1X8 Quasi-Yagi Antenna Array

E. Caspers , M. Abdallah, B. Souid, and S. Arvas

Department of Electrical Engineering and Computer Science
Syracuse University
Syracuse, NY 13244 USA
{ecaspers ,mnabdall}@syr.edu, {bashirsouid, serhend}@gmail.com

Abstract – In this paper a design of 1X8 quasi-Yagi antenna array is introduced. The frequency band is 2.4-2.5 GHz.

Keywords : Sonnet , HFSS, Quai-Yagi , Gain , balun and radiation pattern.

1. Introduction

The initial design for the array elements was adopted from literature [1] and [2] which, like many of the other quasi yagi antennas designed for the 2.4-2.5GHz band, used a substrate of dielectric 10.2. For our design only Rogers 3003 was available so the dimensions were scaled.
This project was part of building an FMCW simple radar system which was taught at Syracuse university in the summer 2011. After designing the quasi-yagi antenna array , a feed network with phase shifters were used to construct a phased array antenna and then be able to steer the beam in the azimuthal direction.

2. Design Description

An assumption was made that translating the widths and lengths from a design for dielectric 10.2 substrate to electrically equivalent widths and lengths to maintain the line impedances and electrical lengths for our substrate would yield acceptable first results (approximately 6dBi).
When designing the eight-by-one antenna element the maximum board size available was 8". According to experiments done in HFSS and [2] and [3], the size of the driver elements had the largest effect on the achievable gain. After running several simulations it was noted that the gain pattern of a dipole element, and that of the quasi-yagi antenna roughly coincided. The optimal gain in the endfire direction seemed to occur when the driver was one wavelength long which is similar to a dipole. When the driver became longer (towards two wavelengths) the gain pattern also behaved distinctly like a dipole of the same length with two main lobes each of lower gain instead of the a single lobe of high gain. Experiments showed that within the 8" board, the optimal size was slightly longer than a full wavelength. This provided good gain in the end-fire direction without sacrificing the radiation pattern shape.

The number and length of the directors was experimented with based on the results in [1], [2], [3] and [4]. In the final design only one director is used because of size constraints for the boards. In particular the directors must be spaced evenly to achieve a benefit from them, and the first director was already approximately 1.5" from the drivers. This meant that while adding more directors would slightly improve gain, it was not worth the added cost.

Another part which received a lot of testing was the widths of the driver elements. It was found that changing the widths had relatively little effect on the gain, but at the same time, wider elements were shown to exhibit better performance over the bandwidth as demonstrated in [4]. The final design of the elements has multi-segment drivers which were derived from these experiments and reference to literature.

The final quasi-yagi design has longer sub-sectioned driver in each element which will act like an array of many dipoles and as a result of this the radiation pattern will be squeezed and the beamwidth will be smaller in the elevation direction, in other words the long driver compensate for the second dimension of the array. There are some advantages of this design: we were limited in the available phase shifters , this design requires 8 phase shifters for each antenna instead of the original plan of designing 4*4 array antenna which requires 16 phase shifters for each antenna. The second advantage of such a design that it makes the feed network design as simple as possible , so instead of using multi feed networks we only used one feed network.

Yagi antennas are difficult to design because of the number of elements increases the number of variables in the final performance characteristics. As such, the design notes for yagi antennas are more guidelines than definitive rules and designers usually make use of optimizers to find an acceptable antenna. Once the basic antenna design was laid out, genetic and pattern search algorithms were used to produce better results.

3. Simulation results

The final results of the work on the antenna elements is shown in the figure below. Note that the gain was increased from roughly 6dB to 9.74dB and the unwanted back lobe is significantly reduced. The sidelobes are mainly the result of choosing a driver slightly longer than one wavelength but they are still around 9dB lower than the main lobe.

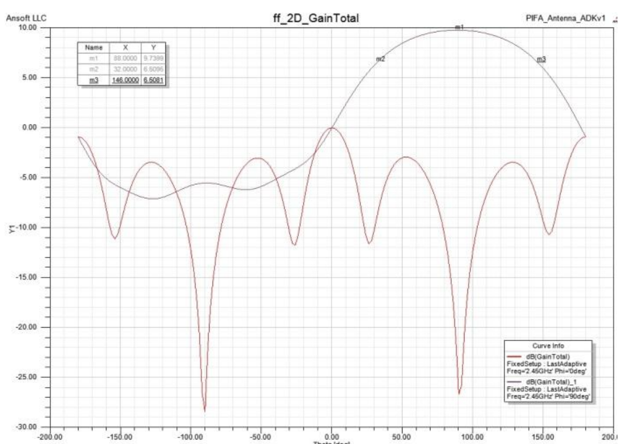

Figure 1: Element Gain Pattern

4. Balun design

The results discussed so far pertain only to the antenna elements starting from the feed lines to the drivers. A balun which feeds these lines with a 180 degree differential phase shift also needed to be designed. The design of the balun was completed in Sonnet because of the accuracy required in order to get the best performance out of each element. The balun is required to provide a 180 degree phase shift, evenly distribute and recombine the signal, and match the feed network to the antenna. The actual antenna input impedance was found in HFSS and later verified using Sonnet in order get the best performance.

The design that was primarily followed was in [5] where there is a simple 50Ohm line that feeds a quarter wave transformer. The quarter wave section then feeds two lines, one of which introduces a 180 degree phase shift, directly to the antenna. Chamfering of the corners is necessary for finding acceptable S-parameters. The balun was designed in successive steps in Sonnet by starting with only the quarter wave section which fed lines to ports at the top and bottom of the box. Once the S-parameters were properly tuned, the box in Sonnet was made larger, and the rest of the balun was laid out. At that point, all that was necessary to tune the balun was to adjust the chamfering of the edges which had a significant effect on |S21| and |S31|. It is also interesting to note that the quarter wave section did not actually turn out to be a quart wave for the transition from the 50 Ohm input line to the real part of the antenna impedance. This is because when the real and imaginary parts of the antenna input impedance were used as the sonnet port impedances, the quarter wave section was modified to get the best S parameters. One way to avoid this in future designs would be to design the antennas to be at resonance near the center frequency.

The return loss at the center frequency is -26dB, |S21|=|S31|=-3.1dB and the phase difference is approximately 180 degrees. These results are similar to those achieved in [5].

Unfortunately, when the balun and antenna were put together and simulated in HFSS, the results for return loss were not acceptable. When a similar simulation was set up and run in Sonnet the results were also unacceptable which meant that tuning with copper tape was necessary. Each element was tuned as closely as possible

5. Test results

Using both the return loss plot and a smith chart representation on the network analyzer. The results are shown in the figures below. Both figures have markers showing the edge of the bandwidth used by the radar system. Note that inside the bandwidth the return loss is at or below -10dB meaning the elements were satisfactorily tuned.

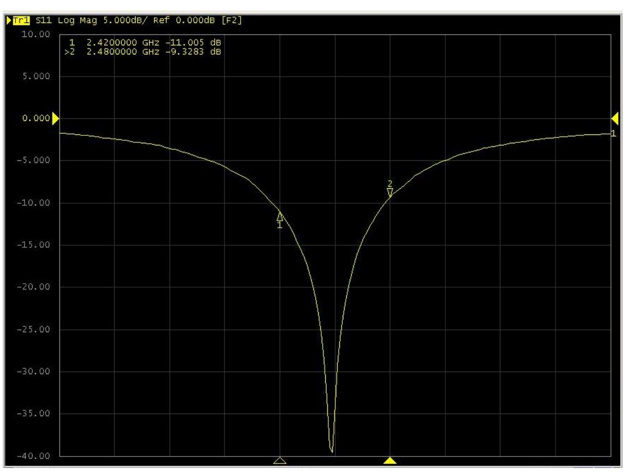

Figure 2: Measured element return loss.

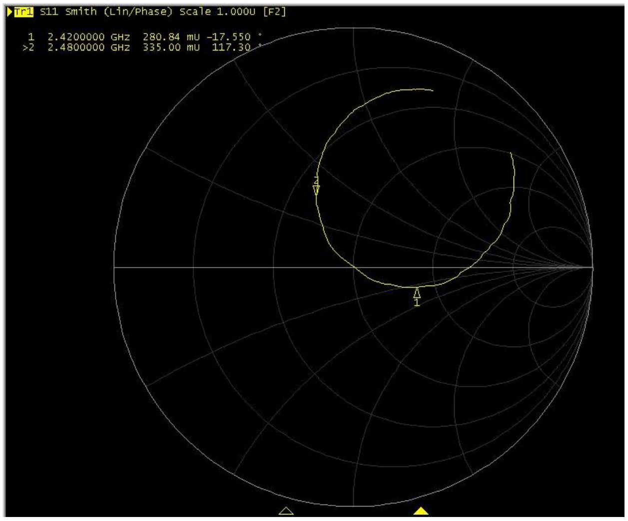

Figure 3: Measured element return loss.

The final radiation pattern results for the antenna was found by running a full simulation of the eight elements in HFSS taking into account mutual coupling. Realistic results are shown in the figures below for no phase shifts between elements.

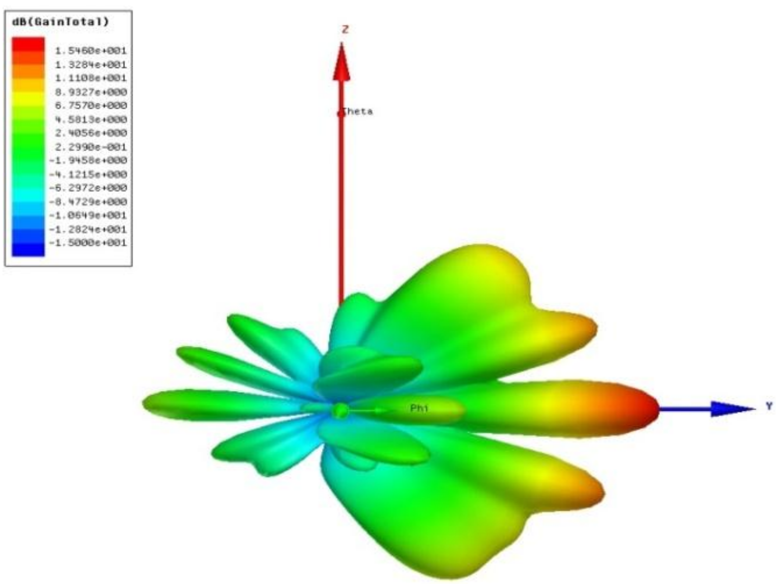

Figure 4: Antenna Pattern without phase shifts.

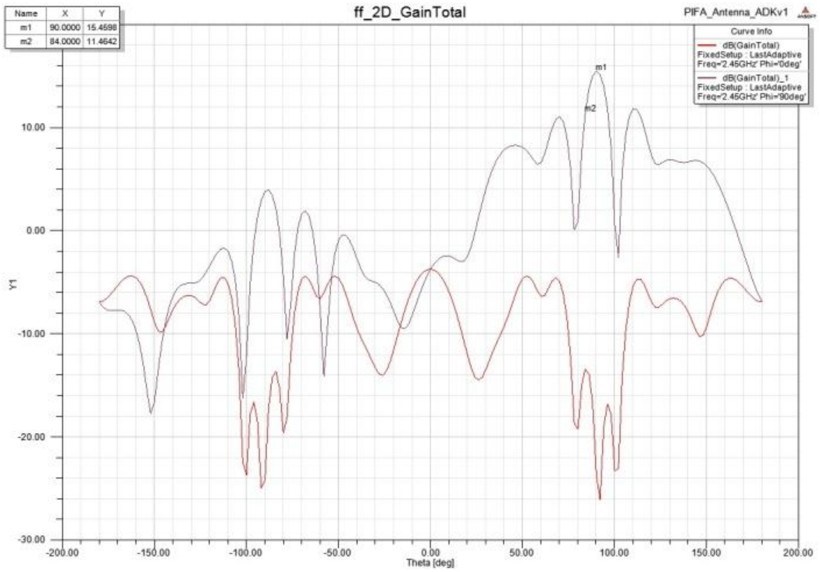

Figure 5: Antenna Pattern without phase shifts.

The gain is around 15.5dB instead of the 18 predicted by the HFSS array factor feature. The 3dB beamwidth remains constant at around 12 degrees when the beam is steered up to about 45 degrees. Other simulations showed that, as expected, the beamwidth and the gain decay as the beam is steered to more extreme angles from broadside where the effective aperture in the direction of the beam is substantially decreased. We also noted that the first side lobe is comparable in magnitude when the array is steered above 60 degrees.

6. Conclusions and future directions

The design of the phased array antenna was very successful especially if we take in our consideration the limitation of time and resources.
If we have more time and more available phase shifters I think we will be able to build a 2-D phased array antenna and be able steer it in both elevation and azimuthal directions.

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