Feed Network for a 1x8 Antenna Array

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Abstract - In this paper, the design, fabrication and testing of the 1:8 feed network for a phased array antenna is discussed. This feed network was designed using sonnet software depending on the Wilkinson power divider concept. The microstrips were fabricated on Rogers 3003 with dielectric constant = 3, loss tan = 0.0013, the substrate thickness = 0.76mm and the frequency band is (2.4-2.5 GHz).

Keywords: Sonnet , phase shifter , S-parameters , quasi-Yagi and Wilkinson power divider.

1. Introduction

This project was part of building FMCW simple radar system to detect targets. To achieve this goal in terms of designing a phased array antenna we need to steer the beam in such a way that we can detect the range and the direction of the target, so we need to design a feed network with phase shifters to steer the beam of the antenna array, also we need the beamwidth to be small as possible (pencil beam) which leads to more directive gain towards the target.

The design of the feed network is very important to achieve a functional array antenna, because we used a 1*8 uniform linear array antenna so we need to excite each radiating element with equal magnitude and progressive phased shifts between the radiating elements to be able to steer the beam in the azimuthal direction otherwise it will not steer the beam perfectly. It is required to divide the input power with equi-phase and magnitude between the antenna elements. There are several techniques of feed network design: series, parallel…etc. The power divider divides the power to equally 1:N or can divide power unequally. The power divider can be easily formed by changing the input and output. Wilkinson is a lossless power divider when all ports are matched, lossy when the ports are not matched at the same time, the output ports are isolated. This is important advantage of Wilkinson divider because as we know a three port network (T- junction) cannot be lossless, matched and reciprocal at the same time. A 100 Ω resistor is added between each two paths because in the phased array antenna each port will have different impedance depending on the phase shift on that port so the resistor is important in our situation.

2. Design technique

I used the parallel power divider (Wilkinson power divider concept) because in addition to the previously mentioned benefits of Wilkinson power divider, we also limited in time and resources and it is easier to equally split the power in the parallel (Wilkinson) divider.

3. Design procedure

I started the design with the simple case of a three ports divider(1:2) equal split , the output ports were spaced 52 mm instead of λ/2 because of the limited work area on the fabricated board for the final design of the 1:8 feed network , the 1:2 Wilkinson divider consists of a 50 ohm line followed by a λ/4 transformer (70.7 Ω) then followed by a 50 Ω line, I avoided any right angle between the microstrips and used a 45 degrees chamfers instead, then basically I tuned the length of λ/4 which includes some sloped traces to achieve the spacing of 1mm where we added the (0805) 100 Ω resistor , in other words it is hard to decide what is the actual length of the used λ/4 transformer unless we do tuning to improve the results as much as possible using the parameter sweep and optimizer features of sonnet software. After achieving the best results, I combined the 1:2 dividers in three stages to come up with the 1:8 divider equal split.

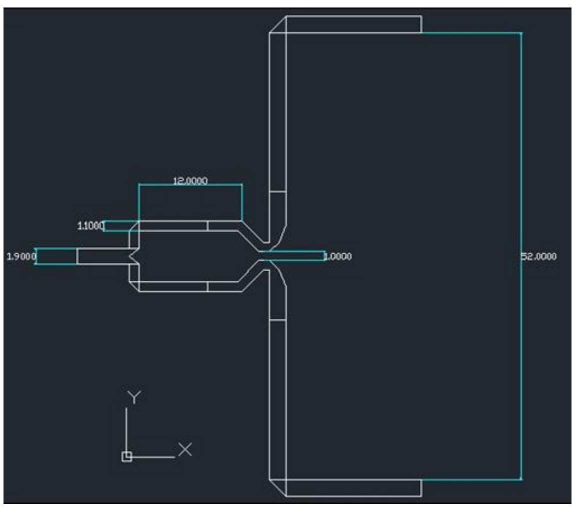

Fig. 1 One to two divider (Dimensions are in mm).

4. Simulation results

Equal split divider 1:8 in the ideal scenario requires that S_{21}, S_{31},.... equals – 9 dB (0.35 magnitude) because we need the power to be equally divided between eight output ports which means each port should have one eighth of the input power and this means that the port power = 0.125 so ${S_{i1}}^2$ = 0.125 then S_{i1} = 0.35 for i = 2,3, 4….,8.
Simulation results using sonnet software were very close to the ideal scenario for the 1:2 divider as shown below in the figures.2 (a-e) where you can see that the return loss is tuned to be min. at the center frequency of our band (2.45 GHz) and also equal magnitude and phase division (S_{21} , S_{31} are approximately -3 dB and the phase is equal in our band) , In addition the output ports are isolated.
My concern was to obtain as much accurate results as possible with the minimum memory needed for each iteration (also minimum iteration time required)

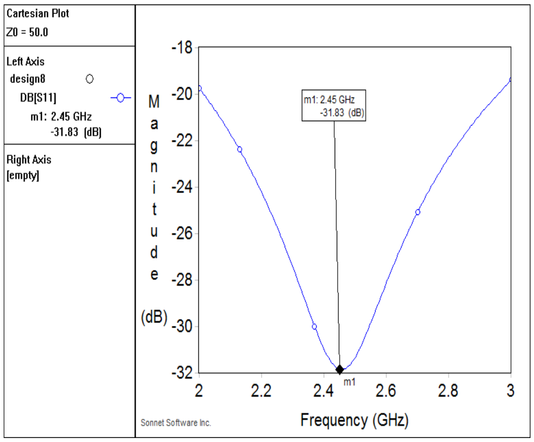

Fig.2 (a)

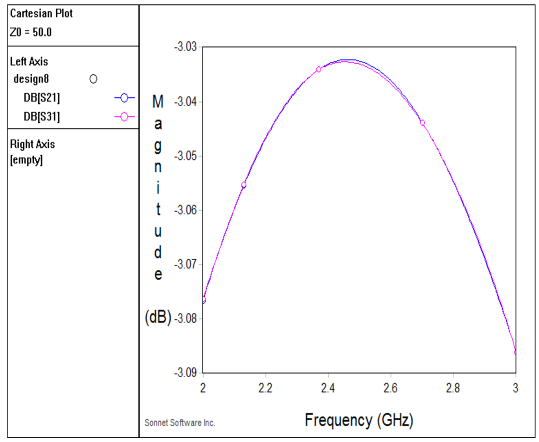

Fig.2 (b)

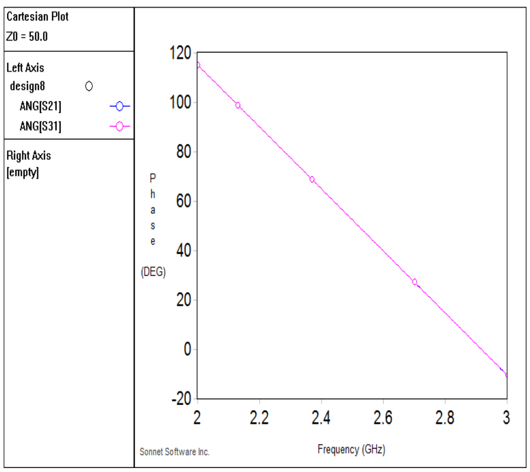

Fig.2 (c)

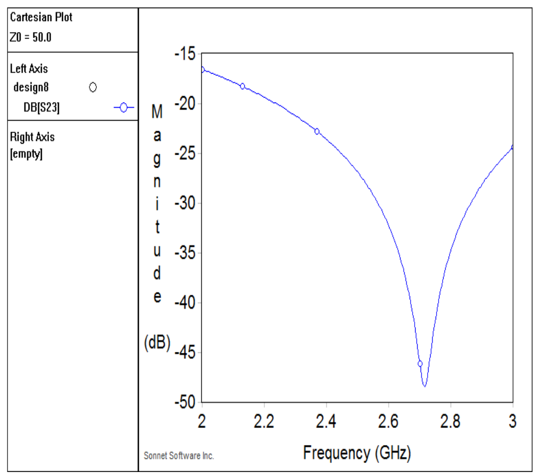

Fig.2 (d)

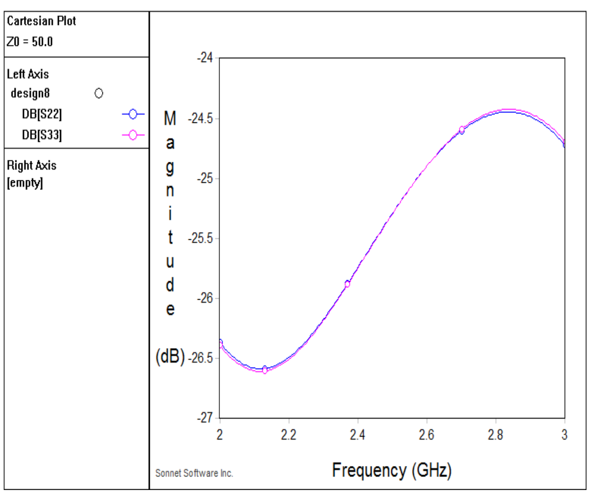

Fig.2 (e)

Fig. 2 The set of figures above shows simulation results for 1:2 divider.

Simulation results for the 1:4 divider were very close to the ideal scenario where $S_{21}, S_{31}, S_{41}, S_{51}$ is approximately - 6 dB and equal phase in our band also the return loss is tuned to be min. at the center frequency.

Simulation results for the 1:8 divider were very close to the ideal scenario but I could not improve the results more because this simulation needs huge RAM memory which is not available for me. The simulation results shown in the figures.3 (a-e) obtained after changing the cell size and use a coarse meshing instead to reduce the RAM memory needed , these changes affect the design shape slightly so the results might not be accurate . In general the results were acceptable for the purpose we are designing for.

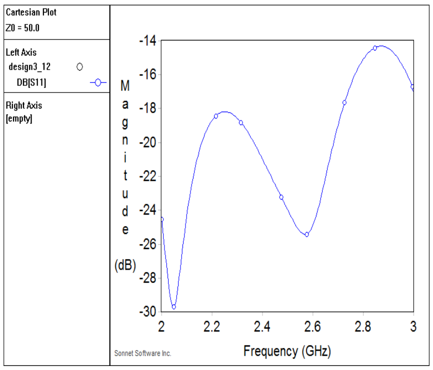

Fig.3 (a)

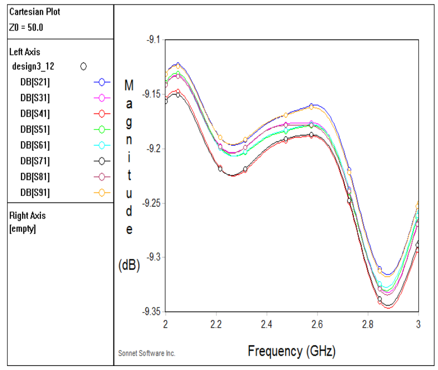

Fig.3 (b)

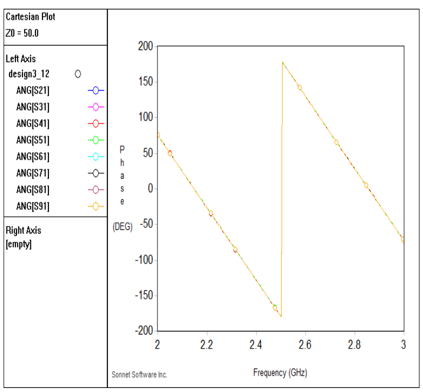

Fig.3 (c)

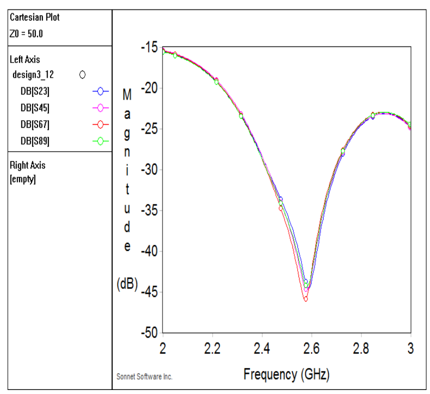

Fig.3 (d)

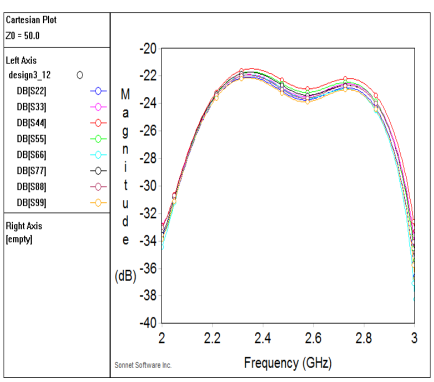

Fig.3 (e)

Fig. 3 The set of figures above shows simulation results for 1:8 divider.

After designing the feed network we need to add a phase shifter into each output port so we can control and set the phase on each port to the needed phase shift to be able to steer the beam left and right. I used AutoCAD to draw the footprint of the phase shifter (Hittite, part No. HMC928LP5E) which gives continuous phase shifts from 0 to 450 degrees using a control voltage signal (0-13 V).With the help of the class's software team we obtained a coded-input voltage (0-5 V) then using eight linear Op-amps we mapped these voltages into the range of (0-13 V) to control the phase shifters depending on a look up table that we got after testing the phase shifters using (0-12.3 V) in 0.1 V step at the center frequency of 2.45 GHz. Then using the following equation we can figure out what voltage needed to steer the beam in some specific angle:

$$\triangle \phi = \frac{360^{o} * d * sin\theta}{\lambda}$$

Where

- d is spacing between radiating elements (52 mm in our case).
- θ is the angle where the beam steered.
- $\triangle \phi$ is the required phase shift between the elements.

So far we built a feed network with a phase shifter on each output port and then connected each SMA connector of these output ports into a quasi-Yagi radiating element, so as a result of all that we implemented a phased array antenna which was the main goal of this project. This was part of building a simple radar system (FMCW) which was taught at Syracuse University in the Summer of 2011.

5. Test procedure

Using a network analyzer we can test two ports at a time so we connected port1 into the input port of the feed network and connected port 2 into the port that we are testing then terminated all others with a 50 Ω termination , the results seems to be identical for all ports. Following is one of these identical results.

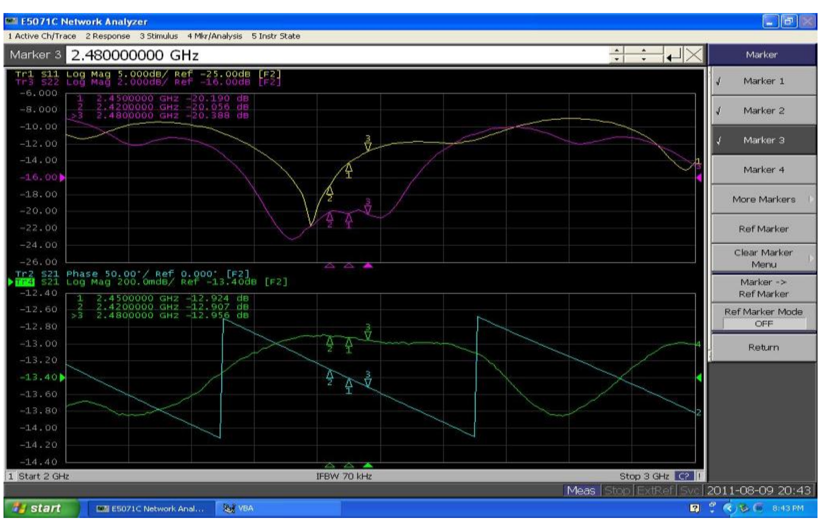

Fig. 4 Test Results.

From the previous results we noticed that the S_{21}, S_{31},.... equals -12.9 dB instead of -9 dB. There are so many expected reasons behind these test results: Huge copper microstrips losses, fabrication errors, simulation inaccuracy where phase shifters return loss was not taking into account and finally mismatch reflections. In general the measurements were acceptable regardless the power loss. Also it is important to mention that the return loss S_{11}, S_{22},.... were less than -12 dB over the whole band (2.4-2.5GHz).

6. Future Directions

Use the series technique instead of the parallel one for the following benefits : Less losses across the copper microstrips because the series technique will reduce the size of the traces as much as 50% compared to the parallel divider according to some papers , also the benefit of the compact size of the whole structure compared to the parallel divider.
There are some complexities in designing such a series divider. For the series feed network it will be harder to equi-split the magnitude and phase. For example in our case the first split in magnitude will be 1/8 to the first port and 7/8 keep in the main branch so we need to design a coupler to do that splitting ,then the second split will be 1/7 to Second port and 6/7 keep in the main branch …. etc. and same for equi-phase split will be difficult because each port has different lengths (which means different phases) so we need to add spirals to the ports near the input port and go straight to the furthest port. We might also need to add some open stubs to match.

7. Conclusion

The design of the feed network is 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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