## 1/4 wavelength ground plane

The 1⁄4 wavelength ground plane antenna is very simple in its construction and is useful for communications when size, cost and ease of construction are important. This antenna is designed to transmit a vertically polarized signal. It consists of a 1⁄4 wave element as half-dipole and three or four 1⁄4 wavelength ground elements bent 30 to 45 degrees down. This set of elements, called radials, is known as a ground plane.
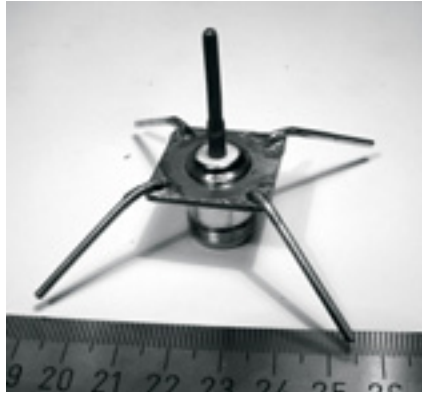


*Figure 4.8: Quarter wavelength ground plane antenna.*

This is a simple and effective antenna that can capture a signal equally from all directions. To increase the gain, the signal can be flattened out to take away focus from directly above and below, and providing more focus on the horizon. The vertical beamwidth represents the degree of flatness in the focus. This is useful in a Point-to-Multipoint situation, if all the other antennas are also at the same height. The gain of this antenna is in the order of 2 - 4 dBi.

## Yagi antenna

A basic Yagi consists of a certain number of straight elements, each measuring approximately half wavelength. The driven or active element of a Yagi is the equivalent of a center-fed, half-wave dipole antenna. Parallel to the driven element, and approximately 0.2 to 0.5 wavelength on either side of it, are straight rods or wires called reflectors and directors, or simply passive elements. A reflector is placed behind the driven element and is slightly longer than half wavelength; a director is placed in front of the driven element and is slightly shorter than half wavelength. A typical Yagi has one reflector and one or more directors. The antenna propagates electromagnetic field energy in the direction running from the driven element toward the directors, and is most sensitive to incoming electromagnetic field energy in this same direction. The more directors a Yagi has, the greater the gain. As more direc-

tors are added to a Yagi, it therefore becomes longer. Following is the photo of a Yagi antenna with 6 directors and one reflector.
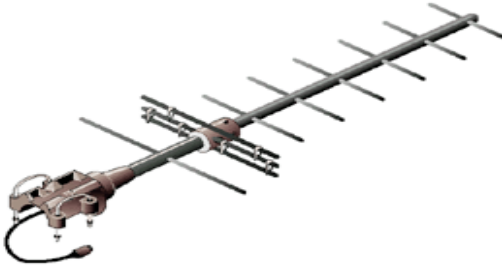


*Figure 4.9: A Yagi antenna.*

Yagi antennas are used primarily for Point-to-Point links, have a gain from 10 to 20 dBi and a horizontal beamwidth of 10 to 20 degrees.

## Horn

The horn antenna derives its name from the characteristic flared appearance. The flared portion can be square, rectangular, cylindrical or conical. The direction of maximum radiation corresponds with the axis of the horn. It is easily fed with a waveguide, but can be fed with a coaxial cable and a proper transition.



*Figure 4.10: Feed horn made from a food can.*

Horn antennas are commonly used as the active element in a dish antenna. The horn is pointed toward the center of the dish reflector. The use of a horn, rather than a dipole antenna or any other type of antenna, at the focal point of the dish minimizes loss of energy around the edges of the dish reflector. At 2.4 GHz, a simple horn antenna made with a tin can has a gain in the order of 10 - 15 dBi.

## Parabolic Dish

Antennas based on parabolic reflectors are the most common type of  directive antennas when a high gain is required. The main advantage is that they can be made to have gain and directivity as large as required. The main disadvantage is that big dishes are difficult to mount and are likely to have a large windage.



*Figure 4.11: A solid dish antenna.*

Dishes up to one meter are usually made from solid material. Aluminum is frequently used for its weight advantage, its durability and good electrical characteristics. Windage increases rapidly with dish size and soon becomes a severe problem. Dishes which have a reflecting surface that uses an open mesh are frequently used. These have a poorer front-to-back ratio, but are safer to use and easier to build. Copper, aluminum, brass, galvanized steel and iron are suitable mesh materials.

## BiQuad

The BiQuad antenna is simple to build and offers good directivity and gain for Point-to-Point communications. It consists of a two squares of the same size of 1⁄4 wavelength as a radiating element and of a metallic plate or grid as reflector. This antenna has a beamwidth of about 70 degrees and a gain in the order of 10-12 dBi. It can be used as stand-alone antenna or as feeder for a Parabolic Dish. The polarization is such that  looking at the antenna from the front, if the squares are placed side by side the polarization is vertical.
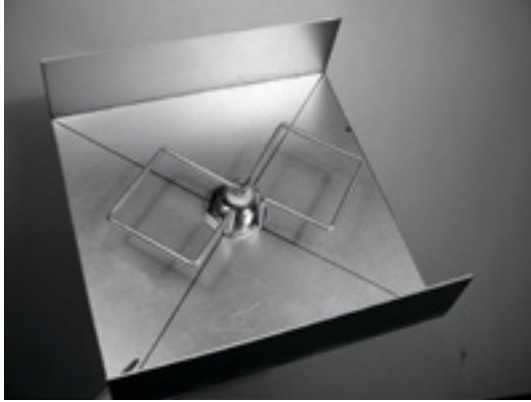
*Figure 4.12: The BiQuad.*

## Other Antennas

Many other types of antennas exist and new ones are created following the advances in technology.

• Sector or Sectorial antennas: they are widely used in cellular telephony infrastructure and are usually built adding a reflective plate to one or more phased dipoles. Their horizontal beamwidth can be as wide as 180 degrees, or as narrow as 60 degrees, while the vertical is usually much narrower. Composite antennas can be built with many Sectors to cover a wider horizontal range (multisectorial antenna).

• Panel or Patch antennas: they are solid flat panels used for indoor coverage, with a gain up to 20 dB.

# Reflector theory

The basic property of a perfect parabolic reflector is that it converts a spherical wave irradiating from a point source placed at the focus into a plane wave. Conversely, all the energy received by the dish from a distant source is reflected to a single point at the focus of the dish. The position of the focus, or focal length, is given by:

$$f = \frac{D^2}{16 \times c}$$

...where D is the dish diameter and c is the depth of the parabola at its center.

The size of the dish is the most important factor since it determines the maximum gain that can be achieved at the given frequency and the resulting beamwidth. The gain and beamwidth obtained are given by:

$$\text{Gain} = \frac{(\pi \times D)^2}{\lambda^2} \times n$$

$$\text{Beamwidth} = \frac{70 \lambda}{D}$$

...where D is the dish diameter and n is the efficiency. The efficiency is determined mainly by the effectiveness of illumination of the dish by the feed, but also by other factors. Each time the diameter of a dish is doubled, the gain is four times, or 6 dB, greater. If both stations double the size of their dishes, signal strength can be increased of 12 dB, a very substantial gain. An efficiency of 50% can be assumed when hand-building the antenna.

The ratio f / D (focal length/diameter of the dish) is the fundamental factor governing the design of the feed for a dish. The ratio is directly related to the beamwidth of the feed necessary to illuminate the dish effectively. Two dishes of the same diameter but different focal lengths require different design of feed if both are to be illuminated efficiently. The value of 0.25 corresponds to the common focal-plane dish in which the focus is in the same plane as the rim of the dish.

# Amplifiers

As mentioned earlier, antennas do not actually create power. They simply direct all available power into a particular pattern. By using a ***power amplifier***, you can use DC power to augment your available signal. An amplifier connects between the radio transmitter and the antenna, and has an additional lead that connects to a power source. Amplifiers are available that work at 2.4 GHz, and can add several Watts of power to your transmission. These devices sense when an attached radio is transmitting, and quickly power up and amplify the signal. They then switch off again when transmission ends. When receiving, they also add amplification to the signal before sending it to the radio.

Unfortunately, simply adding amplifiers will not magically solve all of your networking problems. We do not discuss power amplifiers at length in this book because there are a number of significant drawbacks to using them:

• **They are expensive**. Amplifiers must work at relatively wide bandwidths at 2.4 GHz, and must switch quickly enough to work for Wi-Fi applications.

These amplifiers do exist, but they tend to cost several hundred dollars per unit.

• **You will need at least two**.   Whereas antennas provide reciprocal gain that benefits both sides of a connection, amplifiers work best at amplifying a transmitted signal.  If you only add an amplifier to one end of a link with insufficient antenna gain, it will likely be able to be heard but will not be able to hear the other end.

• **They provide no additional directionality.**  Adding antenna gain provides both gain and directionality benefits to both ends of the link.  They not only improve the available amount of signal, but tend to reject noise from other directions.   Amplifiers blindly amplify both desired and interfering signals, and can make interference problems worse.

• **Amplifiers generate noise for other users of the band.**  By increasing your output power, you are creating a louder source of noise for other users of the unlicensed band.  This may not be much of an issue today in rural areas, but it can cause big problems in populated areas.  Conversely, adding antenna gain will improve your link and can actually decrease the noise level for your neighbors.

• **Using amplifiers probably isn't legal.**  Every country imposes power limits on use of unlicensed spectrum.  Adding an antenna to a highly amplified signal will likely cause the link to exceed legal limits.

Using amplifiers is often compared to the inconsiderate neighbor who wants to listen to the radio outside their home, and so turns it up to full volume. They might even "improve" reception by pointing their speakers out the window.  While they may now be able to hear the radio, so must everyone else on the block.   This approach may scale to exactly one user, but what happens when the neighbors decide to do the same thing with their radios?  Using amplifiers for a wireless link causes roughly the same effect at 2.4 GHz. Your link may "work better" for the moment, but you will have problems when other users of the band decide to use amplifiers of their own.

By using higher gain antennas rather than amplifiers, you avoid all of these problems.  Antennas cost far less than amps, and can improve a link simply by changing the antenna on one end.  Using more sensitive radios and good quality cable also helps significantly on long distance shots.   These techniques are unlikely to cause problems for other users of the band, and so we recommend pursuing them before adding amplifiers.

# Practical antenna designs

The cost of 2.4 GHz antennas has fallen dramatically since the introduction of 802.11b.  Innovative designs use simpler parts and fewer materials to achieve

impressive gain with relatively little machining. Unfortunately, availability of good antennas is still limited in many areas of the world, and importing them can be prohibitively expensive. While actually designing an antenna can be a complex and error-prone process, constructing antennas from locally available components is very straightforward, and can be a lot of fun. We present four practical antenna designs that can be built for very little money.

## USB dongle as dish feed

Possibly the simplest antenna design is the use of a parabola to direct the output of a USB wireless device (known in networking circles as a ***USB dongle***). By placing the internal dipole antenna present in USB wireless dongles at the focus of a parabolic dish, you can provide significant gain without the need to solder or even open the wireless device itself. Many kinds of parabolic dishes will work, including satellite dishes, television antennas, and even metal cookware (such as a wok, round lid, or strainer). As a bonus, inexpensive and lossless USB cable is then used to feed the antenna, eliminating the need for expensive coaxial cable or Heliax.

To build a USB dongle parabolic, you will need to find the orientation and location of the dipole inside the dongle. Most devices orient the dipole to be parallel with the short edge of the dongle, but some will mount the dipole perpendicular to the short edge. You can either open the dongle and look for yourself, or simply try the dongle in both positions to see which provides more gain.

To test the antenna, point it at an access point several meters away, and connect the USB dongle to a laptop. Using the laptop's client driver or a tool such as Netstumbler (see **Chapter 6**), observe the received signal strength of the access point. Now, slowly move the dongle in relation to the parabolic while watching the signal strength meter. You should see a significant improvement in gain (20 dB or more) when you find the proper position. The proper position will vary depending on the shape of the parabola and the construction of the USB dongle. Try various positions while watching your signal strength meter until you find the optimum location.

Once the best location is found, securely fix the dongle in place. You will need to waterproof the dongle and cable if the antenna is used outdoors. Use a silicone compound or a piece of PVC tubing to seal the electronics against the weather. Many USB-fed parabolic designs and ideas are documented online at *http://www.usbwifi.orcon.net.nz/* .

## Collinear omni

This antenna is very simple to build, requiring just a piece of wire, an N socket and a square metallic plate. It can be used for indoor or outdoor point-to-multipoint short distance coverage. The plate has a hole drilled in the mid-

dle to accommodate an N type chassis socket that is screwed into place. The wire is soldered to the center pin of the N socket and has coils to separate the active phased elements. Two versions of the antenna are possible: one with two phased elements and two coils and another with four phased elements and four coils. For the short antenna the gain will be around 5 dBi, while the long one with four elements will have 7 to 9 dBi of gain. We are going to describe how to build the long antenna only.

## Parts list and tools required

- One screw-on N-type female connector
- 50 cm of copper or brass wire of 2 mm of diameter
- 10x10 cm or greater square metallic plate



*Figure 4.13: 10 cm x 10 cm aluminum plate.*

- Ruler
- Pliers
- File
- Soldering iron and solder
- Drill with a set of bits for metal (including a 1.5 cm diameter bit)
- A piece of pipe or a drill bit with a diameter of 1 cm
- Vice or clamp
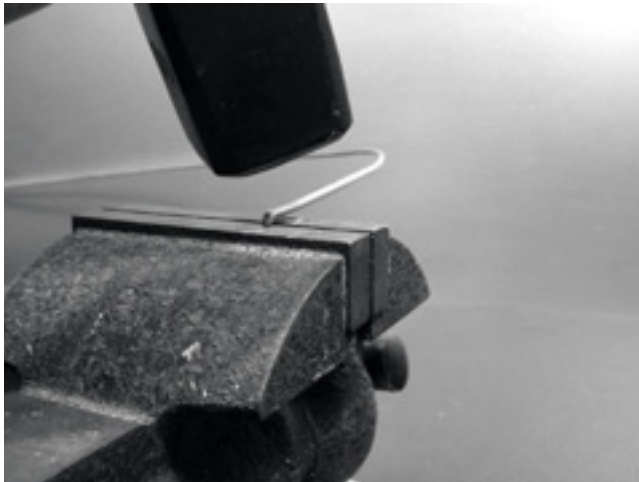- Hammer
- Spanner or monkey wrench

## Construction

1.  Straighten the wire using the vice.

*Figure 4.14: Make the wire as straight as you can.*

2. With a marker, draw a line at 2.5 cm starting from one end of the wire. On this line, bend the wire at 90 degrees with the help of the vice and of the hammer.



*Figure 4.15: Gently tap the wire to make a sharp bend.*

3. Draw another line at a distance of 3.6 cm from the bend. Using the vice and the hammer, bend once again the wire over this second line at 90 degrees, in the opposite direction to the first bend but in the same plane. The wire should look like a 'Z'.

*Figure 4.16: Bend the wire into a "Z" shape.*

4.  We will now twist the 'Z' portion of the wire to make a coil with a diameter of 1 cm. To do this, we will use the pipe or the drill bit and curve the wire around it, with the help of the vice and of the pliers.
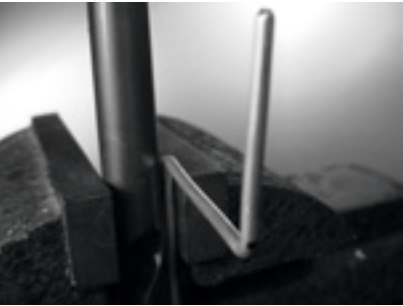



*Figure 4.17: Bend the wire around the drill bit to make a coil.*
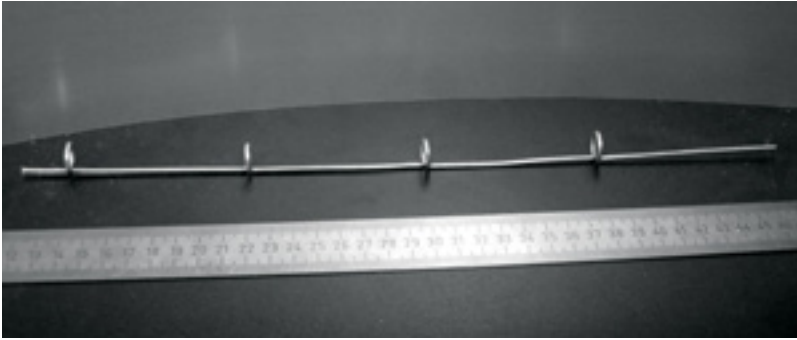
The coil will look like this:
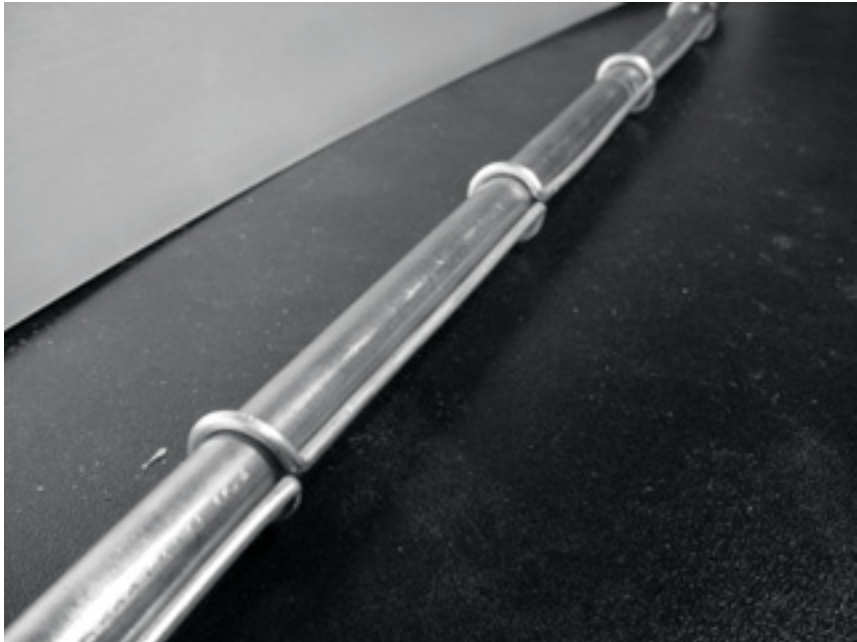


*Figure 4.18: The completed coil.*

5.  You should make a second coil at a distance of 7.8 cm from the first one. Both coils should have the same turning direction and should be placed on the same side of the wire. Make a third and a fourth coil following the

same procedure, at the same distance of 7.8 cm one from each other. Trim the last phased element at a distance of 8.0 cm from the fourth coil.



*Figure 4.19: Try to keep it as straight possible.*

If the coils have been made correctly, it should now be possible to insert a pipe through all the coils as shown.



*Figure 4.20: Inserting a pipe can help to straighten the wire.*

6.  With a marker and a ruler, draw the diagonals on the metallic plate, finding its center. With a small diameter drill bit, make a pilot hole at the center of the plate. Increase the diameter of the hole using bits with an increasing diameter.
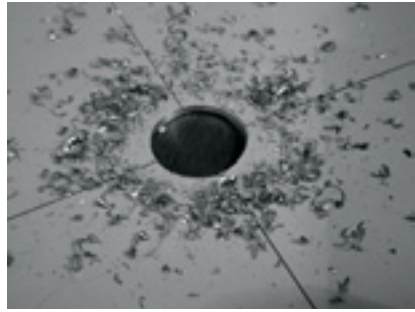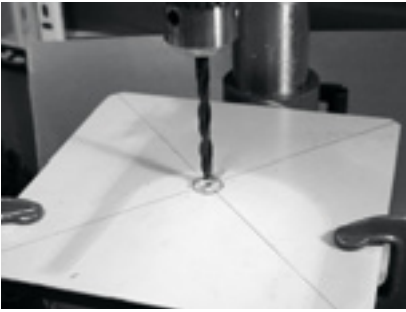
*Figure 4.21: Drilling the hole in the metal plate.*

The hole should fit the N connector exactly. Use a file if needed.



*Figure 4.22: The N connector should fit snugly in the hole.*

7.  To have an antenna impedance of 50 Ohms, it is important that the visible surface of the internal insulator   of the connector   (the white area around the central pin) is at the same level as the surface of the plate. For this reason, cut 0.5 cm of copper pipe with an external diameter of 2 cm, and place it between the connector and the plate.
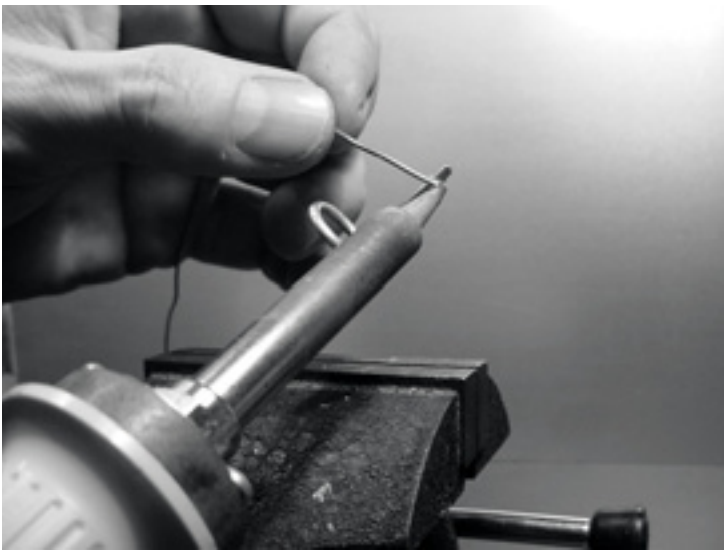


*Figure 4.23: Adding a copper pipe spacer helps to match the impedance of the antenna to 50 Ohms.*

8. Screw the nut to the connector to fix it firmly on the plate using the spanner.



*Figure 4.24: Secure the N connector tightly to the plate.*

9. Smooth with the file the side of the wire which is 2.5 cm long, from the first coil. Tin the wire for around 0.5 cm at the smoothed end helping yourself with the vice.



*Figure 4.25:  Add a little solder to the end of the wire to "tin" it prior to soldering.*

10. With the soldering iron, tin the central pin of the connector. Keeping the wire vertical with the pliers, solder its tinned side in the hole of the central pin. The first coil should be at 3.0 cm from the plate.
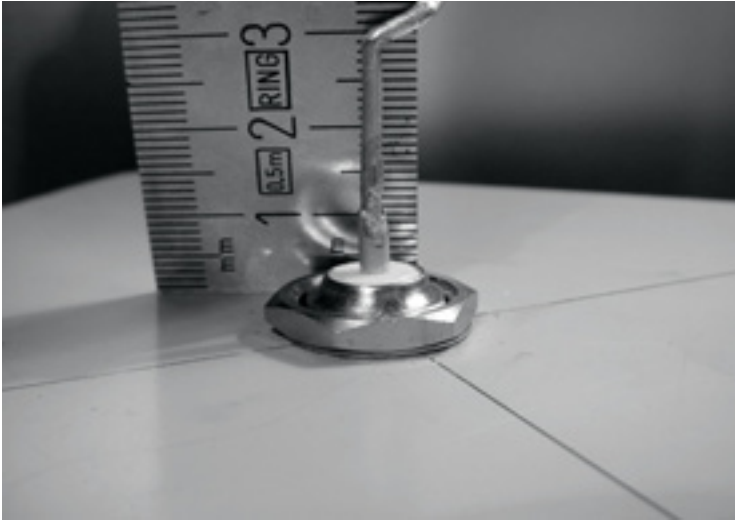
*Figure 4.26: The first coil should start 3.0 cm from the surface of the plate.*

11. We are now going to stretch the coils extending the total vertical length of the wire. Using the use the vice and the pliers, you should pull the cable so that the final length of the coil is of 2.0 cm.



*Figure 4.27: Stretching the coils. Be very gentle and try not to scrape the surface of the wire with the pliers.*

12. Repeat the same procedure for the other three coils, stretching their length to 2.0 cm.

*Figure 4.28: Repeat the stretching procedure for all of the remaining coils.*

13. At the end the antenna should measure 42.5 cm from the plate to the top.



*Figure 4.29: The finished antenna should be 42.5 cm from the plate to the end of the wire.*

14. If you have a spectrum analyzer with a tracking generator and a directional coupler, you can check the curve of the reflected power of the antenna. The picture below shows the display of the spectrum analyzer.
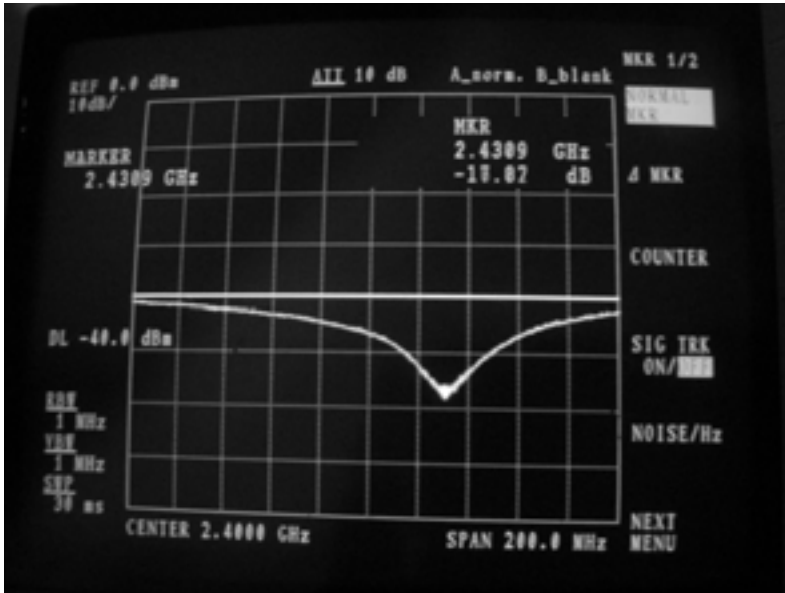
*Figure 4.30: A spectrum plot of the reflected power of the collinear omni.*

If you intend to use this antenna outside, you will need to weatherproof it. The simplest method is to enclose the whole thing in a large piece of PVC pipe closed with caps. Cut a hole at the bottom for the transmission line, and seal the antenna shut with silicone or PVC glue.

## Cantenna

The waveguide antenna, sometimes called a Cantenna, uses a tin can as a waveguide and a short wire soldered on an N connector as a probe for coaxial-cable-to-waveguide transition. It can be easily built at just the price of the connector, recycling a food, juice, or other tin can. It is a directional antenna, useful for short to medium distance point-to-point links. It may be also used as a feeder for a parabolic dish or grid.

Not all cans are good for building an antenna because there are dimensional constraints.

1. The acceptable values for the diameter D of the feed are between 0.60 and 0.75 wavelength in air at the design frequency. At 2.44 GHz the wavelength $\lambda$ is 12.2 cm, so the can diameter should be in the range of 7.3 - 9.2 cm.

2. The length L of the can preferably should be at least 0.75 $\lambda_G$ , where $\lambda_G$ is the guide wavelength and is given by:

$$\lambda_G = \frac{\lambda}{\texttt{sqrt(1 - ($\lambda$ / 1.706D)}^2)}$$

For D = 7.3 cm, we need a can of at least 56.4 cm, while for D = 9.2 cm we need a can of at least 14.8 cm. Generally the smaller the diameter, the longer the can should be. For our example, we will use oil cans that have a diameter of 8.3 cm and a height of about 21 cm.

3.  The probe for coaxial cable to waveguide transition should be positioned at a distance S from the bottom of the can, given by:

$$\texttt{S = 0.25}\ \lambda_G$$

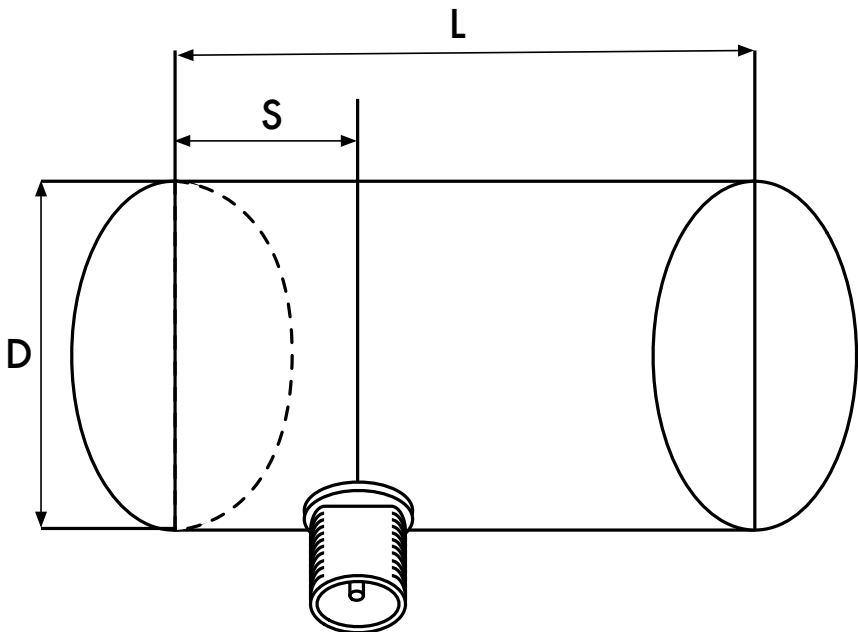Its length should be 0.25 λ, which at 2.44 GHz corresponds to 3.05 cm.



*Figure 4.31: Dimensional constraints on the cantenna*

The gain for this antenna will be in the order of 10 to 14 dBi, with a beamwidth of around 60 degrees.

*Figure 4.32: The finished cantenna.*

## Parts list

- one screw-on N-type female connector
- 4 cm of copper or brass wire of 2 mm of diameter
- an oil can of 8.3 cm of diameter and 21 cm of height



*Figure 4.33: Parts needed for the can antenna.*

## Tools required

- Can opener
- Ruler
- Pliers
- File
- Soldering iron
- Solder
- Drill with a set of bits for metal (with a 1.5 cm diameter bit)
- Vice or clamp
- Spanner or monkey wrench
- Hammer
- Punch

## Construction

1.  With the can opener, carefully remove the upper part of the can.



*Figure 4.34: Be careful of sharp edges when opening the can.*

The circular disk has a very sharp edge. Be careful when handling it! Empty the can and wash it with soap.  If the can contained pineapple, cookies, or some other tasty treat, have a friend serve the food.

2.  With the ruler, measure 6.2 cm from the bottom of the can and draw a point. Be careful to measure from the inner side of the bottom. Use a punch (or a small drill bit or a Phillips screwdriver) and a hammer to mark the point. This makes it easier to precisely drill the hole. Be careful not to

change the shape of the can doing this by inserting a small block of wood or other object in the can before tapping it.



*Figure 4.35: Mark the hole before drilling.*

3.  With a small diameter drill bit, make a hole at the center of the plate. Increase the diameter of the hole using bits with an increasing diameter. The hole should fit exactly the N connector. Use the file to smooth the border of the hole and to remove the painting around it in order to ensure a better electrical contact with the connector.



*Figure 4.36: Carefully drill a pilot hole, then use a larger bit to finish the job.*

4.  Smooth with the file one end of the wire. Tin the wire for around 0.5 cm at the same end helping yourself with the vice.