

Building Antennas

part



in this part

Chapter 1

Building Your Own Wi-Fi
Antenna Cable

Chapter 2

Building a Classic Paperclip
Antenna

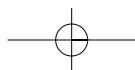
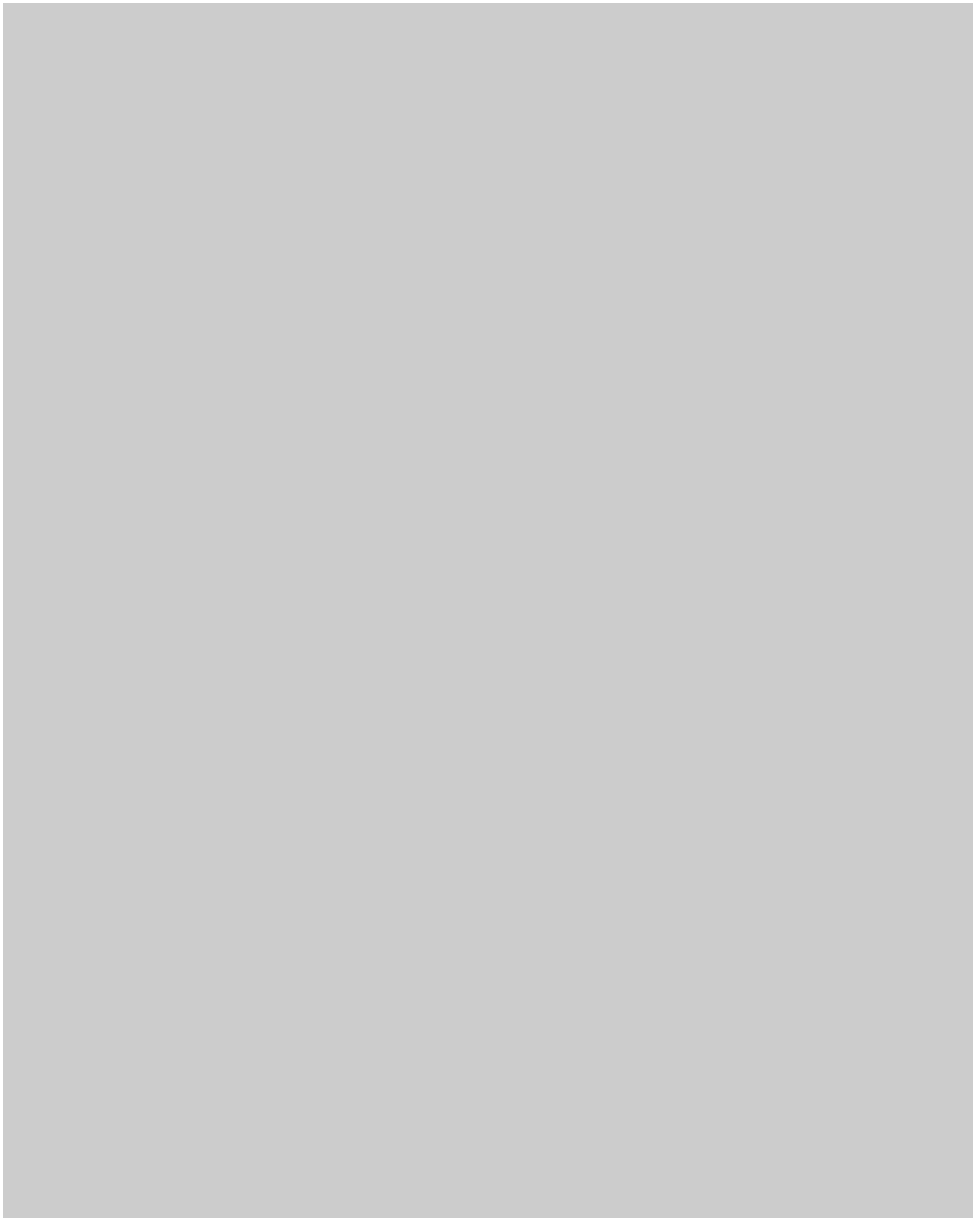
Chapter 3

Building a Directional Tin
Can Antenna

Chapter 4

Modifying Your Access Point
with a High-Gain Antenna

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Building Your Own Wi-Fi Antenna Cable

Think back to the olden days, say three or four years ago, when computers were tied to the desk with a phone line or network cord. Surfing the Web, reading e-mail, or checking your *PetCam* meant plugging in, jacking in, or getting wired. Now just about any device can be “unwired” to use a wireless network. You still need electricity though, so batteries or power cords are still in the picture. At least for a little while.

Ironically, wireless seems to use twice as many cables as wired connections. This wireless paradox arrives in the form of extra power cords, antenna cables, pigtail jumper cables, and Ethernet patch cables.

One critical component to a successful wireless project is the antenna cable, used to extend the reach of the radio to the antenna. This chapter will show how to build an antenna cable for use with many of the projects in this book. You can purchase this type of cable in pre-defined lengths from online sources. However, building your own antenna cable is easy and can take less than 5 minutes.



Note

The instructions in this chapter apply to a Wi-Fi coaxial antenna cable (also called *coax*). The steps in this chapter can be adjusted to apply to any type of coaxial cable, like that used in cable televisions.

You will need the following items:

- Wi-Fi network device with an external connector (client adapter or access point)
- Wi-Fi pigtail cable, if using a wireless client adapter
- Coaxial cable, preferably Times Microwave LMR-400
- Coaxial cable cutters
- Crimp tool, ratcheting style
- Crimp tool “die” with hex sizes .429, .128, and .100

chapter 1

in this chapter

- ☑ Understanding Wi-Fi and radio frequencies
- ☑ Learning about coaxial cables
- ☑ Making your own coax cable connector
- ☑ Selecting a pigtail

4 Part I — Building Antennas

- ▶ Long-nosed pliers
- ▶ Small wire cutters
- ▶ Single-sided razor blade
- ▶ Scissors
- ▶ Type-N connectors, reverse-polarity male
- ▶ Digital multimeter or electrical continuity tester
- ▶ Known-good coax cable for comparison testing

Some of these items are specific to building an antenna cable (crimp tools, connectors, and so on). Don't worry if they are unfamiliar to you. All will become clear as the chapter progresses.

About Wi-Fi

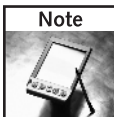
If you want to understand what is going on with a wireless network, you first need to know some of the basics of wireless communication and radio transmission.

Wireless networking is accomplished by sending a signal from one computer to another over radio waves. The most common form of wireless computing today uses the IEEE 802.11b standard. This popular standard, also called *Wi-Fi* or *Wireless Fidelity*, is now supported directly by newer laptops and PDAs, and most computer accessory manufacturers. It's so popular that "big box" electronics chain stores carry widely used wireless hardware and networking products.

**Note**

Wi-Fi is the root of a logo and branding program created by the Wi-Fi Alliance. A product that uses the Wi-Fi logo has been certified by the Wi-Fi Alliance to fulfill certain guidelines for interoperability. Logo certification programs like this one are created and promoted to assure users that products will work together in the marketplace. So, if you buy a Proxim wireless client adapter with the Wi-Fi logo branding, and a Linksys access point with the same logo on the product, they should work together.

The IEEE 802.11b Wi-Fi standard supports a maximum speed of 11 megabits per second (Mbps). The true throughput is actually something more like 6 Mbps, and can drop to less than 3 Mbps with encryption enabled. Newer standards like 802.11a and the increasingly popular 802.11g support higher speeds up to 54 Mbps. So why is 802.11b so popular? Because it was first and it was cheap. Even 3 Mbps is still much faster than you normally need to use the Internet.

**Note**

A *megabit* is one million binary digits (*bits*) of data. Network speed is almost always measured in bits per second (bps). It takes 8 bits to make a *byte*. Bytes are used mostly to measure file size (as in files on a hard disk). A *megabyte* is about 8 million bits of data. Don't confuse the term *megabyte* for *megabit* or you will come out 8 million bits ahead.

The 802.11a standard, which operates in the 5 GHz frequency band, is much faster than 802.11b, but never caught on, partly because of the high cost initially and partly because of the actual throughput in the real-world conditions of a deployed wireless network.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 5

The fast and inexpensive 802.11g standard (which uses the same 2.4 GHz band as 802.11b) is rapidly moving to unseat 802.11b from the top of the heap. The very cool thing about “g” is the built-in backwards compatibility with 802.11b. That means any “b” product can connect to a “g” access point. This compatibility makes 802.11g an easy upgrade without tossing out your old client hardware.

Because of the compatibility with 802.11b and 802.11g, there is no great hurry to push the myriad of funky wireless products to the new “g” standard. Most manufacturers have support for basic wireless infrastructure using 802.11b and 802.11g with access points and client adapter.

Wi-Fi 802.11b really shines when you look at the host of wireless products available. Not only are there the basic wireless networking devices, like adapters, base stations, and bridges, there are also new products that were unthinkable a few years ago. Wireless disk drive arrays, presentation gateways, audiovisual media adapters, printer adapters, Wi-Fi cameras, hotspot controllers, and wireless broadband and video phones dominate the consumer arena. And the enterprise market is not far behind.

We’ve been tossing out the terms *wireless*, *gigahertz* (GHz), and *frequency*. Next, we’ll discuss how Wi-Fi uses wireless radio waves, also called RF, to communicate amongst the devices in a wireless network.

About RF

Entire books, libraries, and people’s careers are devoted to understanding more about radio frequencies (RF) and electromagnetism. The basics are covered here to help make your projects a success.

Wi-Fi wireless products use microwave radio frequencies for over-the-air transmissions. Microwave RF is very similar to the radio used in your car, only at much higher frequencies.



Tip

For a downloadable PDF of the spectrum assignments in the United States, visit www.ntia.doc.gov and look under “Publications” for the “Spectrum Wall Chart.” The chart is a few years old, but most of the information is accurate. And it’s suitable for framing.

For frequency spectrum assignments covering most of Europe, check out the European Radiocommunications Office at www.ero.dk and look under the CEPT National Frequency Tables. The ERO “Report 25” document also covers much of this information in a single report file. To find this deeply buried document, search the Web for *ERO Report 25*.

Visualizing the radio frequency signals helps to understand the behavior of the electromagnetic (EM) spectrum. Imagine dropping a rock in a pond. Waves are created in concentric circles coming from the point where the rock was dropped. These waves are just like radio waves, except at a very low frequency of perhaps 10 waves per second, which are called *cycles per second* or *hertz*.

Now imagine a cross-section of those waves. Perhaps the rock was dropped in a fish tank and the waves are visible from the side. The wave would look similar to that shown in Figure 1-1.

The electromagnetic spectrum spans frequencies from subaudible sound of 1 hertz all the way through radio and visible light to beyond X-rays and cosmic rays at a frequency of 10 followed by

6 Part I — Building Antennas

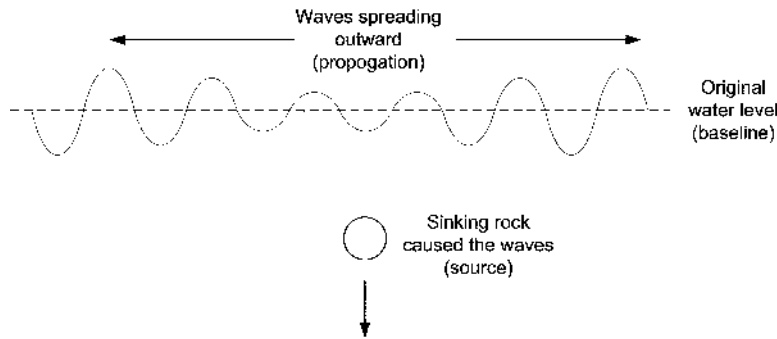


FIGURE 1-1: Waves viewed from the side.

24 zeros. The frequency of an FM car radio operates at about 100 million hertz, or 1 megahertz (MHz). For example, 103.1 MHz FM is a radio station in Los Angeles. Wi-Fi operates at about 2,400 MHz or 2.4 GHz. Table 1-1 shows a frequency chart to help you understand the scale.



Microwave ovens also operate at 2.4 GHz, but at *much* higher power than Wi-Fi gear. One-tenth of a watt (0.1 W) is typical for a Wi-Fi device, versus 1,000 watt for a microwave oven. That's a difference of over 10,000 times the power! Still, to be safe, always observe caution and minimize unnecessary exposure when working with RF.

Frequency versus Wavelength

Frequency and wavelength are inseparably related to each other. As frequency increases, wavelength decreases and vice versa.

- *Frequency*: The rate at which a radio signal oscillates from positive to negative.
- *Wavelength*: The length of a complete cycle of the radio signal oscillation.

Table 1-1 Frequency Ranges

Range	Abbreviation	Cycles Per Second	Application
Hertz	Hz	1	Ripples in a pond, ocean waves
Kilohertz	kHz	1,000	AM radio, CB radio
Megahertz	MHz	1,000,000	FM radio, television, cordless phones, 2-way radios, older cell phones
Gigahertz	GHz	1,000,000,000	Wi-Fi, satellite, microwave ovens, cordless phones, newer cell phones, GPS

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 7

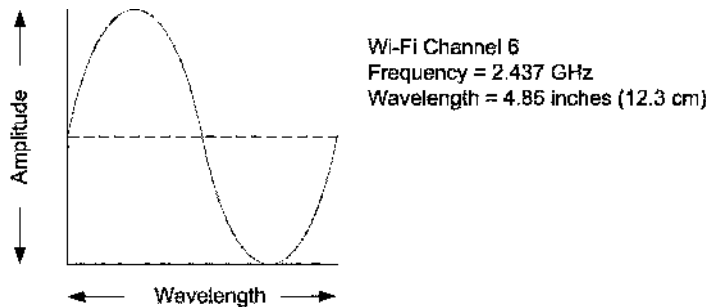


FIGURE 1-2: Dimensions of a Wi-Fi channel 6 (2.437 GHz) radio wave.

Wavelength is, of course, a length measurement, usually represented in metric (meters, centimeters, and so on). And frequency is a count of the number of waves occurring during a set time, usually per second. Cycles per second is represented as *Hertz* (Hz).

Figure 1-2 shows a Wi-Fi radio wave for channel 6 (2.437 GHz). The dimensions are important to note, because the physical properties of the wave define antenna, cable, and power requirements. Wavelength is critical for antenna design and selection as we will cover in the next chapter.

Wi-Fi signals operating at a frequency of 2.4 GHz have an average wavelength of about 12 cm. Since the wavelength is so short, antennas can be physically very small. A common design for antennas is to make them 1/4 of a wavelength or less in length, which is barely more than an inch long. That's why Wi-Fi antennas can perform so well even though they are physically very small. As a comparison, a car radio antenna is much longer to get a decent signal because FM radio signals are an average of 10 feet long.

Wavelength and antenna length go together. To oversimplify, the longer the antenna, the more of the signal it can grab out of the air. Also, antenna length should be in whole, halves, quarters, eighths, and so on of the intended wavelength for best signal reception. The highest reception qualities come from a full wavelength antenna.



Tip

Perform this simple math formula to find wavelength: $300 / \text{frequency in megahertz}$. The answer will be the wavelength in meters. So, $300 / 2437 = 0.12$ meters or 12 cm.

Unlicensed 2.4 GHz Wi-Fi

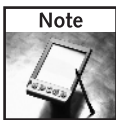
Wi-Fi makes use of the internationally recognized unlicensed frequency band at about 2.4 GHz. The IEEE standards body created 802.11b and defined the “channels” and frequencies for use by manufacturers worldwide. Different countries accepted the standard and allowed the use of devices in this frequency range with few restrictions. The word *unlicensed* as it applies to Wi-Fi specifically means that products can be installed and used without prior approval from the local governing body. That's the Federal Communications Commission (FCC) for users in the United States. Radio systems that operate in “licensed” bands require an application and permission

8 Part I — Building Antennas

procedure before turning on or using a radio system. For example, FM radio stations require permission from the FCC before broadcasting.

Certain other unlicensed products have been in use for some time: CB radios, walkie-talkies or consumer two-way radios, cordless phones, and many other radio products operate in unlicensed bands.

Unlicensed is not equivalent to unregulated, though. There are still rules that need to be followed to stay legal, especially regarding power output. This is covered in Chapter 2.



Note

In the United States, 802.11b usage is regulated by the FCC. The FCC laws define maximum power output, among other more specific regulations. In addition, the FCC approves products for use in the U.S. market. Manufacturers must submit their product for testing and authorization. The FCC then grants an “FCC ID” for the product. Anyone can look up an FCC ID from the Web site at www.fcc.gov (look under Search, for “FCC ID Number” searches). This can help you track down the true manufacturer of a Wi-Fi radio product, despite the label or brand.

Wi-Fi Channels

As defined in 802.11b, Wi-Fi consists of 14 channels worldwide. Only channels 1 to 11 are available in North America. Channels in other countries vary. Table 1-2 shows each channel and frequency, and the countries with approval to use that channel. (The lucky ones in Japan can use all 14!)

What is not easily shown in Table 1-2 is *channel separation*. To make the channel numbering scheme work with different radio technologies, the IEEE community defined these 802.11b channels with significant overlap. For example, channel 6 is centered on 2.437 GHz, but it extends in both directions by 11 MHz (0.011 GHz). That means channel 6 uses 2.426 GHz

Table 1-2 802.11b Specified Channels

Channel	Center Frequency (GHz)	Countries
1	2.412	USA, Europe, Japan
2	2.417	USA, Europe, Japan
3	2.422	USA, Europe, Japan
4	2.427	USA, Europe, Japan
5	2.432	USA, Europe, Japan
6	2.437	USA, Europe, Japan
7	2.442	USA, Europe, Japan
8	2.447	USA, Europe, Japan
9	2.452	USA, Europe, Japan

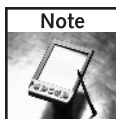
Chapter 1 — Building Your Own Wi-Fi Antenna Cable 9

Channel	Center Frequency (GHz)	Countries
10	2.457	USA, Europe, Japan, France, Spain
11	2.462	USA, Europe, Japan, France, Spain
12	2.467	Europe, Japan, France
13	2.472	Europe, Japan, France
14	2.484	Japan

to 2.448 GHz, which, as shown in Table 1-2, means it uses frequencies already assigned to channels 4, 5, 6, 7, and 8. Clearly, Wi-Fi devices using channels 6 and 7 would not operate together in harmony because of the interference.

To ensure trouble-free operation, with little interference from any other Wi-Fi devices, the channels need to be separated.

In the United States, channels 1, 6, and 11 are the sweet-spots for maximum usage with the least interference. In Europe, the recommended channels are 1, 7, and 13, and in Japan, the channels are 1, 7, and 14. For this very reason, most products come with one of these channels as the default setting, and most Wi-Fi hotspots are set to one of these three channels.



Note

Recently, users have been squeezing these nonoverlapping channels down to minimal-overlapping channels 1, 4, 8, and 11. This opens up significantly more options for Wi-Fi device and access point placement. There are possible downsides due to the increased interference, but it's worth testing if your setup needs a lot of devices in a small space.

Now you would have a basic understanding of how Wi-Fi works in a physical and logical sense. There's lots more to Wi-Fi technology and specifications, but that's all you need to know about the theory for now. Next, we'll get down to the specifics about building your own Wi-Fi projects.

Parts of a Wi-Fi Project

Every Wi-Fi project contains specific primary components to make the system work properly. These are broken down into five simple components:

- Data signal (Ethernet, computer interface, USB, and so on)
- Data to RF converter
- Radio transceiver
- Transmission line
- Antenna system

10 Part I — Building Antennas

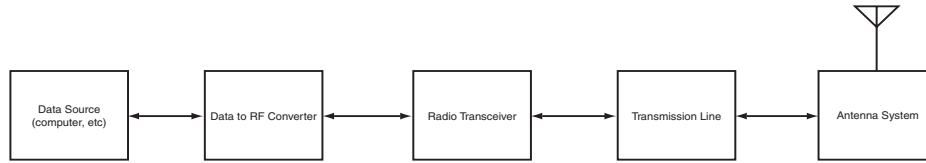


FIGURE 1-3: Parts of a Wi-Fi project.

Figure 1-3 shows the breakdown. The data to RF converter and radio transceiver are nearly always in the same appliance, and even on the same circuit board as on a PC card.

Data Signaling

The data signal is the digital signal with which every Wi-Fi access point or client project will interface. In some cases, the data will come from a computer via PC card slot or USB cable. In others it may be an Ethernet camera or the network itself.

The data signal is usually based on the Internet protocol, TCP/IP. TCP/IP is a protocol used to transmit data between computers on normal, wired networks. Wi-Fi is meant to convert TCP/IP traffic into radio waves and back.

Wi-Fi Devices

The category of Wi-Fi devices consists of the digital data to RF converter and the radio transceiver. Most often, these two items are in the same product. In this book, projects will not break down these two components; we're describing them separately here for clarity. For example, cable and antenna modifications to a wireless access point are covered in several chapters throughout the book. Wi-Fi devices have two jobs: convert the data from the computer into a radio signal, and transmit and receive radio signals to and from the data converter. They come in several forms that can be broken down into the following four major groups:

- *Wireless Access Point*: Attached to an Ethernet network, an access point provides a wired network gateway to wireless clients. An access point is the essential component for setting up a typical wireless network.
- *Wireless Client Adapter*: Connected or installed in a computer, a client adapter provides wireless connectivity to a wireless access point and then to a wired network. This can be inserted into a desktop computer, a laptop, a USB adapter, or any other computer interface.
- *Wireless-to-Ethernet Bridge*: Provides a direct connection between a wireless and wired (Ethernet) network without the need of a computer interface. It usually acts as a client connecting to an access point.
- *Specialized Components*: These include dedicated wireless networking devices, audiovisual devices, music streaming devices, digital picture frames, wireless scanners, wireless printers, and many more to come.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 11



Note

A radio transceiver is merely a transmitter and receiver in one unit. Your car radio is a receiver. An AM or FM radio station uses a transmitter. A CB radio is a transceiver. Wi-Fi devices are transceivers constantly sending and receiving radio signals when in use.

Transmission Lines

When you work with Wi-Fi products, you will find that the transmission line is nearly always a *coaxial cable*. Internal transmission lines may be of very small diameter, high loss cable. But usually the cable run is less than a few inches, so line loss is not much of a factor. See Figure 1-4 for an internal view of a transmission line for the Linksys WAP11, a popular 802.11b wireless access point.

An RF transmission line transfers RF energy from the transmitter to the antenna while both losing and radiating as little as possible. Radiation should be left to the antenna system. It also transfers RF energy from the antenna to the receiver in the same fashion.

Antenna System

The antenna system is where the rubber hits the road, so to speak. The antenna emits the electromagnetic radio frequency signal out of the Wi-Fi device. Antenna systems will be covered in Chapter 2 while building a simple antenna for a laptop PC card.

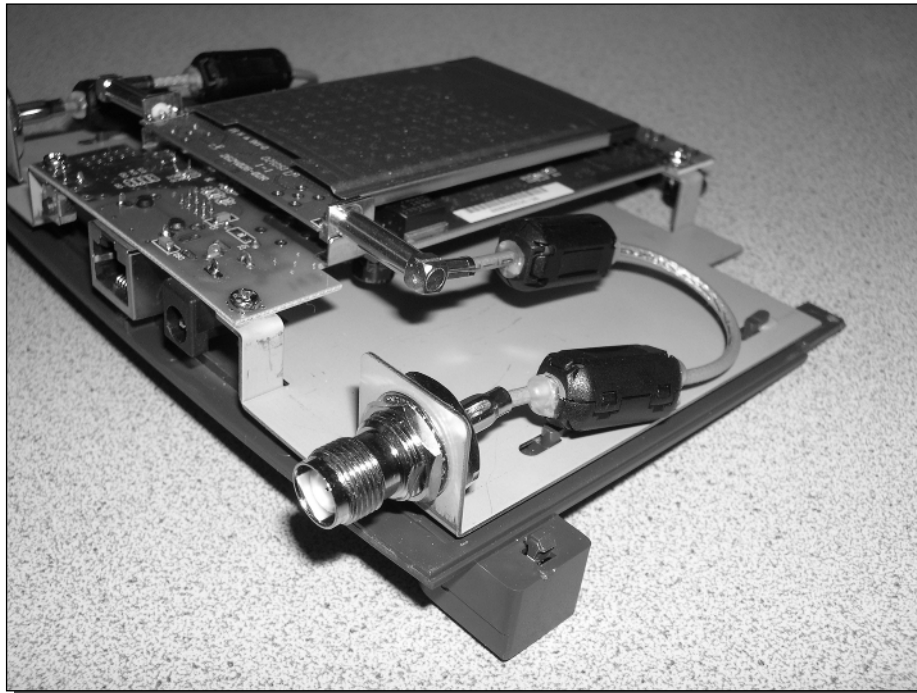


FIGURE 1-4: Internal RF transmission line on a Linksys WAP11.

12 Part I — Building Antennas

At this point, what you need to know is that the antenna is where you want to send as much signal as possible. The transmission line should be designed to be as short as possible with the least line loss to pass power to the antenna.

Once the RF signal leaves the antenna, it immediately begins to lose power. (Really, as soon as it leaves the transceiver it begins to lose power.) The design of the antenna can redirect the amount of power available to shape the beam pattern as needed, much like a flashlight reflecting a tiny light bulb into a bright light.

Now that you know more about Wi-Fi projects in general, we can start to focus on the project for this chapter: building an antenna cable. Before you pick up your tools, though, you need to understand how coaxial cable works, which is the subject of the next section.

Understanding Coaxial Cables

Coaxial cables (commonly called *coax*) are used as the transmission line in a Wi-Fi system. There are probably instances of Wi-Fi systems using a different transmission line, but the most common is coax.

A coax cable is built in layers of the following materials (see Figure 1-5):

- *Core*: A center of electrically conducting material like copper (solid or stranded)
- *Dielectric*: A nonconducting material surrounding the core
- *Shield*: An outer layer of conducting material like steel (solid and/or stranded)
- *Jacket*: A nonconducting protective surface like rubber or plastic

The RF signal is created or received and then placed (or *injected*) onto the core of the cable. In theory, the signal is meant to travel along the core of the cable, while the shield prevents the signal from emanating outside the cable. In reality, some signal is radiated outside the cable, while electrical resistance in the cable reduces the signal within the cable.

Coax cables come in two flavors when used with Wi-Fi:

- Coax jumper
- Coax pigtail

A *coax jumper* is a larger diameter cable with low loss, meant for runs between larger diameter connectors. A common use of a jumper would be from a wireless access point antenna jack directly to an antenna.

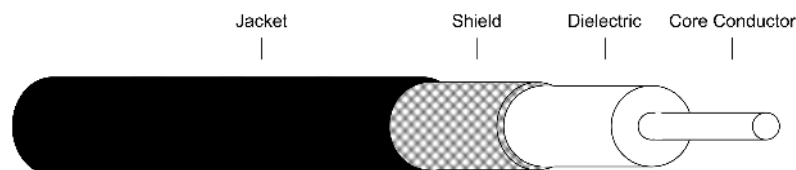


FIGURE 1-5: Diagram of the layers of a coaxial cable.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 13

A *coax pigtail* is used as an interface between larger diameter cables and the very small connectors commonly used on PC cards. A common use of a pigtail would be to connect a PC card to a coax jumper to an antenna.

Constructing pigtails takes much skill and patience in soldering the tiny connectors to the small diameter cable necessary for PC card connectors. For best results, purchasing a pre-configured pigtail is the way to go. Selecting a pigtail is covered in detail later in the chapter.

What Sizes of Coax Are Available

Cables come in many forms from different manufacturers. We have found the optimum cable for ease-of-use and low-loss performance is the LMR-400 cable from Times Microwave. This cable has become the popular choice in building wireless networks.

Table 1-3 shows various cable sizes from Time Microwave. These represent the most commonly available cables for use with 2.4 GHz Wi-Fi gear. The larger diameter cables are harder to work with than the smaller cable because of their rigidity and bulkiness. However, the larger cables have lower signal loss. It's a trade-off between ease of use, performance, and cost. LMR-400 is a good balance and costs about half the price of LMR-600.

Keep It Short!

As shown in Table 1-3, cable loss is measured by distance. Therefore, to keep the strongest signal and the lowest loss, you should keep the cable as short as possible. For most of the projects in this book, you will need cables of less than 10 feet in length. For larger projects, such as creating a free wireless hotspot, you would need a longer cable.

Also, the cable type is very important at high frequencies. For example, using 10 feet of LMR-100 cable induces a loss of 3.9 dB, while the same length of LMR-400 induces a tiny loss of 0.7 dB.

Because of the high loss factor of LMR-100, an access point should have no more than 3 feet of LMR-100 cable between it and the antenna. On the other hand, an access point using the more efficient LMR-400 cable could have a 20 foot-long cable and work just as well.



Note

Manufacturers list cable line loss as measured in 100 feet of cable. This does not mean you should, or even can, use 100 feet in your cable runs. You usually want as strong a signal as possible coming out of the other end of the cable, so either keep it short or use a larger diameter cable.

Table 1-3 Cable Sizes Commonly Used for 2.4 GHz

TM Part Number	Diameter	Line Loss at 2.4 GHz (Per 100 Feet)
LMR-100	1/10"	-38.9 dB
LMR-240	3/16"	-12.7 dB
LMR-400	3/8"	-6.6 dB
LMR-600	1/2"	-4.4 dB

14 Part I — Building Antennas



Tip

Many radio enthusiasts and some manufacturers host line loss or attenuation calculators on the Web. Search the Web for *coax line loss* to find some of these simple-to-use calculators.

Measuring Line Loss in Decibels

The concept of *decibel* measurement, or dB, is covered more in Chapter 2. But for now, it's easy to think of it as the higher the number, the stronger the signal. Remember that negative numbers descend as they get higher (−80 is less than −30). Transmission line loss is represented as negative dB.



Note

Wi-Fi radio transceiver effectiveness is described as a measurement of power output and receive sensitivity. Generally, these two measurements are expressed as power in *milliwatts* (expressed as mW, meaning 1/1000 of a watt) or as “dBm” (decibels related to 1 mW).

Decibel measurement can be confusing. But there are two key concepts to make this easy to understand:

- Decibels are relationship-oriented
- Decibels double by threes

Relationship-oriented means that there is no set value for a dB. The trailing letter in a dB measurement defines the relationship. For example, dBm means decibels related to 1 mW of power. 1 dBm equals 1 mW. When you know the value of the relationship, decibels are easy to calculate.

Doubling by threes is due to the logarithmic nature of RF energy. When comparing a signal of 1 dBm (1 mW) to a signal of 3 dBm (2 mW) you see that it's double the power.

This doubling nature of power measurement or line loss makes it easy to see how a cable can quickly reduce the RF signal to almost nothing.

Calculating Line Loss

Continuing the last example (LMR-100 versus LMR-400), let's start with a signal of 100 mW (+20 dBm) and send it out along the 100 foot-cable, as shown in Table 1-3.

Start with the transmit power, +20 dBm or 100 mW, subtract the negative dB of line loss, and the result is the power at the other end of the cable:

1. LMR-100 (38.9 dB loss): $+20 \text{ dBm} - 38.9 \text{ dB} = -18.9 \text{ dBm}$ (about 0.001 mW)
2. LMR-400 (6.6 dB loss): $+20 \text{ dBm} - 6.6 \text{ dB} = +13.4 \text{ dBm}$ (about 20 mW)

In each case, it's a large drop. But look at the difference! LMR-100 drops power to a tiny fraction of the original signal. LMR-400, on the other hand, while inefficient, still has a usable signal. With either cable, once the signal gets to the antenna and out into the air, there will be even more signal loss. (See Chapter 13 for more on airspace loss and link budget.)

The significant loss in the cable makes repetition important: keep it short!

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 15



Tip Cable usually comes in bulk on reels of 500 feet. Bulk cable vendors will happily cut a length of cable for your order. When ordering bulk cable, select a length of cable that is several feet longer than required. Although it adds a few extra dollars to the order, the extra cable makes it easy to repair construction mistakes or connector problems.

Types of Coax Connectors

Connectors, obviously, are used to connect RF components together. In Wi-Fi there are only a few common connectors for large diameter coax. Unfortunately, the connector styles are not commonly used outside of the Wi-Fi arena. So, picking up a connector at your local consumer electronics store is generally out of the question. Hopefully in the future, more specialized retail establishments will carry this type of equipment. But for now, expect to buy online or purchase directly from distributors.

Male versus Female Coax Style

Connectors are designated as male and female, which is another way of describing them as plug and socket. A male coax connector has a solid center pin or plug with an outer casing that enshrouds the female connector (see Figure 1-6). A female coax connector has an open center socket which accepts the male center pin.

In Wi-Fi coax cables there are often other components to the cable connectors, such as the inner ring on a Male N-type connector. The male/female designation is defined by the center conductor (plug or socket).

Reverse Polarity

Reverse polarity is another way of saying that a connector has gone from plug to socket or socket to plug, reversing its polarity. This adds confusion to the entire male/female designation. When using reverse polarity connectors, male and female is reversed, where a male connector is the same design except that its center conductor is a socket. Female reverse polarity connectors use a plug for the center conductor.

The outer casing is generally the same for normal and reverse polarity. The RP style only changes the center conductor. So a male RP connector still enshrouds the female connector. See Figure 1-7 for a diagram of reverse polarity connectors. Hopefully that will make it a bit less confusing.

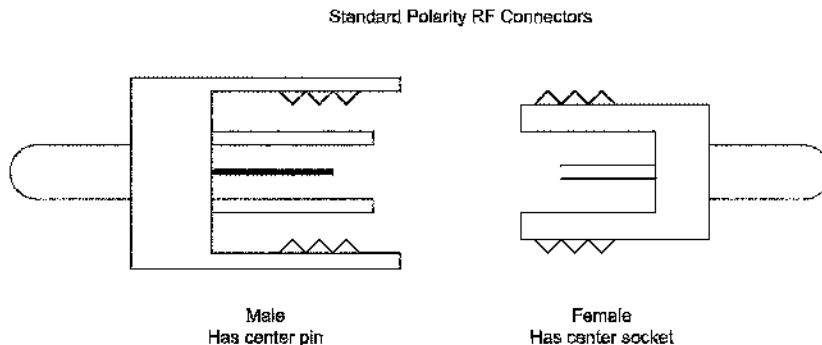


FIGURE 1-6: Diagram of male and female coax connectors.

16 Part I — Building Antennas

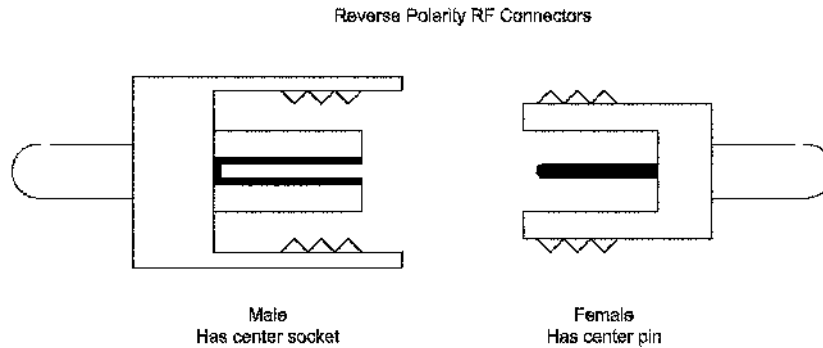


FIGURE 1-7: Diagram of reverse polarity male and female connectors.

Reverse polarity is a commonly used connector type in Wi-Fi devices. The style is not commonly used in other coax applications. The general understanding regarding reverse polarity connectors is that it fulfills government requirements to make it more difficult for the average consumer to modify Wi-Fi devices. Now that you know the secret, you're not an average consumer.

Building a Coaxial Cable

That's enough theory! Now it's time to get your hands dirty and get started on this chapter's project, which is building a coax antenna cable.

Cable construction opens new freedom to creating wireless projects. With this skill, you can order the components you need and custom-build a cable that fits your application perfectly. And the cost of the components is usually lower than buying a pre-built cable.

N-Male is the most commonly used connector for Wi-Fi cabling, because most antennas have N-Female connectors. And, as you know, N-Male mates to N-Female. So, these steps will assume you have chosen LMR-400 cable with the standard N-Male connector. Please adapt the steps to your application where needed. Figure 1-8 shows the necessary dimensions for a Times Microwave N-Male connector.

Table 1-4 shows a list of connectors for use with LMR-400 cable. These connectors are solderless and each requires only two crimps. The connector types listed here are for hand-tightening. A myriad of other connector types are also available.

With the right set of tools, building a cable is a step-by-step process:

1. Prepare the cable
2. Slide the crimp ring onto the cable
3. Strip off the outer jacket
4. Pull back the inner shield
5. Strip the dielectric foam core

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 17

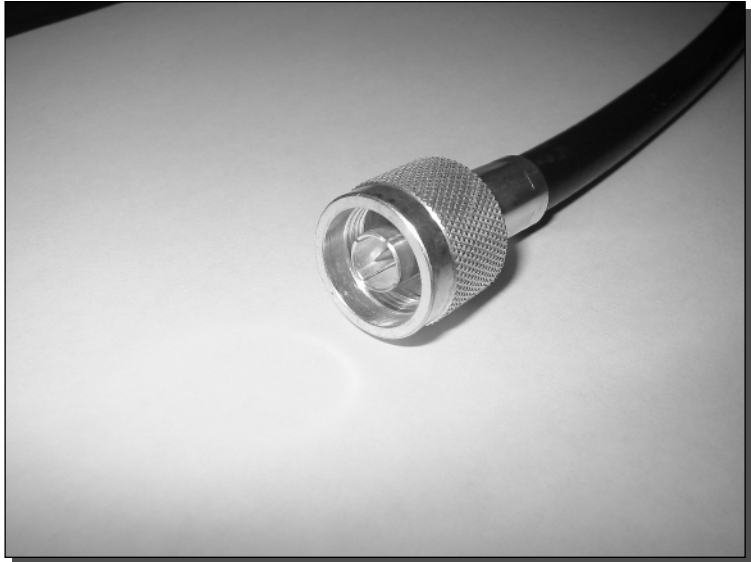


FIGURE 1-8: Times Microwave N-Male Reverse Polarity connector.

6. Remove any shorting material on the foam core
7. Cut the center conductor to correct size
8. Place the center pin onto the center conductor
9. Crimp the center pin
10. Place the connector body onto the cable
11. Replace shield over the connector body
12. Place the crimp ring over the shield and connector body
13. Crimp the crimp ring
14. Inspect your finished product

Table 1-4 Common Connector Types for LMR-400 Cable		
Connector Type	Application	Times Microwave Part Number
N-Male	Cable jumper ends	EZ-400-NMK
N-Female	Antenna termination	EZ-400-NF
TNC Male	Cable jumper ends	EZ-400-TM
TNC Female	Antenna or pigtail termination	EZ-400-TM-RP

18 Part I — Building Antennas

There are a lot of steps, but it's actually very simple. Each step is discussed in detail in the paragraphs that follow.

Step 1: Preparing the Cable

The cable is treated as a bulk item until ready to assemble the end connectors. So the ends are often cut into an irregular shape.

Use the cable cutters to square off the end of the cable, as shown in Figure 1-9.

After cutting the cable, the dielectric foam will become elongated. Use a set of pliers to reform the foam into a rounded shape, as shown in Figure 1-10. This will make it easier to strip later. Don't worry about the shape of the shield and outer jacket.

Step 2: Placing the Crimp Ring

Before going any further, place the crimp ring onto the cable as shown in Figure 1-11. Slide it out of the way down the length of the cable. Later, you'll pull the crimp ring into place on the back of the connector shell.

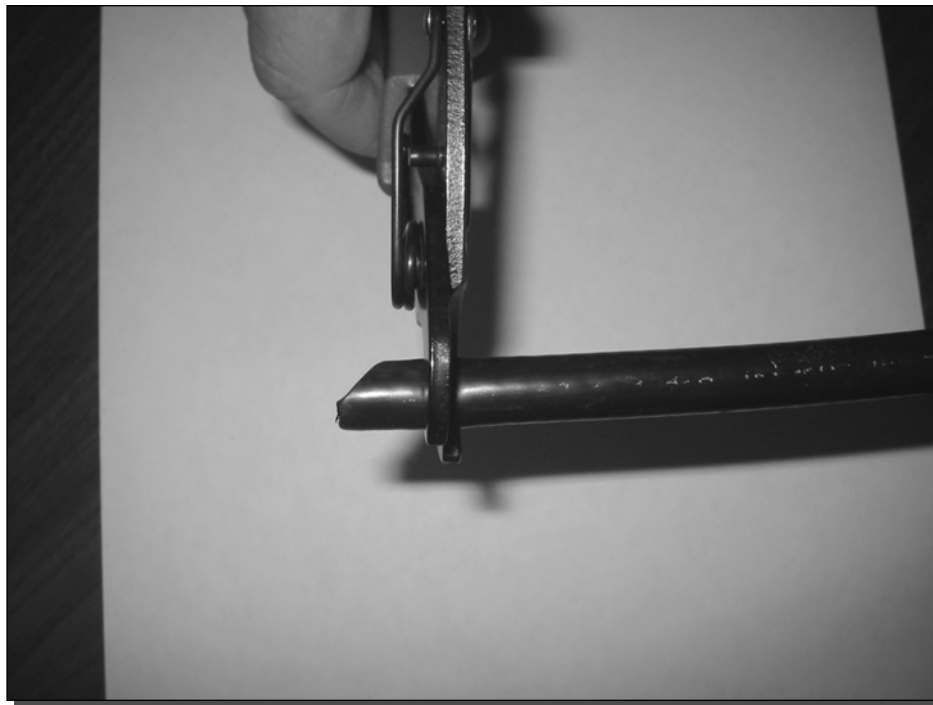


FIGURE 1-9: Cutting the end of the cable to make it square.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 19



FIGURE 1-10: Using pliers to reform the white foam core.

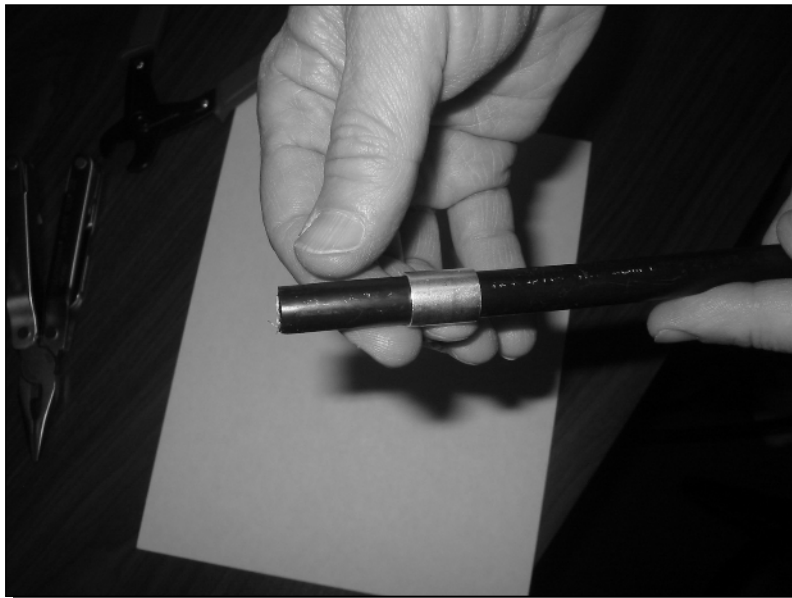


FIGURE 1-11: Placing the crimp ring before any other work.

20 Part I — Building Antennas



FIGURE 1-12: Stripping using a rocking motion. Watch those fingers!

Step 3: Stripping and Removing the Outer Jacket

There are special tools for stripping all types of cables, but a razor blade works well, costs less, and is more versatile. If you are very good at handling sharp objects, a pocket knife works too. Check the instructions that came with the connector for exact dimensions needed. Strip off about 1/2 inch more than necessary to leave room for trimming.



Tip

When stripping a cable with a razor blade or sharp knife, try not to nick the underlying elements of the cable. By rocking the razor blade, you will score through the jacket without harming the shield underneath.

Figure 1-12 shows a cut taking place around the entire circumference of the cable. It's a little unclear at this angle, but my fingers are being kept well out of the way!

Cut through the outer jacket just enough to be able to pull away the jacket without harming the shield.

After stripping around the cable, make a groove along the length of the cable. Make three or four cuts with just enough force to cut a little deeper each time, as shown in Figure 1-13. The goal is to come as close to the shield as possible without cutting all the way through the cable.

Now grab the end of the outer jacket with a set of long-nosed pliers and pull away the jacket. Tear along the grooves scored into the jacket and peel off the jacket with your fingers to reveal the shield mesh underneath, as shown in Figure 1-14.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 21

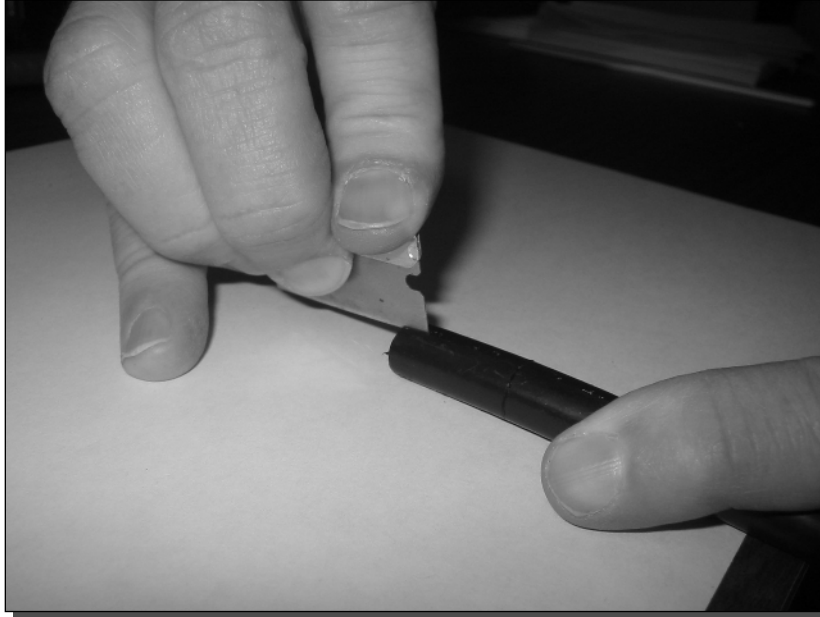


FIGURE 1-13: Scoring along the length of cable.

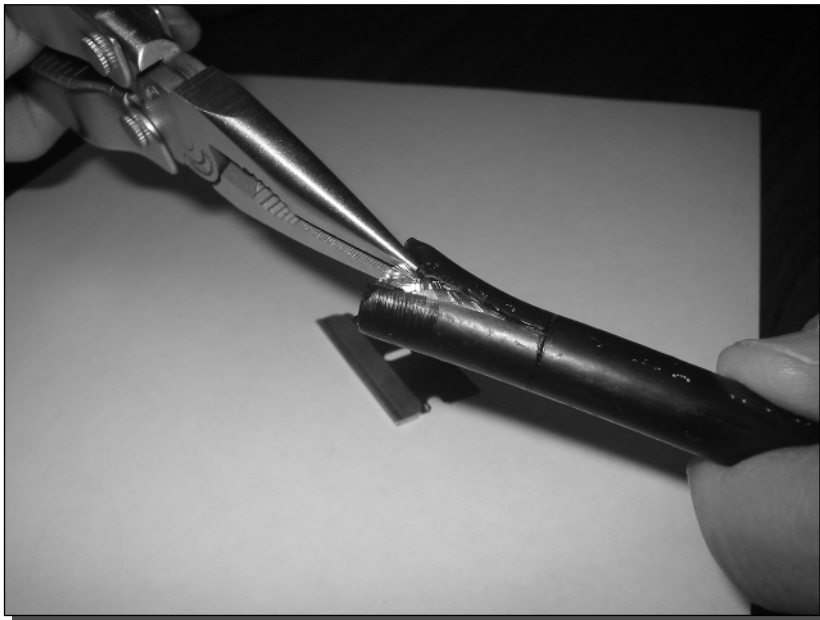


FIGURE 1-14: Peeling off the outer jacket of the cable.

22 Part I — Building Antennas

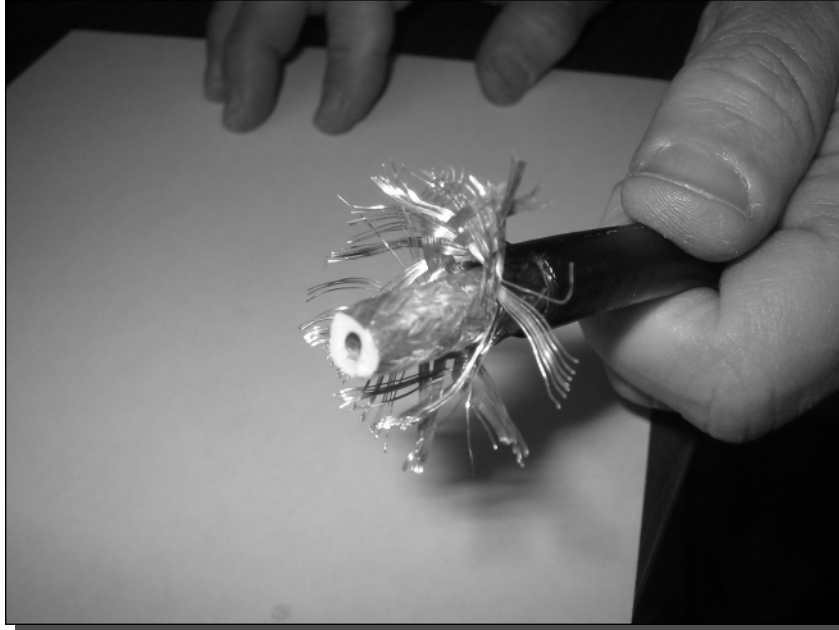


FIGURE 1-15: Fanning out and pulling back the shield.

Step 4: Pulling Back the Inner Shield

To get the next cut ready, use your fingers to carefully fan out and pull back the shield mesh layer, as shown in Figure 1-15.

Step 5: Stripping the Dielectric

Now strip off the foam dielectric core along with the solid aluminum wrapping. This requires much less force than the cable jacket. Be sure to apply light pressure and try not to nick the center conductor. (See Figure 1-16.)

To remove the foam core from the center conductor, just twist and pull.

Step 6: Checking for Shorts

At this stage, you need to inspect the cable for shorts along the dielectric. Remember that the dielectric material is a nonconductor of electricity. If there is an electrical short from the center conductor to the outer shield, the cable will not perform well, i.e. if it works at all.

The easiest way to accomplish this is with a visual inspection. Check for any stray shielding strands or aluminum foil material. See Figure 1-17 for an example of foil shorting the center pin.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 23

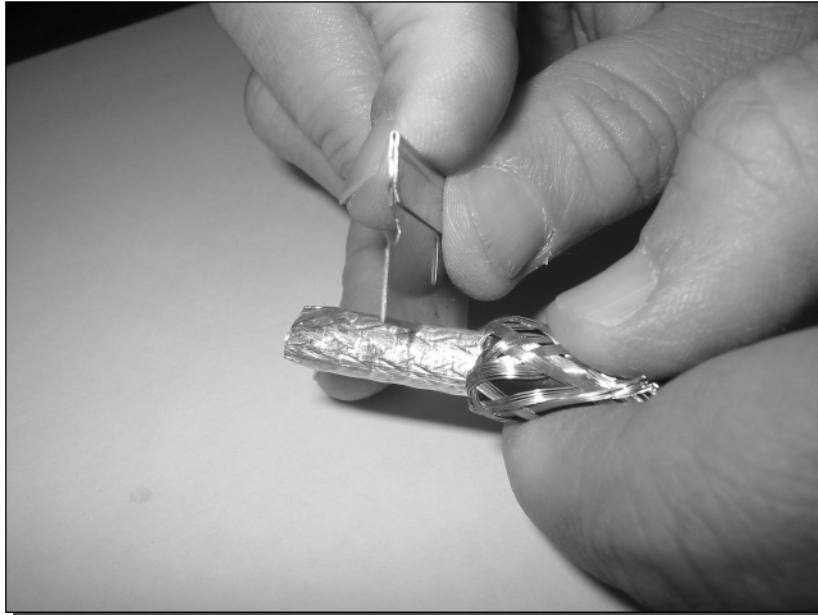


FIGURE 1-16: Make gentle cuts to remove the dielectric and foil.

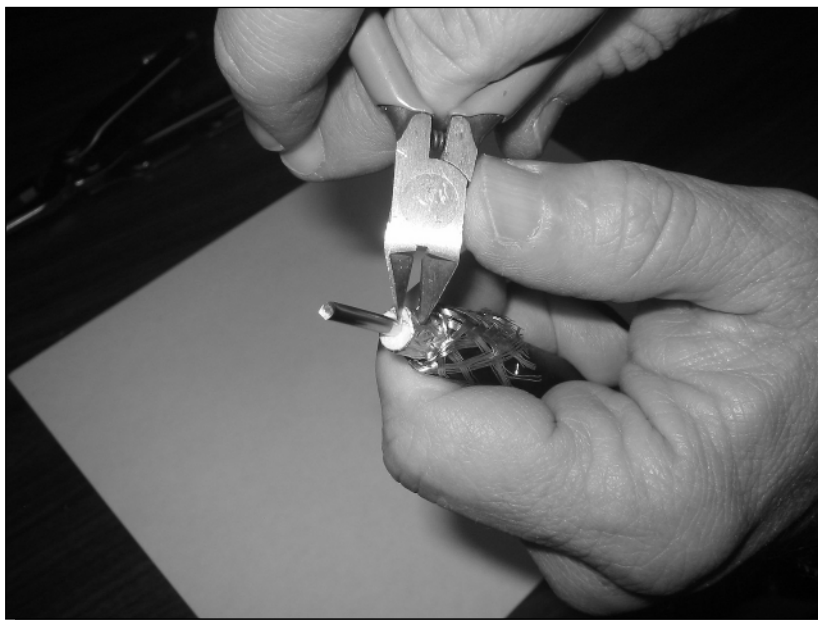


FIGURE 1-17: Shorts must be removed at this stage.

24 Part I — Building Antennas



FIGURE 1-18: Clipping the core conductor.

To remove a foil short, use small wire cutters to scrape away and cut the foam at an angle. You can also use a fingernail for any smaller, more elusive bits. The corrected foam should be white all the way around.

Step 7: Clipping the Core

Clip off the center core to the proper length for the connector being used. The connector packaging or data sheet should have this specific measurement. In the case of this connector, we clipped it to $3/16$ of an inch. If the center conductor is too short or too long, the connector shell will not seat correctly. Figure 1-18 shows the relative length for an N-Male connector.

After trimming back the core, remove any ridges or burrs around the cut edge. This will allow the pin to seat properly.

Step 8: Inserting the Center Pin

Place the center pin onto the conductor as shown in Figure 1-19. Ensure the center conductor bottoms out at the first stop of the pin. Also, ensure the pin rests within 1–2 mm of the foam dielectric.



FIGURE 1-19: Placing the center pin onto the conductor.

Step 9. Crimping the Core

This is the first of two crimps for the connector. Ensure your crimp tool has the correct die for the type of cable and connector being used. For LMR-400, the crimp tool should have a die with hex sizes of 0.429 for the outer ring, and 0.128 and 0.100 for the center pins.

The center pin for an N-Male connector is crimped using size 0.128.



When you crimp coax cables, press all the way down once only. The hex design of the crimp tool die ensures the pin will grip the core properly in six places. If another crimp is applied to "make it tighter," it could misshape the pin.

Place the pin into the crimp tool as shown in Figure 1-20. The bottom edge of the pin usually will have a small ridge to help line it up and keep the pin seated on the core.

Crimp down with even, strong pressure. If your crimp tool has the ratcheting feature, it will apply only the necessary amount of pressure before releasing.

26 Part I — Building Antennas

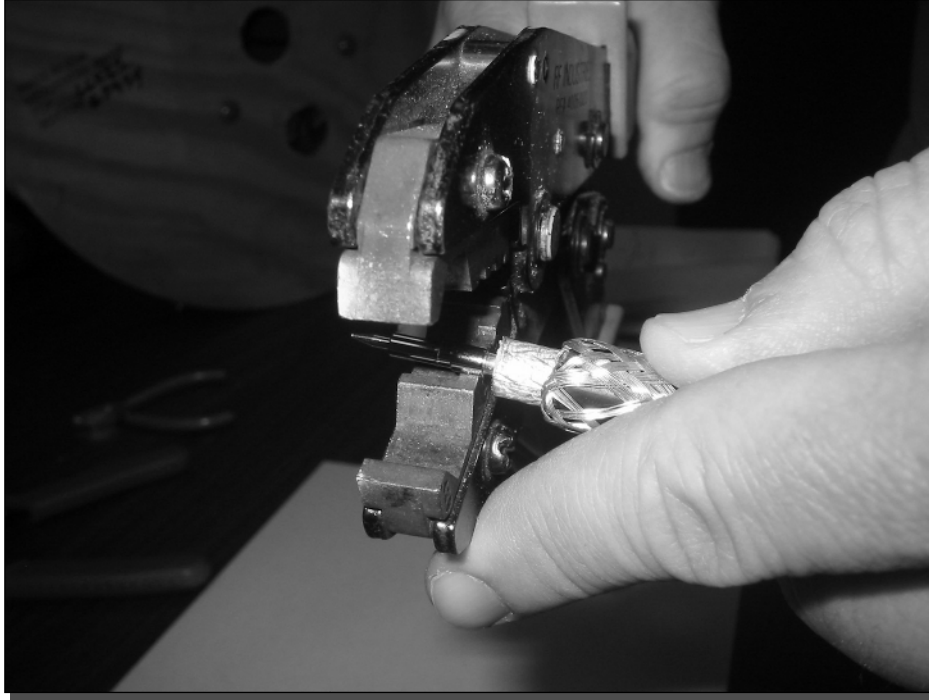


FIGURE 1-20: About to crimp the center pin onto the center conductor.

Figure 1-21 shows a properly crimped center pin. Notice the marking around the edges where the crimp actually clamped the pin to the center conductor.

Step 10: Placing the Connector Body

It's time to place the connector body over the pin. Figure 1-21 shows the connector about to slide onto the pin.

Before continuing, be very sure that the crimp ring from Step 2 is still waiting for you down the cable behind the splayed out shield before you place the connector body onto the cable.



Ensure the crimp ring is on the cable before snapping the connector shell into place. Once the shell is snapped into place, it will be difficult to remove. Also, removing and replacing the shell would degrade the cable performance. If the ring is not in place, you'll need to cut the connector off and rebuild the cable with a new connector.

Line up the connector, and begin to slide the connector over the pin, over the dielectric foam, and butt it up against the shield strands. If all goes well, there may be an audible click when the

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 27

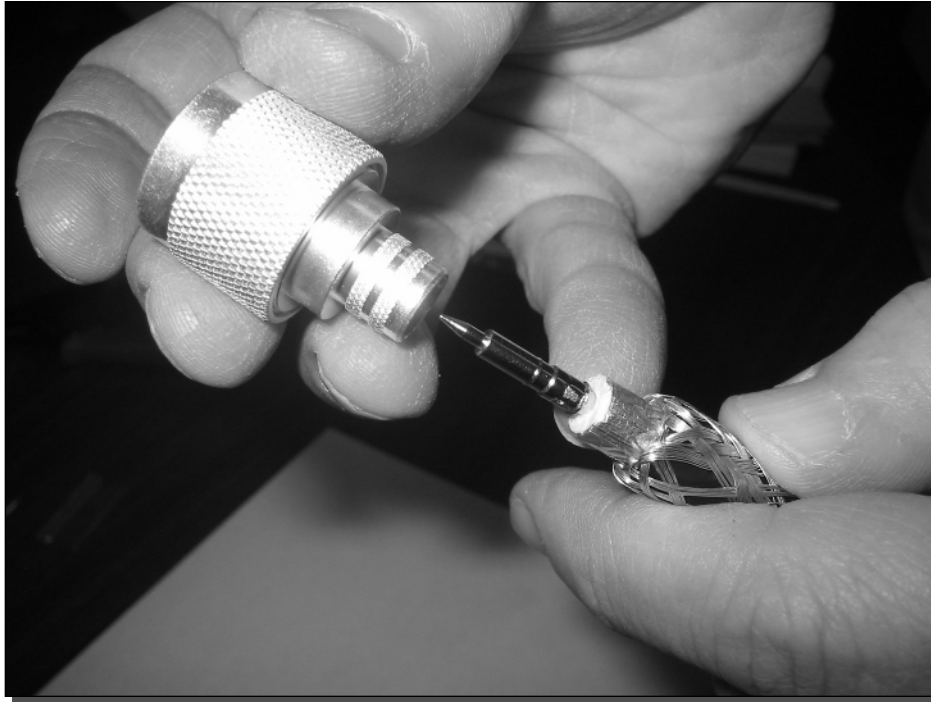


FIGURE 1-21: Moving the connector into position.

connector mates with the pin. This mating is meant to hold the connector on the pin until the last crimp.

Tug lightly at the connector like you are going to pull it back off. It should stay in place under light pressure. If forced or yanked, it may come off, so be gentle.

Figure 1-22 shows the connector fully inserted with the shield still pulled back. Notice that the center pin does not extend past the inner ring of the connector.

Step 11: Shields Up!

Fan out the shield strands and trim down with scissors, as shown in Figure 1-23. To help cleanup, hold the cable over a wastebasket. The goal is to trim down the shield but still have enough to fit under the crimp ring. Trim the shield down to about a quarter of an inch.



Shield strands are made of steel. The thin wires can pierce the skin like a needle in some circumstances. Make sure to handle the waste strands with care, and clean up the area to minimize the chance of accidents.

28 Part I — Building Antennas



FIGURE 1-22: Connector and pin are in position.

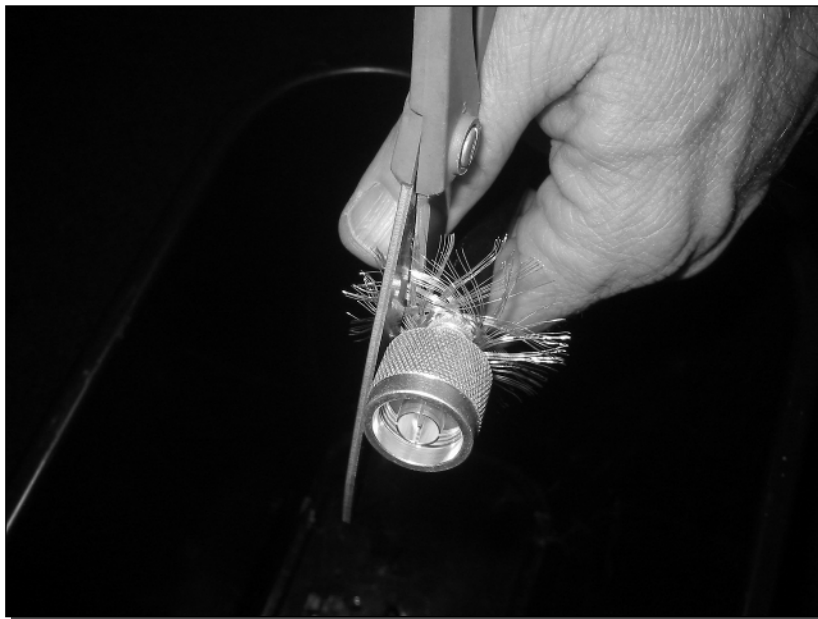


FIGURE 1-23: Trimming the shield with scissors.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 29

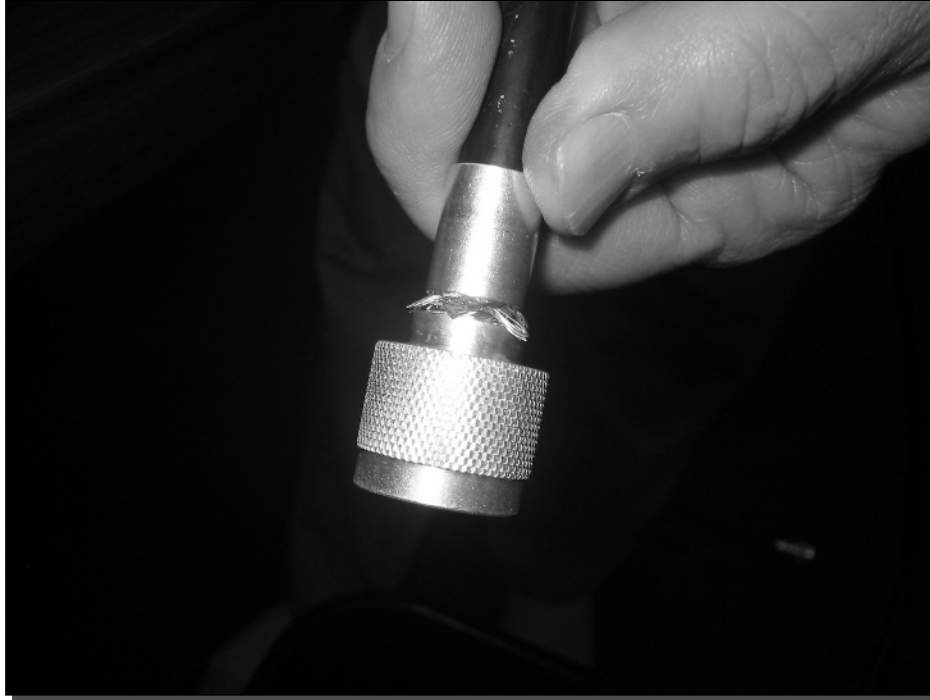


FIGURE 1-24: The shield splayed out under the crimp ring.

Step 12: Placing the Crimp Ring

Now pull up the crimp ring you placed in Step 2. The shield will slip under the crimp ring and should be splayed out evenly around the connector body, as shown in Figure 1-24.

If the shield is still too long, move the crimp ring out of the way and trim a little more of the shield with the scissors. Try to get just enough shield under the crimp ring, but not sticking out past the ring.

Step 13: Crimping the Ring

Finally, it's time to crimp the crimp ring onto the cable. This is the second of the two crimps needed to make the cable. As in Step 9, use the crimping tool. But this time crimp with the larger diameter hex size of 0.429.

Place the tool at the upper edge of the crimp ring, butted against the connector body as shown in Figure 1-25. Crimp with strong, even pressure, and only crimp once, just like in Step 9.

30 Part I — Building Antennas



FIGURE 1-25: Crimping the crimp ring onto the cable.

Step 14: Inspecting the Finished Product

Now that the cable is complete, it's time for a visual inspection. Check the back of the connector at the seam of the crimp ring. If there are any shield strands sticking out, cut them off with the razor blade, as shown in Figure 1-26.

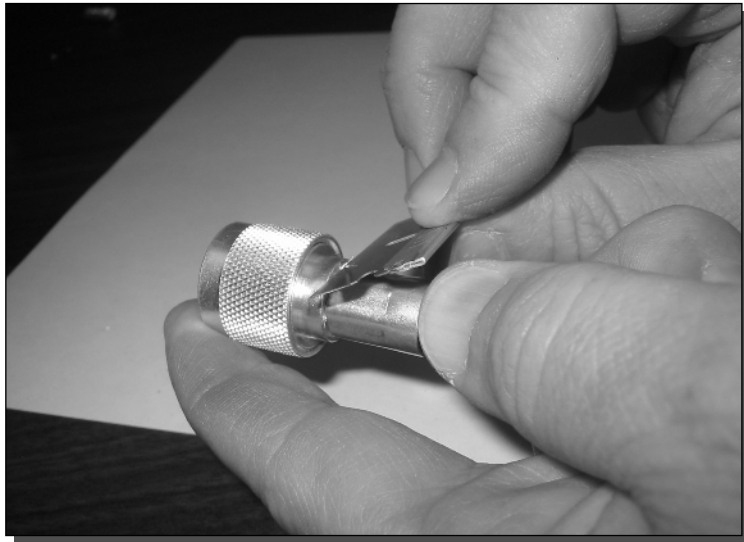


FIGURE 1-26: Cutting off the pokey bits.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 31



Clipping off the loose strands at the back of the connector reduces the chance of injury when you're screwing on the cable. Loose strands are like splinters that may pierce the skin of unwary fingers.

Visually check the front of the connector for any loose bits of metal that may have dropped into the connector during construction. If you find any, remove them to prevent shorts.

That's it! Now repeat steps 1 to 12 for the other end of the cable. After doing a few of these, it will become second nature. With practice, building a cable connector can take just a few minutes.

Choosing a Wi-Fi Pigtail

A *pigtail* acts as a converter between large diameter cables and small connectors commonly used on Wi-Fi cards.

Because of the very small connector sizes, pigtails are difficult to build and require highly skilled soldering techniques. We recommend that you purchase pigtails for use in your projects. Several online stores sell pre-built pigtails in specific lengths.

To purchase a pigtail, the vendor will need to know a few things:

- *Length of pigtail*: should be less than 2 feet to keep signal loss low
- *Cable connector*: the type of connector to plug into the larger cable (usually male)
- *Device connector*: the type of connector to plug into the Wi-Fi device (usually female)

The device connector is specific to the type of Wi-Fi card or access point being used.

Table 1-5 Connector Types for Common Wi-Fi Products

Connector	Type of Product	Wi-Fi Product
MMCX	PCMCIA Card	Cisco, Engenius, Proxim, Senao, Symbol
MC-Card	PCMCIA Card	Apple Airport, Avaya, Orinoco
RP-SMA	Access Point, PCI Card, Wi-Fi Camera, Wireless Media Adapter	Belkin, D-Link, Linksys, Netgear, SMC, U. S. Robotics
RP-TNC	Access point, Bridge, Wireless Booster	Linksys
MCX	Base Station, Adapter Card	Apple Airport Extreme

Note: RP in the connector designation refers to "Reverse Polarity."

32 Part I — Building Antennas



FIGURE 1-27: Various Wi-Fi connector types.

Connector Types for Wi-Fi Cards

There are almost as many connector types as there are Wi-Fi device manufacturers. Table 1-5 lists some of the most popular connectors.

The MMCX, MC-Card, RP-SMA, and RP-TNC male connectors and some of the female devices to which they attach are shown in Figure 1-27.

Finding Pigtails

Pigtails are not available in stores. They must be purchased from vendors that construct them on a regular basis. Sometimes you can find them locally at swap meets or user group meetings. Usually it's easier to buy them online. Here are some popular sites:

- www.ecwest.com
- www.fab-corp.com
- www.hyperlinktech.com
- www.wlanparts.com
- www.ydi.com

These stores generally sell antennas, wireless devices, and cables as well as pigtails.

Chapter 1 — Building Your Own Wi-Fi Antenna Cable 33

Cheap Cable Testing

When a transmission problem arises in a Wi-Fi system, the first place to look is at the cables and connectors. Connectors generally take the most physical stress in a system, and also can be the first piece to break down while operating in poor conditions. The middle of the cable or the inside of an antenna is less likely to sustain damage if stressed when compared to the cable ends and connectors.

This is where simple cable testing can be of great value to troubleshoot a system. To check for continuity and for shorts, use the ohm-meter function on a multimeter. Test the entire length of the cable through each connector.

1. Check for continuity from center pin to center pin. This should be a short or zero ohms.
2. Check from connector body to connector body. This should be a short or zero ohms.
3. Check from center pin to connector body. This should be open or infinite ohms.



Tip

Often when you're testing a cable, it's already installed on-site, which limits access to the cable ends. To get around this, disconnect both ends of the cable and short the center pin to the connector body on one end only. Then measure resistance of the pin to the body on the other end. The resistance should still be zero ohms (or very close).

For the unlimited budget, products like a time domain reflectometer (TDR), spectrum analyzer, RF Power meter, and network analyzer can be used to test entire transmission systems, including the cable. These usually cost several thousand dollars to buy and hundreds to rent.

If the connector is presumed bad, replacing it is often much less costly than extensive testing. And very often, the only way to fix a bad connector is to replace it and start over.

Summary

Wi-Fi is radio at microwave frequencies. Transmission lines at 2.4 GHz are more prone to signal loss and must therefore be considered an important part of the entire Wi-Fi system.

A low-loss, large diameter cable and a pigtail adapter makes it easy to position the antenna for the best radiation pattern and signal strength.

Building connectors on-the-fly opens up a new realm of independence. By obtaining the cable in bulk, and the various types of connectors, it becomes a simple process to build your own custom cables tailored to each application. And the cable will be exactly as long as necessary.

Read on to the next chapter to explore antennas: how antennas are defined, antenna radiation patterns, choosing an antenna, and pros and cons of high-gain antennas. You'll even see how to build a simple omni antenna that will boost your range by up to 200 feet.

