

INSTRUCTION MANUAL



RF401A-Series Spread Spectrum Radios

Revision: 3/17



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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.

Table of Contents

PDF viewers: These page numbers refer to the printed version of this document. Use the PDF reader bookmarks tab for links to specific sections.

1. Introduction	1
2. Precautions	1
3. Initial Inspection.....	2
4. QuickStart.....	2
4.1 Remote Station Radio	2
4.2 Base Station Radio	2
4.3 LoggerNet Setup	2
5. Overview	3
5.1 Retired Radios.....	3
5.1.1 RF401-Series and RF430-Series Radios	3
5.1.2 RF400-Series Radios	3
6. Specifications.....	3
7. Product Description.....	6
7.1 Mounting.....	6
7.2 Power	6
7.3 USB.....	6
7.4 CS I/O	7
7.5 RS-232	8
7.6 LEDs	9
7.7 Antenna	9
7.7.1 Compatible Antennas.....	9
7.7.2 Electrostatic Issues and Surge Protection	10
7.7.3 Antenna Cables	11
8. Configuring the RF401A Series.....	11
8.1 Device Configuration Utility.....	11
9. LoggerNet Setup	12
9.1 Basic Setup.....	12
9.2 Using a Repeater	16
10. Installation Best Practices.....	16
10.1 Avoiding Interference	16
10.2 Antenna Selection, Placement, and Mounting	17
10.3 Antenna Cables	17

11. Operation17

11.1	Main	18
11.1.1	Active Interface	18
11.1.2	SDC Address	19
11.1.3	RS-232 Baud Rate.....	19
11.1.4	Protocol	19
11.1.5	RF Hop Sequence.....	20
11.1.6	RF Network.....	20
11.1.7	RF Radio Address	20
11.1.8	Power Mode	20
11.1.9	Retry Level.....	21
11.1.10	Radio TX Power Level.....	22
11.2	PakBus®.....	22
11.2.1	PakBus Address	22
11.2.2	PakBus Beacon Interval	22
11.2.3	PakBus Verify Interval.....	22
11.2.4	Central Router	23
11.2.5	Neighbors Allowed	23
11.3	Advanced.....	23
11.3.1	Serial Number	23
11.3.2	Operating System Version	23
11.3.3	Radio Firmware Version	23
11.3.4	Received Signal Strength	23
11.3.5	Retransmit Failures	25
11.3.6	ME Baud Rate	25
11.3.7	RS-232 Parity	25
11.3.8	RS-232 Stop Bits.....	25
11.3.9	RS-232 Character Length.....	25
11.3.10	RS-232 Auto Power Down.....	26
11.3.11	AT Sequence Character.....	26
11.3.12	Silence Time Before Command Sequence	26
11.3.13	Silence Time After Command Sequence	26
11.3.14	AT Command Mode Timeout	26
11.3.15	Net Address Mask	26
11.3.16	Radio Address Mask	26

12. Attributions.....26

Appendices

A. Part 15 FCC Compliance Warning.....A-1

B. Distance vs. Antenna Gain, Terrain, and Other Factors.....B-1

B.1	Introduction	B-1
B.2	How Far Can You Go?.....	B-2
B.2.1	Overview	B-2
B.2.2	Link Budget.....	B-2
B.2.3	Transmitter Power.....	B-3
B.2.4	Cable Loss.....	B-3
B.2.5	Antenna Gain	B-4
B.2.6	Receiver Sensitivity	B-5

B.2.7	Path Loss	B-5
B.3	Real World Distance Estimates	B-5
B.4	Examples	B-7

Figure

6-1.	RF401A-series dimensions	5
------	--------------------------------	---

Tables

7-1.	USB Pinout (USB Type B Jack)	7
7-2.	CS I/O Pinout (9-PIN D-SUB MALE)	8
7-3.	RS-232 Pinout (9-PIN D-SUB FEMALE)	9
B-1.	Transmitter Power	B-3
B-2.	Cable Loss	B-4
B-3.	LMR-195 Cable Loss vs. Length @ 900 MHz	B-4
B-4.	Antenna Gain of Recommended Antennas	B-4
B-5.	Free Space Path Loss	B-5
B-6.	915 MHz Distance vs. Path Loss (Lpath in dB) per Two Propagation Models	B-6
B-7.	Path Type vs. Path Characteristics Selector	B-6
B-8.	Lpath vs. Distance for 2-Ray Propagation Model in Example #1	B-7
B-9.	Fade Margin (dB) vs. Distance for 2-Ray Propagation Model in Example #1	B-8
B-10.	Lpath vs. Distance for 2-Ray Propagation Model in Example #2	B-8
B-11.	Fade Margin (dB) vs. Distance for 2-Ray Propagation Model in Example #2	B-9

CRBasic Example

11-1.	Retrieving RSSI Information	25
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RF401A-Series Spread Spectrum Radio

1. Introduction

This manual discusses the configuration, operation, and maintenance of the Campbell Scientific RF401A and RF411A frequency-hopping spread spectrum (FHSS) radios. This manual will refer to these devices collectively as either “radio,” “RF401A series,” or “RF401A-series radio” unless otherwise noted.

The RF401A-series radios are designed for license-free use in several countries. The RF401A has a 910 to 918 MHz operating-frequency range appropriate for use in the United States and Canada. The RF411A has a 920 to 928 MHz operating-frequency range appropriate for use in Australia and New Zealand.

The RF401A-series radios provide a high level of RF compatibility with previous products. The RF401A is compatible with the RF400, RF401, RF430, CR205, CR206, CR206X, and AVW206. The RF411A is compatible with the RF410, RF411, RF431, CR210, CR211, CR211X, and AVW211.

NOTE

The RF401A is factory upgradeable to an RF407 for use in RF407 networks. Contact Campbell Scientific for a Returned Material Authorization (RMA).

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 16.5 volts measured without a load to avoid damage to the radio. Over-voltage damage is not covered by factory warranty.
- Campbell Scientific does not recommend using RF401A-series, RF401-series, or RF430-series radios in networks containing RF450 radios. The RF450 radios will interfere with the transmission of the RF401A-series, RF401-series, and RF430-series radios.
- 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 RF401A-series radios ship with an SC12 serial cable, a USB A to USB B Cable, 2 grommets, and 2 screws.
- Upon receipt of the RF401A-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 inside it. 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* to change the radio's **Active Interface** to **USB**. To learn more about connecting with *Device Configuration Utility* see Section 8.1, *Device Configuration Utility* (p. 11). Using *Device Configuration Utility*, set the radio's **Active Interface** setting to **USB**. If using the base radio to connect to a CR200 series, you will also need to change the **Power Mode** setting to **1 Sec**. The **Power Mode** setting should match that of the device you are connecting to. **Apply** the change(s), close *Device Configuration Utility*, 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.

- From the EZ View of the *LoggerNet Setup* screen, press **Add**, select your datalogger type, enter a name for your datalogger, and press **Next**.
- Under **Connection Type**, select **Direct Connect**. Press **Next**.
- Under **COM Port Selection**, select the port designated as **RF401A-Series**.
- 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**.
- Under **Datalogger Settings – Security**, enter any security codes that have been previously configured in the datalogger, if any. Press **Next**.
- Review the **Communication Setup Summary** and verify that all settings are correct. Press **Next**.

- On the **Communication Test** screen, select **Yes** and press **Next** to verify that you are able to communicate with your datalogger. If you are unable to communicate, press the **Previous** button and review your settings. Once you have successfully communicated with your datalogger, press the **Finish** button.
- 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 RF401A-series radios reduce susceptibility to RF interference from other spread spectrum devices by providing user-selectable frequency hopping patterns.

The RF401A-series radios can provide up to one mile transmission range when using an inexpensive whip antenna. The radios can provide up to 10 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. 9).

5.1 Retired Radios

5.1.1 RF401-Series and RF430-Series Radios

In June 2014, the RF401A and RF411A replaced the RF401 and RF430, and RF411 and RF431, respectively. It should be noted that the RF401-series and RF430-series radios have a maximum transmit power of 100 mW. The RF401A-series radio has a maximum transmit power of 250 mW, configurable via software. Please ensure that when replacing an existing RF401-series or RF430-series radio with an RF401A-series radio that the legal transmit power limits are not exceeded with existing cabling and antenna configuration.

5.1.2 RF400-Series Radios

The RF401A series have a choice of three communication protocol settings: Transparent, PakBus Aware, and PakBus Node. Transparent is the protocol used by the RF400, RF410, and CR205. RF401-series radios in networks that also have RF400-series radios must use the Transparent protocol setting.

CAUTION

Do not mix the Transparent protocol with any of the PakBus® protocols. This will produce RF traffic without any RF communications.

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

RF401A: 910 to 918 MHz

RF411A: 920 to 928 MHz

Transmit Power Output: 5 to 250 mW, software selectable

Receiver Sensitivity: -109 dBm

Channel Capacity: 7 hop sequences share 25 frequencies

RF Data Rate: 10 kbps

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

Transmit: < 80 mA (250 mW TX Power)

Receive: 15 mA

Stand-by: < 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 Master communication modes

Does not support Modem Enable Peripheral mode

Diagnostics

LEDs: Power/Tx, Rx

Received Signal Strength Indicator for Last Packet (PakBus® mode)

Retransmit Failure Counter (PakBus® mode)

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

(RF411A Only) Australia C-Tick: N3013

RoHS

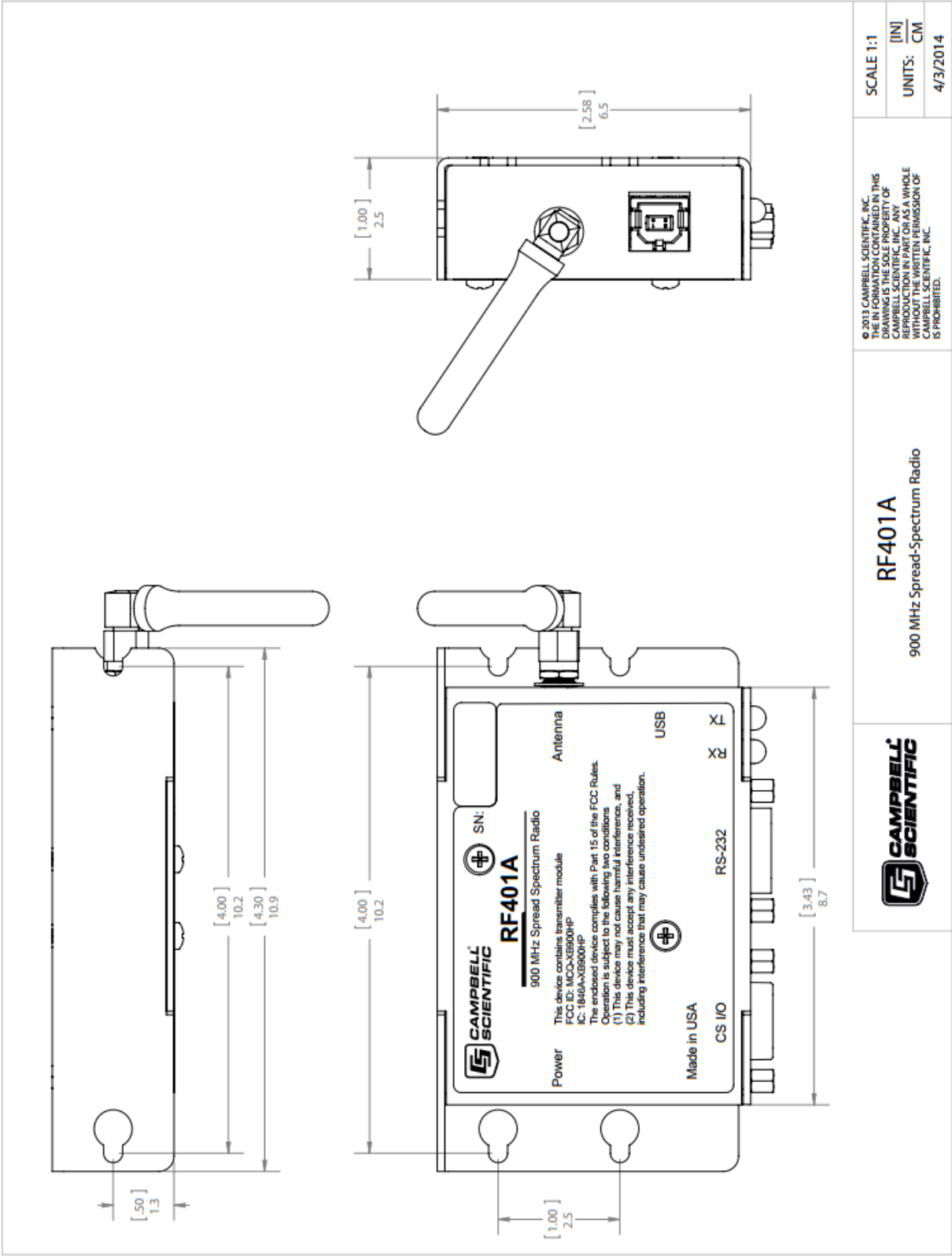


FIGURE 6-1. RF401A-series dimensions

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 RF401A 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 16.5 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 *Device Configuration Utility* from our website. Under **Device Type**, select **Radio | RF401A 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 “RF401A 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 *Device Configuration Utility* for radio configuration.

The USB interface is only available for operational, network communication when the radio’s **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 the *Device Configuration Utility*.

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. 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 RF401A series, O = Signal out of the RF401A 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 *Device Configuration Utility*.

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 RF401A series, O = Signal out of the RF401A series		

7.6 LEDs

The radios have a red LED labeled **Pwr/TX** and a green LED labeled **RX**. When 12V power is applied, the red LED lights for ten seconds. About three seconds after power-up, the green LED lights for a second. Ten seconds after power-up, the selected standby mode begins to control the red LED.

The red LED lights to indicate when the receiver is actively listening. When the receiver detects RF traffic (header or data with the same hopping sequence), the red LED will light steadily. When radio is transmitting, the red LED will pulse OFF as the RF packets are transmitted (it will not be on solid).

Green LED activity indicates that there is an RF signal being received whose hopping sequence corresponds to the configured hopping sequence of the RF401A series. This does not necessarily mean that the network/radio address of the received packet corresponds with that of the RF401A series. (Where a neighboring network exists it is a good idea to choose a unique hopping sequence.)

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 RF401A 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 out of doors 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 RF401A-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 RF401A-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 RF401A Series

8.1 Device Configuration Utility

Device Configuration Utility is the primary tool for configuring the radio. *Device Configuration Utility* version 2.08 or later is required. *Device Configuration Utility* 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 the *Device Configuration Utility*, select **Radio | RF401A Series** under **Device Type**. Click the **Install the USB device driver** link and follow the prompts.

- Open *Device Configuration Utility*.
- Under **Device Type**, select **Radio | RF401A Series**.
- Carefully review the Connect Instructions text provided on the right.
- 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.
- Click the browse button next to **Communication Port**.
- Select the port labeled **RF401A-Series**.
- Click **OK**.
- Click **Connect**.
- Configure the radio as needed for your application. See Section 11, *Operation (p. 17)*.
- 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.

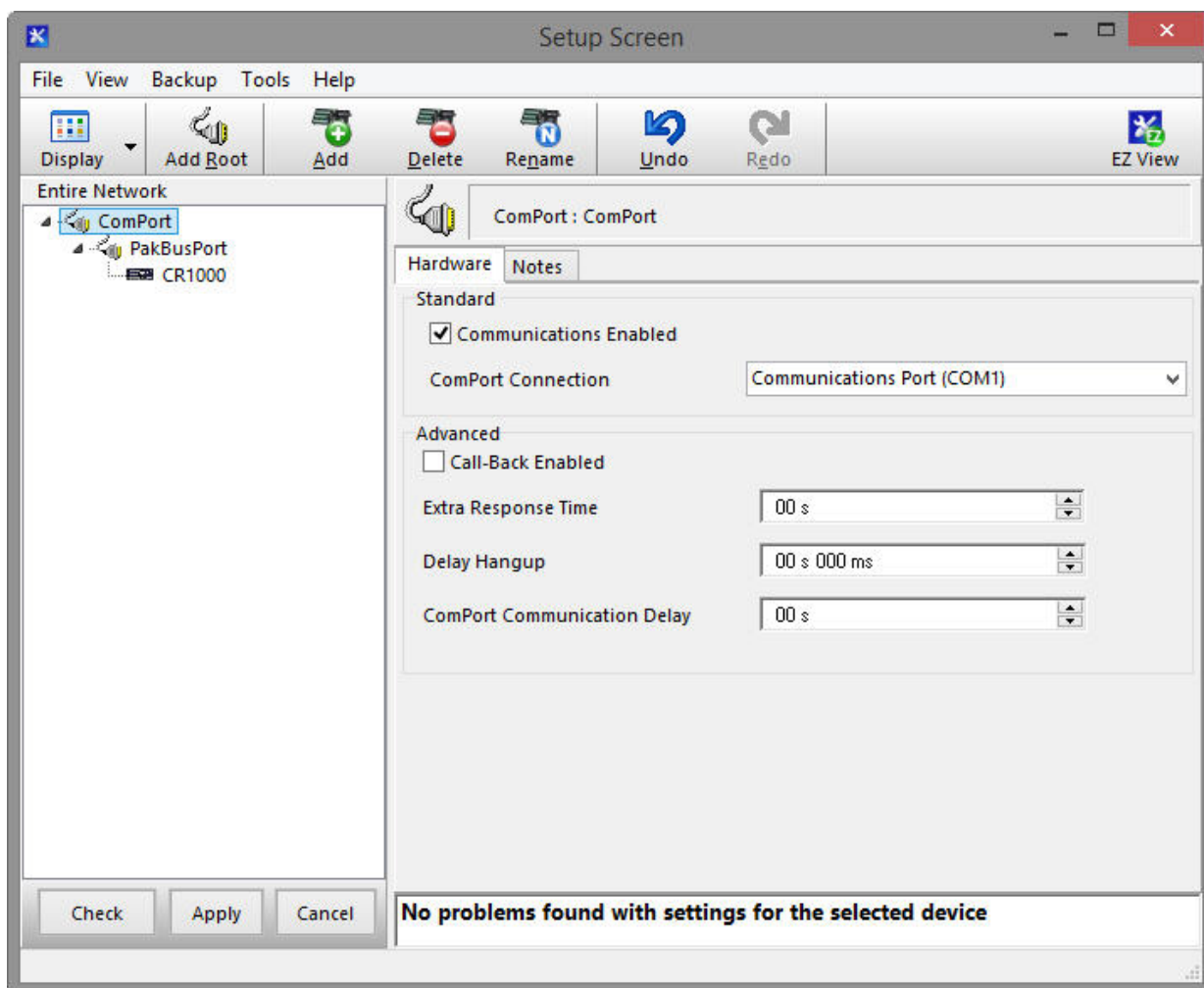
9. LoggerNet Setup

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:

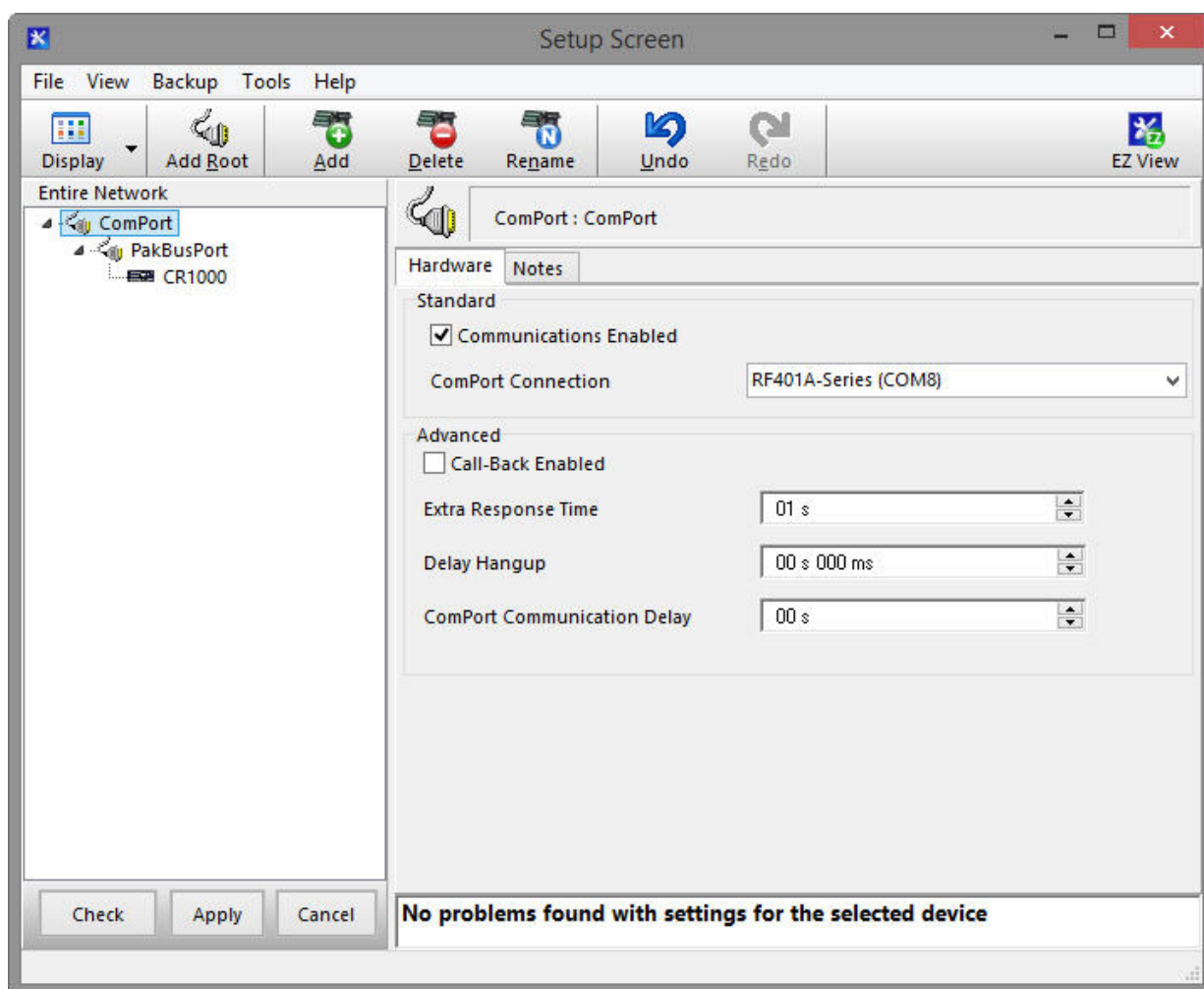
- ComPort
- PakBusPort
- Your datalogger

Finally, click the **Close** button on the **Add** submenu. Your setup tree should appear as shown below:

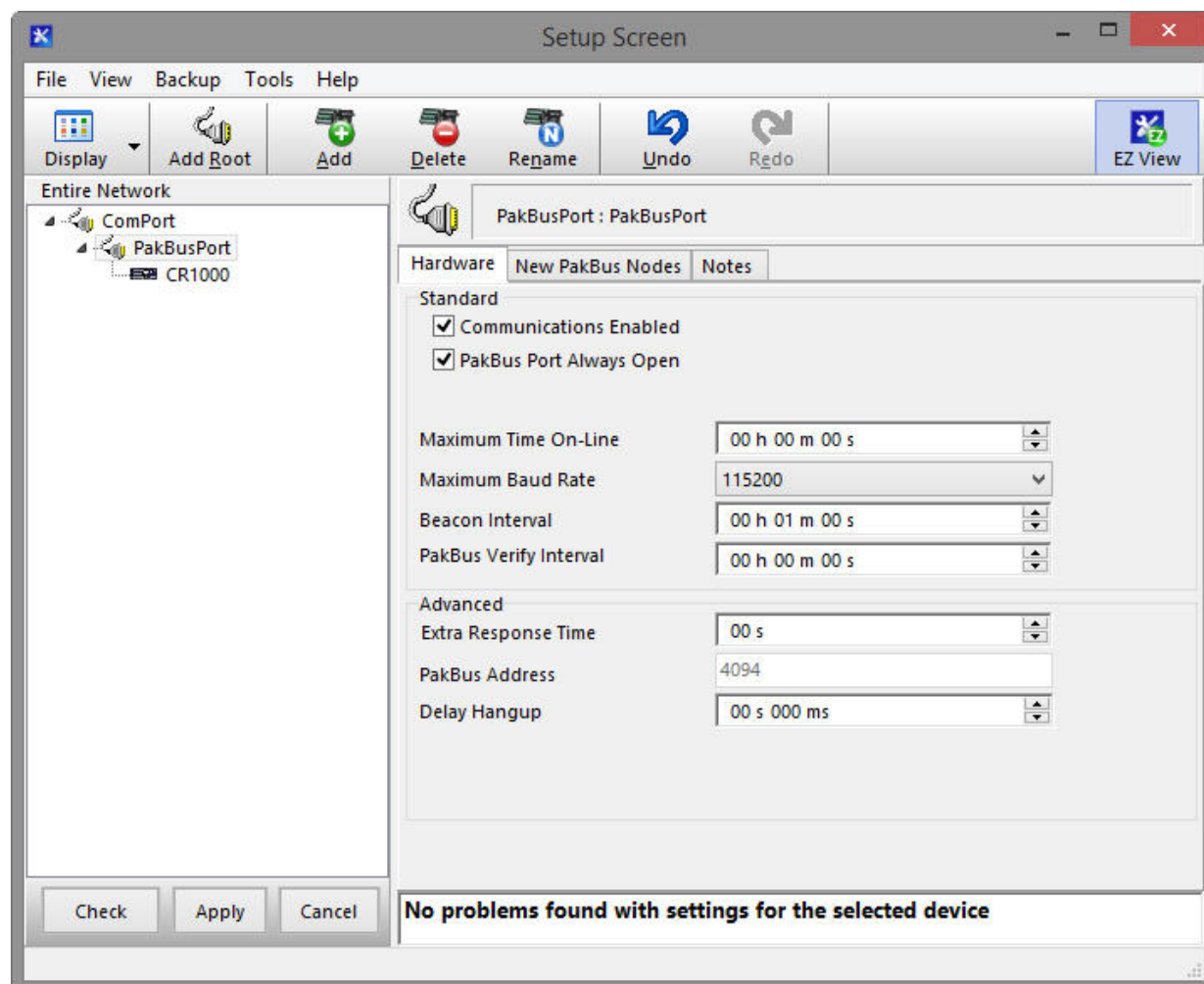


With the setup tree entered, you will now need to complete the configuration of each element. Start with selecting the **ComPort** element at the root of the tree. Under **ComPort Connection**, select port labeled **RF401A-Series**.

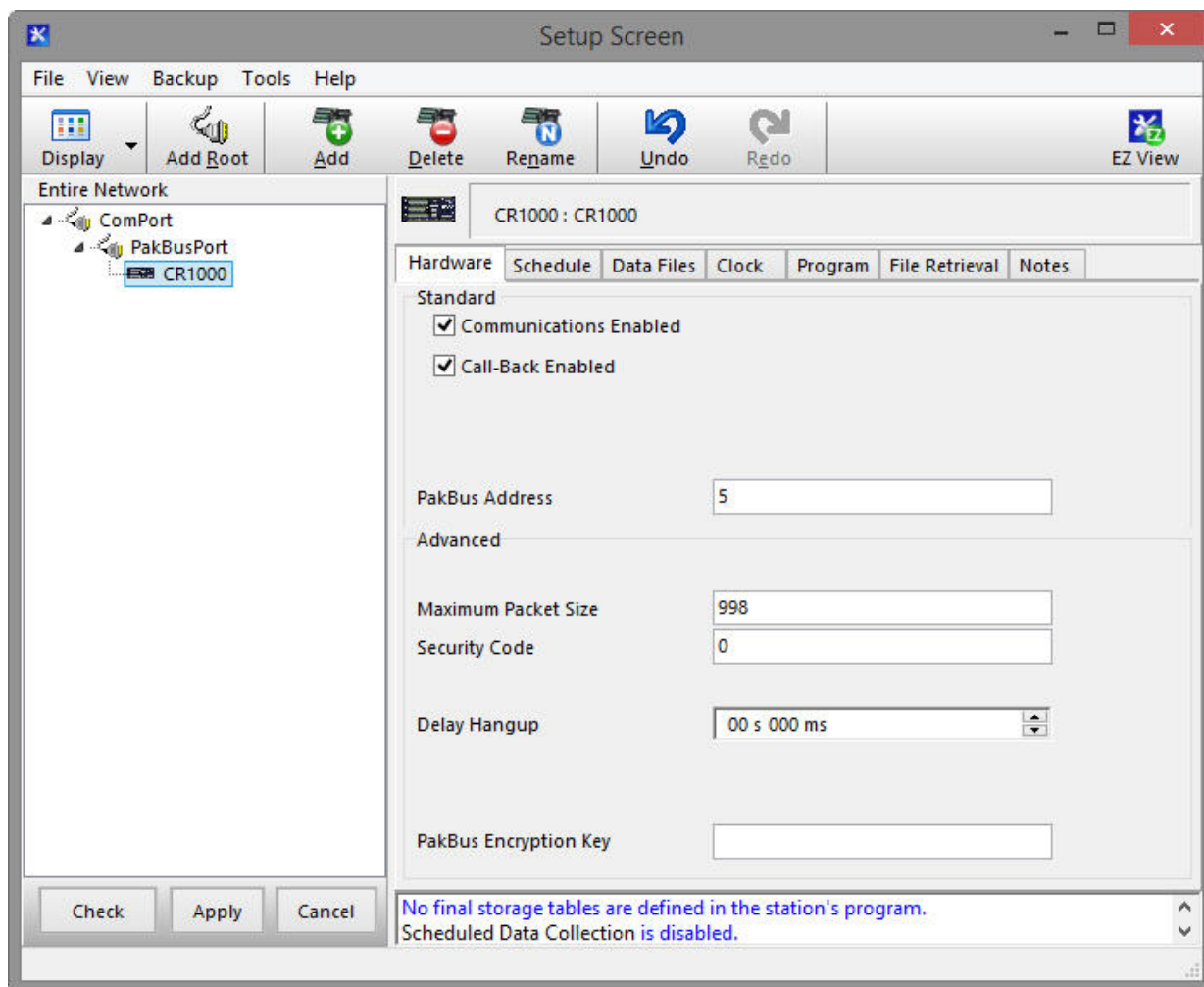
Set the **Extra Response Time** to match the **Power Mode** of the RF401A series. The image below is for a radio with **Power Mode** set to **1 sec**.



Select the **PakBusPort** element in the tree, and select the **PakBus Port Always Open** checkbox. Set the **Maximum Baud Rate** to **115200**.



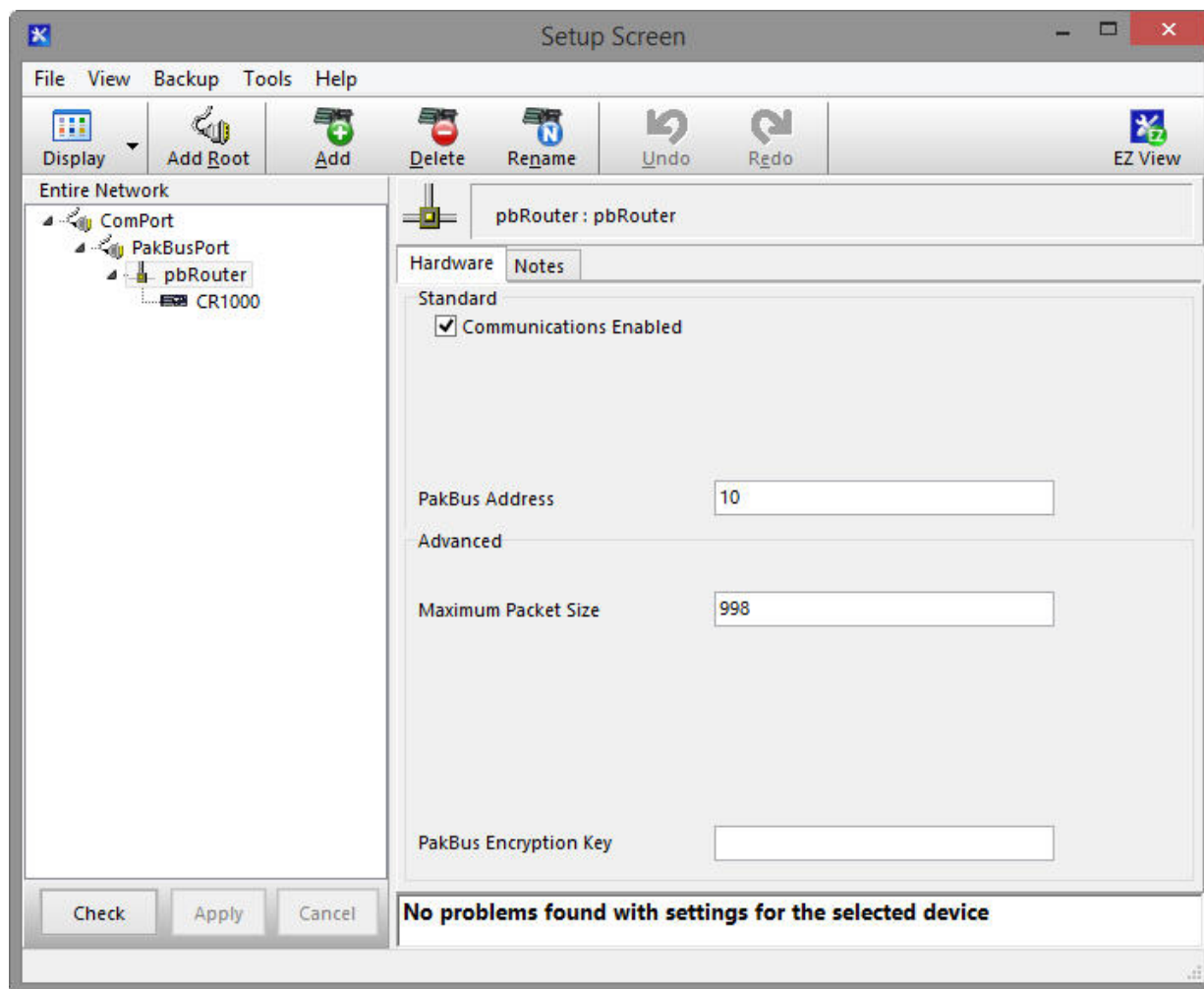
Finally, select your datalogger in the tree. Set the **PakBus Address** field to the PakBus® address of your datalogger. Enter the **Security Code**, if security has been set up in your datalogger.



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 RF401A-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 RF401A 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 that 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 RF401A-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 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 and the advanced settings RS-232 Parity, Stop Bits, Character Length, and Auto Power Down.
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 stand-alone 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 ME Baud Rate.

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, and it must be used when communicating with other transparent devices such as the RF400/410/415 and CR205/210/215. 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 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 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 RF Network

Specifies the RF network. This setting must match in all radios in the same RF network. Valid entries are 0 to 3 for radios with Protocol set to PakBus Aware or PakBus Node. Valid entries are 0 to 63 for radios with Protocol set to Transparent.

11.1.7 RF Radio Address

Specifies the radio address. The radio address is only used when Protocol is set as Transparent. Radios must have matching radio addresses in order to communicate. Valid addresses are 0 to 1023.

11.1.8 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	Description
Always on, No Header	< 15 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.
Always on, 1 Sec Header	< 15 mA	The radio receiver is always on. A wakeup header of 1.2 seconds is transmitted at the beginning of the first transmission occurring after a period of RF inactivity to ensure that other radios in the network set to a 1 second mode are awake and ready to communicate. Using this setting is uncommon, generally only used in a base radio that communicates with a CR200-series datalogger configured with a power mode of “1 second” (no header).
Always on, 8 Sec Header	< 15 mA	The radio receiver is always on. A wakeup header of 8.2 seconds is transmitted at the beginning of the first transmission occurring after a period of RF inactivity to ensure that other radios in the network set to an 8 second mode are awake and ready to communicate. Using this setting is uncommon, generally only used in a base radio that communicates with a CR200-series datalogger configured with a power mode of “8 second” (no header).

Power Mode	Typical Avg. Current Draw	Description
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 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 the most common setting in networks that contain CR200(X)-series dataloggers.
8 Second	< 0.3 mA	The radio receiver is turned on every 8 seconds for 100 milliseconds to look for RF activity. The radio transmits an 8.2 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 an average an additional 1 to 1.5 mA is essential.

11.1.9 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	Random Delay Slots	Transmit Timer
None	0	0	65535
Low	3	1	400
Medium	5	2	400
High	7	3	400

NOTE

Set Retry Level to None when Protocol is set to Transparent for the purpose of communicating with RF400/RF410 radios, CR205/CR210 dataloggers, or RF401/RF411 radios and CR206/CR211 dataloggers with Protocol also set to Transparent.

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.

11.1.10 Radio TX Power Level

This setting specifies the power level at which the RF module transmits. Levels are approximate.

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 RF401A series will use as a **Central Router**. A valid setting is a single address between 1 and 4094. When set, the RF401A 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 RF401A 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 RF401A 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 RF401A series.

11.3 Advanced

11.3.1 Serial Number

Stores the serial number of the device.

11.3.2 Operating System Version

Device operating system version

11.3.3 Radio Firmware Version

Radio firmware version

11.3.4 Received Signal Strength

Indicates the signal strength of the last packet received addressed to this radio and with a valid CRC. The range of values reported, generally between 6 and 54, represent the approximate range from -110 dBm to -35 dBm with each

value representing a little less than 2 dB. The table below displays signal strength values and the corresponding dBm level. 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

Appox. Signal Level (dBm)	Indicator Value
-35	50
-40	49
-45	48
-50	47
-55	46
-60	45
-65	44
-70	42
-75	41
-80	39
-85	37
-90	34
-95	30
-100	24
-105	17
-108	11

Accessing the received signal strength indicator (RSSI)

- Direct connection –
Using a direct connection from the PC to the RF401A USB port, *DevConfig* can be used to view the received signal strength indicator (RSSI). Once a connection is established using *DevConfig*, the **Received Signal Strength** can be located under the **Advanced** tab.
- Datalogger Query –
The RF401A must be set up as a PakBus Node using *DevConfig*. Under the **Main** tab, set the **Protocol** to **PakBus Node**. This setting makes the RF401A an independent device in the network. The RF401A 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 RF401A last received communication from. A datalogger can request the RSSI information from any RF401A node in the network as long as there is a known communication route. Once the datalogger has received the RSSI information, 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 RF401A 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** (RF401A must be running OS Version OBJ30596V05.obj or greater) – The RF401A series must be configured as a PakBus node using *DevConfig*. Under the **Main** tab, set the **Protocol** to **PakBus Node**. This setting makes the RF401A an independent device in the network. The RF401A series must also be given a unique **PakBus Address** under the **PakBus** tab. The RSSI and radio settings can be remotely accessed for any RF401A 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 RF401A last received communication from will both be displayed in the same field.

11.3.5 Retransmit Failures

Records the number of retransmit failure.

11.3.6 ME Baud Rate

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

11.3.7 RS-232 Parity

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

11.3.8 RS-232 Stop Bits

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

11.3.9 RS-232 Character Length

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

11.3.10 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.

11.3.11 AT Sequence Character

Specifies the character that should be sent three times sequentially in order to put the modem in “local” mode.

11.3.12 Silence Time Before Command Sequence

Specifies the amount of time (in tenths of seconds) that the RS-232 interface must be silent after accepting the AT command sequence before the RF401A series will enter command mode.

11.3.13 Silence Time After Command Sequence

Specifies the amount of time (in tenths of seconds) that the RS-232 interface must be silent after accepting the AT command sequence before the RF401A series will enter command mode.

11.3.14 AT Command Mode Timeout

Specifies the amount of time (in tenths of seconds) that must elapse with no activity on the RS-232 interface before the RF401A series exits command mode automatically.

11.3.15 Net Address Mask

Specifies the network portion of the address mask.

11.3.16 Radio Address Mask

Specifies the radio address portion of the address mask.

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 RF401A-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 RF401A series depends on a number of factors that are unique to every installation. These unique factors are the path of propagation, relative antenna elevations, and the link budget.

PATH OF PROPAGATION

Signal loss associated with the path of propagation (path loss) is often the single, largest factor determining system performance. The reflection, diffraction, or attenuation of the propagating RF wavefront due to terrain or man-made obstacles in the path of propagation can significantly reduce the level of signal reaching the receiver. For optimal performance, one should make every effort to achieve an unobstructed line-of-sight path between radios. For an in-depth discussion on the effects of obstructions in the path of propagation as well as methods for predicting the induced signal loss, refer to the Campbell Scientific application note [Line of Sight Obstruction](#).

ANTENNA ELEVATIONS

The relative elevation of the transmitting and receiving antennas—to the surrounding terrain as well as to each other—plays a critical role in determining the maximum link distance. Greater antenna elevations not only provide greater obstacle clearance, but also increase the maximum unobstructed line-of-sight distances over apparently flat terrain. For example, given 10-foot antenna elevations for both ends of a link and flat, level terrain, the maximum allowable distance between the antennas before the curvature of the earth begins to obstruct the RF line of sight is approximately 9 miles. Increasing the elevation of one or both antennas will increase the maximum line-of-sight distance.

LINK BUDGET

A link budget is the summation of the systems gains and losses and provides a means of estimating the signal level arriving at the receiver. By comparing the signal level reaching the receiver with the signal level required by the receiver to produce a minimal level of performance, one can estimate the link's fade margin. The fade margin—received signal level in excess of the receiver's sensitivity—provides a measure of the link's operational viability. The greater the fade margin, the greater the potential long-term reliability. A minimally acceptable fade margin is 10 dB. For optimal system performance and reliability, it is generally recommended that one should design for a fade margin of 20-30 dB. For detailed information on calculating a link budget and fade margin, see the Campbell Scientific application note [The Link Budget and Fade Margin](#).

B.2 How Far Can You Go?

Estimating Distance for Spread Spectrum Radios

B.2.1 Overview

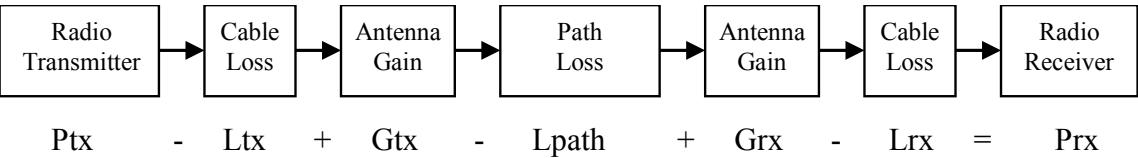
Because the factors affecting communication distance are different for every system, a generalized estimate of distance cannot be stated with any practical degree of accuracy. Reasonable estimates of distance can only be achieved by means of a case-by-case analysis and accounting of these factors. The link budget is a simple and convenient tool for this purpose.

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.

B.2.2 Link Budget

In any RF system, there are gains and losses. Gains most commonly derive from the relative gain of the transmitting and receiving antennas. In some cases, an in-line RF amplifier may be used to provide additional system gain, but this is rare and not typical of Campbell Scientific installations. Losses derive from the attenuation of the RF signal as it propagates through the transmission lines (coaxial cables, surge suppressor, etc.) connecting the transmitter and receiver to their respective antennas, and more importantly, as it traverses the path of propagation between the antennas (path loss).

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



Where:

- P_{tx} = transmitter output power, in dBm (24 dBm in the case of the RF401A series at maximum transmitter power)
- L_{tx} = cable loss between transmitter and antenna in dB (see Appendix B.2.4, *Cable Loss* (p. B-3))
- G_{tx} = transmit antenna gain in dBi (dBi = dBd + 2.15)
- L_{path} = path loss between antennas in dB (see TABLE B-5, TABLE B-6)
- G_{rx} = receive antenna gain in dBi
- L_{rx} = cable loss between antenna and receiver in dB
- P_{rx} = signal power at the radio receiver in dBm

Most of these values can be readily obtained from data sheets or direct measurements. The notable exception is path loss. Path loss is very difficult to derive analytically. Probably the best approach is to do a site survey that considers the topography, elevation, and location of the antennas, any potential obstructions to the line of sight, and make some assumptions about the path losses (see the Campbell Scientific application note *Line of Sight Obstruction*).

NOTE

If losses due to obstructions in the line-of-sight path of propagation are anticipated and a highly reliable link is required, it is strongly recommended that a professional path study be conducted before proceeding with the installation.

By algebraically summing the transmitters output power with the links gains and losses, the signal power at the receiver's input (Prx) can be estimated. If Prx is greater than the receiver's sensitivity (−109 dBm for the RF401A), a connection is possible. The amount by which Prx exceeds the receiver's sensitivity is the fade margin. A minimum fade margin of 10 dB is recommended for a reliable link.

B.2.3 Transmitter Power

Transmitter output power is often expressed in dBm, which is a decibel power rating relative to 1 mW. The conversion formula between transmitter power in mW (Pt) and transmitter power in dBm (Ptx) is:

$P_{tx} \text{ (in dBm)} = 10 \log (P_t)$ with Pt expressed in mW

TABLE B-1. Transmitter Power	
Transmitter Power (Pt) (milliWatts)	Ptx dBm
1	0
5 (RF401A series minimum)	7
10	10
50	17
100	20
250 (RF401A 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 at a given frequency. Using a low loss cable becomes more important as the cable run distances increase. Here are some typical cable types and their properties:

TABLE B-2. Cable Loss		
Cable Type	Outside Diameter	Loss (dB/100 ft) @ 900 MHz
RG-58A/U	0.195 in	21.1
COAX RPSMA-L	0.195 in	11.1
RG-8	0.405 in	6.9
COAX NTN-L	0.405 in	4.5
LMR-400	0.405 in	3.9
*CSI stocked antenna cables are shaded.		

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

TABLE B-3. 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

Increasing antenna gains improves signal strength and, potentially, distance. For example, in the context of free space path loss and all other factors being equal, an increase of 6dB in antenna gain theoretically extends the attainable distance by a factor of 2. An antenna's gain is a function of directivity. For highly directive antennas such as the Yagi, the narrower beam width makes antenna alignment and orientation more critical.

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:

$$\text{dBi} = \text{dBd} + 2.15$$

Some antennas that are FCC approved for use with the RF401A series are:

TABLE B-4. Antenna Gain of Recommended Antennas							
Mfg.	Antenna Type	Band	Model	CSI 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 RF401A series is specified at -109 dBm at $\sim 10^{-4}$ raw BER.

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 fade margin, and is a very good thing; a minimum of 10 dB of fade margin should be sought.

B.2.7 Path Loss

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

$$L_p (\text{dB}) = 32.4 + 20 \times \log(f) + 20 \times \log(d) \quad \text{dB} \quad (f \text{ in MHz, } d \text{ in km})$$

$$L_p (\text{dB}) = 36.6 + 20 \times \log(f) + 20 \times \log(d) \quad \text{dB} \quad (f \text{ in MHz, } d \text{ in miles})$$

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

TABLE B-5. 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, also, 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 greater the antenna elevations relative to the terrain in the line-of-sight path, the closer to free space conditions. Antenna height is everything!

B.3 Real World Distance Estimates

It is clear from the above discussion that free space path loss should seldom be used as the basis for estimating real world distance.

Ground Reflections

As discussed in Section 5 of the Campbell Scientific application note [The Link Budget and Fade Margin](#), ground reflections will almost always be a factor in terrestrial RF telemetry links. These are caused by the RF signal being reflected from the ground (or water), and undergoing a phase shift so that it destructively or constructively 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. This phenomenon gives rise to the 2-Ray Multipath Propagation Model for estimating real world distances.

The path geometry defined by the relative elevations of the antennas and the distance between the antennas is a significant factor in determining the degree of interference from the reflected wave. The terrain along the path of propagation is always assumed to be relatively flat and smooth.

The equation for estimating path loss using the 2-Ray propagation model is:

$$L_{\text{path}} (2\text{-Ray}) = 120 - 20\log(h_{\text{tx}} \cdot h_{\text{rx}}) + 40\log(d) \quad (h \text{ in meters, } d \text{ in km})$$

TABLE B-6 compares path loss (L_{path}) calculations for the free space and 2-Ray propagation models. The antenna elevations used for the 2-Ray path loss are 9 m (30 ft) and 3 m (10 ft) respectively.

TABLE B-6. 915 MHz Distance vs. Path Loss (L_{path} in dB) per Two Propagation Models*										
Path Type	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
Free Space	102	108	111	114	116	119	121	123	124	125
2-Ray	112	124	131	136	140	145	150	153	156	159
*(30 ft and 10 ft antenna elevations)										

Often the maximum path distance may be constrained more by the antenna elevations than the path loss. This is because the maximum unobstructed line of sight distance in kilometres over a flat earth is defined by the following equation:

$$LOS_{\text{MAX}} = (4.124\sqrt{h_1}) + (4.12\sqrt{h_2}) \quad (h \text{ is in meters})$$

For the preceding antenna elevations, the maximum unobstructed line-of-sight distance is 19.5 km (12 miles).

TABLE B-7 helps select a Path Type in TABLE B-6 to best fit your situation.

TABLE B-7. Path Type vs. Path Characteristics Selector	
Path Type	Path Characteristics
Free Space	Mountaintop to mountaintop or Tall antenna towers Line of sight
2-Ray	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 RF401A-series 900 MHz radio at maximum transmitter power, and will use -109 dBm as the required power level at the radio receiver.

Here's the equation we will use, from Appendix B.2.2, *Link Budget* (p. B-2):

$$P_{tx} - L_{tx} + G_{tx} - L_{path} + G_{rx} - L_{rx} = P_{rx}$$

As previously stated, the amount by which P_{rx} exceeds the receiver's sensitivity is the fade margin. Therefore, in this example:

$$\text{Fade margin} = P_{rx} - (-109 \text{ dBm})$$

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?

$$P_{tx} = 24 \text{ dBm}$$

$$L_{tx} = 20 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 2.22 \text{ dB}$$

$$G_{tx} = G_{rx} = 3 \text{ dBd} = 5.15 \text{ dBi}$$

$$L_{rx} = 10 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 1.11 \text{ dB}$$

From Appendix B.3, *Real World Distance Estimates* (p. B-5), we know:

$$L_{path} (2\text{-Ray}) = 120 - 20\log(h_{tx} \cdot h_{rx}) + 40\log(d) \quad (h \text{ in meters, } d \text{ in km})$$

$$L_{path} (2\text{-Ray}) = 120 - 20\log(3.05 \cdot 3.05) + 40\log(1.609 \cdot d \text{ in mi})$$

$$L_{path} (2\text{-Ray}) = 120 - 19.37 + 40\log(1.609 \cdot d \text{ in mi})$$

$$L_{path} (2\text{-Ray}) = 100.36 + 40\log(1.609 \cdot d \text{ in mi})$$

Using the above equation to calculate L_{path} at different distances, gives:

TABLE B-8. L_{path} vs. Distance for 2-Ray Propagation Model in Example #1										
Distance	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
L_{path}	121	133	140	145	149	155	159	162	165	168

Now we will calculate the fade margin for each distance:

$$\text{Fade margin} = P_{rx} - (-109 \text{ dBm})$$

$$\text{Fade margin} = P_{tx} - L_{tx} + G_{tx} - L_{path} + G_{rx} - L_{rx} + 109 \text{ dBm}$$

$$\text{Fade margin} = 24 - 2.22 + 5.15 - L_{path} + 5.15 - 1.11 + 109$$

$$\text{Fade margin} = 140 - L_{path}$$

Using the Lpath values from TABLE B-8, gives:

TABLE B-9. Fade Margin (dB) vs. Distance for 2-Ray Propagation Model in Example #1										
Path Type	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
2-Ray	19	7	0	-5	-9	-15	-19	-22	-25	-28

From TABLE B-9 we see that this link should be very reliable up to a distance of 2 miles and reasonably reliable at a distance of 4 miles. LOS_{MAX} for this link is approximately 9 miles, so it would be possible to increase distance by substituting higher gain antennas.

Example #2

Base has MaxRad BMOY8905 Yagi, with 50 ft of LMR195 cable on a 30 ft tower, also a surge suppressor (lightning protection device) with a 0.34 dB loss; 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?

$$\begin{aligned} P_t &= 24 \text{ dBm} \\ L_t &= 50 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 5.55 \text{ dB} \\ G_t &= 9 \text{ dBd} = 11.15 \text{ dBi} \\ L_r &= 5 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 0.55 \text{ dB} \\ G_r &= 9 \text{ dBd} = 11.15 \text{ dBi} \end{aligned}$$

Need to include an additional loss from the surge suppressor:

$$L_{ss} = 0.34 \text{ dB loss.}$$

From Appendix B.3, *Real World Distance Estimates (p. B-5)*, we know:

$$L_{\text{path}} (2\text{-Ray}) = 120 - 20\log(h_{tx} \cdot h_{rx}) + 40\log(d) \quad (h \text{ in meters, } d \text{ in km})$$

$$L_{\text{path}} (2\text{-Ray}) = 120 - 20\log(9.14 \cdot 1.22) + 40\log(1.609 \cdot d \text{ in mi})$$

$$L_{\text{path}} (2\text{-Ray}) = 120 - 20.95 + 40\log(1.609 \cdot d \text{ in mi})$$

$$L_{\text{path}} (2\text{-Ray}) = 99.05 + 40\log(1.609 \cdot d \text{ in mi})$$

Using the above equation to calculate Lpath at different distances, gives:

TABLE B-10. Lpath vs. Distance for 2-Ray Propagation Model in Example #2										
Distance	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
Lpath	119	131	138	143	147	153	157	161	164	166

Now we will calculate the fade margin for each distance:

$$\text{Fade margin} = P_{rx} - (-109 \text{ dBm})$$

$$\text{Fade margin} = P_{tx} - L_{tx} + G_{tx} - L_{\text{path}} + G_{rx} - L_{rx} - L_{ss} + 109 \text{ dBm}$$

$$\text{Fade margin} = 24 - 5.55 + 11.15 - L_{\text{path}} + 11.15 - 0.55 - 0.34 + 109$$

$$\text{Fade margin} = 149 - L_{\text{path}}$$

Using the L_{path} values from TABLE B-10, gives:

TABLE B-11. Fade Margin (dB) vs. Distance for 2-Ray Propagation Model in Example #2										
Path Type	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
2-Ray	30	18	11	6	2	-4	-8	-12	-15	-17

From TABLE B-11 we see that this link should be very reliable up to a distance of 6 miles and somewhat reliable at a distance of 8 miles. LOS_{MAX} for this link is approximately 10.5 miles, so increasing antenna gain would not provide much of an increase in distance. However, increasing antenna elevation at one or both ends of the link could be beneficial.

Example #3

You need to run 125 ft of cable for the transmitter:

How much loss if I use LMR195 cable? $125 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 13.9 \text{ dB}$

How much loss if I use LMR400 cable? $125 \text{ ft} \cdot (3.9 \text{ dB}/100 \text{ ft}) = 4.9 \text{ dB}$

If I am using path loss from the 2-Ray model, and operating fine at 8 miles with LMR195 cable, how much more fade margin could I expect if I use LMR400 cable (assuming similar terrain and antenna elevations)?

$$13.9 \text{ dB} - 4.9 \text{ dB} \Rightarrow 9 \text{ dB more fade margin}$$

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