Chapter 2

Preparing to Install the SubSpace 2001

This chapter describes information you need to consider before installing your SubSpace 2001 Wireless Router. It contains the following sections:

- Initial Link Analysis
- Installation Worksheet
- Equipment Checklist

2.1 Initial Link Analysis

The link analysis, or path analysis, consists of the following tasks:

1. Examine the direction and length of a desired line-of-sight path.
2. Review environmental issues (terrain, climate, and interference sources).
3. Select configurable radio parameters.
4. Select antennas, cables, and other equipment.
5. Determine the fade margin of your signal.
6. Verify the effective radiated power (ERP) for each Wireless Router system.

In situations where a clear line-of-sight path of less than 8 kilometers (5 miles) exists, a detailed link analysis might not be necessary.

2.1.1 Verifying Line-of-Sight Paths

Radio line of sight is the most important consideration for installing your antenna. If you cannot achieve radio line of sight, ensure that your antennas are within 3 kilometers (2 miles) of each other.

Caution Distance recommendations for when you cannot achieve a clear line of sight are only guidelines; you might need to adjust them for your environment.

Perform the following steps to ensure line of sight:

1. Identify physical obstructions to the antenna that will affect system performance. Near-field obstructions are generally those that are within a 3-meter (10-foot) radius of the antenna; for example, guy wires, air conditioning or heating units, and other antennas. Far-field obstructions are objects such as trees or buildings that are in the area but not in close proximity to the antenna. Ensure that the antenna is mounted away from large metal objects that might affect the antenna's radiation pattern. Also, mount the antenna away from power lines, and high enough so that people do not walk in the antenna path and block the signals.
2. Use a directional antenna with a spectrum analyzer to make signal-level and interference measurements:
   - Identify the direction and polarity of interfering signals. Signals will always be strongest when both the antenna direction and polarity (horizontal or vertical) correspond to that of the competing signal.
   - Check for strong out-of-band signals, especially when considering installations that might use an L-band frequency (902- to 928-megahertz [MHz]). Consider using supplemental bandpass filters in your installation if you detect strong signals.
   - Note any type of signals, especially their strength, bandwidth, center frequency, and modulation type.

2.1.2 Understanding Environmental Conditions

Before you install your SubSpace 2001, evaluate the site for environmental conditions that will affect the installation and the performance of the SubSpace 2001. Moisture, wind, and lightning can all have adverse affects.

You can protect your antenna installation if you ensure that the installation is suited to the environment and is in conformance with good engineering practice. As a general rule, place your SubSpace 2001 in a weather-protected location. The environmental conditions within this location must conform to the operating environment specifications listed in Appendix A, "Hardware Specifications."

Moisture

Moisture can affect your system in the following ways:

- Unusually humid or rainy locations can accelerate corrosion and deterioration of improperly prepared antennas and connectors.
- Poorly installed or inadequately weatherproofed connectors can allow moisture into the coaxial cable's dielectric (inside the coax). This might cause internal corrosion that can greatly increase the cable's loss and make a link unusable.
- If the location is prone to ice storms, ice buildup on unprotected antennas can make them inoperable until the ice melts.
- High humidity, for example from fog or rain, causes more signal loss than low humidity.

Wind

Any antenna mounted outdoors will be subject to winds. Antenna manufacturers usually specify the following characteristics related to wind:

- Wind loading area—The effective area that a given antenna model presents to the wind. Different antenna designs experience different forces for a given wind velocity, based on the wind loading area.
- Wind survivability—The maximum wind speed that a given antenna model can experience without damage. This specification is useful for determining if the antenna is suited to a particular environment, but does not help at all in the determination of wind load to the mounting structure.

High wind can affect the system in the following ways:

- High winds can misalign or destroy antennas and their mounting structures.
- Coaxial cable runs that are not properly secured can flap around in the wind, causing broken internal connections.

Lightning

Lightning protection is an important part of system design and reliability. The radio's receiver is sensitive enough that it can be made inoperable by near strikes of lightning energy; that is, although the lightning does not touch the antenna or power systems directly, the energy might be coupled into the antenna or power systems. We recommend that you use high-quality AC power surge protectors and UHF antenna lightning arrestors. For these to be effective, you must adequately ground them by attaching a grounding rod that is driven approximately 2.5 meters (8 feet) into the ground.

2.1.3 Selecting Radio Parameters

Before you install your SubSpace 2001, you must determine the initial settings for the following radio parameters:

- Transmission frequency—The L-band model operates in the 902- to 928-MHz frequency range with nine 160-kilobits per second (kbps) overlapping channels (five nonoverlapping channels). The S-band model operates in the 2400- to 2483.5-MHz frequency range and has fifteen 160-kbps nonoverlapping channels.
- Transmission power level—The L-band model supports from 1- to 800-milliwatt (mW) radio frequency (RF) transmission power. The S-band model supports from 1- to 650-mW RF transmission power.
- Pseudorandom noise (PN) code—The radio contains a direct sequence (DS) spread-spectrum transceiver that includes 8 different PN codes and has 12 decibels (dB) of process gain.

Note Frequency and power considerations might dictate antenna choices, or antenna requirements might influence available frequency and power settings. Refer to Section 2.1.4 for more information about selecting antennas.

During the hardware installation process, set the frequency channel, output power, and PN code using the switches on the back of the radio. See Appendix A for switch settings. Modify these parameters to optimize performance during the installation and testing process described in Chapter 3 and during general network use. After you install your SubSpace 2001 and configure your network software, set these parameters using the TALnet software.

Transmission Frequency

All radios within your network that communicate with each other must use the same transmission frequency. Consider the following when selecting a transmission frequency:

- Avoid in-band interference—Use a spectrum analyzer to identify other signals that might be operating in the same band. Do not use the same or an adjacent frequency.
- Avoid out-of-band interference—Select a frequency in the middle of the band. For example, if you are using an L-band radio, you might select a frequency of 915 MHz. If you are using an S-band radio, you might select a frequency of 2443.457 MHz. Selecting a frequency near the edges of the band might result in interference from radios operating in adjacent bands. If you must select a frequency on the edges of the band, you might need RF filters. Refer to Section 2.1.4, "Selecting Antennas, Filters, and Cables," for more information.
- Follow country-specific regulations—Different countries have different requirements and regulations regarding frequency use. Make sure you follow these regulations.

Table 2-1 lists available frequencies and their channels.

Table 2-1 Transmission Frequencies

Channel	L-Band	S-Band
1	904.601	2407.067
2	907.201	2412.265
3	909.801	2417.465
4	912.401	2422.663
5	915.000	2427.863
6	917.599	2433.060
7	920.199	2438.259
8	922.798	2443.457
9	925.397	2448.659
10	—	2453.857
11	—	2459.056
12	—	2464.254
13	—	2469.454
14	—	2474.653
15	—	2479.851

Power Level

Select the lowest possible output power level that provides reliable data transmission. Analyze the links you need to make with the radio, and select the lowest setting that will allow you to achieve an acceptable signal strength on all links.

During hardware installation and wireless link testing, use the switches on the back of the radio to configure the power level. Table 2-2 lists power settings you can select with the switches; refer to Appendix A for switch settings. After you configure the TALnet software, use the TALnet commands to set the power level. The software allows you to configure additional power levels.

Table 2-2 Power Settings

L-Band		S-Band	
mW	**dBm**	**mW**	**dBm**
1	0	1	0
3	4.8	3	4.8
10	10	10	10
32	15	32	15
100	20	100	20
250	24	250	24
500	27	400	26
800	29	650	28.1

Note Exact output power for individual radios might vary slightly.

PN Code

PN codes, also called spreading codes, allow you to encode network data for transmission. Using PN codes helps to increase channel capacity by allowing you to use a frequency that another network in the area might also be using. In particular, selecting a PN code might help you avoid in-band interference if that interference is caused by other spread-spectrum transmitters.

PN codes are represented by integers between 1 and 8; all radios in your network that communicate with each other must use the same code.

2.1.4 Selecting Antennas, Filters, and Cables

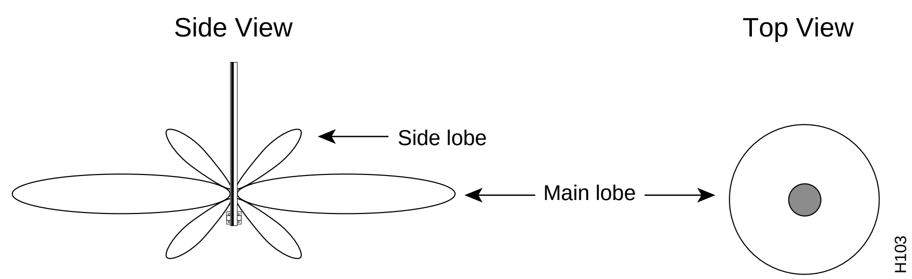
The equipment you select will vary depending on many factors, including the radio line of sight, interference factors, and environmental conditions. This section discusses guidelines for selecting antennas, RF filters, and cables.

Antennas

You can use directional or omnidirectional antennas with your Wireless Router. These antennas are typically mounted on a roof and connected to the radio with a coaxial cable.

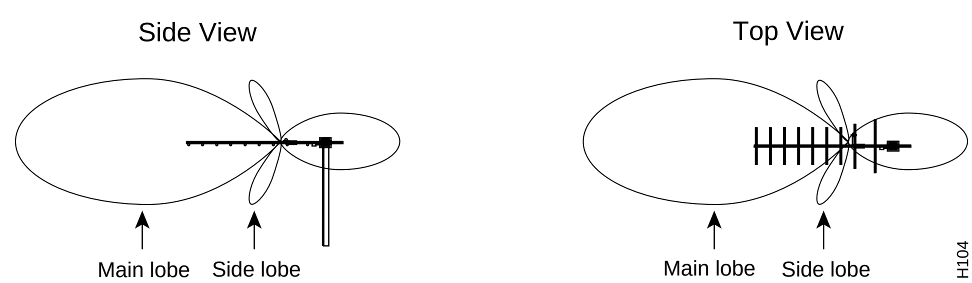
An omnidirectional antenna is capable of transmitting or receiving signals from all directions in a horizontal plane with equal power in each direction. Figure 2-1 shows an omnidirectional antenna. Use an omnidirectional antenna when trying to make multiple links, the links have widely varying directions, or your fade margin is within acceptable limits.

Figure 2-1 Omnidirectional Antenna



A directional antenna focuses RF energy in a specific direction. Ensure that you direct the antenna toward the opposite end of the link. Figure 2-2 shows a directional antenna. Use a directional antenna when making only a few links, the links are in similar directions, or you need more antenna gain to achieve an acceptable fade margin.

Figure 2-2 Directional Antenna



In addition to selecting an omnidirectional or directional antenna, you need to consider the following:

- Polarization—Vertical or horizontal orientation of the signal.
- Antenna gain—The measure of an antenna's ability to amplify the RF energy into a preferred direction.
- Weight and wind—The antenna structure (including supporting wires, if any) must be designed to handle both the additional weight and wind loading.

- Cold weather performance—If snow and ice are likely to develop, you might select an antenna in a *radome*, which encases the antenna in a fiberglass cover and prevents ice and frost from forming on the elements of the antenna itself.

Appendix B, “Antenna Options,” lists recommended antennas and their characteristics.

RF Filters

Some installations (primarily in the 902- to 928-MHz band) require filtering. The type of filtering depends on the site and on the type of interference encountered. Some interference is *in band*; that is, within the 902- to 928-MHz operating band of the radio. Use one or more of the following techniques to mitigate some of this interference:

- Change the antenna orientation.
- Select a different antenna type (a directional antenna rather than an omnidirectional antenna).
- Install a notch filter to eliminate or reduce the level of interfering signal.
- Avoid operations on affected frequencies.

Not all sources of severe interference fall within the passband of the radio. High levels of interference that are present outside the radio band can also cause problems. In North America and those locations following North American frequency allocation conventions, cellular telephone base stations operating below 902 MHz and pager transmitters operating above 928 MHz can cause interference. In these cases, install a bandpass filter to reduce signals outside of the 902- to 928-MHz band to an acceptable level.

Use the site survey or actual operations to determine if you need an RF filter. Keep in mind, however, that installing the radio at a communications site where other transmitters are nearby (such as on a mountain top) will almost always require external filtering.

Cables and Power

The antenna cable used for the SubSpace 2001 radio is standard communications-grade 50-ohm coaxial cable. We recommend using Belden 9913 or Times Microwave LMR-400 cable. Both of these cables exhibit signal losses of 4.1 dB per 100 feet at 900 MHz and 7 dB per 100 feet at 2400 MHz. This type of cable is flexible and is relatively low-cost compared to hardline/semirigid cable. If you use other types of cables, ensure that they meet the following criteria:

- The impedance of the cable must be 50 ohms.
- If you use cables with higher signal losses, the loss must not be excessive for your network, based on your link analysis and fade margin analysis.
- The jacket should be ultraviolet resistant and noncontaminating.
- The cable must be able to accept Type-N coaxial connectors.

The length and type of antenna cabling directly affects transmitted power and receiver sensitivity. In other words, the longer the antenna cable is, the shorter the radio range will be. As a general rule, we recommend a maximum RF cable length of 30 meters (100 feet) in the L-band frequency range and 23 meters (75 feet) in the S-band frequency range for flexible-type cable.

For longer distances, consider doing one of the following:

- Move both the router and radio so that they are closer to the antenna.
- Move the radio closer to the antenna and use a longer EIA-530 cable to separate the radio from the router. Your EIA-530 cable should be no longer than 500 meters (1,600 feet).
- Use hardline/semirigid coaxial cable. If you use a hardline/semirigid cable, never connect it directly to the radio and antenna. Instead, connect it to the appropriate equipment using short lengths of flexible, low-loss cable.

Ensure that you can connect both the router and the radio to a properly grounded and filtered source of AC power. If the site experiences frequent power disruptions, plan to connect the equipment to an uninterruptable power supply (UPS). If the site experiences regular power outages, you might need to operate the radio and the router directly from a source of DC power such as a storage battery or solar system. Contact you technical support representative about 12- to 48-volt DC power options.

2.1.5 Determining Your Fade Margin

To achieve reliable communication, the radio path must have an average received signal level high enough to protect the link against fluctuations in the signal power caused by fading and other propagation conditions. This safety factor is referred to as the fade margin.

The fade margin is a measure of how much additional signal loss the system can endure without dropping below the required bit error rate (BER) level. A fade margin of 15 dB or more is sufficient in most situations.

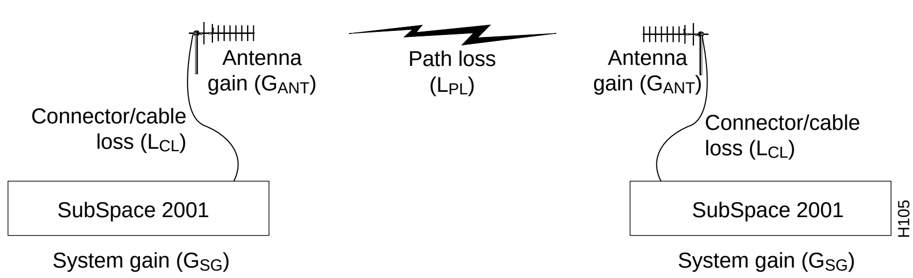
Use the following formula to calculate the fade margin (see Figure 2-3):

Fade Margin = $G_{SG} + G_{ANT} - L_{CL} - L_{PL}$

In this formula, G_{SG} is the total system gain, G_{ANT} is the sum of the antenna gain at the two ends of the link, L_{CL} is the total connector and cable loss of the cables at both ends of the link, and L_{PL} is the path loss. These are described in more detail in the following subsections. The last subsection in Section 2.1.5 includes a worksheet to help you determine your fade margin.

Figure 2-3 illustrates fade margin calculations.

Figure 2-3 Fade Margin Calculations



System Gain

System gain is the total gain of the *radio* system, without any consideration of the antennas or cables. It is the arithmetic difference between the transmitter's output power and the receiver's sensitivity threshold. System gain (G_{SG} in the formula) is measured in decibels (dB). To calculate the system gain, subtract the receiver sensitivity from the output power:

(Output Power) - (Receiver Sensitivity) = (System Gain)

Table 2-3 lists the maximum output power for your SubSpace 2001.

Table 2-3 Maximum Transmission Power and System Gain

Radio Type	Milliwatts	dBm	System Gain
L-band	800	+ 29	124
S-band	650	+ 28	123

The receiver sensitivity for the SubSpace 2001 is –95 dBm, based on a BER of 10^{-6}. If you use an S-band radio operating at a maximum power of 28 dBm, your system gain is 123 dBm:

(+28 dBm) - (-95 dBm) = 123 dBm

Note Because the output power might be different on either side of a link, the system gain from Router A to Router B might differ from the gain from Router B to Router C.

Antenna Gain

Antenna gain is the measure of the antenna's ability to amplify the RF energy into a preferred direction. Antenna gain (G_{ANT} in the formula) is measured in decibels in relation to isotropic radiators (dBi)—the ratio between the power radiated by the antenna in a specific direction and the power radiated in that direction by an isotropic antenna fed by the same transmitter. An isotropic antenna is a theoretical model of an antenna that radiates a signal equally in all directions.

Refer to the antenna manufacturer's specifications to determine the antenna gain for the antenna you will be using. Some antennas are specified in decibels in relation to a dipole antenna (dBd). This number can be converted to dBi by adding 2.1 dB.

Cable and Connector Loss

An antenna is connected to the radio with a coaxial cable. The cable loss (L_{CL} in the formula) is measured in dB, and depends on the length and the type of cable you are using. (Cable loss is also referred to as attenuation.) You can use any 50-ohm coaxial cable whose loss does not contribute significantly to the total link loss. (The cable loss should be between 3 and 15 dB per hundred feet.) You can purchase quality cables with lower loss from TAL or a distributor. Table 2-4 shows the cable loss for the standard LMR-400 cables that TAL provides. If you use other cables, refer to the manufacturer's specifications for attenuation.

Table 2-4 LMR-400 Cable Loss

Operating Frequency	Loss per 100 Feet	Loss per Foot (LPF)
900 MHz	4.1 dB	0.041 dB
2400 MHz	7 dB	0.070 dB

Path Loss

Typically, the largest contributor to path loss is the loss of power as the signal travels through space. To determine the path loss (L_{PL} in the formula), determine the distance between the radios that you will be using for your application and refer to Table 2-5, or use the following formula:

loss in dB = (96.6 + 20 LOG [distance in miles] + 20 LOG [frequency in GHz])

Table 2-5 Path Loss between Two Isotropic Antennas

Distance in miles (km)[1]	Path Loss @ 915 MHz (L-Band)	Path Loss @ 2400 MHz (S-Band)
1 mile (1.6 km)	96 dB	104 dB
2 (3.2)	102 dB	110 dB
3 (4.8)	105 dB	114 dB
4 (6.4)	108 dB	116 dB
5 (8.0)	110 dB	118 dB
6 (9.7)	111 dB	120 dB
7 (11.3)	113 dB	121 dB
8 (12.9)	114 dB	122 dB
9 (14.5)	115 dB	123 dB
10 (16.1)	116 dB	124 dB
15 (24.1)	120 dB	128 dB
20 (32.2) [2]	123 dB	130 dB
25 (40.2)	125 dB	132 dB
30 (48.3)	126 dB	134 dB

1. The calculation for loss using kilometers is:
   loss in dB = (92.4 + 20 LOG [distance in kilometers] + 20 LOG [frequency in GHz])
2. Distances greater than 20 miles (32.2 km) are difficult to obtain.

Reflections from the ground and other objects might cause the actual path loss between the transmitting and receiving antennas to differ significantly from the calculated path loss when both antennas are placed in a line-of-sight environment. Unfortunately, the additional loss due to these effects is difficult to calculate and requires precise knowledge of the geometry of the link and surrounding materials.

Fade Margin Worksheet

The previous subsections described how to calculate the fade margin. Use the following worksheet to help in your calculations. Remember that system gain might vary in either direction of a link. This difference means your fade margin will be different. Fill out a worksheet for both directions in the link. If your fade margin is less than 15 dB, review your choice of cables and antennas, and the location of the antenna and the two subsystems.

Table 2-6 Fade Margin Worksheet

A. Calculate System Gain	
Total output power: ____ dBm + 95 = _____ dB system gain	*See Table 2-3.*
B. Calculate Total Antenna Gain	*See manufacturer antenna specifications.*
Gain of antenna at site 1: _____ dBi	
+ Gain of antenna at site 2: _____ dBi	
= Total antenna gain: _____ dBi	
C. Calculate Coaxial Cable Loss	
Cable loss in dB/100 feet: _____ ÷ 100 = _____ cable loss per foot (LPF)	*See Table 2-4 for cable loss.*
Length of coaxial cable at site 1: _____ feet x _____ LPF = _____ dB cable loss	
Length of coaxial cable at site 2: _____ feet x _____ LPF = _____ dB cable loss	
= Total coaxial cable loss: _____ dB	
D. Calculate Miscellaneous Losses	
Filter or other losses at site 1: _____	
Filter or other losses at site 2: _____	
Total miscellaneous losses: _____	
E. Calculate Total System Losses	
Total cable loss: _____ dB + Miscellaneous loss: _____ = _____ System loss	*Add totals from Sections C and D.*
F. Calculate Fade Margin	
System gain: _____	*From Section A.*
+ Antenna gain: _____	*From Section B.*
– System losses: _____	*From Section E.*
– Path loss: _____	*See Table 2-5.*
= **Fade margin**: _____	

2.1.6 Verifying ERP

Effective radiated power (ERP) is the strength of the signal as it leaves the antenna; in other words, it is the sum of the gains and losses of a single wireless subsystem (including the radio, the RF cable, and the antenna). Every country regulates the maximum ERP; ensure that your system does not exceed regulations. You must verify the ERP for every Wireless Router system in your network.

Unlike fade margin, ERP is a per-system characteristic; do not add the losses and gains on both ends of a link. To calculate the ERP, add the output power and antenna gains, then subtract any cable or filter losses, as described in Table 2-7.

Table 2-7 ERP Worksheet

	Total output power: ____ dBm	*See Table 2-3.*
+	Gain of antenna: _____ dBi	*See manufacturer antenna specifications.*
–	Cable loss: _____ dB (length of cable: _____ feet x _____ LPF)	*See Table 2-4 for LPF.*
–	Filter or other losses: _____	
=	**ERP**: _____	

If your ERP exceeds maximum allowable limits, adjust the output power, cable length, or antenna type as appropriate. Note, however, that adjusting these variables might affect your fade margin.

2.2 Installation Worksheet

This section contains a worksheet that will be important during the installation process and when troubleshooting the SubSpace 2001. For example, this worksheet provides information that might be useful in the following situations:

- The site owner might need to be informed of such issues as antenna mounting procedures or antenna weight and wind load.
- Depending on what the building is used for, different regulations regarding antennas and their mounts might apply.
- The building construction might affect antenna mounts and the type of antenna you select.
- The type of roof affects whether the antenna will bolt onto an existing structure, if you must drill into the building, or if you must secure it with guy wires.
- During maintenance or troubleshooting steps, others might need to know how to access the equipment.
- Others might need to know the radio parameters for later software configuration.

We recommend that you photocopy the worksheet, then fill out as much information as possible. Attach drawings where appropriate. For example, you might provide a map of the site, room layouts, or antenna structures.

Table 2-8 Installation Worksheet

Contact Information			
Site contact: ______________________		Phone: ________________	
Site owner: ______________________		Phone: ________________	
Site Location			
Street address: ______________________		Mailing address: ______________________	
Longitude: ________	Latitude: ________	Determined with: Map	GPS
Building Information			
Type of building:	Office	Residence	Apartment
Building material:	Wood or Plaster	Cement	Glass or Steel
Number of floors: (including ground floor) ________			
Roof material:	Shingle	Tile	Other: ________
Roof construction:	Flat	Sloped	
Permanent roof access:	None	Stairs	Ladder
Heliport:	Yes	No	
Power			
AC power:	Volts ____________	Frequency ________	
Available on roof?	Yes	No	
Filtered/isolated?	Yes	No	
Brownouts:	Yes (Answer below)	No	
Blackouts:	Yes (Answer below)	No	
	Typical length ______	Frequency ________	
Power backup?	UPS (How long) _____	Generator (How long) _______	
Grounding rod:	Yes	No	Location: ________

Table 2-8 Installation Worksheet

Equipment			
Mounting:	Table	Shelf	Rack (19-inch)
Antenna cable:	Length: _______________	Connection to antenna:	______________________________
Antenna mount:	New structure	Existing structure (include description) ________________	
		____	
Link to nearest radio node:	Distance: _____________	Bearing (True): _________	
Line-of-sight obstructions:	____		
	____		
Initial Radio Parameters			
Radio model:	L-band	S-band	
Frequency: __________	Power: _____________	PN code: (1–8) ________	

2.3 Equipment Checklist

Before you begin your hardware installation, ensure that you have the necessary equipment. The following subsections list the items that shipped with your order, required tools and equipment, and recommended tools and equipment.

2.3.1 SubSpace 2001 Checklist

Ensure that you received the following with your shipment:

- Wireless Router
- SubSpace 2001 (or SubSpace 2001s) radio
- Serial cable to connect the router and the radio
- Two power supplies and their cables

If you ordered them, your shipment might include lightning arrestors, RF cables, and antennas.

2.3.2 Required Tools and Equipment

Before you begin the installation procedure, ensure that you have the following:

- Soldering iron, 25-45W pencil, grounded
- Soldering iron, 150-300W gun—for solder-type Type-N connectors only
- Crimping tool—for crimp-type Type-N connectors
- Heat gun or butane torch
- Coaxial cable cut/preparation tool
- Small diameter pipe cutting tool—for installations using hardline/semirigid cable
- Solder Flux remover solvent—for solder-type Type-N connectors only
- Tape, electrical
- Tape, water sealing and/or weather-sealing heat-shrink tubing
- UV-resistant nylon wire ties
- Sledge hammer—for installing grounding rods
- Safety glasses
- Multimeter, hand-held, Fluke 77 or equivalent
- Wattmeter, Radio Frequency/Thruline, Bird Model 43 or equivalent, fitted with Type-N female connectors
  - Element, wattmeter, power/frequency determining, Bird 801-1, 1-watt maximum power, 800-1000 MHz
  - Element, wattmeter, power/frequency determining, Bird 431-20, 1-watt maximum power, 2400-2500 MHz
- Adapters, RF: Adapter kit of BNC, UHF, Type-N connectors
- Termination load, RF, 50-ohm, 2-watt minimum rating, at least 900-2500 MHz rating

2.3.3 Recommended Tools and Equipment

In addition to standard tools required for installations, you might need the following tools:

- Radio, portable two-way, or cellular phone—Might be necessary for coordinating antenna installation, alignment activities
- Receiver, global positioning system (GPS)—To accurately determine exact location, bearing and distance between sites
- Spectrum analyzer: -120 dBm sensitivity or better. Recommended options:
  - “Max hold” CRT display
  - Adjustable video and resolution bandwidth
  - Portable operation
  - AM and FM audio demodulation
  - Similar to Hewlett Packard 8595 series
- BER tester, for example, a Cylink Mini-BERT or a FireBERD 4000, that has the following features:
  - Supports EIA-530.
  - Can synchronize up to 160 kbps.
  - Can recognize a 2^{20-1} standard BER test pattern.
  - Does not require data loopback at the far end of the link.
- Compass
- Binoculars
- Local map showing topology
- Software, path analysis—When installing large networks and attempting to closely predict signal propagation and coordinate radio systems