

INSTRUCTION MANUAL



RF451 Spread Spectrum Radio

Revision: 3/18



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- **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**.
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- Use appropriate equipment and safety practices.
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- 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.

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RF451 Spread Spectrum Radio

1. Introduction

The RF451 Spread Spectrum Radio is a 900 MHz license-free radio specifically designed to work with Campbell Scientific dataloggers and existing RF450/RF451 networks. RF451 radios consist of a FreeWave® MM2 LV-T radio module and an interface board.

This manual addresses the RF451 interface with CR1000X, CR300, CR6, CR3000, CR1000, and CR800-series dataloggers and a PC running *LoggerNet*. Though the radios may be set up in a point-to-point mode, this manual will only address multi-point applications, as this is the only way to take advantage of the low-power mode of the slave radios at the datalogger site. This reduces the required power at remote sites from about 75 mA to less than 10 mA in most applications.

Before using the RF451, please study

- Section 2, *Precautions* (p. 1)
- Section 3, *Initial Inspection* (p. 1)
- Section 4, *QuickStart* (p. 2)

2. Precautions

- **IMPORTANT** — Radios must be configured to use the proper hop table version to comply with local laws and to avoid interference with other RF installations such as cellular services. Available hop table versions are listed in the *Device Configuration Utility (DevConfig) Settings Editor* for the RF451. Hop table versions include **North America** (default), **Australia**, **New Zealand**, **Taiwan**, **Brazil**, **International**, and **Notch** (custom). See Appendix C, *Settings Editor* (p. C-1), for more information.
- **READ AND UNDERSTAND** the *Safety* section at the front of this manual.
- 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, *FCC Notifications* (p. A-1), for more information.

3. Initial Inspection

- The RF451 radios ship with an SC12 cable, a USB A to USB B cable (pn 17648), 4 grommets, and 4 screws.
- Upon receipt of the RF451, 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

1. Using *DevConfig* (see Section 7.1, *Using the Device Configuration Utility (p. 5)*), set a unique **PakBus® Address** for each datalogger in the network. Keep the other settings at their default.
2. Decide on a unique **Network ID** between 0 and 4095, excluding 255. All radios in the network will have the same **Network ID**.
3. Select a **Frequency Key** between 0 and 14. It is recommended that you change this from the default value of 5. Generally all radios in the network will have the same **Frequency Key**.
4. Select one radio to be the master; the others will be designated as slaves.
5. Slave Radios: Using *DevConfig*, set the **Radio Operation Mode** to **Multi-Point Slave**. Set the **Network ID** to the number decided upon in step 2 above. Set the **Frequency Key** to the number decided upon in step 3 above. Set the **Radio ID** to the **PakBus Address** assigned in step 1 above. Keep the remaining settings at their defaults. (See note below regarding repeaters.)
6. Master Radio: Using *DevConfig*, set the **Radio Operation Mode** to **Multi-Point Master**. Set the **Network ID** to the number decided upon in step 2 above. Set the **Frequency Key** to the number decided upon in step 3 above. Set the **Radio ID** to the **PakBus Address** assigned in step 1 above. If the master radio will be at PC running *LoggerNet*, set the **Active Interface** to **USB** or **RS-232** depending on how *LoggerNet* will be communicating with the RF451. Keep the remaining settings at their defaults. (See note below regarding repeaters.)
7. Select a datalogger or a PC running *LoggerNet* to be a router. Using *DevConfig*, set this node to beacon. (See Section 7.8, *LoggerNet Software Setup (p. 16)*.) Attach the master radio to this node.

NOTE

If RF450/RF451 repeaters will be used, select **Multi-Point Slave/Repeater** as the **Radio Operation Mode** for all slave/repeaters in the network (that is, radios that are being used as a repeater but also have a datalogger attached). Select **Multi-Point Repeater** as the **Radio Operation Mode** for all standalone repeaters in the network (that is, radios that are being used only as a repeater without a datalogger attached). Check the **Repeaters Used** box for all radios in the network.

5. Overview

Theory of Radio Operation

In a point-to-multi-point network (multi-point network), the transceiver (radio) designated as a master is able to simultaneously communicate with numerous slaves. In its simplest form, a multi-point network functions with the master broadcasting its messages to all slaves, and the slaves responding to the master when given data by the datalogger connected to the data port (see FIGURE 5-1).

NOTE

There may be only one RF451 or RF450 master in a network, and it must be connected to a PakBus® router. The PakBus router may be software, such as *LoggerNet* or *PC400*, or a datalogger configured as a router.

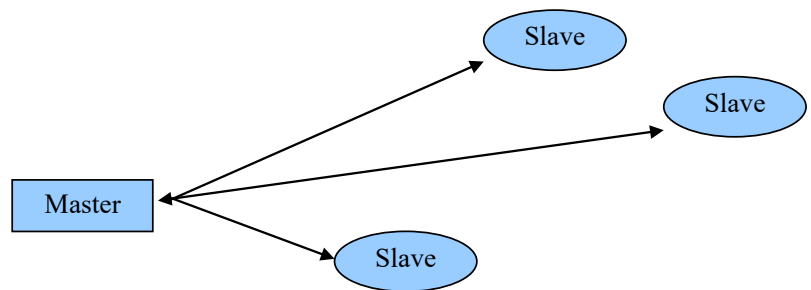


FIGURE 5-1. Simplest Form of a Multi-Point Network

In a multi-point network, outbound packets from the master or repeater to the slaves or other repeaters are sent a set number of times determined by the user. The receiving transceiver, slave or repeater, will accept the first packet received with the correct signature (32-bit CRC). However, the packet is not acknowledged. On the return trip to the master, all packets sent are acknowledged or retransmitted until they are acknowledged. Therefore, the return link in a multi-point network is generally very robust.

Traditionally, a multi-point network is used in applications where data is collected from one to many dataloggers and reported back to one central site. The central site is typically a PC running *LoggerNet*, but could be a datalogger. Refer to Appendix B, *Installation Scenarios (p. B-1)*, for different installation scenarios.

Though the radios may be set up in a point-to-point mode, this manual will only address multi-point applications, as this is the only way to take advantage of the low-power mode of the slave radios at the datalogger site. This reduces the required power at remote sites from about 75 mA to less than 10 mA in most applications.

6. Specifications

Frequency:	902 to 928 MHz
Transmit	
Output Power:	10 mW to 1 W, user selectable
Range:	20 to 25 miles assuming ideal conditions, line-of-sight, and appropriate antenna. Note that line-of-sight obstructions, RF interference, and antenna type will affect transmission distance. Maximum distances can be greatly reduced by vegetation, line-of-sight obstacles, humidity levels, and other environmental and physical factors.
Modulation:	2 level GFSK
Spreading Method:	Frequency hopping
Occupied Bandwidth:	142 kHz (applicable to FCC ID KNYAMM0921TT)
Hopping Patterns:	15 per band, 105 total, user selectable
Hopping Channels:	50 to 111, user selectable
Hopping Bands:	7, user selectable
Frequency Zones:	16 zones
Receive	
Sensitivity:	-108 dBm at 115.2 kbps for 10^{-4} bit error rate -103 dBm at 153.6 kbps for 10^{-4} bit error rate
IF Selectivity:	40 dB at $f_c \pm 230$ kHz
RF Selectivity:	60 dB at 896 MHz, 935 MHz
Dynamic Range:	+10 dBm 3 rd Order Intercept Point at Input Connector
Data Transmission	
Error Detection:	32-bit CRC, retransmit on error
Data Encryption:	Proprietary Spread Spectrum Technology
Link Throughput:	115.2 kbps, max
Data Interface	
Protocol:	RS-232, USB, CS I/O SDC, and CS I/O ME Master; user selectable
RS-232 Baud Rate:	1200 bps, 4800 bps, 9600 bps, 19.2 kbps, 38.4 kbps, 57.6 kbps, 115.2 kbps; user selectable
Connectors:	DB9, USB Type B
Antenna:	RPSMA female connector (external antenna required)
Power Requirements	
Voltage:	7 to 28 Vdc
Current:	Transmit 650 mA Receive 40 mA Idle 15 mA Sleep 6 mA

Environmental

Operating Temperature:	-40 to 85 °C
Dimensions:	2.74 x 7.01 x 13.61 cm (1.08 x 2.76 x 5.36 in)
Weight:	0.18 kg (0.4 lb)
Humidity:	0 to 95% non-condensing

Compliance

FCC ID:	KNYAMM0921TT
Industry Canada (IC):	2329B-AMM0921TT

7. Installation

7.1 Using the *Device Configuration Utility*

Radios are configured using the Campbell Scientific *Device Configuration Utility (DevConfig)* software tool that comes with *LoggerNet* (see FIGURE 7-1). *DevConfig* is also available for free from the Campbell Scientific website. The following general procedure is used to configure an RF451 radio via *DevConfig*:

1. Launch *DevConfig* from the *LoggerNet* toolbar, by double clicking the icon on the Windows® Desktop, or through the Windows Start Menu: **Start | All Programs | LoggerNet | Device Configuration Utility**.
2. From the **Device Type** list, select the **RF451**. Information, instruction, and help are provided on each screen.

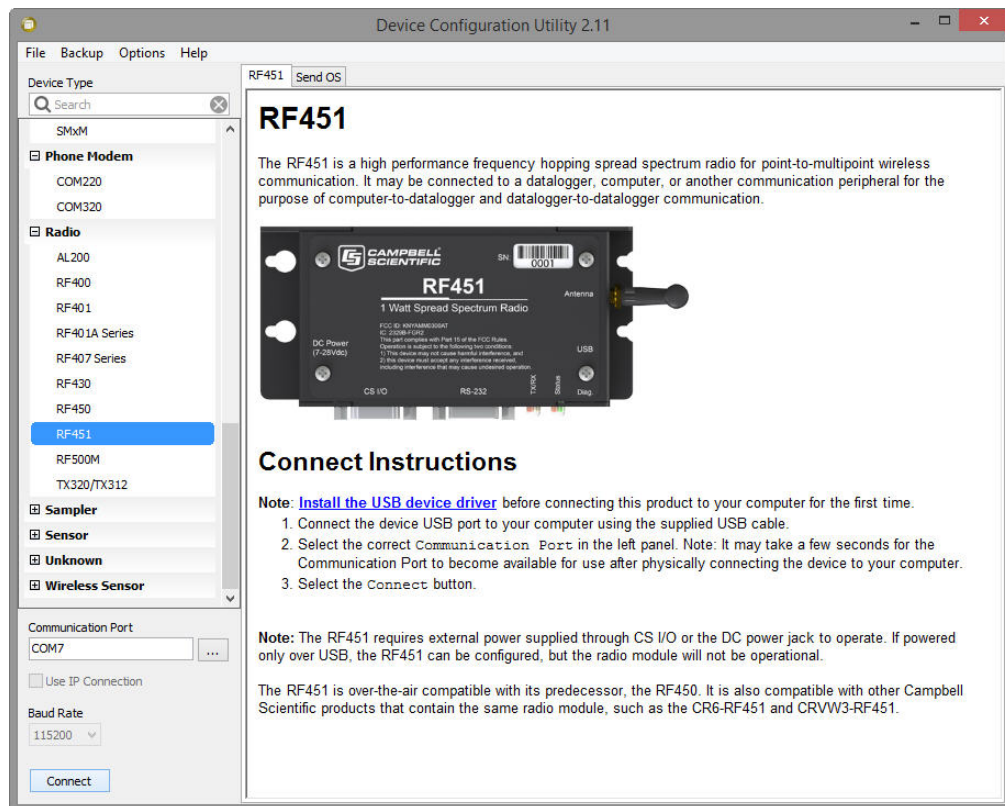


FIGURE 7-1. Startup DevConfig Screen for Configuring the RF451

3. Install the USB device driver for the RF451 by clicking on the blue link on the **RF451** tab. Carefully review the Connect Instructions text provided on the right side of the *DevConfig* screen. This only needs to be done the first time the computer is connected to an RF451.

NOTE

Install the device driver before plugging a radio into your PC for the first time. You will need to have the device driver properly installed before you can connect to the radio via USB.

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. Select the correct COM port for serial communications over USB with the radio using *DevConfig*. It should be listed in the dialog as **RF451 (COM#)** where # is the COM port number.

NOTE

It may take a few seconds for the Communications Port to become available for use after physically connecting the RF451 to your computer.

6. Click **Connect**. The radio **Status** LED will turn yellow. After several seconds, a screen similar to FIGURE 7-2 will appear:

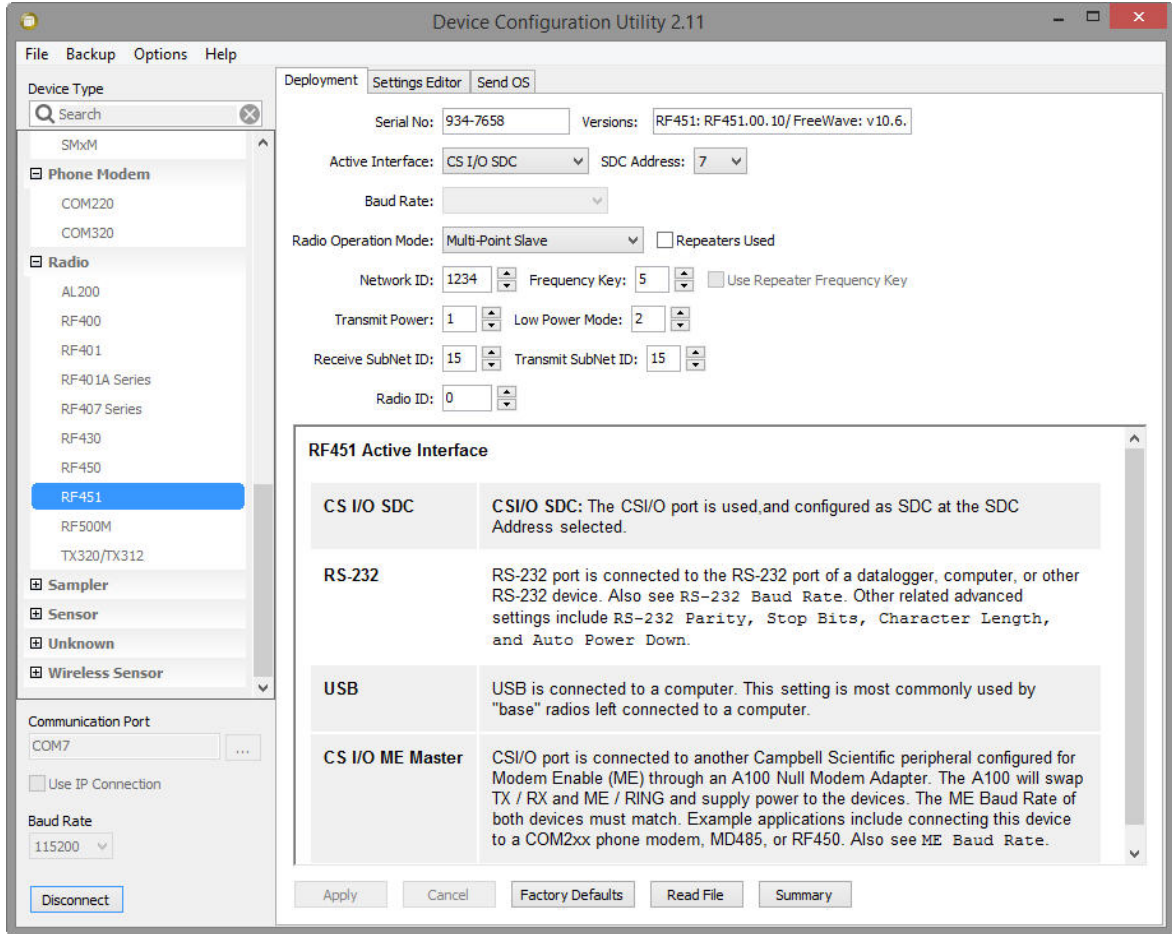


FIGURE 7-2. DevConfig Screen Showing the RF451 Settings

Deployment, **Settings Editor**, and **Send OS** tabs are available. The **Deployment** tab contains all the standard parameters that need to be set for a PakBus® network. The **Settings Editor** tab may be used to access all of the FreeWave® Radio settings. It should be used by experienced FreeWave Radio users only. New operating systems for the Campbell Scientific board are loaded through the **Send OS** tab.

DevConfig makes applying the same settings to multiple devices easy. Once settings are configured for one device, click **Apply**; a summary screen similar to FIGURE 7-3 will be shown. Click **Save** to save a configuration file. This file can then be used to load the settings into another RF451. Click **Read File** to load the settings in *DevConfig*. Then click **Apply** to load the settings into the RF451.

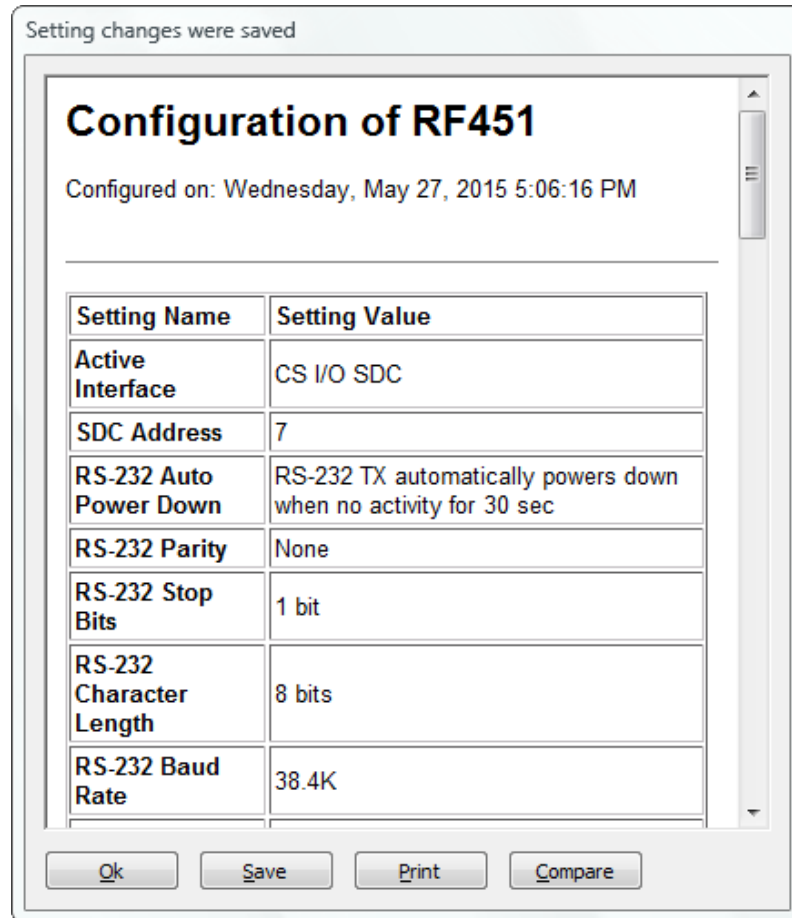


FIGURE 7-3. DevConfig RF451 Summary Screen

7.2 Deployment Settings

This section describes the RF451 **Deployment** tab settings shown in FIGURE 7-2.

NOTE See Appendix B, *Installation Scenarios (p. B-1)*, for example radio settings in different network configurations.

7.2.1 Active Interface

Specify the interface that will be used for normal operations. The following active interfaces are available:

- **RS-232:** The RS-232 port is used at the **Baud Rate** selected.
- **CS I/O SDC:** The CS I/O port is used and configured as SDC at the **SDC Address** selected.
- **CS I/O ME Master:** The CS I/O port is used and configured for direct connection to a CSI COM200, COM210, COM220 or other ME-configured device (MD485, RF416, and so forth). The connection

is a type of “null modem” that crosses TX & RX, and ME & RING; this line swapping is done by using an A100. The baud rates of both the COM2xx (or other device) and the RF451 must be the same.

- **USB:** The USB port is used.

7.2.2 SDC Address

Specifies the SDC address that will be used on the RF451 CS I/O port when **CS I/O SDC** is selected as the **Active Interface**.

7.2.3 Baud Rate

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

7.2.4 Radio Operation Mode

The **Radio Operation Mode** option designates the method FreeWave transceivers use to communicate with each other. FreeWave transceivers operate in a master-to-slave configuration. Before the transceivers can operate together, they must be set up to properly communicate.

In a point-to-point configuration, master or slave mode may be used on either end of the communication link without performance degradation. When setting up the transceiver, remember that a number of parameters are controlled by the settings in the master. Also, radio network diagnostics can only be accessed at the master radio. Therefore, we suggest you deploy the master on the communications end where it will be easier to access.

For a datalogger PakBus network, the multi-point radio modes should be used. For other configurations, the **Operation Mode** will need to be set through the **Settings Editor** tab.

7.2.4.1 Operation Mode Description

Multi-Point Master

This mode designates the transceiver as a master in multi-point mode. This mode allows one master transceiver to simultaneously be in communication with numerous slaves and repeaters. A multi-point master communicates only with other transceivers designated as multi-point slaves or multi-point repeaters.

Multi-Point Slave

This mode designates the transceiver as a slave in multi-point mode. This mode allows the slave to communicate with a multi-point master. The slave may communicate with its master through one or more repeaters.

Multi-Point Repeater

This option allows the transceiver to operate as a repeater in a multi-point network.

Multi-Point Slave/Repeater

This option allows the transceiver to operate as a repeater and a slave in a multi-point network. The radio will repeat packets sent across the network as well as use the active interface. Choosing this setting effectively sets the operation mode to **Multi-Point Repeater** and sets the slave/repeater mode.

Repeaters Used Setting

In a multi-point network, it is critical to transmission timing to configure this parameter correctly. This box should be checked (set to **1** in **Settings Editor**) if there are **any** repeaters in the network. It should be left unchecked (set to **0** in **Settings Editor**) if there are no repeaters present.

This parameter should be set to the same value in all transceivers in a multi-point network.

NOTE This box should be checked (set to **1** in **Settings Editor**) when running diagnostics from the master.

7.2.5 Network ID

All radios in a multi-point network need to have the same **Network ID**. The value must be between 0 and 4095 (excluding 255). The ID of 255 is reserved for point-to-point networks.

A slave will link with the first master or repeater that it hears with a matching **Network ID**. Assigning a unique **Network ID** will reduce the chance a radio in your network links with another, unrelated network in the same RF area.

If necessary, the **Network ID** function can be used in conjunction with the **SubNet ID** feature.

7.2.6 Frequency Key

The **Frequency Key** determines the frequency hopping sequence of the transceiver. There are 15 choices available (0-14) which represent 15 unique pseudo-random hop patterns. This setting allows you to minimize RF interference with other FreeWave transceivers operating in the same RF area.

NOTE The **Frequency Key** setting should be the same for all radios in the entire network. The exception to this is if the **Repeater Frequency Key** setting is used. If this is used, the repeaters' **Frequency Key** would be different from the master radio, and downstream radios intended to connect to the repeater would have the same **Frequency Key** setting as the repeater.

7.2.7 Repeater Frequency Key

This is a setting that is only used by repeaters. The **Use Repeater Frequency Key** checkbox must be checked when you want a repeater to use a **Frequency Key** other than that of the master.

This is useful when there are parallel repeaters in a network, and you want to force communication through a particular repeater. When this setting is used, the repeater will receive on the **Frequency Key** of the upstream master (or repeater), and transmit on its **Frequency Key** setting (which typically is set to a different value than the master's).

The default setting of box, not checked (use master frequency), causes the repeater to transmit on the master's **Frequency Key**.

NOTE

When this setting is not used, the **Frequency Key** setting should match that of the master or of the repeater acting as the master for that transceiver.

7.2.8 Transmit Power

This setting specifies the RF transmit power. Use a transmit power of **0** when bench testing to reduce RF exposure.

The FCC specifies a maximum EIRP (Effective Isotropic Radiated Power) of 36 dBm.

$EIRP = (\text{Transmitter Power}) + (\text{Antenna Gain}) - (\text{Cable Losses})$ [all in dB or dBm]

Radio installations should be performed by a professional. It is very important that the transmit power level selected and the gain of the attached antenna do not exceed the maximum allowed ERP permitted by local regulations. Regulations vary by country and region. As the equipment owner, you are responsible for making sure that your installation and maintenance of the radio equipment ensure local regulations are met. For example, in much of the United States, FCC part 15 rules limit the 900 MHz, ISM band transmission from the RF451 to a maximum effective radiated power of +36 dBm.

The RF451 maximum power is 30.0 dBm; therefore, a 6 dB (or lower) gain antenna can be used with any **Transmit Power** setting. If a higher gain antenna is used, the cable loss will need to be determined, and the **Transmit Power** adjusted so as not to exceed the FCC limit of +36 dBm.

Note that lower **Transmit Power** can be used (to conserve battery power) if the required range allows it.

TABLE 7-1 shows the RF451 RF transmit power versus the setting.

TABLE 7-1. Transmit Power Settings		
RF Transmit Power Setting	RF Power (dBm)	RF Power (mW)
10	30.0	1000
9	29.5	900
8	27.8	600
7	26.8	480
6	25.2	330
5	23.6	230
4	21.5	140
3	19.0	80
2	15.4	35
1	10.0	10
0	7.0	5

7.2.9 Low Power Mode

This setting allows a multi-point slave to consume less power. This is achieved primarily by dimming the transceiver LEDs. When set to 2 through 31, the transceiver will sleep between slots. For example, at a setting of 2, the transceiver sleeps 1 out of 2 slots; at a setting of 3, the transceiver sleeps 2 out of 3 slots, and so on.

TABLE 7-2 shows the changes at different **Low Power Mode** settings. The actual current draw depends on many factors. The table below gives only a qualitative indication of supply current savings. A low number reduces latency and a high number reduces current consumption. An optimum setting (balancing latency and power savings) is 2 or 3.

TABLE 7-2. Low Power Mode Settings	
Setting	Description
0	Disabled
1	Transceiver remains awake, listening for the master radio's transmission on every slot.
2	Transceiver sleeps every other slot
3	Transceiver sleeps 2 of 3 slots
4–31	Transceiver sleeps the number of slots corresponding to the setting. For example, with a setting of 31, the transceiver sleeps 30 of 31 slots.

NOTE Low power mode is used only in multi-point slaves. Power savings occur only when the slave is linked. There are no power savings when the slave is transmitting data. Low power mode is of little value when a slave has a constant, high throughput.

7.2.10 SubNet ID

In a multi-point network, a slave or repeater will connect with the first repeater or master that it hears with the same **Network ID**. There are scenarios, however, where communications need to be forced to follow a specific path. For instance, the **SubNet ID** is particularly helpful to force two repeaters in the same network to operate in series rather than in parallel; or, if desired, to force slaves to communicate to a specific repeater for load-balancing purposes.

There are two components to the **SubNet ID**:

1. **Receive SubNet ID:** This setting identifies which transceiver a repeater or slave will listen to.
2. **Transmit SubNet ID:** This setting identifies the **Network ID** on which this device transmits, and, in turn, which devices will listen to it. This setting is only relevant to repeaters in multi-point networks.

The default setting for both receive and transmit is 15 which disables SubNetwork functions. For the master, this setting (15) causes the master to actually use 0. So, if the SubNet ID is to be used, the downstream radios that need to connect to the master will need their **Receive SubNet ID** set to 0.

NOTES Changing these settings on the master is not recommended, under normal circumstances. The **Receive SubNet ID** on the master has no effect on the network. If both **Receive SubNet ID** and **Transmit SubNet ID** are set to **0**, a mobile slave can roam from subnet to subnet and possibly from network to network.

7.2.11 Radio ID

This setting allows a transceiver to be designated with an arbitrary, user-selectable, 4-digit number which identifies the transceiver in diagnostics mode. When used in conjunction with PakBus dataloggers, it is recommended that this value be assigned the PakBus address of the station. This is because the Radio ID appears in the FreeWave Diagnostics Program, and allows the user to associate a particular datalogger with its attached radio.

To further this association of the RF451 RF network with the PakBus network, the dataloggers (CR1000, CR800, CR6, etc.) read the serial number of the attached radio and include this in the datalogger settings when the CS I/O SDC interface is used. This serial number is the main radio identifier used by the FreeWave Diagnostics Program.

7.3 Master Radio

A multi-point network may only contain a single master radio, either an RF450 or RF451. Slave radios communicate from and to the master radio.

NOTE

The master RF451/RF450 must be connected to a PakBus router. The PakBus router may be software, such as *LoggerNet* or *PC400*, or a datalogger configured as a router.

Selecting **Multi-Point Master** in the **Radio Operation Mode** designates the transceiver as a master in multi-point mode. This mode allows one master transceiver to simultaneously be in communication with numerous slaves and repeaters. A multi-point master communicates only with other transceivers designated as multi-point slaves or multi-point repeaters.

One setting, **Low Power Mode**, is not applicable to master radios, and thus is greyed out in *DevConfig* (see FIGURE 7-4).

The screenshot shows the 'Settings Editor' window for a radio configuration. The 'Radio Operation Mode' is set to 'Multi-Point Master'. The 'Low Power Mode' field is greyed out. Other settings include Serial No: 861-3809, Versions: RF451: 1/FreeWave: v10.6, Active Interface: CS I/O SDC, SDC Address: 7, Baud Rate: (empty), Network ID: 1042, Frequency Key: 9, Use Repeater Frequency Key: (unchecked), Transmit Power: 1, Low Power Mode: 3, Receive SubNet ID: 0, Transmit SubNet ID: 10, and Radio ID: 8.

FIGURE 7-4. *DevConfig* Screen Showing Settings for Multi-Point Master

7.4 Slave

Radios configured as slaves in a multi-point network are allowed to communicate with a multi-point master (see FIGURE 7-5). The slave may communicate with its master through one or more repeaters.

Deployment

Serial No: 861-3809 Versions: RF451: 1/ FreeWave: v10.6

Active Interface: CS I/O SDC SDC Address: 7

Baud Rate:

Radio Operation Mode: Multi-Point Slave Repeaters Used

Network ID: 1042 Frequency Key: 9 Use Repeater Frequency Key

Transmit Power: 1 Low Power Mode: 3

Receive SubNet ID: 0 Transmit SubNet ID: 10

Radio ID: 8

FIGURE 7-5. DevConfig Screen Showing Settings for a Slave in a Multi-Point Network

7.5 Repeater

Setting the **Radio Operation Mode** to **Multi-Point Repeater** allows the transceiver to operate as a repeater in a multi-point network. The **Repeaters Used** checkbox should be checked if there are **any** repeaters in the network; it should be set the same for all transceivers in a multi-point network (see FIGURE 7-6).

Deployment

Serial No: 861-3809 Versions: RF451: 1/ FreeWave: v10.6

Active Interface: CS I/O SDC SDC Address: 7

Baud Rate:

Radio Operation Mode: Multi-Point Repeater Repeaters Used

Network ID: 1042 Frequency Key: 9 Use Repeater Frequency Key

Transmit Power: 1 Low Power Mode: 3

Receive SubNet ID: 0 Transmit SubNet ID: 10

Radio ID: 8

FIGURE 7-6. DevConfig Screen Showing Settings for Repeater in a Multi-Point Network

7.6 Location of the Transceivers

Placement of the transceivers is likely to have a significant impact on its performance. The key to the overall robustness of the radio link is the height of the antennas and the line-of-sight between antennas.

7.7 Power Considerations

The RF451 radio requires 6 to 30 Vdc power. This may be supplied through either a wall charger (pn 15966) connected to the DC power jack on the side of the radio or through the datalogger via the CS I/O port.

NOTE The RF451 can be powered by USB for configuration only. When power is being supplied by USB, the internal radio is not operational.

Networks configured in multi-point mode take advantage of the low power mode of the slave radios at the datalogger site. This reduces the required power at remote sites from about 75 mA to less than 10 mA in most applications. Power savings occur only when the slave is not transmitting data. Also, low power mode is of little value when a slave has a constant, high throughput. Master and repeater radios do not go into a low power mode. RF451 power requirements in the various states of operation are listed in TABLE 7-3.

For help with determining a power budget and solar panel sizes for remote sites, see the Campbell Scientific Application Note titled “Power Supplies” available from our web site: <https://s.campbellsci.com/documents/us/technical-papers/pow-sup.pdf>.

Transmit current, for 1 W power at 100% duty cycle	650 mA
Receive current	40 mA
Idle current	15 mA
Sleep current	6 mA

7.8 LoggerNet Software Setup

The **Network Map** is configured from the *LoggerNet Setup* screen. Configure the **Network Map** as described below (see FIGURE 7-7).

1. Select **Add Root | COM Port**.
2. Add a **PakBusPort**. Set the **Maximum Baud Rate** to **115200**. Set the **Beacon Interval** to **1 minute**, if the master radio will be at the PC.
3. Add datalogger. Set the **PakBus Address** to match that of the datalogger.
4. **Apply** settings.

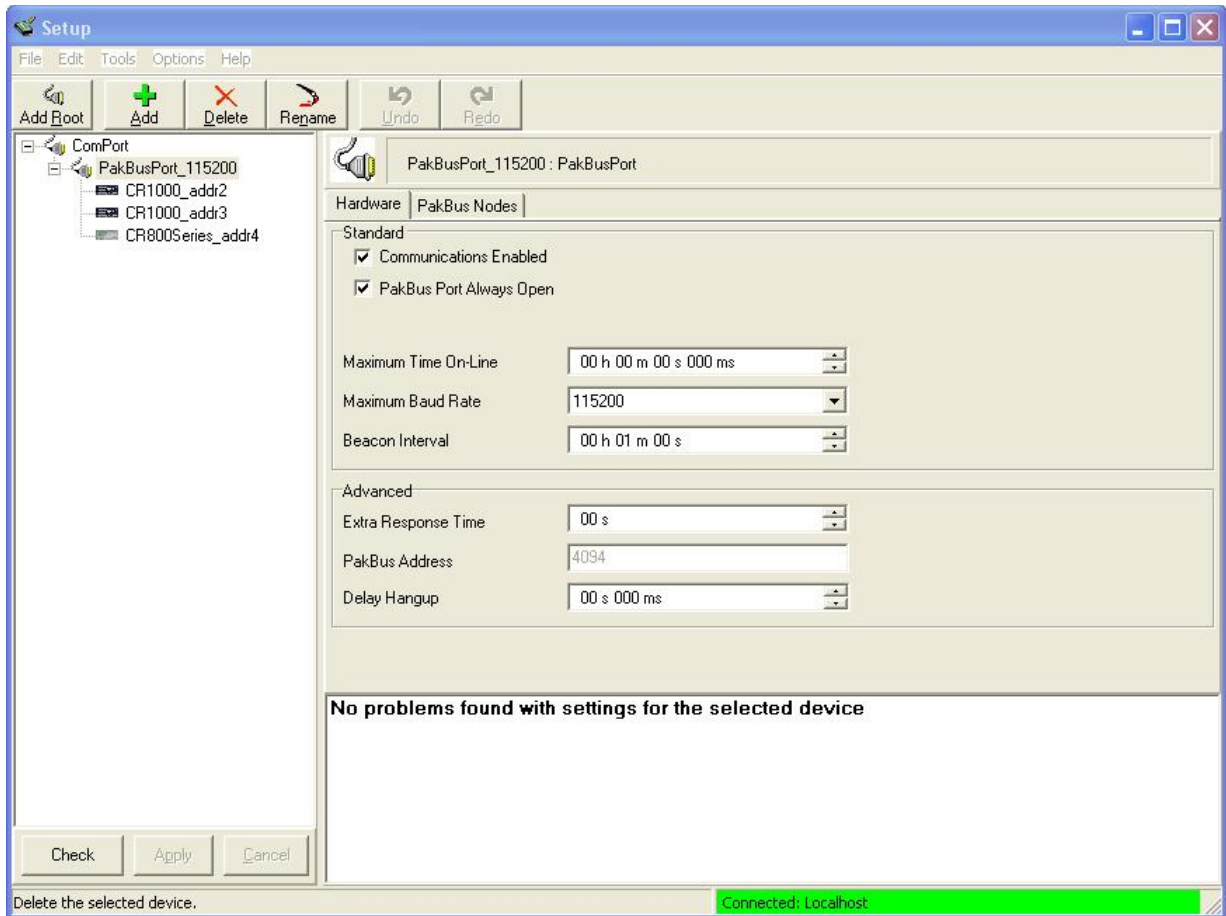


FIGURE 7-7. LoggerNet Setup Screen for an RF451 Multi-Point Network

7.9 PakBus Graph

PakBus Graph is a *LoggerNet* utility that graphically depicts the devices and connections in a PakBus datalogger network. In *PakBus Graph*, the *LoggerNet* server is typically represented by PakBus address 4094, and each of the PakBus dataloggers that have been configured in *Setup* will be shown by its PakBus address in brackets followed by its name assigned through *LoggerNet Setup*.

Because RF451 networking protocols, not PakBus protocols, are used to direct packets, the network representation in *PakBus Graph* may be significantly different than one would expect. FIGURE 7-8 depicts the physical network of five dataloggers and one *LoggerNet* server. Dataloggers numbered 1 and 2 route packets to other dataloggers from the *LoggerNet* server.

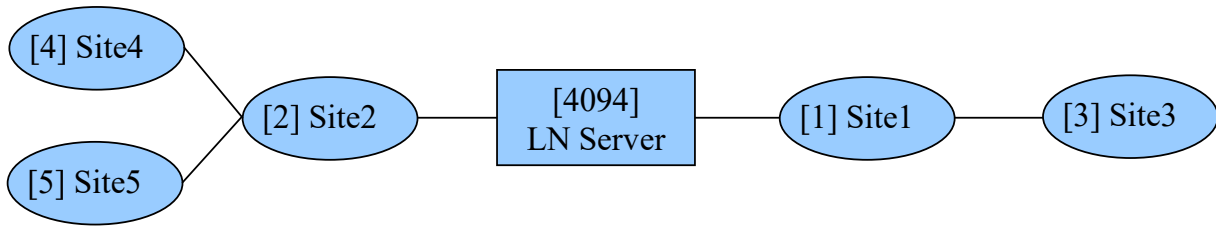


FIGURE 7-8. Point to Multi-Point Network with Two Routers

This same network will be depicted in *PakBus Graph* as shown in FIGURE 7-9. Dataloggers numbered 1 and 2 have RF451 radios configured as slave/repeaters. The RF451 radios are doing the networking, not the PakBus dataloggers.

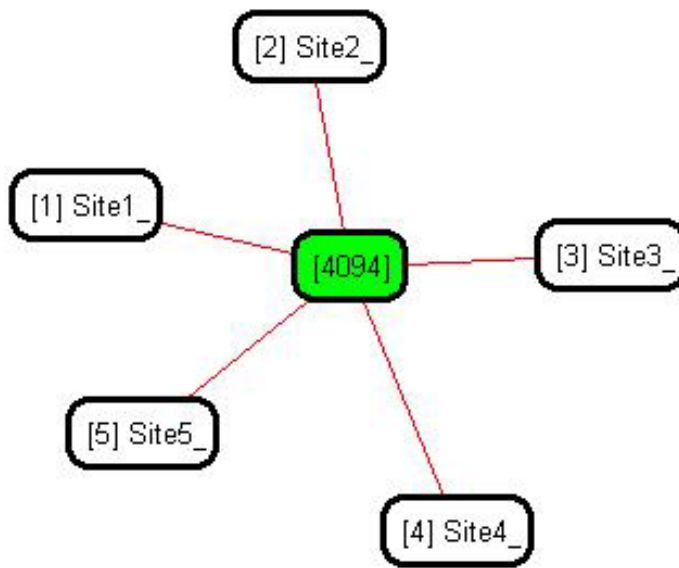


FIGURE 7-9. RF451 Point to Multi-Point network with a single router (in this case, LoggerNet) as displayed in *PakBus Graph*

8. Antennas

8.1 Antennas for the RF451

Several antennas are offered to satisfy the needs for various master and slave requirements. These antennas have been tested at an authorized FCC open-field test site and are certified to be in compliance with FCC emissions limits. 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 user.

NOTE

An FCC authorized antenna is a **REQUIRED** component. You must provide one of the antennas listed below.

Omnidirectional antennas are normally used at the base station and nearby stations. Yagi antennas are needed at distant stations or other special cases. Call one of our application engineers for help in choosing an antenna. Only the following FCC approved antennas can be used.

Indoor, Omnidirectional	
14204	0 dBd, 1/2 wave whip. RPSMA connector attaches directly to the radio; no antenna cable is needed.
15970	1 dBd, dipole, with window/wall mount. The antenna is shipped with a 79 in. cable that has an RPSMA female connector that attaches to the radio.
Outdoor, Omnidirectional	
14221	3 dBd with rugged FM2 antenna mounts and a Type N female connector. It requires an antenna cable to connect to the radio.
Outdoor, Yagi	
14205	6 dBd, with mounts and a Type N female connector. It requires an antenna cable to connect to the radio.
Antenna Cables and Surge Protectors for Outdoor Antennas	
Recommended for cable lengths less than 10 ft.	
COAXRPSMA-L	LMR195 antenna cable with type RPSMA to type N Male Connector
Recommended for cable lengths greater than 10 ft and/or use with lightning protection	
COAXNTN-L	Low-loss (4.1 dB/100 ft) RG8 antenna cable with type N male to type N male connectors (requires 31314 surge protector). Specify length, in feet, after the L.
31314	Surge Suppressor that is recommended when the length of the antenna cable is greater than 10 feet. The surge suppressor helps protect the radio from electrical discharge being conducted down the antenna cable.
31312	Similar to the 31314 but installed by Campbell Scientific, bulkhead-mounted through the enclosure wall.
Additional Accessories	
15966	AC Wall charger for base station radio
14291	Optional DC power cable
18663	Null modem cable used to connect the radio to the RS-232 port on the datalogger.
CM230	Adjustable Angle Mounting Kit for attaching an outdoor antenna to a tripod or tower.
20625	FreeWave® Diagnostics Cable and Software CD

FCC OET Bulletin No. 63 (October 1993):

“Changing the antenna on a transmitter can significantly increase, or decrease, the strength of the signal that is ultimately transmitted. Except for cable locating equipment, the standards in Part 15 are not based solely on output power but also take into account the antenna characteristics. Thus, a low power transmitter that complies with the technical standards in Part 15 with a particular antenna attached can exceed the Part 15 standards if a different antenna is attached. Should this happen it could pose a serious interference problem to authorized radio communications such as emergency, broadcast, and air-traffic control communications.”

CAUTION

In order to comply with the FCC RF exposure requirements, the RF451 may be used only with **approved antennas** that have been tested with this radio and a minimum separation distance of 23 cm must be maintained from the antenna to any nearby persons.

8.2 Antenna Cables and Surge Protection

8.2.1 Antenna Cables

The 14205 and 14221 antennas require an antenna cable; either (1) the COAXRPSMA-L cable or (2) the COAXNTN-L cable with surge protector. Indoor omnidirectional antennas (14204 and 15970) are either supplied with an appropriate cable or connect directly to the radio.

8.2.2 Electrostatic Issues

Many RF451 installations are outdoors and, therefore, susceptible to lightning damage, especially via the antenna system. Also, depending on climate and location, electro-statically charged wind can damage sensitive electronics, if sufficient electric charge is allowed to accumulate on the antenna and cable. To protect against this, Campbell Scientific offers the pn 31314 and pn 31312 Antenna Surge Protection Kits.

Antenna surge protection is recommended in the following applications:

- When the antenna cable length exceeds 10 feet
- When use of COAXRPSMA cable would result in too much signal loss
- When the radio will be used in an environment susceptible to lightning or electro-static buildup

8.2.3 Antenna Surge Protector Kit

The Surge Protector Kit includes the following:

- Polyphaser protector
- COAXRPSMA-L cable with 1.5 ft length (its type N male connector fastens to the polyphaser equipment connector; its RPSMA connector fastens to the radi antenna connector)

- Screw (pn 505) and grommet (pn 6044) to secure the polyphaser protector to the backplate of an enclosure
- 1.5 ft, 10 AWG ground wire (insert one end of the wire between the pn 505 screw and the polyphaser, then secure the other end to a ground lug)

9. Troubleshooting

9.1 LED Status

The RF451 has two red/green/orange LED status indicator lights. TABLE 9-1 and TABLE 9-2 show the status of each light when the RF451 is in various states of communication.

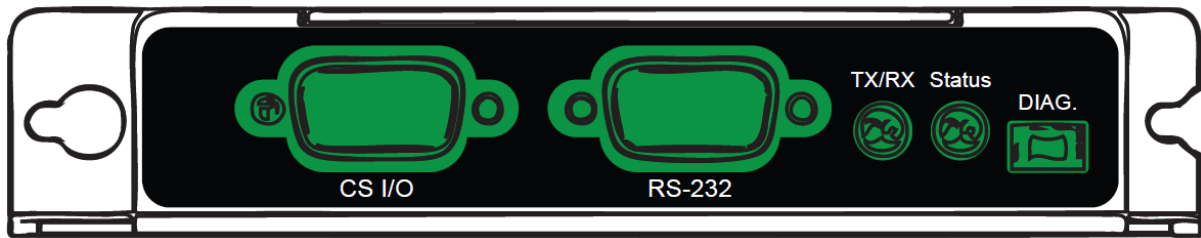


FIGURE 9-1. RF451 Front Side View

LED State	Meaning
Red (solid)	Not used
Green (solid)	Not used
Orange (solid)	Configuration of Processor or Radio (OS or Settings)
Red (blink)	RF451 powered by USB – Radio not operational
Green (blink)	Device powered – Configured in Master or Slave mode
Orange (blink)	Device powered – Configured in Repeater mode
OFF	No power

TABLE 9-2. TX/RX LED

LED State	Meaning
Red (solid)	Not used
Green (solid)	Not used
Orange (solid)	Not used
Red (blink)	Transmit
Green (blink)	Receive
Orange (blink)	No Master Detected (applies only to Slaves and Repeaters)
OFF	No activity / No power

9.2 Troubleshooting Scenarios

DevConfig is unable to establish a connection with the RF451:

1. Check that all other Campbell Scientific software is closed.
2. Check power to the radio. The Status LED should be flashing green if 12 volt power is supplied or red if only USB power is applied.
3. Check USB cable connections.
4. Check serial port assignment for *DevConfig*.

Radios not networked together, not communicating:

1. Check the baud rate of all RF451s/RF450s; they should be the same.
2. Check Network IDs of all RF451s/RF450s; they should be the same.
3. Check Frequency Key Number of all RF451s/RF450s; they should be the same, unless two branches of the network are operating in a parallel manner. See Appendix B.3, *Example 3: PC-to-RF Network with Parallel Repeaters (using the SubNet ID) (p. B-5)*, for settings used in a parallel network.
4. If one or more radios are configured as repeaters, check the **Repeaters Used** box for all RF451s/RF450s.
5. Check the PakBus® address of dataloggers connected to RF451s/RF450s and in *LoggerNet*.
 - a. Check that antenna and antenna cables are correct for each radio type. RF451 radios use RPSMA (Reverse Polarity SubMiniature version A). RF450 radio us SMA (SubMiniature Version A). SMA antennas will have a yellow heat shrink label to distinguish them from RPSMA.

LEDs flash when *LoggerNet* command transmitted but no response from datalogger:

1. Check SC12 cable on the datalogger CS I/O port.
2. Check SDC address in RF451/RF450.
3. Check SDC address in datalogger.
4. Check the baud rate of all RF451s/RF450s; they should be the same.
5. Check the baud rate of *LoggerNet*; it should match the baud rate of the RF451s/RF450s.

9.3 Using the Diagnostics Port

A special FreeWave® Diagnostics Cable and Software (pn 20625) can be useful in troubleshooting radio problems. Contact FreeWave, Inc. for more information on using the Diagnostics Cable.

Appendix A. FCC Notifications

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. This device must be operated as supplied by Campbell Scientific, Inc. Any changes or modifications made to the device without the express written approval of Campbell Scientific, Inc. may void the user's authority to operate the device.

CAUTION

The MM2 transceiver has a maximum transmitted output power of 1 watt. It is recommended that the transmit antenna be kept at least 23 cm (approximately 10 in) away from nearby persons to satisfy FCC RF exposure requirements.

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 an experienced radio/TV technician for help
- Consult Campbell Scientific

Appendix B. Installation Scenarios

B.1 Example 1: PC-to-RF Network

In this example, the master radio is connected to a PC running *LoggerNet* (see FIGURE B-1). Slave radios are connected to CR1000s in the field. *LoggerNet* may be used to view real-time values from the dataloggers, collect data, set datalogger clocks, and send programs.

Remember, each datalogger must have a unique PakBus® address.

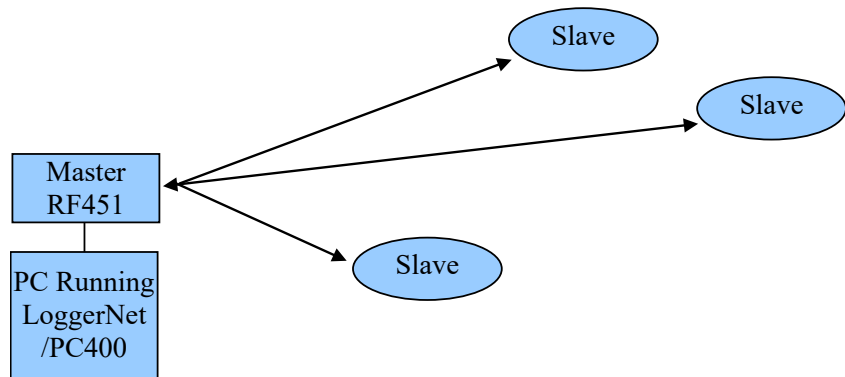


FIGURE B-1. Schematic of PC-to-RF451 Network

Using *DevConfig*, set up the master and slave RF451 radios according to TABLE B-1 below. The **Deployment** tab of *DevConfig* should look similar to FIGURE B-2.

TABLE B-1. RF451 Settings for Example 1		
	Master	Slave(s)
Hardware	RF451 connected to PC running <i>LoggerNet</i>	RF451 connected to CR1000 CS I/O port
Keep all factory default settings except:		
Active Interface	USB or RS-232 (to match how <i>LoggerNet</i> will be communicating with the radio)	CS I/O SDC (with SDC Address set to an unused SDC address on the datalogger)
Radio Operation Mode	Multi-Point Master	Multi-Point Slave
Network ID	1726 (yours may be different)	1726 (yours may be different)
Frequency Key	1 (yours may be different)	1 (yours may be different)
Radio ID	4094 (to match <i>LoggerNet</i> PakBus address)	2 (to match CR1000 PakBus address)*
* All slave Radios in the network will have these same settings except for the Radio ID . The Radio ID should match the PakBus address of the datalogger it is connected to.		

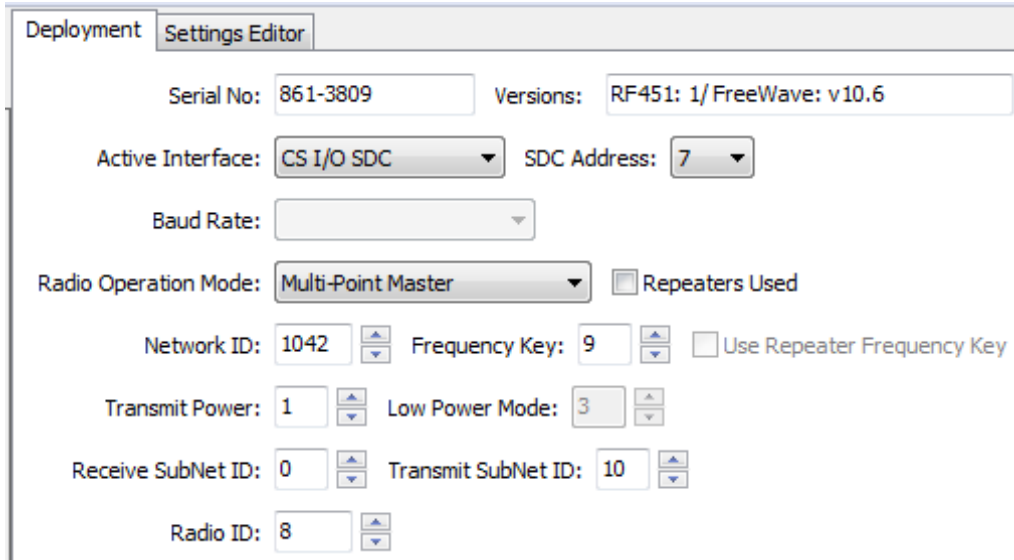
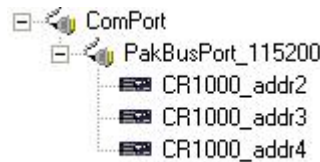


FIGURE B-2. DevConfig Screen Showing Master Radio Settings for Example 1

The **Network Map** in the *LoggerNet Setup* screen should look something like this:



B.2 Example 2: PC-to-RF Network with Repeater

In this example, the master radio is connected to a PC running *LoggerNet* (see FIGURE B-3). Slave radios are connected to CR1000s in the field. One slave radio, also connected to a CR1000, is used as a repeater to go around an obstacle such as a hill. To take advantage of the low power mode, those devices that are NOT repeaters should be configured as multi-point slaves and not as multi-point slave/repeaters. In this configuration, it may be desirable to use an external omnidirectional antenna at the repeater.

Note that when a repeater is used, the RF throughput is cut in half. However, when more than one repeater is used, there is no further degradation in the RF throughput of the link. Throughput is the rate at which data is sent or received. Reducing throughput means less data can be transmitted in a specified amount of time.

Remember, each datalogger must have a unique PakBus address.

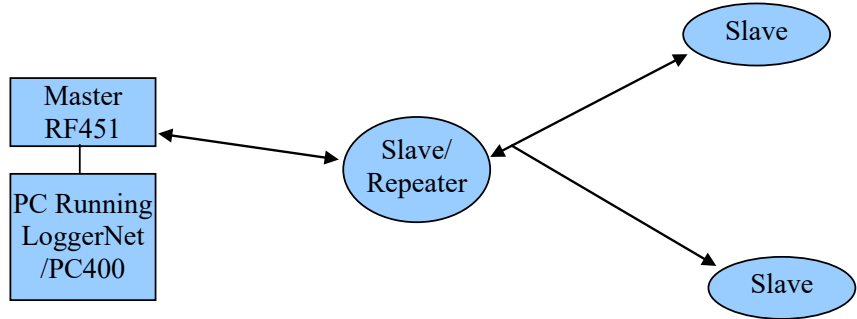


FIGURE B-3. Schematic of PC-to-RF451 Network with Repeater

Using *DevConfig*, set up the master, slave/repeater RF451, and slave RF451 radios according to TABLE B-2 below. The **Deployment** tabs of *DevConfig* should look similar to FIGURE B-4 through FIGURE B-6.

TABLE B-2. RF451 Settings for Example 2			
	Master	Slave/Repeater	Slave(s)
Hardware	RF451 connected to PC running <i>LoggerNet</i>	RF451 connected to CR1000 CS I/O port	RF451 connected to CR1000 CS I/O port
PakBus Address	4094	2	3
Keep all factory default settings except:			
Active Interface	USB or RS-232 (to match how <i>LoggerNet</i> will be communicating with the radio)	CS I/O SDC (with SDC Address set to an unused SDC address on the datalogger)	CS I/O SDC (with SDC Address set to an unused SDC address on the datalogger)
Radio Operation Mode	Multi-Point Master	Multi-Point Slave/Repeater	Multi-Point Slave
Repeaters Used	Yes, check box	Yes, check box	Yes, check box
Network ID	1726 (yours may be different)	1726 (yours may be different)	1726 (yours may be different)
Frequency Key	1 (yours may be different)	1 (yours may be different)	1 (yours may be different)
Radio ID	4094 (to match <i>LoggerNet</i> PakBus address)	2 (to match CR1000 PakBus address)*	3 (to match CR1000 PakBus address)*
* All slave radios in the network will have these same settings except for the Radio ID . The Radio ID should match the PakBus address of the datalogger it is connected to.			

Deployment Settings Editor

Serial No: 861-3809 Versions: RF451: 1/ FreeWave: v10.6

Active Interface: USB SDC Address: 7

Baud Rate:

Radio Operation Mode: Multi-Point Master Repeaters Used

Network ID: 1726 Frequency Key: 5 Use Repeater Frequency Key

Transmit Power: 1 Low Power Mode: 3

Receive SubNet ID: 15 Transmit SubNet ID: 15

Radio ID: 4094

FIGURE B-4. DevConfig Screen Showing Master Radio Settings for Example 2

Deployment Settings Editor

Serial No: 861-3809 Versions: RF451: 1/ FreeWave: v10.6

Active Interface: CS I/O SDC SDC Address: 7

Baud Rate:

Radio Operation Mode: Multi-Point Slave/Repeater Repeaters Used

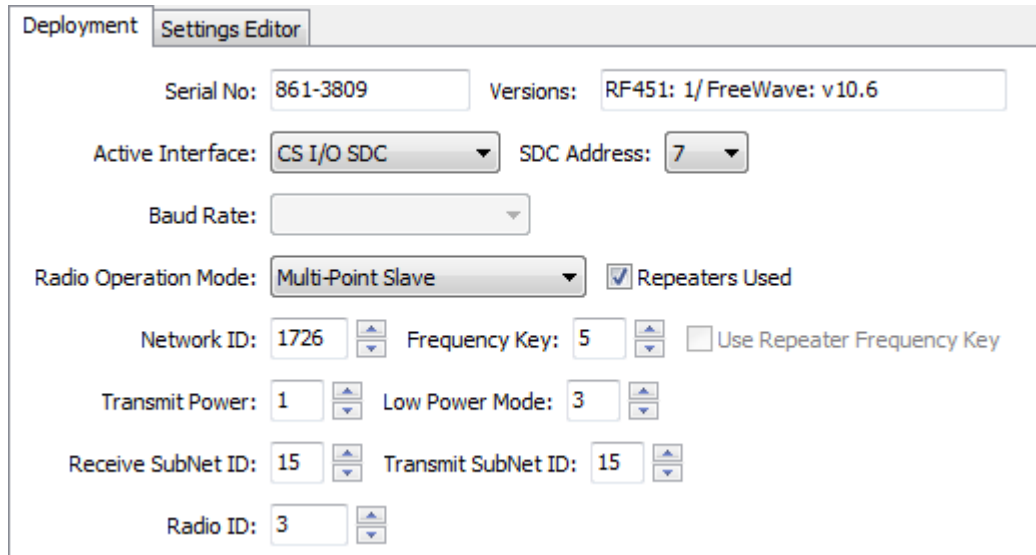
Network ID: 1726 Frequency Key: 5 Use Repeater Frequency Key

Transmit Power: 1 Low Power Mode: 3

Receive SubNet ID: 15 Transmit SubNet ID: 15

Radio ID: 2

FIGURE B-5. DevConfig Screen Showing Slave/Repeater Radio Settings for Example 2



Deployment Settings Editor

Serial No: 861-3809 Versions: RF451: 1/ FreeWave: v10.6

Active Interface: CS I/O SDC SDC Address: 7

Baud Rate:

Radio Operation Mode: Multi-Point Slave Repeater Used

Network ID: 1726 Frequency Key: 5 Use Repeater Frequency Key

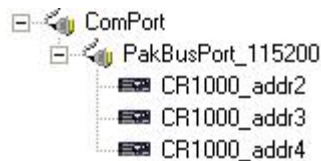
Transmit Power: 1 Low Power Mode: 3

Receive SubNet ID: 15 Transmit SubNet ID: 15

Radio ID: 3

FIGURE B-6. DevConfig Screen Showing Slave Radio Settings for Example 2

The **Network Map** in the *LoggerNet Setup* screen should look something like this:



B.3 Example 3: PC-to-RF Network with Parallel Repeaters (using the SubNet ID)

In this example, the master radio is connected to a PC running *LoggerNet* (see FIGURE B-7 and TABLE B-3). One stand-alone repeater (Repeater 1) is used to access several slave radios connected to CR1000s in the field. The stand-alone repeater consists of an RF451, power supply, and antenna. Another repeater (Slave/Repeater) connected to a CR1000 is used to access several other slave radios on CR1000s.

To take advantage of the low power mode, those devices that are NOT repeaters should be configured as multi-point slaves and not as multi-point slave/repeaters. In this configuration, it may be desirable to use an external omnidirectional antenna at the repeaters.

Note that when a repeater is used, the RF throughput is cut in half. However, when more than one repeater is used, there is no further degradation in the RF throughput of the link. Throughput is the rate at which data is sent or received. Reducing throughput means less data can be transmitted in a specified amount of time.

Remember, each datalogger must have a unique PakBus address.

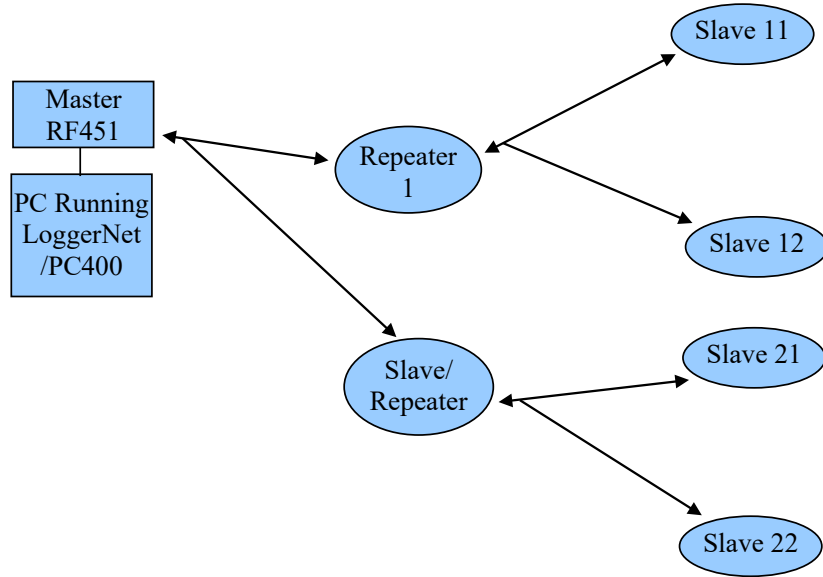


FIGURE B-7. Schematic of PC-to-RF Network with Parallel Repeaters (using the SubNet ID)

TABLE B-3. RF451 Settings for Example 3

	Master	Repeater	Slave/Repeater	Slave 11, 12 etc.	Slave 21, 22 etc.
Hardware⁴	PC running <i>LoggerNet</i> , RF451	RF451	CR1000, RF451	CR1000, RF451	CR1000, RF451
Baud Rate	115.2K	115.2K	115.2K	115.2K	115.2K
Active Interface	USB or RS-232 (to match how <i>LoggerNet</i> will be communicating with the radio)	NA	CS I/O SDC (with SDC Address set to an unused SDC address on the datalogger)	CS I/O SDC (with SDC Address set to an unused SDC address on the datalogger)	CS I/O SDC (with SDC Address set to an unused SDC address on the datalogger)
Radio Operation Mode	Multi-Point Master	Multi-Point Repeater	Multi-Point Slave/Repeater	Multi-Point Slave	Multi-Point Slave
Repeaters Used	Yes; check box	Yes; check box	Yes; check box	Yes; check box	Yes; check box
Network ID¹	1726	1726	1726	1726	1726
Frequency Key¹	1	1	1	1	1
Receive SubNet ID	NA	0	0	1	2
Transmit SubNet ID	15 (default)	1	2	0	0

Radio ID	4094 ²	2	3 ³	11, 12 etc. ³	21, 22, etc ³
Notes: ¹ your Network ID and Frequency Key may be different ² to match <i>LoggerNet</i> PakBus address ³ to match CR1000 PakBus address ⁴ not inclusive; other typical hardware items may include power supply, antenna, enclosure, etc. NA = not applicable					

B.4 Example 4: Phone-to-RF Base

In this example, a COM220 phone modem and master radio are connected without a datalogger to a network of CR1000s in the field (see FIGURE B-8 and TABLE B-4). The computer running *LoggerNet* uses a phone modem to call into the master site and connect to the rest of the network. The rest of the network can be configured as in other examples. In this configuration, datalogger-to-datalogger communications and datalogger call-back is NOT supported; see Example 5.

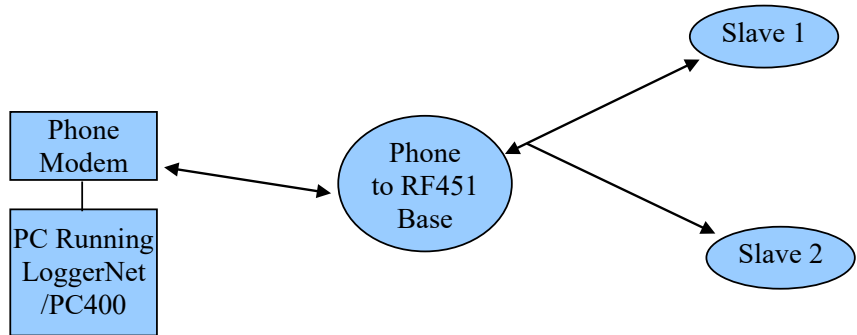


FIGURE B-8. Schematic of Phone-to-RF Base

		Phone to RF451 Base	Slaves
Hardware³	PC running <i>LoggerNet</i> , Phone Modem	COM220, RF451, A100	CR1000, RF451
Active Interface		ME Master	Auto-Sense
Baud Rate		115.2K	115.2K
Radio Operation Mode		Multi-Point Master	Multi-Point Slave
Network ID¹		1726	1726
Frequency Key¹		1	1
Radio ID		2	3 ²
Notes: ¹ your Network ID and Frequency Key may be different ² to match CR1000 PakBus address ³ not inclusive; other typical hardware items may include power supply, antenna, enclosure, etc.			

B.5 Example 5: Call-back

Call-back is the ability of a remote site to initiate a call to *LoggerNet* and have *LoggerNet* call back to collect data. Call-back is supported in networks consisting of RF451s as the single communication device as in Examples 1, 2, and 3. Example configurations where call-back is supported:

LN-RF451 Master ~~~~~RF451 Slave-DL

LN-RF451 Master ~~~~~RF451 Slave/Repeater-DL~~~~~RF451 Slave-DL

LN-RF451 Master ~~~~~RF451 Repeater ~~~~~RF451 Slave-DL

LN-Phone Modem ----COM220-DL-RF451 Master ~~~~~RF451 Slave-DL

NOTE: LN=*LoggerNet*; DL=*Datalogger*

In a mixed-communication devices network, for example, phone to RF451, the base site makes the transition between communication types. Call-back is NOT supported when the base RF451s **Active Interface** is configured as **CS I/O ME Master**. The RF451 **Active Interface** is configured as **CS I/O ME Master** when the CS I/O port is used for direct connection to an ME device (COM200, COM210, COM220, MD485, etc). The connection is done by using an A100. Example configurations where call-back is NOT supported:

LN-Phone Modem ----COM220-CSI null modem-RF451 Master~~~~~RF451 Slave-DL(1)

LN--Ethernet--RavenXT-rs232nullmodem-RF451 Master~~~RF451 Slave-DL

NOTE: LN=*LoggerNet*; DL=*Datalogger*

In this example, the RF451s are set up as described in Example 1. In the following program the datalogger will send a variable named **Callback** to *LoggerNet* (PakBus address 4094) when the **CallbackFlag** variable is true. After *LoggerNet* receives the variable **Callback** it will begin collecting data from the datalogger and store it into a file based on the data collection settings in the *LoggerNet Setup* screen. Note that the **PakBus Port** in the *LoggerNet Setup* screen must have **PakBus Port Always Open** selected.

```
'CR1000 Series Datalogger
'Declare Public Variables
Public counter, Result
Public CallbackFlag As Boolean
Dim scratch                               'this variable is a place-holder it is not used

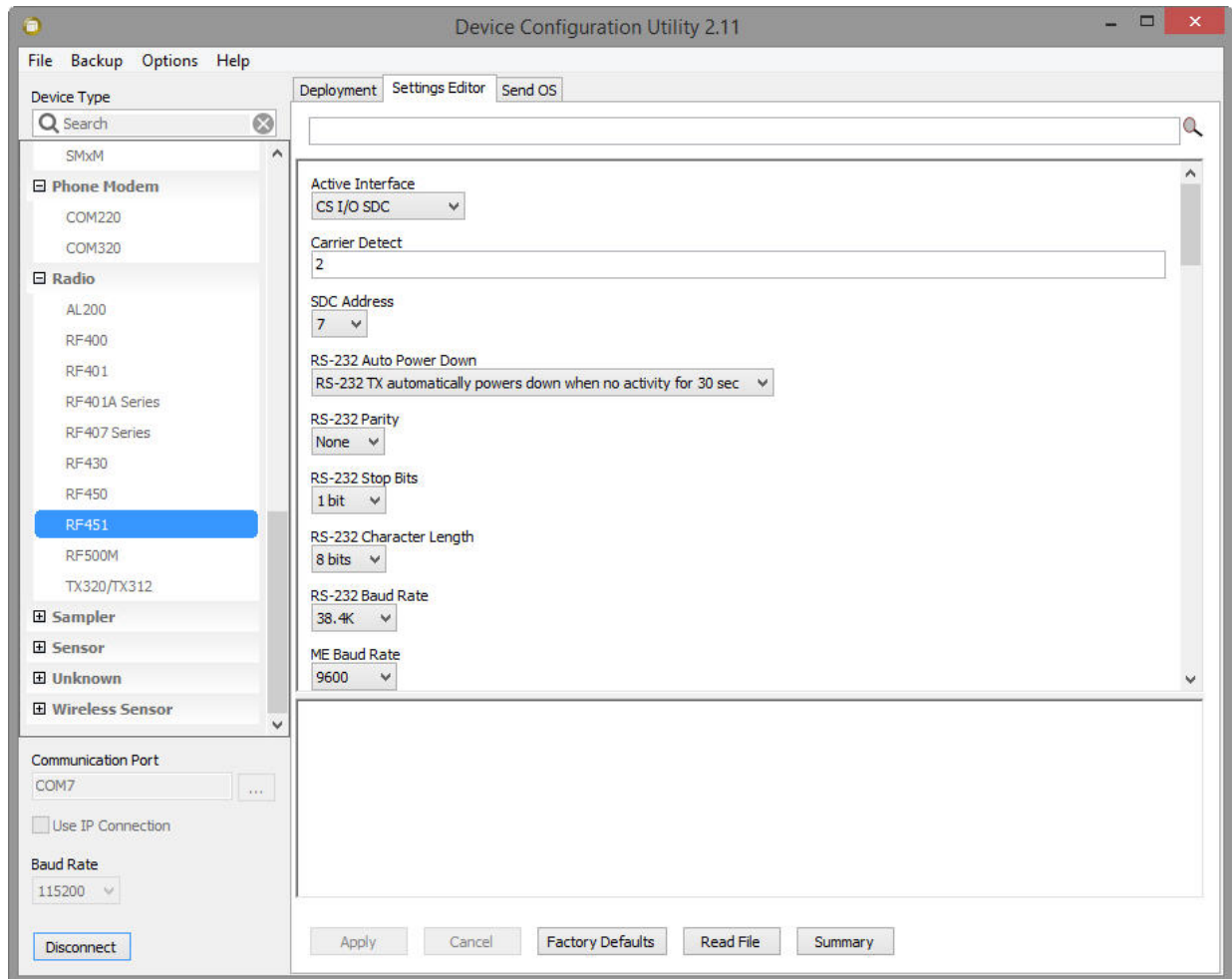
'Define Data Tables
DataTable (Test,true,-1)
  DataInterval (0,15,Sec,10)
  Sample (1,counter,FP2)
EndTable

'Main Program
BeginProg
'Configure the CR1000's CS I/O port to match the SDC address and baud rate
'set in the RF451
SerialOpen (ComSDC7,-115200,0,0,10000)
Scan (1,Sec,0,0)
```

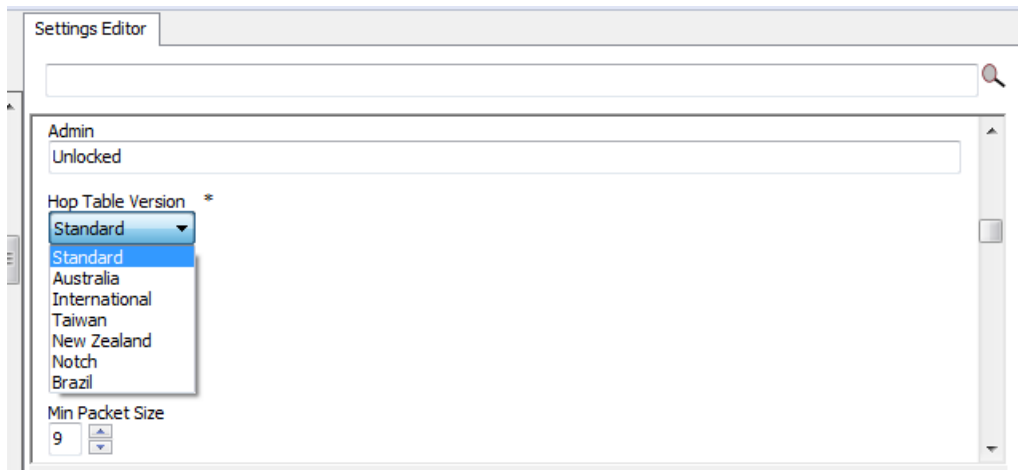
```
counter = counter + 1
If CallbackFlag = true Then
  SendVariables (Result,ComSDC7,0,4094,0000,0,"Public","Callback",Scratch,1)
  CallbackFlag = false
EndIf
'Call Output Tables
CallTable Test
NextScan
EndProg
```


Appendix C. Settings Editor

The **Settings Editor** of *DevConfig* provides access to additional settings not shown on the **Deployment** tab. Most RF451/RF450 networks do not need to make changes through the **Settings Editor**.



Radios deployed outside of the United States must use a **Hop Table Version** other than zero (the default). This setting can be changed through the **Settings Editor** tab.



The **Hop Table Version** setting allows the user to choose the portion of the band in which the transceiver will operate.

0	Standard	Full 902-928 MHz
1	Australia	915-928 MHz
2	International	903.744-926.3232 MHz, 16 fewer frequencies than full U.S. set
3	Taiwan	916-920 MHz
4	New Zealand	921-928 MHz
5	Notch	Uses 902-928 MHz with center frequencies of 911-919 MHz notched out
6	Brazil	902-915 MHz

NOTE Do not use a **Frequency Key Setting** of 14 with a **Hop Table Version** of 1, 2, or 4.

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

D.1 Introduction

The communication distance you can expect to obtain using the RF451 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](#).

D.2 How Far Can You Go?

Estimating Distance for Spread Spectrum Radios

D.2.1 Overview

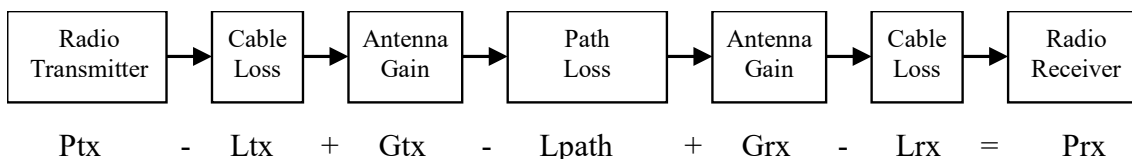
Because the factors affecting communication distance are different for every system, a generalized estimate of distance cannot be stated with any practical degree of accuracy. Reasonable estimates of distance can only be achieved by means of a case-by-case analysis and accounting of these factors. The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

D.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 (30 dBm in the case of the RF451 at maximum transmitter power)

L_{tx} = cable loss between transmitter and antenna in dB (see [Appendix B.2.4, Cable Loss \(p. D-3\)](#))

G_{tx} = transmit antenna gain in dBi (dBi = dBd + 2.15)

L_{path} = path loss between antennas in dB (see [TABLE D-5](#), [TABLE D-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 (–108 dBm for the RF451), 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.

D.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:

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

TABLE D-1. Transmitter Power	
Transmitter Power (Pt) (milliWatts)	Ptx dBm
1	0
5	7
10 (RF451 minimum)	10
50	17
100	20
250	24
1000 (RF451 maximum)	30
5000	37

D.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:

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.

Length (ft)	Loss (dB)
100	11.1
50	5.6
25	2.8
10	1.1
6	0.7

D.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:

$$dBi = dBd + 2.15$$

Some antennas that are FCC approved for use with the RF451 series are:

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
Larsen	Yagi	900 MHz	YA6900W	14205	6	8.15	17.5 in

D.2.6 Receiver Sensitivity

Receiver sensitivity is usually specified in dBm for a specific bit error rate (BER). The transceiver module used in the RF451 is specified at -108 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.

D.2.7 Path Loss

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

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

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

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

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!

D.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:

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

TABLE D-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.

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

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)

D.4 Examples

Some examples will help illustrate the trade-offs in a link analysis. These examples will all use the RF451 900 MHz radio at maximum transmitter power, 30 dB, and will use -108 dBm as the required power level at the radio receiver.

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

$$\text{Fade margin} = P_{rx} - (-108 \text{ dBm})$$

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?

$$P_{tx} = 30 \text{ dBm}$$

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

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

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

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

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

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

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

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

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

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:

$$\text{Fade margin} = P_{rx} - (-108 \text{ dBm})$$

$$\text{Fade margin} = P_{tx} - L_{tx} + G_{tx} - L_{path} + G_{rx} - L_{rx} + 108 \text{ dBm}$$

$$\text{Fade margin} = 30 - 2.22 + 5.15 - L_{path} + 5.15 - 1.11 + 108$$

$$\text{Fade margin} = 145 - L_{path}$$

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

Path Type	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
2-Ray	24	12	5	0	-4	-10	-14	-17	-20	-23

From TABLE D-9 we see that this link should be very reliable up to a distance of 4 miles and reasonably reliable at a distance of 6 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?

$$\begin{aligned}
 P_t &= 30 \text{ dBm} \\
 L_t &= 50 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 5.55 \text{ dB} \\
 G_t &= 9 \text{ dBd} = 11.15 \text{ dBi} \\
 L_r &= 5 \text{ ft} \cdot (11.1 \text{ dB}/100 \text{ ft}) = 0.55 \text{ dB} \\
 G_r &= 9 \text{ dBd} = 11.15 \text{ dBi}
 \end{aligned}$$

Need to include an additional loss from the surge suppressor:

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

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

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

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

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

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

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

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:

$$\text{Fade margin} = P_{rx} - (-108 \text{ dBm})$$

$$\text{Fade margin} = P_{tx} - L_{tx} + G_{tx} - L_{\text{path}} + G_{rx} - L_{rx} - L_{ss} + 108 \text{ dBm}$$

$$\text{Fade margin} = 30 - 5.55 + 11.15 - L_{\text{path}} + 11.15 - 0.55 - 0.34 + 108$$

$$\text{Fade margin} = 154 - L_{\text{path}}$$

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

Path Type	2 mi.	4 mi.	6 mi.	8 mi.	10 mi.	14 mi.	18 mi.	22 mi.	26 mi.	30 mi.
2-Ray	35	23	16	11	7	1	-3	-7	-10	-12

From TABLE D-11 we see that this link should be very reliable up to a distance of 8 miles and somewhat reliable at a distance of 10 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)?

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

Appendix E. RF451s with RF401A or CR206(X) in the Same Network

Using RF451s in the same network as Campbell Scientific RF401A/RF401 radios or CR206(X) dataloggers is not recommended. RF451s will not communicate directly with RF401A/RF401s and CR206(X)s. The RF451s will interfere with the RF401A/RF401s' and CR206(X)s' transmissions. If RF451s and RF401A/RF401/CR206(X)s must be used in the same network, there are some things you can do to obtain better performance out of the RF401A/RF401 portion of your network:

1. Use Yagi antennas and separate them.
2. On the RF451, disable **Frequency Zone 4** through **Frequency Zone 11** (set them to **0**) or set the **Hop Table Version** to **Notch**. This is done through the **Settings Editor** Tab of *DevConfig*.

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