HIGHPOINT SECURITY TECHNOLOGIES Inc.

White Paper

A Compact and Rugged Antenna Design

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Introduction

The following paper will outline the design of a simple and rugged antenna. This design has elements of both a patch and a slot antenna design. The purpose of this paper is to explore the design concept and not to work through the mathematics of the physical characteristics. Several design examples will be presented and the reader will be provided with sufficient information to construct an antenna of their own design. A 2.4GHz band antenna was constructed using the methods described and will be used for comparison purposes, to a commercial design. While no gain measurements were possible with the 2.4GHz antenna, its gain should be at least comparable if not better than the commercial design. Yes. This is a directional antenna design. The commercial designer claims 9dBi gain. You should expect at least that.

The directionality or front to back gain of these antennas is considerable. This should allow the investigator to determine the approximate direction of an RF source. The purpose of this paper is not to be a lesson in direction finding, however with a bit of practice it should be possible to determine if the signal is coming from the building in front of, or behind you. It is also possible to determine the maximum detection range from a building for an 802.11x signal. How far away do the bad guys have to be? If you are the one doing the snooping, how far away from the target can you be, and still get useful information ?

Basic Design

The basic design consists of two pieces; the radiating element and the reflector or ground element. The radiating element is connected to the center conductor of the coax feeding the antenna, while the shield of the coax is connected to the reflector. The two pieces are connected together electrically and mechanically in the exact center of both using a metal stand off. The reflector should be approximately two times the size of the radiator. The feed point for the coax is located half way across and one quarter of the way in from one side of the radiator, as shown in the example below.

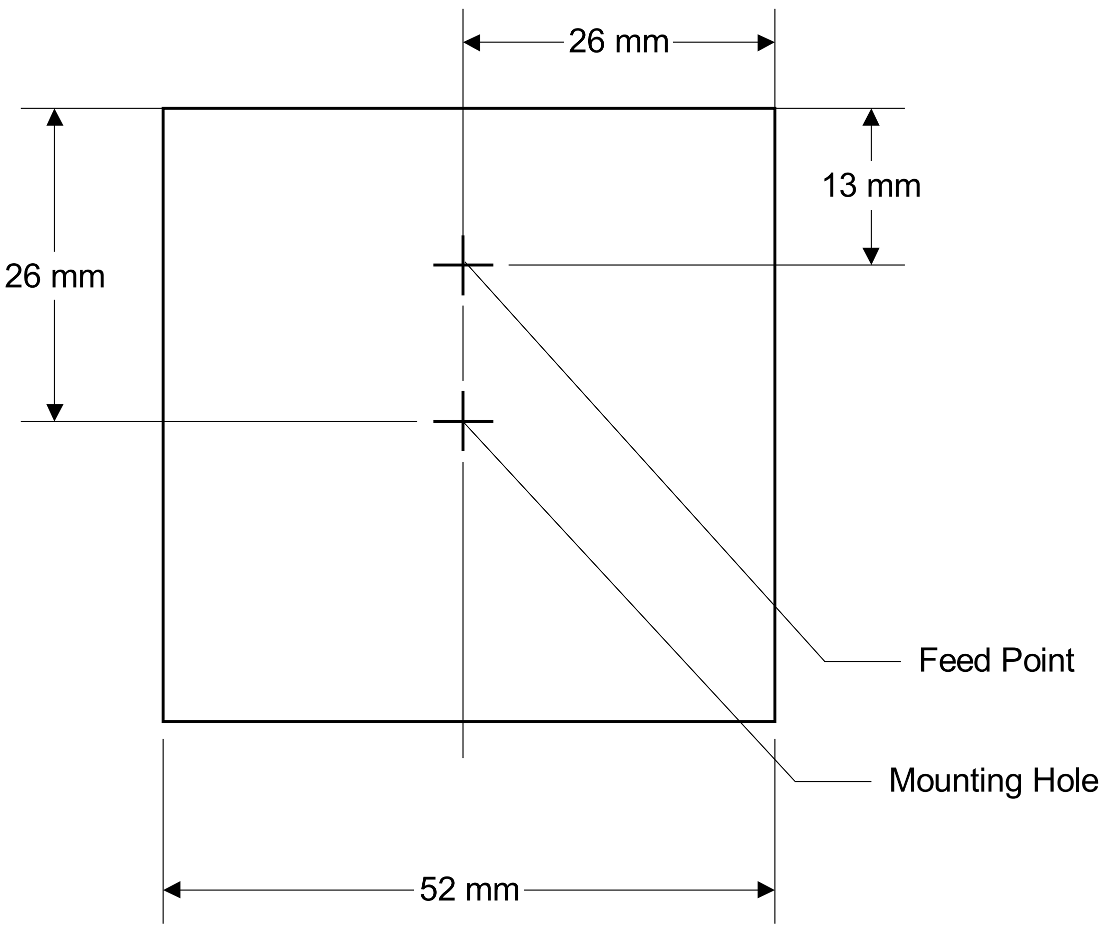

Figure 1 Radiator

The reflector or ground element is a plate that is two times the area of the radiator with a mounting hole for the metal stand off drilled in the center of the plate. A second hole is drilled so as to line up with the feed point of the radiator. This hole should be of sufficient diameter to accommodate the body of the type connector being used. I highly recommend an SMA connector for most applications. Reasonable care must be taken when using these connectors, so as not to damage the threads. Depending on the physical dimensions of the antenna, and weather or not it will be enclosed in a protective case, it may be necessary to support the radiator at the corners. If this is a requirement, then ***insulated*** standoffs should be used. There must be no electrical connection between the two plates because of these supports.

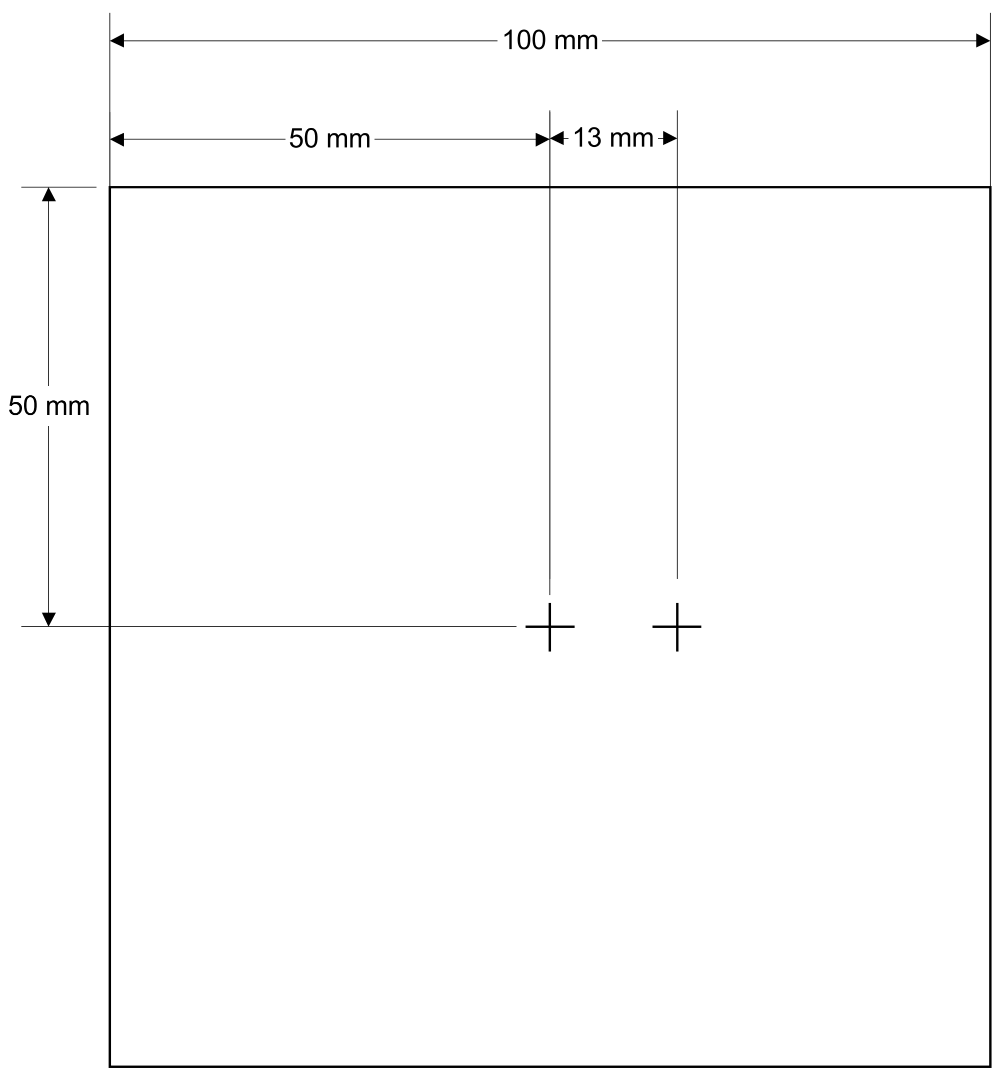

Figure 2 Reflector

Design Example #1

A 1.43GHz commercial antenna was used as a reference. The procedure for designing a 2.4GHZ antenna for the 802.11x band is a follows.

The dimensions of the commercial antenna are:

Radiator: 87 mm
Reflector: 152 mm

1430 MHz / 2400 MHz = .59

If we multiply 87 mm X .59 we get about 52 mm. This is the size of the new radiator.

The minimum size of the reflector can be calculated in the same way.

152 X .59 = 89.7 or about 90 mm

We now have the dimensions required to make our new antenna.

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Design Example #2

An antenna for the 1.2GHz band is required. This band is popular with some types of older covert video transmitters.

1430 MHz / 1200 MHz = 1.19

Because the new frequency, is lower, the antenna will be larger than the commercial example.

87 X 1.19 = 103.7 or about 104 mm for the radiator and

152 X 1.19 = 181 mm for the reflector.

Due to the physical size of this antenna it would probably be best to support the corners of the radiator as described above.

Design Example #3

An antenna for the 5.6GHz band is required. This is the band used by 802.11g Wi-Fi as well as some cordless phones. The same method as before is used.

1430 MHz / 5600 MHz = .255

87 X .255 = 22 mm

152 X .255 = 38.8 or about 39 mm

As you can see from the calculations above the resulting antenna is quite small. The smaller the antenna, the more critical the measurements become. A sharp band saw or shear should be used to cut the pieces. They can be cut slightly larger, and filed down to size if you like. The material I used was .060" thick, single sided printed circuit board. For larger designs such as the 1.2GHz antenna, it may be best to use a thicker material, such as .125" circuit board. If this material was used for the base, the mounting holes could be counter sunk. These design examples will get you 'in the ball park' as far as VSWR and Return Loss are concerned. A network analyzer is required for optimum design. Figures 3 and 4 show the 2.4GHz antenna design.

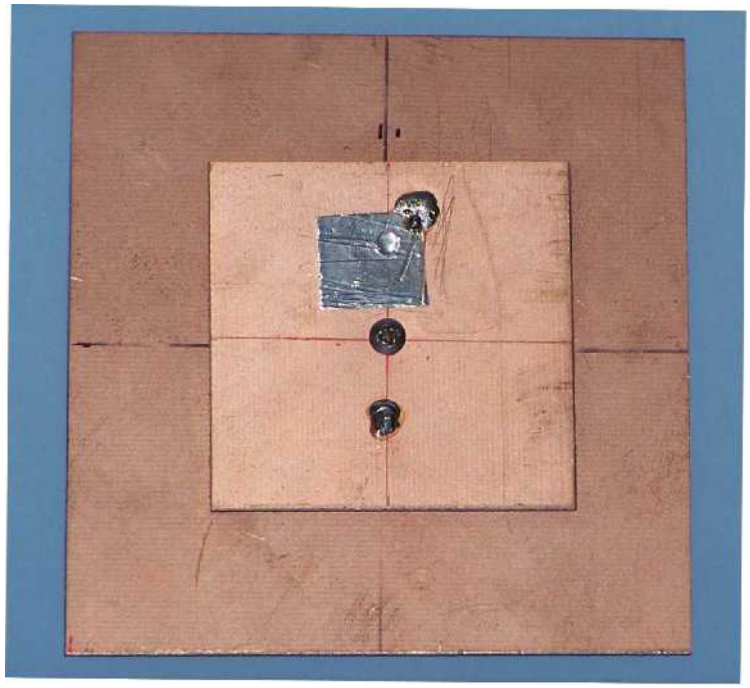


Figure 3 Prototype 2.4GHz Antenna

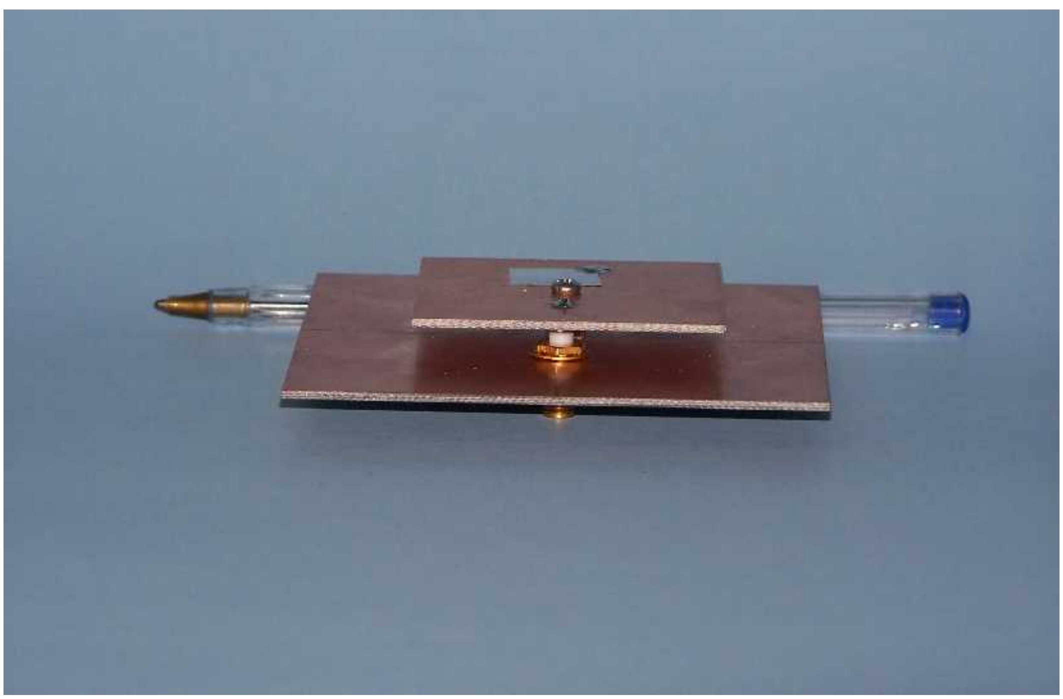


Figure 4 Side View of Antenna

Figure 4 shows the side view of the antenna. The distance between the radiator and the reflector should be kept as small as physically possible. This is done to control the impedance at the feed point of the radiator. The antenna is assembled with the copper side of the reflector up. This is to minimize the distance between radiator and reflector, and to minimize any effects of the PCB material. Note the ball point pen used as a reference for size. The prototype was installed inside an ABS box as shown below in Figure 5.

Figure 5 Antenna in ABS Box

When the antenna was installed inside the box there was a 135MHz frequency shift in the return loss. The size of the radiator was reduced by 2 mm to compensate for the shift. If the antenna is to be hidden inside a container such as a cooler or a fiberglass camper, additional measurements should be made to see what effect the container has on the antenna. The return loss measurement is shown below in Figure 6.

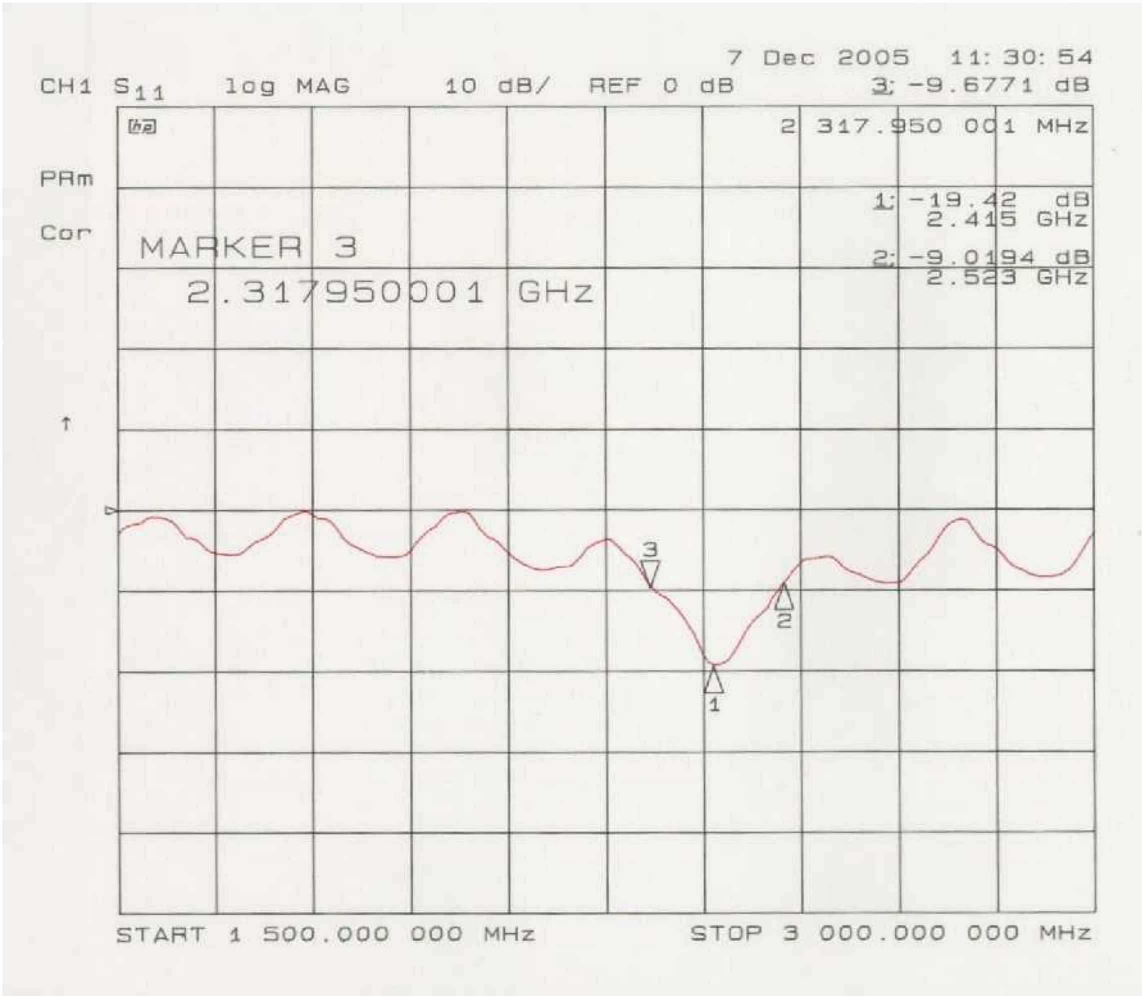


Figure 6 Return Loss of 2.4GHz Antenna

Marker 1 shows a return loss of –19dB at 2.415GHz. The bandwidth of the antenna is the difference between marker 2 and marker 3, or 205MHz. The wavy portions of the plot to the left and right of the markers are artifacts caused by the cable connecting the antenna to the network analyzer. Had the cable been 'calibrated out' these dips would not be there.

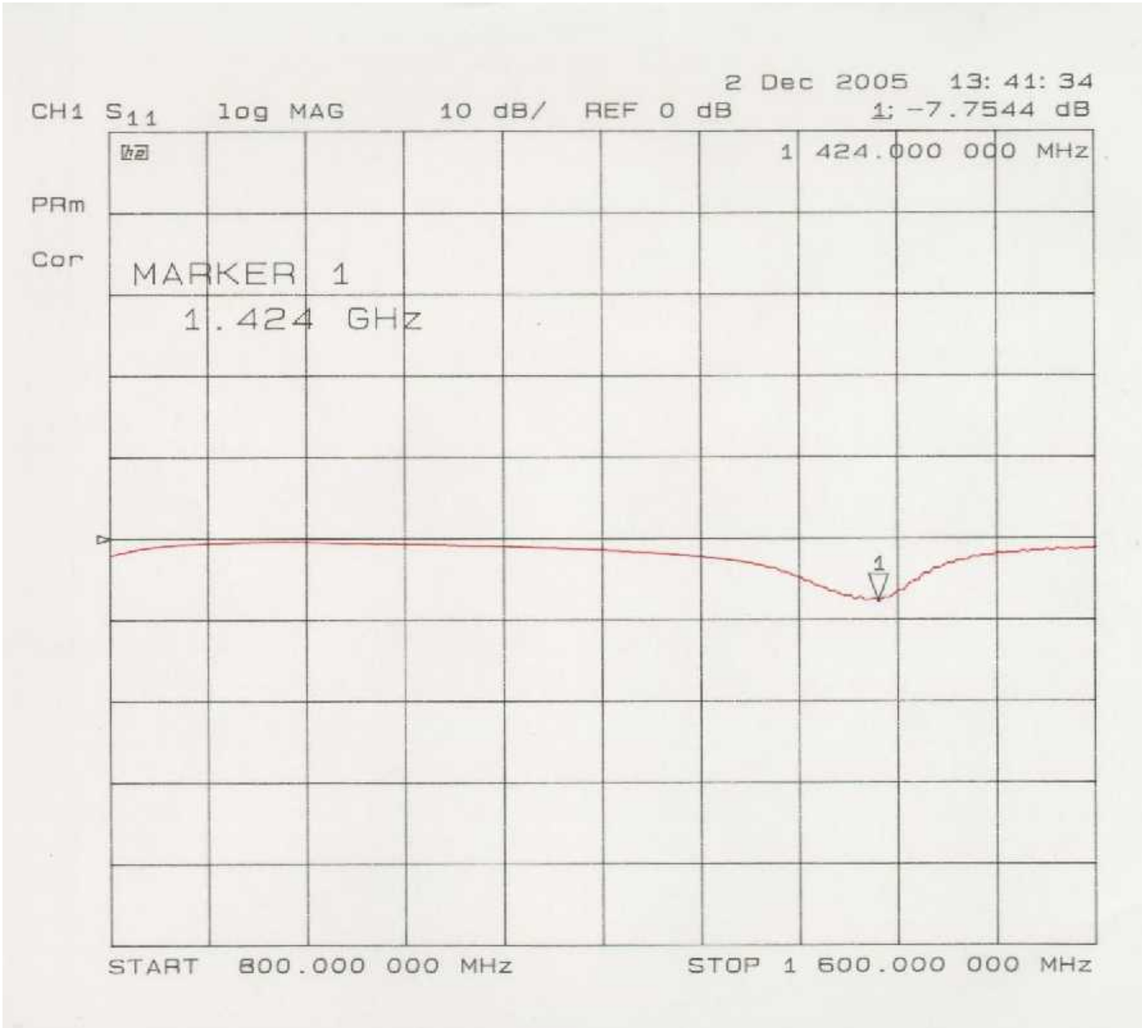


Figure 7 Return Loss of 1.43GHz antenna

Figure 7 above shows the return loss of the commercial antenna for comparison purposes. Note that the commercial antenna has a return loss of about –8dB. The antenna was connected directly to the analyzer, for this reason the dips seen in the 2.4GHz measurement are not present.

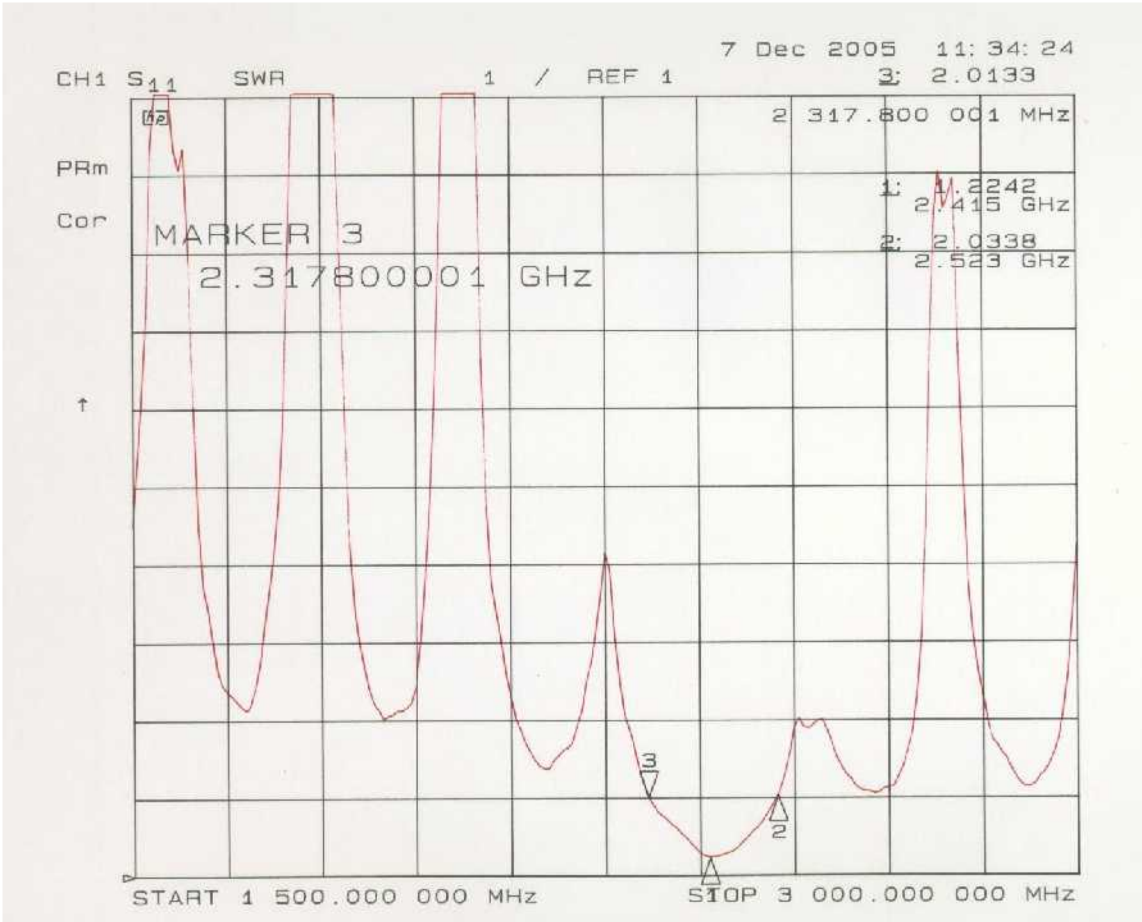


Figure 8 VSWR of 2.4GHz Antenna

The VSWR of the prototype antenna was also measured. Marker 1 is the center frequency of the antenna. The VSWR at this point is about 1.22

It should be noted at this point, that this antenna was constructed using a sheet metal shear as the precision cutting device! The pieces were used as cut, and no further machining was done. Any reputable PCB manufacturer should be able to replicate this precision in mass production, provided proper QA standards are in place.

Plans for constructing the 2.4GHz antenna are provided in the appendix. Steel machine screws and split lock washers were used to fasten the pieces to the ¼" aluminum stand off. It would also be prudent to use a thread locking compound on the hardware. A piece of solid wire about ¼" long is soldered to the center terminal of the SMA connector. A ¼ watt resistor lead would work well. The SMA connector is threaded into the reflector and held in place with the hardware provided with it. Once again, thread locking compound would be useful to keep the connector from moving once the antenna is assembled. The stand off should now be fastened to the reflector, using #4 hardware.

Once this is done, mount the radiator to the reflector by sliding the wire protruding from the SMA connector through the hole drilled at the feed point. Make sure that the hole in the radiator is properly aligned with the SMA connector and fasten the two plates together with more #4 hardware. Solder the wire from the SMA connector to the radiator and trim off any excess. This completes the assembly of the antenna. It is now ready for final test.

A simple qualitative test, is to compare the new antenna to the ‘rubber duck’ or the magnet mount ‘omni’ antenna which comes with most wireless cards. While this is not a laboratory grade test, it is reliable for all practical purposes.

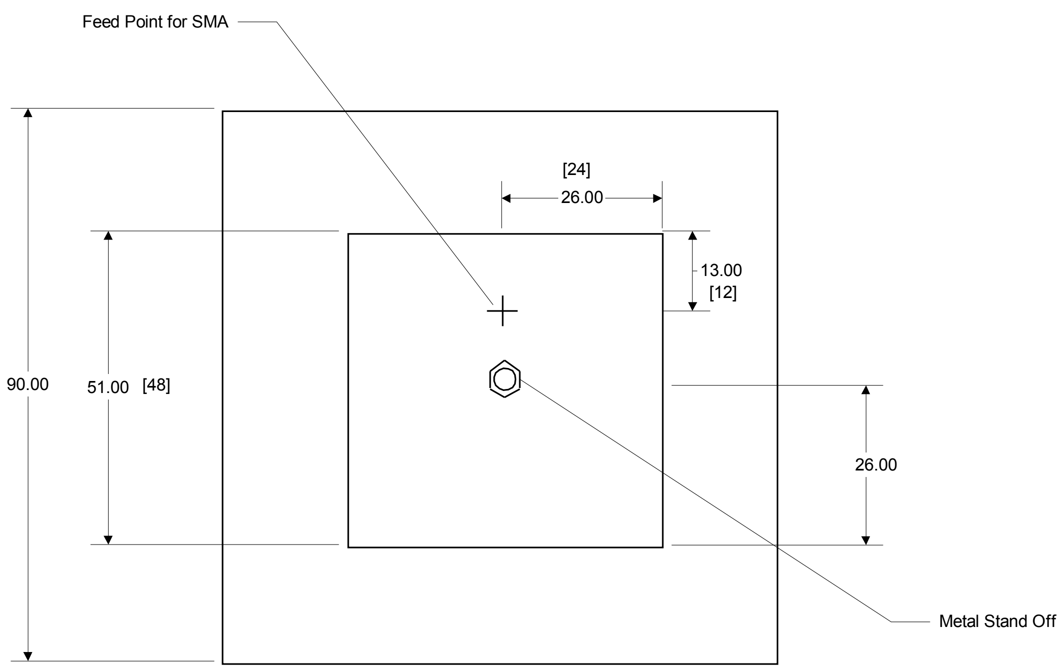
Ideally this test should be performed outdoors with clear line of site between the source and the antenna. The hub and the laptop should be set on a non-metallic base at least 12” above the ground. Plastic lawn furniture would be perfect! Get yourself a wireless hub. Most of these are powered by 12VDC so operation outdoors should not be an issue. Pace off a distance of about 50 yards, or what ever is practical in your case. The distance doesn’t matter as long as it is the same for both parts of the test. Set up the hub and turn it on. It doesn’t have to be connected to a computer for these tests. For the purpose of these tests we will assume that the rubber duck antenna on the hub is isotropic and therefore has 0 dB gain. Connect another rubber duck antenna to your laptop and fire up your wireless software. Most wireless software packages have a method of measuring and displaying signal strength. Record the signal strength measurement when the rubber duck is connected. Now ***shut down the laptop*** and connect the new antenna to it. The laptop should be shut down because some low end wireless cards do not like running without an antenna. Perform the same measurement, in the same place as before. The radiator should be pointed toward the hub. Point the antenna and then step back. At these frequencies you are part of the antenna! A piece of ABS conduit makes a good antenna mount. You can rotate the antenna left and right and also tilt it up and down. You should see a considerable difference between this antenna and the rubber duck. If you are lucky enough to have software that measures signal strength in dB, then the approximate ‘gain’ is the difference between the two numbers. You

should see the effect of the directionality as you point the antenna away from the hub. This type of antenna has what is known as ‘side lobes’ so the signal strength may not change immediately when the antenna is pointed at an angle to the hub. This is normal. This is in no way a laboratory test, so your results will vary, depending on the test conditions and your choice of a test site. For example the 2.4GHz band is absorbed by water. This is why it is the frequency of choice for microwave ovens! You may get different results across a parking lot as opposed to a grassy field. This is due to the absorption effects of the grass.
If you have constructed the antenna carefully, you should see a marked improvement over the rubber duck antenna.

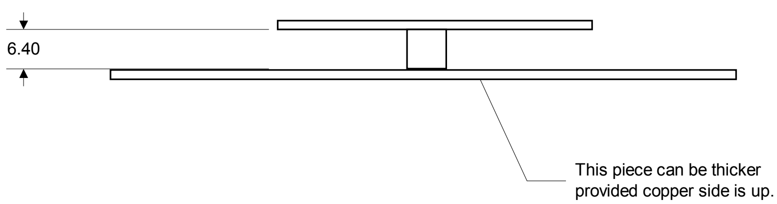
Good hunting …

Appendix
Assembly Plans

ALL DIMENSIONS IN mm UNLESS
STATED OTHERWISE

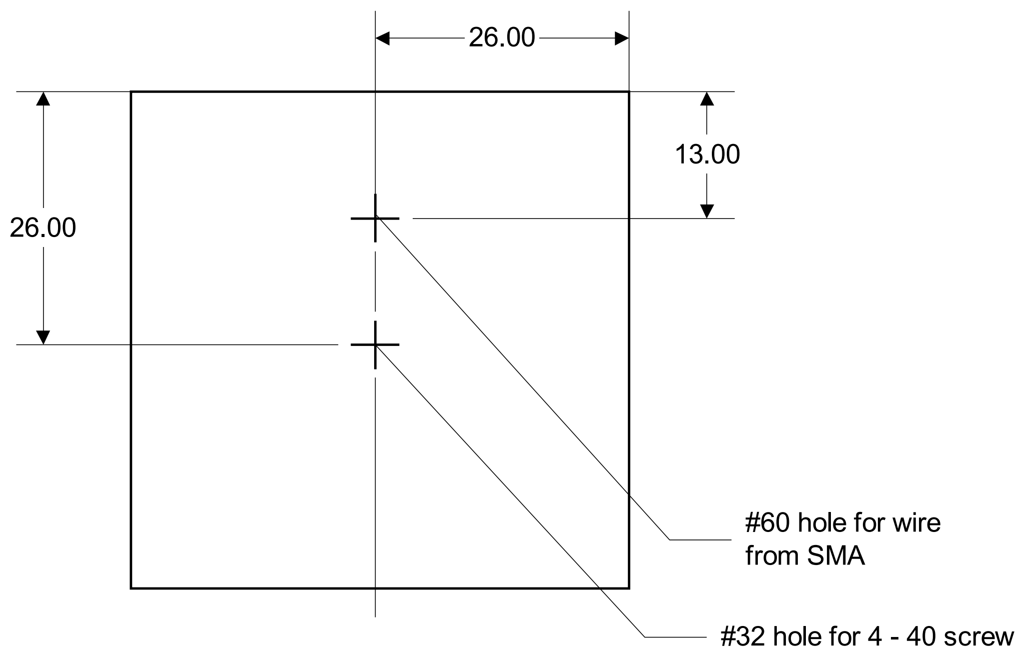


Material: FR-4 / 1 oz copper single sided
SMA: 9412-1113-000 AEP (Allied Engineering Products)
Dimensions in [ ] are for ABS case



ALL DIMENSIONS IN mm UNLESS
STATED OTHERWISE

Radiator



ALL DIMENSIONS IN mm UNLESS STATED OTHERWISE

Dimensions in [ ] are for ABS case

Ground Plane