

2.4 Ghz 2x2 Bowtie Array Antenna

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Background

Antenna performance is often a critical limiting factor in the performance of a communications system. Different types of antennas can be utilized to meet different goals. For example a short range or mobile platform will likely need an omnidirectional antenna while a long range point to point system will require a highly directional antenna. Dipole and bowtie type antennas in their single element form have minimal amounts of directionality when used as a single element. By combining many of these simple antennas into an array the directionality can be greatly influenced and tuned to the requisite specifications by changing the feed phasing or the element phasing. Reflectors can be added to further increase directionality by removing the backwards facing lobes.

Design Overview

Wire bowtie antennas are very similar to dipole antennas with the exception that each element is split into a 'V' shape. Although I have not done any quantitative analysis of it, bowtie antennas appear to give a wider bandwidth and reduced length when compared to a dipole of equal operating frequency. Maximum length can be traded for increased width by switching to a bowtie design. For example at 2.4Ghz a dipole antenna would be expected to be about 62mm in length, while a bowtie antenna could be design to be about 44mm in length- representing about a 30% reduction in length.

This project incorporates 4 sets of bowtie elements into an array with a square spacing of 0.75λ . The elements were constructed from copper wire with a radius of 1.27mm. The wire was chosen to be thick enough to be durable while still thin enough to accurately shape to the requisite dimensions.

Computer Simulations

Several simulation platforms were evaluated prior to the construction of a model. Possible choices included Microwave Office, CST, and HFSS. Microwave Office does not support three dimensional solutions and CST was unavailable for testing. An evaluation of HFSS resulted in a conclusion that it would meet the requirements of this project. HFSS includes many features to help in the design of antenna systems including default setups for the excitation of antenna designs as well as array factor calculations.

The first step was the creation of a 3-d model to run the calculations on. HFSS allows the creation of variables that can be used in place of any user input. This allows the creation of a fully parameterized model- that is a model in which the change of a few variables will automatically redraw the entire model to match the changes. While variables are not unique to HFSS their implementation is second to none.

The screenshot shows a window titled "Properties" with a table of variables. The table has five columns: Name, Value, Unit, Evaluated Value, and Type. The rows are grouped into sections: Dipole Dimensions, Air Box, and Virtual Object Radiation. The "array_space" variable is marked as "Post Processing".

Name	Value	Unit	Evaluated Value	Type
--Dipole Dimensions				
wire_rad	1.27	mm	1.27mm	Design
dipole_length	42	mm	42mm	Design
port_gap	3	mm	3mm	Design
bowtie_angle	45	deg	45deg	Design
reflector_distance	5	mm	5mm	Design
wire_bend_rad	2*wire_rad		2.54mm	Design
--Air Box				
Airbox_dist	41.6378	mm	41.6378mm	Design
--Virtual Object Radiation ...				
VirtualObject_dist	dipole_length*sin(b...		16.0727041593...	Design
bend_radius	wire_bend_rad-wire...		1.27mm	Design
wire_bend_z_offset	(port_gap/2)+wire_...		4.33798408179...	Design
wire_bend_y_offset	-((bend_radius+wire...		-2.3466540125...	Design
array_space	78.12484375	mm	78.12484375mm	Post Processing

Variables

HFSS allows variables to be defined as functions of other variables, and can evaluate mathematical operations. For example: one variable was defined as another variable plus the cosine of a second variable divided by two. Without the mathematical evaluation it would be much less useful. It should be obvious that this is a powerful tool that allows quickly tuning the model to create the desired specifications.

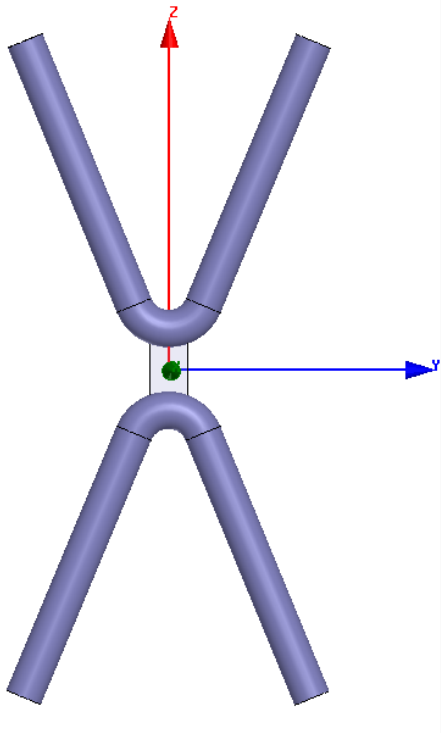


Figure 1: Computer simulation model.

HFSS includes systematic optimization tools where desired parameters are set and parameters to be changed are identified, at which point it will try thousands of combinations to find the best one. I did not use these features for a couple reasons. They are fairly complex to setup and would take away from my learning of what each parameter (for example length of wire or thickness) does when changed. My experimentation with the model has shown me that changing the angle of the bowtie can be used to trade off between low return loss and wider bandwidth while changing the length primarily influences

frequency of operation. The width of the wire and the feed gap can be used for further tuning of the antenna.

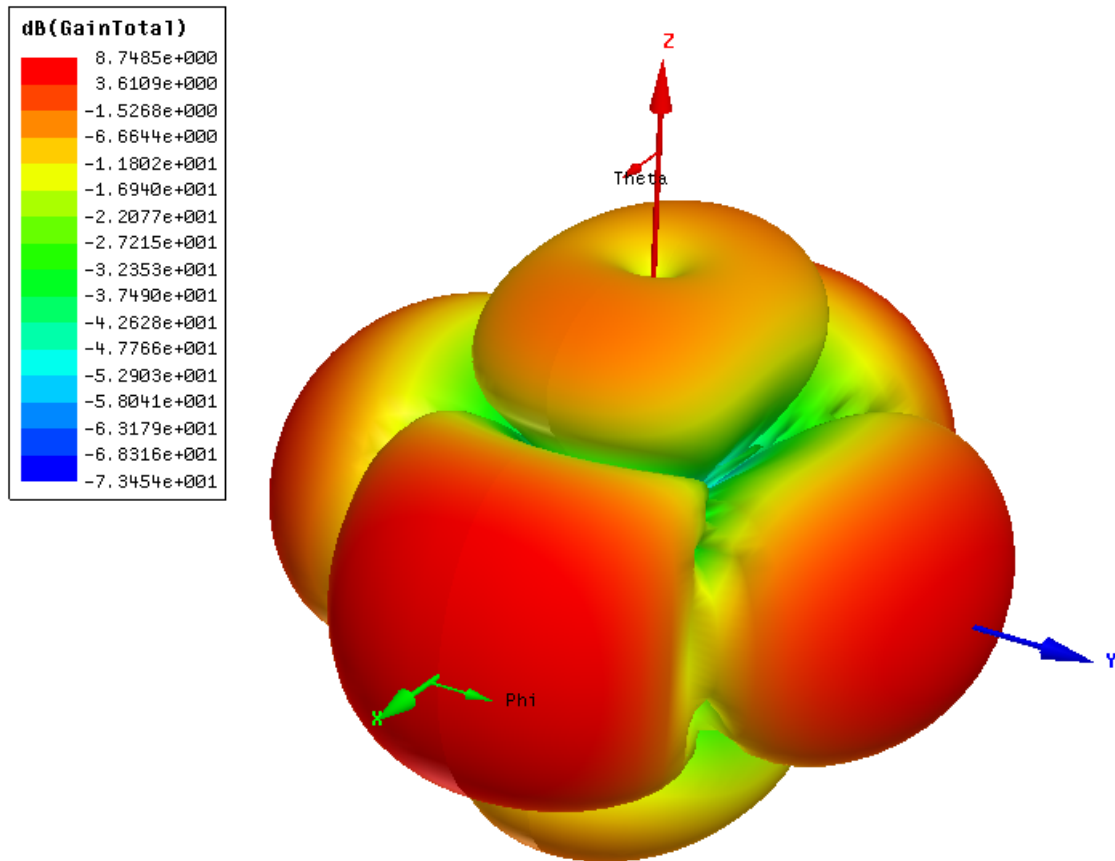


Figure 2 One of the 'Pretty Pictures' that 3d analysis tools provide.

Antenna Construction and Verification

Before creating the final antenna a simple antenna consisting of a single element was created. This was to provide experimental verification of the computer model and gain practice constructing antennas and troubleshooting any problems.

When creating the antenna elements special care was taken to ensure that they had a uniform shape that was as accurate to the computer simulation model as possible. This was accomplished by

cutting the pieces of wire longer than necessary and filing them down until they just fit into the jaws of a caliper that was locked at the desired length.

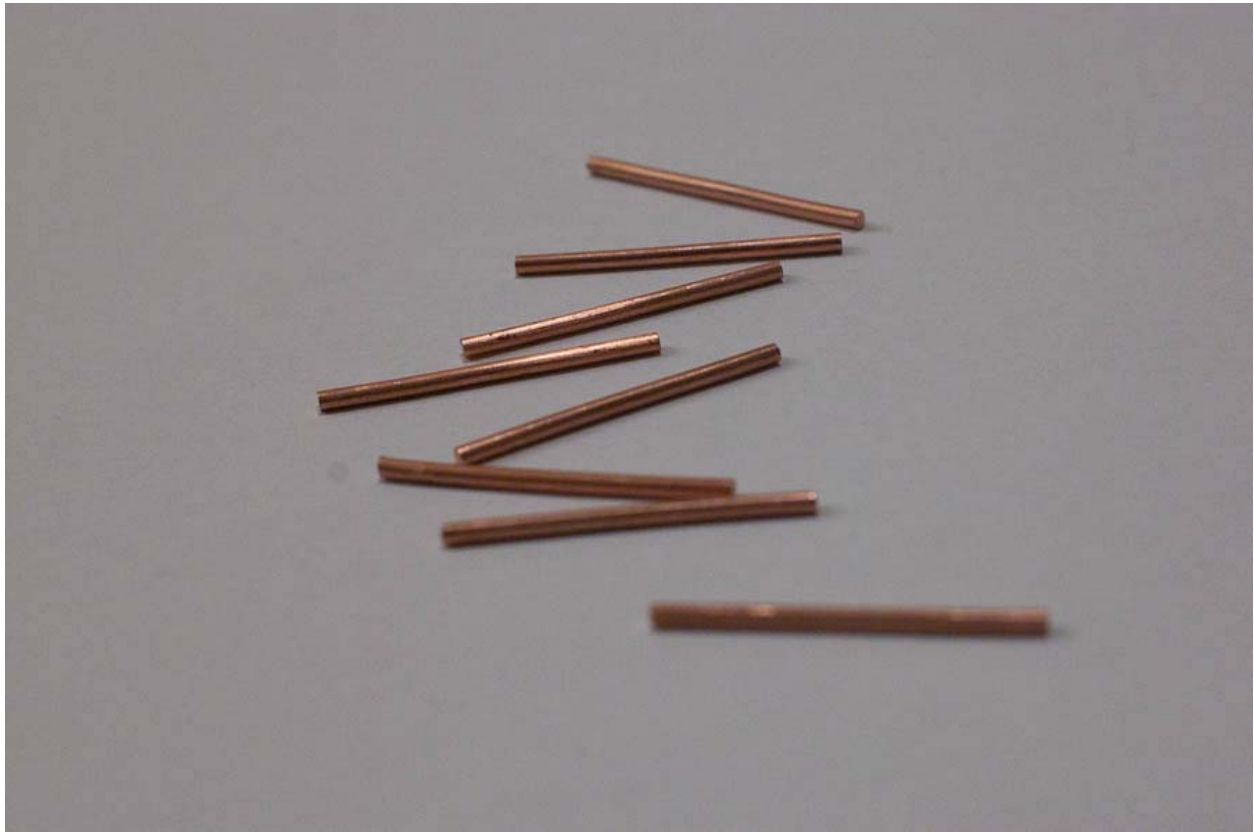


Figure 3 Antenna elements cut and filed to length.

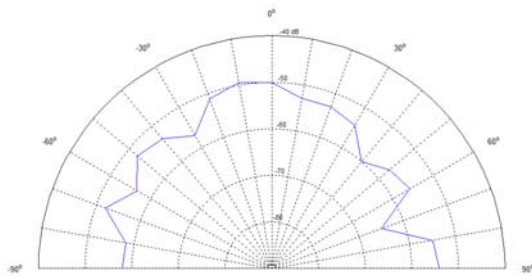
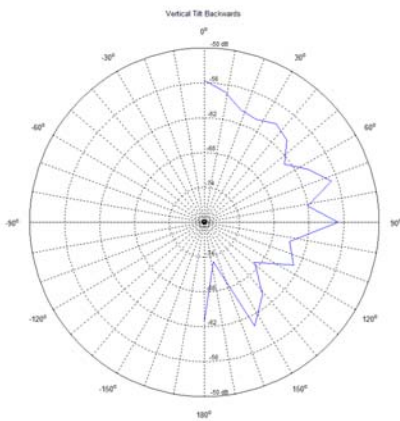
Test Results

Testing the antenna consisted of measuring three quantities: return loss, radiation pattern, and gain. The numbers on the network analyzer jittered a lot during s12 or s21 measurements, while s11 measurements were quite stable unless objects very close to the antenna were moved or placed. This reduced the accuracy of measuring the radiation pattern and gain.

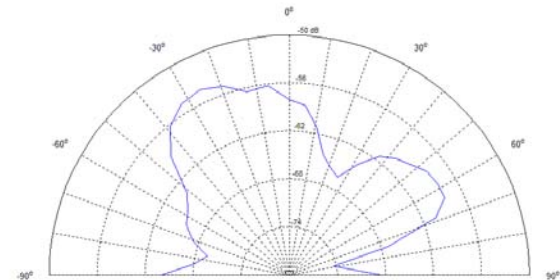
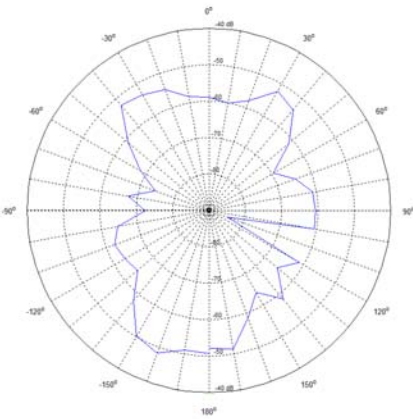
Return loss was the least involved measurement. The antenna was simply connected to the network analyzer and set to measure the S11 parameter. The value can be read directly off the screen. The single element prototype attained a return loss of about -24dB while the final array only provided -15db. I suspect two main causes of the degraded return loss in the final product. The first cause is that

there are more pieces in the array, and each piece has to have a connection that could be a little bad, so it adds up. The second cause I've identified is the power distribution network. The single element did not need such a network and the array did. The network utilized two quarter wave segments of transmission line which are sensitive to length errors.

The radiation pattern plots are not very close to the expected results, but are similar.



[Images] Two different tilt back plots. The first from 0 to 180 degrees. The second from -90 to 90.



[Images] Two different horizontal plots. The first one is a full 360 degrees. The second -90 to 90.

The final test was the gain of the antenna. Gain was measured by taking the return loss between my antenna and any other antenna of the same frequency. Then my antenna was substituted for a standard antenna with a 10dbi gain. The difference is the gain with respect to 10dbi. Example: -48db with standard, -55db with my antenna. So the array I constructed is 7db worse than the 10dbi standard, which can be expressed as 3dbi. Not quite as good as the 6-8 db predicted by HFSS. This is probably due to manufacturing errors.

Conclusion

Through the successful completion of this project I've gained lots of valuable knowledge in practical antenna design, simulation, and construction. The use of HFSS to simulate the antenna's electrical performance was valuable in my ability to quickly gain a feeling for how changes in the shape can affect the measurable properties of the antenna, such as operating frequency. This is because trying out a new design using a simulation program costs nothing more than about 3 minutes of computer time- a great improvement over building the antenna to be able to test it.