to vegetation (trees, bushes, etc.) cause the path loss to increase by the 3rd to 4th power of the distance, instead of the 2nd power. This is just like in the severe ground reflection case above.

Rain, Snow, and Fog

Below 10 GHz, these don't have much effect on path loss (see Ground Reflections above).

B.3 Real World Distance Estimates

From the above discussion of departures from the ideal "free space" path loss, it is clear that we should usually use something other than the 2nd power distance table.

TABLE B-7 gives calculated path loss (Lp) values at 900 MHz for the 2nd, 3rd, and 4th powers of distance; the equations (for 915 MHz) are:

$$\text{Lp } (2^{nd} \text{ power}) = 95.8 + 20 \cdot \log (d) \text{ dB} \qquad (\text{d in miles})$$
$$\text{Lp } (3^{rd} \text{ power}) = 95.8 + 30 \cdot \log (d) \text{ dB} \qquad (\text{d in miles})$$
$$\text{Lp } (4^{th} \text{ power}) = 95.8 + 40 \cdot \log (d) \text{ dB} \qquad (\text{d in miles})$$

TABLE B-7. 900 MHz Distance vs. Path Loss (Lp in dB) per Three Path Types										
Path Type	**Distance**									
	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
2nd power	102	108	111	114	116	119	121	123	124	125
3rd power	105	114	119	123	126	130	133	136	138	140
4th power	108	120	127	132	136	142	146	149	152	155

The following table helps select a Path Type in the above "Distance vs. Path Loss" table to best fit your situation.

TABLE B-8. Path Type vs. Path Characteristics Selector	
Path Type	**Path Characteristics**
2nd power	Mountaintop to mountaintop or tall antenna towers Line of sight
3rd power	Dominantly line of sight Low antenna heights Some trees
4th power	At water's edge (very reflective) Across field of grain (reflective) Lots of Trees (absorptive)

B.4 Examples

Some examples will help illustrate the trade-offs in a link analysis. These examples will all use the RF407-series 900 MHz radio at maximum transmitter power, and will use –95 dBm as the required power level at the radio receiver. This is 6 dB higher than the quoted sensitivity of –101 dBm, which will give us a 6 dB margin.

Here's the equation we will use, from the first page:

$$Pt – Lt + Gt – Lp + Gr – Lr = Pr$$

Solved for Lp:

$$Lp = Pt – Lt + Gt + Gr – Lr – Pr$$

Example #1

Antenex FG9023 antennas on each end, 20 ft of LMR195 cable on one end, 10 ft of LMR195 on the other end, antennas at 10 ft height, fairly open terrain with a few trees. How far can I go?

Pt = 24 dBm
Lt = 20 ft • (11.1 dB/100 ft) = 2.22 dB
Gt = Gr = 3 dBd = 5.15 dBi
Lr = 10 ft • (11.1 dB/100 ft) = 1.11 dB

Use –95 dBm for Pr

Lp = 24 – 2.22 + 5.15 + 5.15 – 1.11– (–95) = 126 dB

Use the 3rd to 4th power tables: **Range from ~6** (4th power) **to ~10** (3rd power) **miles**

Example #2

Base has MaxRad BMOY8905 Yagi, with 50 ft of LMR195 cable on a 30 ft tower, also a lightening protection device with a VSWR of 1:1.75; remote also has a MaxRad BMOY8905 Yagi with 5 ft of LMR195 cable on a 4 ft pole. Terrain is mostly flat, with sagebrush. How far can I go?

$Pt = 24$ dBm
$Lt = 50$ ft • (11.1 dB/100 ft) = 5.55 dB
$Gt = 9$ dBd = 11.15 dBi
$Lr = 5$ ft • (11.1 dB/100 ft) = 0.55 dB
$Gr = 9$ dBd = 11.15 dBi

Need to include the loss from the surge arrestor: VSWR of 1:1.75 = 0.34 dB loss

Use –95 dBm for Pr

$Lp = 24 – 5.55 + 11.15 + 11.15 – 0.55 – (–95) – 0.34 = 135$ dB

Use the 3rd to 4th power tables: **Range from ~10** (4th power) **to 22+** (3rd power) **miles**

Example #3

You need to run 125 ft of cable for the transmitter:
How much loss if I use LMR195 cable?   125 ft • (11.1 dB/100 ft) = 13.9 dB
How much loss if I use LMR400 cable?   125 ft • (3.9 dB/100 ft) = 4.9 dB

If I am using path loss from the 2nd power table, and operating fine at 8 miles with LMR195 cable, how much more range could I expect if I use LMR400 cable (assuming similar terrain)?

13.9 dB – 4.9 dB => 9 dB more link margin

Loss at 8 miles: 114 dB; could tolerate 114 + 9 dB = 123 dB loss =>>> 22 miles (14 miles more)

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