Contents

Second Year Design Exercise in Communications

Design and Evaluation of a 1 GHz Yagi-Uda Antenna

1 - Abstract

This report covers the theory, simulation, creation and measurements of a Yagi-Uda Antenna. Basic antenna concepts are introduced, before going into detail about the matching BALUN circuit and simulation package theory. Then it follows the simulation of a Yagi-Uda Antenna before it's construction and measurement using a Vector Network Analyser and an anechoic chamber. Simulated results are then compared against measured resuls before being analysed for their differences. The measured results within an acceptable range of simulated results, therefore this constructed Yagi-Uda Antenna can be considered a successful build.

2 - Introduction

Antennas are objects constructed to either receive radio signals and turn them into electricity, or to transmit signals by turning electricity into radio waves [1]. They have many uses in television, radio, telecommunications and more [1]. This report will cover the design and creation of a Yagi-Uda Antenna more commonly known as a Yagi Antenna. The Yagi Antenna was created Shintaro Uda and Hidetsugu Yagi in 1926, although did not become popular until it's use in World War II and is still widely used today for many applications [2].

Yagi Antennas are created from a driven element, a boom, a reflector and multiple elements. The boom is the long shaft of the antenna, while the reflector, folded dipole and the elements are positioned at right angles to the boom as this improves the gain and direction of the Yagi [3]. The reflector is the longest element as this helps 'reflect' radiation in the correct direction [3]. The driven element is where the source is fed into the antenna, in this case it is a folded dipole element as folded dipoles give improved bandwidth [4].

The Yagi works by propagating waves along the length of the boom in the direction of the multiple elements. These elements cause the waves to have an additive effect upon one another as they are in phase, increasing radiation. The reflector works in the opposite way by being in anti-phase it has a destructive effect upon the waves propagated in that direction, thus reducing the radiation in that direction.

There are three main parameters to consider when designing a Yagi Antenna: antenna gain, radiation patterns and matching.

Gain is the measurement of how much the antenna amplifies the electrical signals before transmitting it as radio waves. The higher the gain, the better the amplification of the signal and the more efficient the antenna is. A typical gain for a Yagi Antenna is 10-15 dB [3]. Gain is also effected by other properties, such as front to back ratio, input impedance, sidelobe levels and bandwidth [5]. Front to back ratio is the ratio of how much power is radiated forward compared to power radiated backward, for the best results this must be as high as possible so less power is lost in the backwards direction. This is similar to sidelobe levels, which is the amount of power lost to the side of the antenna and must be a small as possible to reduce the amount of power lost in the sidelobes. Increased input impedance would have a negative effect on the gain as more power would be lost as heat. Bandwidth is detailed later in this report.

In MININEC, the computer aided design program used to simulate results for this report, the gain is measured in dBi, which means the value of dB above isotropic radiation. Isotropic radiation is a uniform circle around the radiating element.

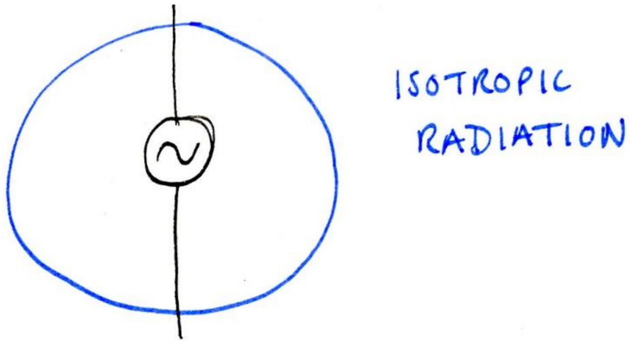

Figure 1 – Isotropic Radiation

Radiation patterns are a function of gain against direction of a radio wave. Without additional elements the folded dipole of a Yagi would transmit two equal radiation patterns either side of it. However, with additional elements added on to the Yagi, the radiation pattern can be manipulated to narrow and focus power, thus increasing gain. The addition of a reflector, the largest element, further helps direct the radiation pattern in the desired direction by reflection a larg amount of the loci in the correct direction.

The final key parameter is matching. This is where the input impedance of the antenna is designed in such a way to have a maximum power output and minimal power reflection [6]. Matching is carried out by a BALUN circuit connected to the input of the Yagi and is detailed in this report.

3 - Basic Transmission Line Theory

Transmission lines are cables created to transmit high frequency currents. As the tuned frequency used in this experiment is 1 GHz, it is considered to be a high frequency system and thus transmission line theory needs to be taken into account.

A BALUN, short for **bal**anced-**un**balanced, circuit is used. It is a circuit which takes unbalanced connections and balances them. The coaxial feed cable is connected to port 1 which is connected to both ports 2 and 4. The Yagi Antenna is connected across ports 2 and 4.

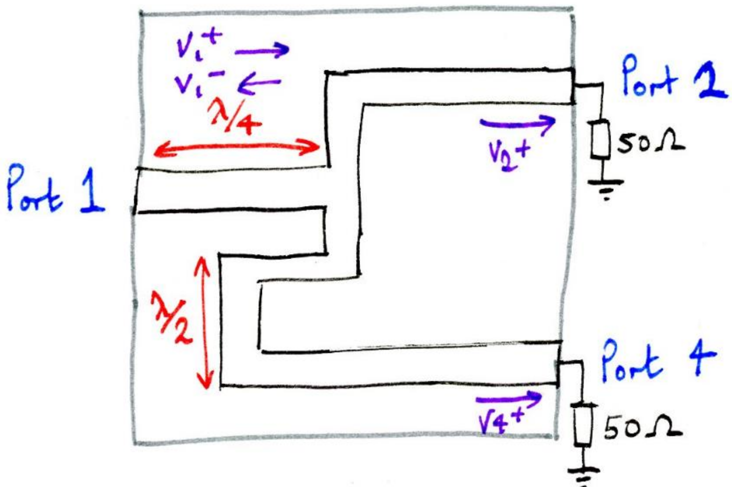

Figure 2 – BALUN Circuit

The main parameters of the BALUN to be considered are: Z_0, Z_L, S_{11}, S_{21} and S_{41}.

Z_0 is the characteristic impedance of the transmission line. It is the same value at any point. In this circuit it is the impedance of the BALUN, which is 50 Ω.

Z_L is the imput impedance of the Yagi Antenna. For a matched circuit and thus minimal voltage reflection, Z_L should be equal to Z_0. This is gathered from the equation:

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

In the case of a matched circuit, i.e. $Z_L = Z_0$, therefore $\rho = 0$ and there is no reflection.

S_{11} is the reflection co-efficient of the Yagi. This is the value of how much of the voltage injected into the BALUN circuit is reflected back towards the input. Ideally this is low as possible, however the desired value is -40 dB or less. It is given by the equation:

$$S_{11} = 20\log_{10}\left(\frac{V_1^-}{V_1^+}\right)$$

S_{21} and S_{41} are the measurement of the ratio of input voltage from port 1 than goes into port 2 and port 4 and are given by the equations:

$$S_{21} = 20\log_{10}\left(\frac{V_2^+}{V_1^+}\right)$$

$$S_{41} = 20\log_{10}\left(\frac{V_4^+}{V_1^+}\right)$$

Ideally, both values should be -3 dB as this implies half of the input voltage goes to each port, thus giving a balanced system, as shown by:

$$20\log\left(\frac{1}{2}\right) = -3$$

There are also two more factors to consider. The extra thickness of the $\frac{\lambda}{4}$ long section that goes from port 1 to the point where the BALUN legs split to ports 2 and 4, and the extra microstrip length of $\frac{\lambda}{2}$ between ports 1 and 4.

For this matched circuit, Z_0, is 50 Ω and equal to Z_L must be as close to it as possible to reduce the reflection co-efficient. Z_L represents two 50 Ω loads in parallel, thus giving a total resistance of 25 Ω. A special case occurs when the transmission line is $\frac{\lambda}{4}$ long and uses the equation:

$$Z\left(\frac{\lambda}{4}\right) = \frac{Z_0^2}{Z_L}$$

Thus, if $Z\left(\frac{\lambda}{4}\right) = 50\ \Omega$, the equation can be re-arranged to give:

$$Z_0 = 35.35\ \Omega$$

Characteristic impedance, Z_0, is a function of width, therefore this section of the BALUN circuit needs to be thicker in order to increase Z_0 to 50 Ω.

Finally, without the extra $\frac{\lambda}{2}$ length the positive voltage of the oscillating input voltage would go to port 2 and the negative voltage would go to port 4, as they would be out of phase by π radians. In order to ensure maximum voltage transmitted by the Yagi, the voltages must be in phase. Consider the general equation for the propagation of a wave:

$$A cos\big(\beta(ct - x)\big)$$

A is amplitude, c is velocity, t is time, x is distance and $\beta = \frac{2\pi}{\lambda}$. The equation for velocity can be expanded to:

$$c = f\lambda$$

Lambda is wavelength and f is frequency. Substituting this into the general equation and then re-arranging gives:

$$\cos\left(\frac{2\pi}{\lambda}(f\lambda t - x)\right)$$

$$\cos\left(2\pi f t - \frac{2\pi x}{\lambda}\right)$$

By inspection, if for one of the legs, $x = \frac{\lambda}{2}$, then there will be a phase shift of π. This is why the leg from port 1 to port 4 is $\frac{\lambda}{2}$ longer than the leg from port 1 to port 2.

4 - NEC Theory

The Yagi Antenna was designed on a computer aided design program called MININEC that allows you to create an antenna by inserting wires in a 3D space. MININEC simulates antenna behaviour by allowing the user to input various parameters, such as element length, spacing between elements, tuned frequency, excitation and gives out various outputs such as impedance and current distribution over the elements in the form of radiation patterns.

MININEC does this by using Method of Moments (MoM). MoM assigns each element of the antenna a specified amount of 'segments'. It then calculates the effect that the excitation current has on these segments and the effect that segments produce on other segments. It uses this data to complete sets of simultaneous equations to calculate the current, which it then can use to output the impedance and radiations patterns of the simulated Yagi [7].

The voltage at the 'source', the excited segment, is the only voltage which is not 0, and is calculated using the simultaneous equation:

$$V_S = Z_{S1}I_1 + Z_{S2}I_2 + \cdots$$

V_S is the voltage at the source, Z_{S1} is the impedance from the source segment to the segment 1 and I_1 is the current at segment 1. This equation is done for every segment within the antenna. MININEC uses these values along with the antenna structure and Maxwell's equations to calculate the current in the antenna. [8]

The current can then be used to calculate the radiation pattern, which gives the gain of the antenna, and the input impedance of the Yagi, from the equation:

$$Z_{in} = \frac{V_S}{I_S}$$

I_S is the current at the source. It is important to obtain a good value of Z_{in} when designing a Yagi Antenna as it made up of multiple parameters. Z_{in} can also be calculated using an equivalent circuit of the Yagi Antenna, shown in figure 3.

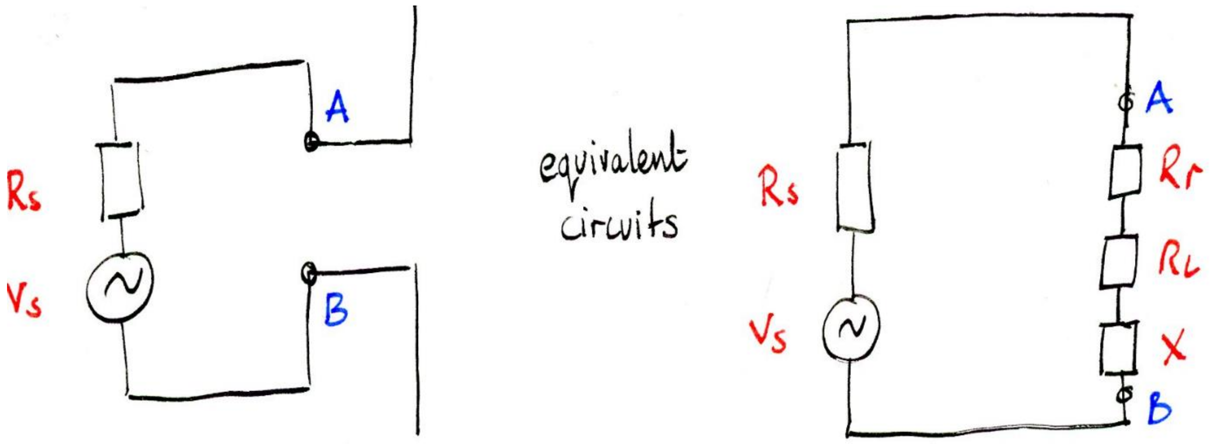

Figure 3 – Yagi Equivalent Circuit

R_s is source resistance, R_r is radiation resistance. R_l is loss resistance and jX is reactance. This gives the equation:

$$Z_{in} = R_r + R_l + jX$$

The higher the value of R_l the more power is lost as heat by the antenna, thus this is required to be as low as possible. The value of R_r wants to be 100 Ω to be matched with the BALUN circuit and equal to the internal resistance of the source, R_s. The reactance is desired to be 0 as to make the antenna resonant. If the length of individual elements are greater than $\frac{\lambda}{2}$ they are generally inductive, while if they are less than $\frac{\lambda}{2}$ they are generally capacitive. Resonance is typically achieved when the length is greater than $\frac{\lambda}{2}$, however this depends on the number of segments present on the element.

The final parameter to consider is the gain, which is desired to be as high as possible. When designing the Yagi Antenna in MININEC it outputs gain with relation to position in the form of a radiation pattern. Antennas radiate in 3D space, therefore it is difficult to graph radiation patterns on 2D graphs. To specify radiation patterns on 2D graphs we use a spherical polar co-ordinate system, as this is unambiguous, in two planes: E-plane and H-plane.

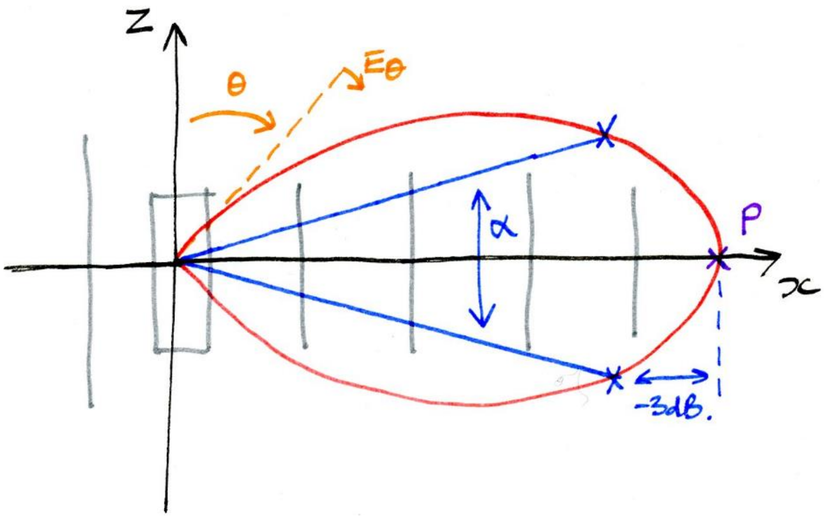

Figure 4 – E-Plane Radiation Pattern

The E-plane is situated on the Z-X axis on a spherical polar co-ordinate system and is a function of the equation:

$$E_\theta(\theta, \phi = 0^o)$$

This implies that the radiation pattern in the E-plane is viewed from above or below the antenna and that θ increases as it moves away from the Z-axis, sweeping through the antenna along the length of the elements. φ would be increasing going into the page, however is fixed at 0^o.

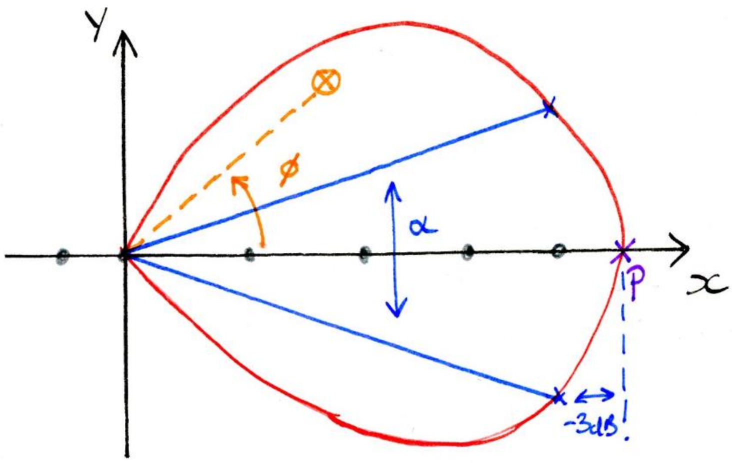

Figure 5 – H-Plane Radiation Pattern

The H-plane is situated on the X-Y axis, also on the spherical co-ordinate system, and is a function of the equation:

$$E_\theta(\theta = 90^o, \phi)$$

This implies that the radiation pattern in the H-plane is viewed from the side of the antenna and that φ increases as it moves toward the Y-axis, sweeping through the length of boom of the antenna. θ would be increasing going into the page, however is fixed at 90^o.

Each point on the locii of the radiation pattern is proportional to the radiated power. Point P, the maximum gain point, is the same point in 3D space in both the E-plane and H-plane figures above. The beamwidth, α, is defined as the point -3 dB away from the point P. The E-plane radiation pattern is narrower than the H-plane radiation pattern, with a smaller value of α and a 'better' gain. This is because the graph of the E-plane contains more of the Yagi Antenna structure.

5 - Simulated Results

5.1 - Simulated Results – PUFF Pre-NEC

First, a computer aided design program called PUFF was used to simulate the effects of connecting the Yagi to the BALUN circuit.

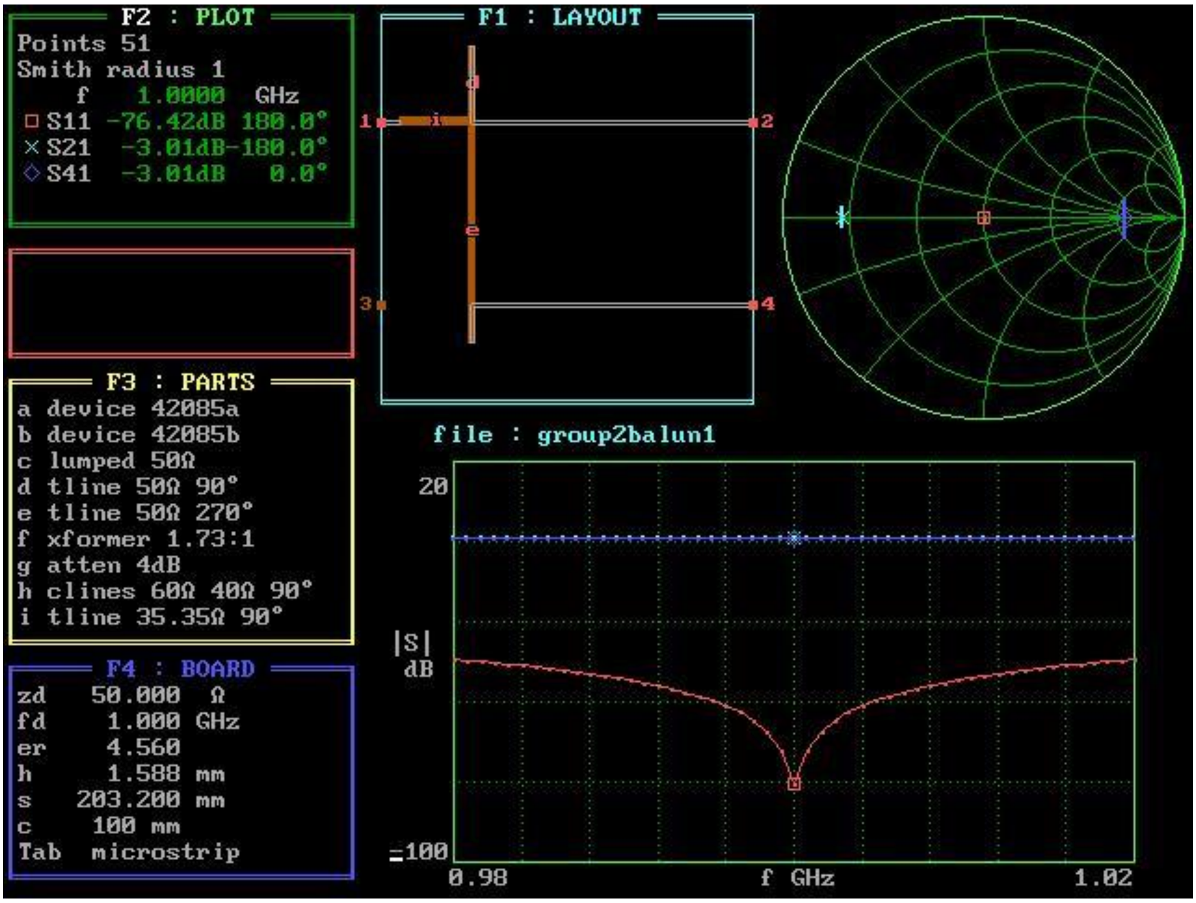

Figure 7 – PUFF of Theoretical Results

The BALUN circuit is recreated in the LAYOUT window. The letters correspond to the PARTS window. There is a 35.35 Ω transmission line connected to port 1, simulating the $\frac{\lambda}{4}$ long section. There two legs connected to that, one going to port 2 and the other to port 4. It can be seen that one is 90 degrees and the other is 270 degrees, thus having the 180 degree (π radian) phase shift between them.

Observing the PLOT window and the graph in the bottom right, it can be seen that the simulated value of S_{11} is -76.42 dB, which is far greater than the desired maximum of -40 dB, this value is reached at 1 GHz, the desired tuning frequency. S_{21} and S_{41} are both -3.01 dB which implies that half of the power goes to each one.

5.2 - Simulated Results – Half-Wave Dipole

MININEC was used to design a half-wave dipole, a folded dipole and the full Yagi Antenna. The half-wave dipole was created first. The wavelength was calculated using the equation:

$$\lambda = \frac{c}{f} = \frac{3x10^8}{1x10^9} = 0.3m$$

c is the speed of light, and f is the tuned frequency. The wavelength is 0.3 m, therefore the half-wave dipole should be half of this length, 0.15 m. The half wave dipole is a single wire with the source in the centre.

The half-wave dipole was first created at a length of 0.15 m, λ*0.5, the value of Z_{in} at this length was:

$$Z_{in} = 82.55 + j38.64\,\Omega$$

This result has a value of reactance that is far above zero. Therefore the size of the dipole needed to be altered in order to reduce the reactive component of the impedance. After much trial and error, the best result was found at a length of 0.143 m, λ*0.476, this gave an value of Z_{in} of:

$$Z_{in} = 70.45 - 0.29\,\Omega$$

This contained a much smaller reactive part than previously. Although it is still slightly capacitive, it is very difficult to achieve resonance and a value of reactance within 0.3 of resonance is good. The gain of this dipole was 2.11 dBi.

This model used 10 segments along with a uniform diameter. Changing the amount of segments on the dipole and the diameter had an effect on the Z_{in} and the gain so they were kept constant for each model created. The diameter was 0.162 cm. This dipole will be used to model one of the four elements on the Yagi.

5.3 - Simulated Results – Folded Dipole

Next, the folded dipole was created. The structure was a rectangular shape with two parallel wires separated by two shorter wires. The two shorter wires were kept at a length of 0.01 m long each. The source was at the centre of one of the longer wires.

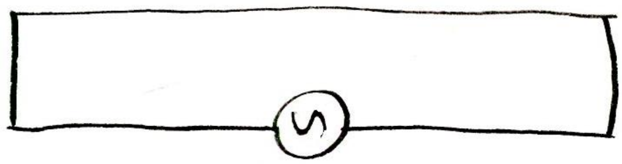

Figure 8 – Folded Dipole

The length of the longer wires was altered until a Z_{in} was found that gave the lowest reactance, in this case the best result was found when they were a length of 0.1317 m, λ*0.439. This gave a value of Z_{in} of:

$$Z_{in} = 280.69 + j0.16\,\Omega$$

Again, the dipole is not resonant, but the reactive part was smaller than the half-wave dipole. It is slightly inductive this time. This had a gain of 2.11 dBi in the E-plane and 2.48 dBi in the H-plane.

This model used 10 segments on the longer wires and 2 sections on the smaller wires. This dipole will be used as the excited element on the Yagi.

5.4 - Simulated Resulsts – Full Yagi Antenna

The full Yagi Antenna was then simulated. Using the previously created folded dipole and half-wave dipole as models, multiple elements were added on to the boom. The boom is the large shaft that all of the elements are connected to. It is slightly thicker than the other elements, with a diameter of 0.32 cm, and has 30 segments. One of the elements was known as the reflector. This was the longest element on the antenna. It is used to reflect the radiation in the direction the Yagi is facing, thus reducing the forward to backward ratio and increasing the gain. The other elements generally decreased in length along the Yagi. The full Yagi was made of 1 reflector, 1 folded dipole and 4 elements.

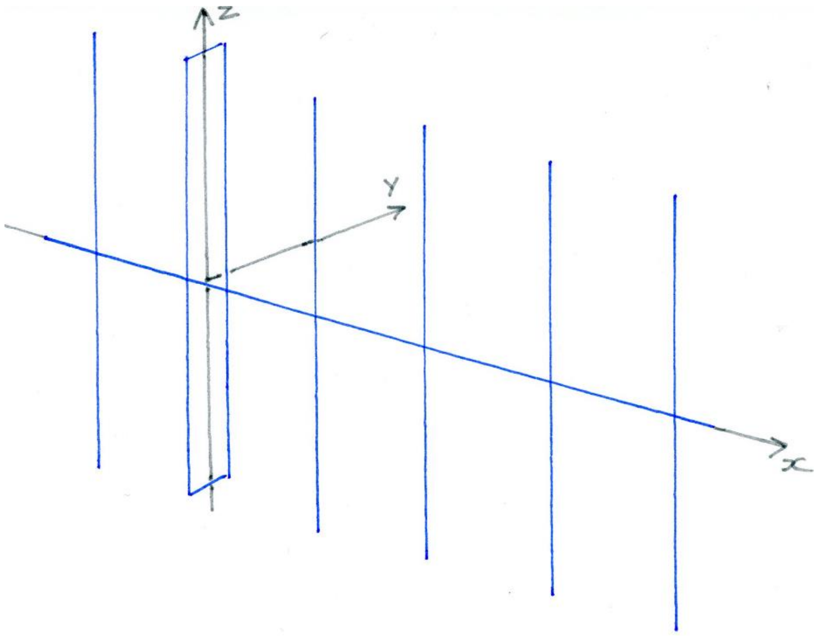

Figure 9 – 3D Model of Simulated Yagi Antenna

The more elements added on to the Yagi, the more difficult it was to maintain good results as there became an increasing amount of factors having effect on the output of the MININEC.

There was a large amount of changing multiple factors of the Yagi, such as element length and element spacing. It was generally found that changing the length of the elements has the greatest effect on the impedance, while changing the spacing between the elements has the greatest effect on the gain. It was also discovered that changing the elements closer to the excited element had the greatest effect on results.

Both the impedance and the gain are important factors. The Z_{in} needs to be kept close to 100 Ω as possible to perfectly match it with the BALUN circuit, whilst keeping reactance to a minimum, and the gain is desired to be as high as possible. The results that gave a best balance between matched impedance, low reactance and high gain were:

$$Z_{in} = 99.93 + j1.43\ \Omega$$

$$Gain = 12.02\ dBi$$

The exact lengths and spacings of the Yagi can be seen in figure 10.

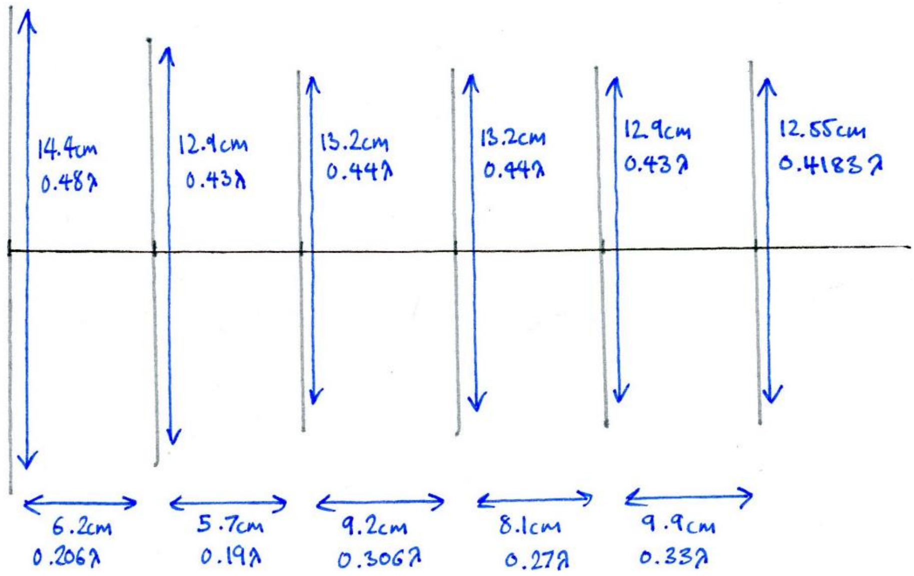

Figure 10 – Lengths and Spacing of Simulated Yagi

5.5 - Simulated Results – PUFF Post-NEC

Before the Yagi is built, the simulated values are put into PUFF to simulate the effect that this Yagi will have on the matching circuit.

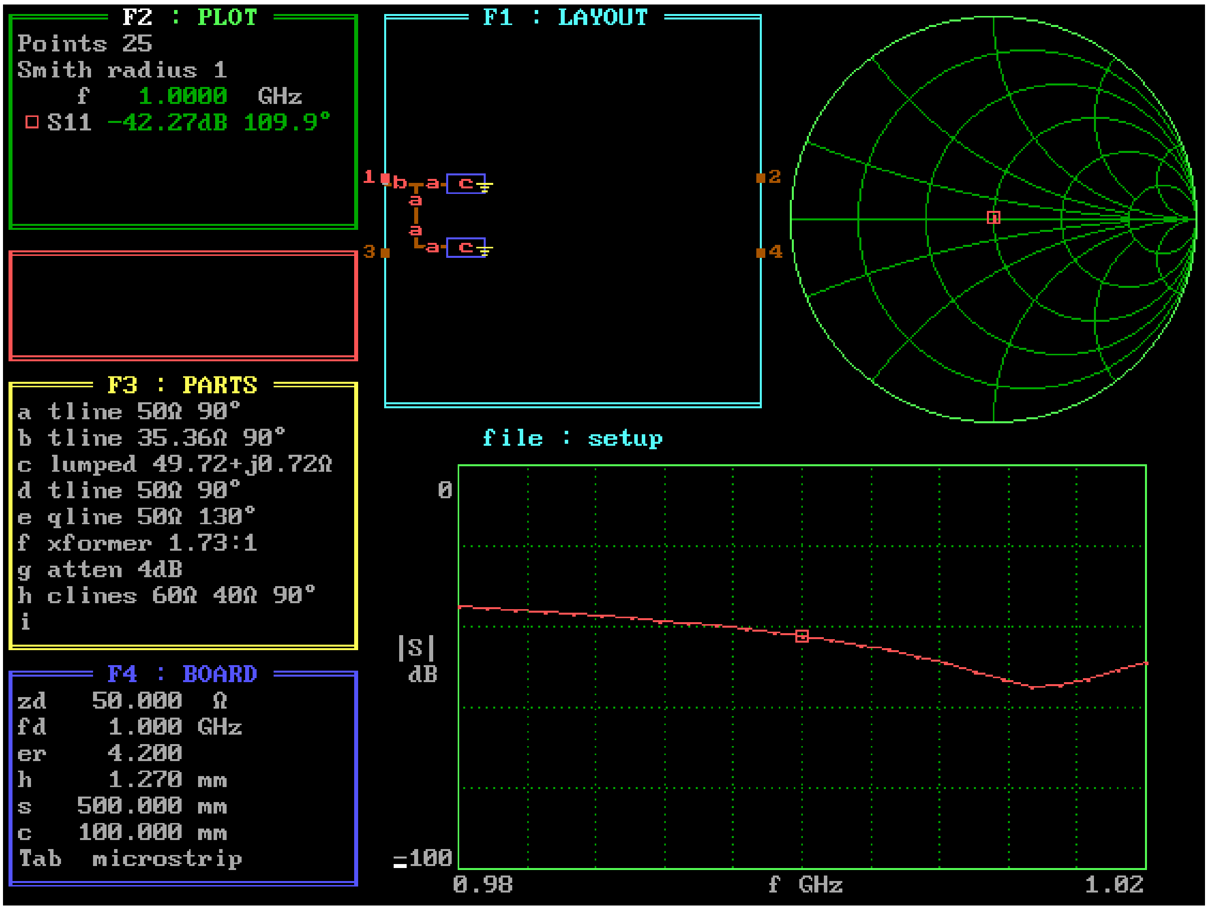

Figure 11 – PUFF of Simulated Design

Comparing this to the original PUFF results in figure 7 some differences can be noted. The new value of S_{11} is -42.27 dB, compared to the original value of -76.42 dB. Also, the best value of S_{11} is no longer exactly at the tuned frequency of 1 GHz, and is offset to approx. 1.014 GHz.

6 - Measured Results

6.1 - Measured Results – Building the Yagi

Once simulated had been completed the Yagi was ready to be physically built. Pieces of copper wire cut into size, following the measurements from figure 10, and then filed down to remove any rough parts. The elements were soldered on to the top of the boom, as it is impossible to get the elements through the actual boom as in the simulated design. The folded dipole was made of a single long wire of copper that was bent into shape with the boom through the centre of it. The folded dipole was soldered on to ports 2 and 4 of the BALUN.

6.2 - Measured Results – VNA Results

The Yagi Antenna was then connected to the Vector Network Analyser (VNA), a device that measures the S_{11} and Z_{in} of the Yagi. The VNA is connected to a coaxial cable, which is connected to port 1 of the BALUN. The initial results of the Yagi Antenna were:

$$Z_{in} = 68 + j24\ \Omega$$

$$S_{11} = -12\ dB$$

These results were declared insufficient as the maximum allowed value of S_{11} was -10 dB and the created Yagi barely performed better than this, thus would reflect a large amount of power and represents an unbalanced load. The desired Z_{in} of this measuredment was 50 **Ω**, not 100 **Ω**, as it is connected to the 50 Ω characteristic impedance of port 1 of the BALUN, not across the two 50 Ω loads at ports 2 and 4. This Yagi structure not only had an increased value of resistance, it had a large reactive part as well. Iterative design was then carried out in order to improve the results of the Yagi Antenna.

6.3 - Measured Results – Iterative Design

The spacing between the elements was then changed in order to improve the results of the Yagi as this was considered an easier way to change the results than changing the lengths of the elements. As stated in section 5.4, simulated results of full Yagi Antenna, the elements closer to the excited element have the greatest effect on the results of the Yagi. The changes were: the reflector being brought closer to the folded dipole by 0.2 cm, the first element moving away from the dipole by 1.4 cm, the second element moving closer to the first element by 1.3 cm and the third element moving away from the second element by 0.1 cm. The distance between the third and fourth element remained the same, although the fourth element was moved along the boom to accommodate the elements moving. Figure 12 shows the new spacing of the elements.

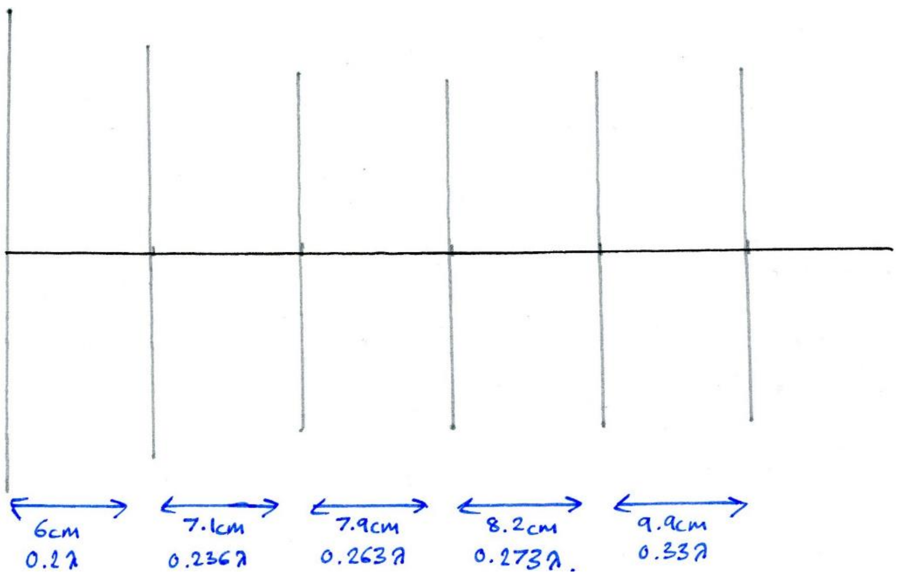

Figure 12 – Lengths and Spacings After Iterative Design

6.4 – Measured Results – VNA Results Post-Iterative Design

This new Yagi Antenna structure was then connected to the VNA to measure the results. The results were then graphed over a range of frequencies.

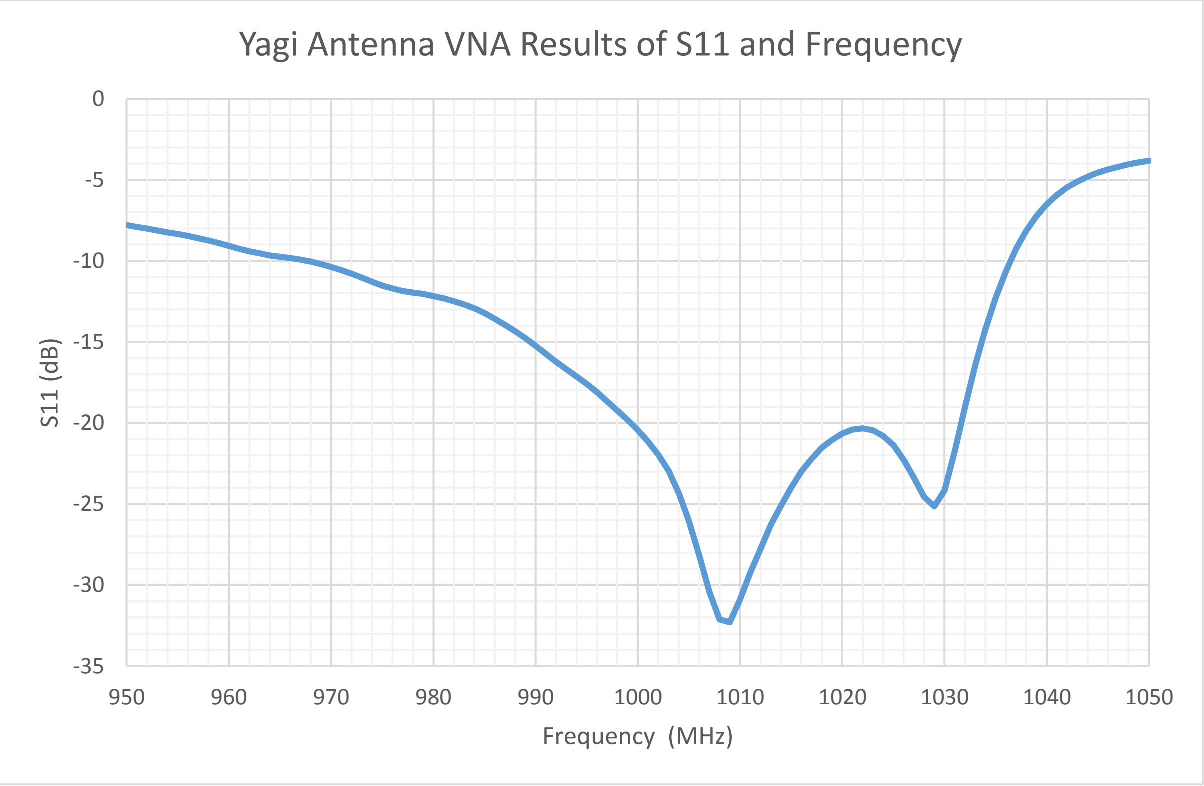

Figure 13 – Graph of VNA Results After Iterative Design Process

The improved results were:

$$Z_{in} = 49.5 - j0.5\ \Omega$$

$$S_{11} = -33\ dB$$

As shown, the value of Z_{in} and S_{11} are vastly improved over the previous antenna structure. The Z_{in} is now much closer to being perfectly matched with the 50 Ω impedance with only a very small reactive part. The S_{11} is now 3 times greater than before and is now far below the -10 dB minimum required value of S_{11}.

It can be see that the best value of S_{11} is at a frequency of 1009 MHz, not the desired tuned frequency of 1 GHz. However this result is similar to the simulated results from the PUFF analysis.

It is possible to calculate the bandwidth from this graph as it is the difference between the -10 dB points. From observation, it can be seen to be approximately 68 MHz.

This new antenna structure was then inserted into MININEC and simulated in order to see what effect the changes had on the impedance and gain of the antenna. The MININEC results were:

$$Z_{in} = 89.82 + j50.82\ \Omega$$

$$Gain = 12.23\ dBi$$

Compared these results to the simulated ones from section 5.4, simulated resuls of the full Yagi Antenna, it can be observed that the Z_{in} is considerably worse, due to the largely increased reactive part, however the gain has slightly improved. However, as the Zin from MININEC is only a simulated result it can be ignored as, from the VNA results, we can see that the actual measure Zin is accurate.

6.5 - Measured Results – Anechoic Chamber Results

The final stage of testing was completed in the anechoic chamber. The anechoic chamber is a sealed, soundproof room designed to remove any outside interference when measuring the radiation patterns of the Yagi. This is done by the foam spikes covering all of the surfaces inside the anechoic chamber. These spikes absorb any sound waves.

The purpose of the chamber is to excite the Yagi so it transmits signals. These signals are then measured so that they can be graphed in the form of E-plane and H-plane radiation patterns. This is done by attaching the Yagi to a polystyrene stand, as this is a good approximate of free space, and having it face a receiver. The receiver must be co-planar in order to receive accurate results.

It is then excited and rotated 360 degrees. This is done once with the Yagi on its side, and once with the Yagi upright, to measure both the E-plane and H-planes. In order to ensure accurate results, the Yagi is kept at the same height and the same distance away from the receiver for both measurements.

Measurements are done at 5 frequencies. Two either side of the frequency that gave the best S_{11} in the VNA results. In this case the frequencies were: 989, 999, 1009, 1019 and 1029 MHz.

The measurements taken from the chamber are S_{12}, a power ratio. In order to convert them to gain in dBi, they must be normalised. This is done by measuring S_{12} for a ‘standard gain horn’ and the gain of the horn then using the equation:

$$Gain = P - \alpha + \gamma$$

P is the peak S_{12} measured by the Yagi, as detailed in the ‘NEC Theory’ section, this value should be he same in both the E-plane and H-plane. α is the peak S_{12} measured by the standard gain horn. γ is the gain of the standard horn which is given as 6.7 dBi.

The peak values of gain in the E-plane and H-plane are:

$$Gain_E = 9.9670\ dBi$$

$$Gain_H = 10.604\ dBi$$

These values are both found at a frequency of 1009 MHz. A value of gain was calculated for all 360 degrees that the Yagi was rotated and can then be graphed in the form of radiation patterns, as shown in figures 14 and 15.

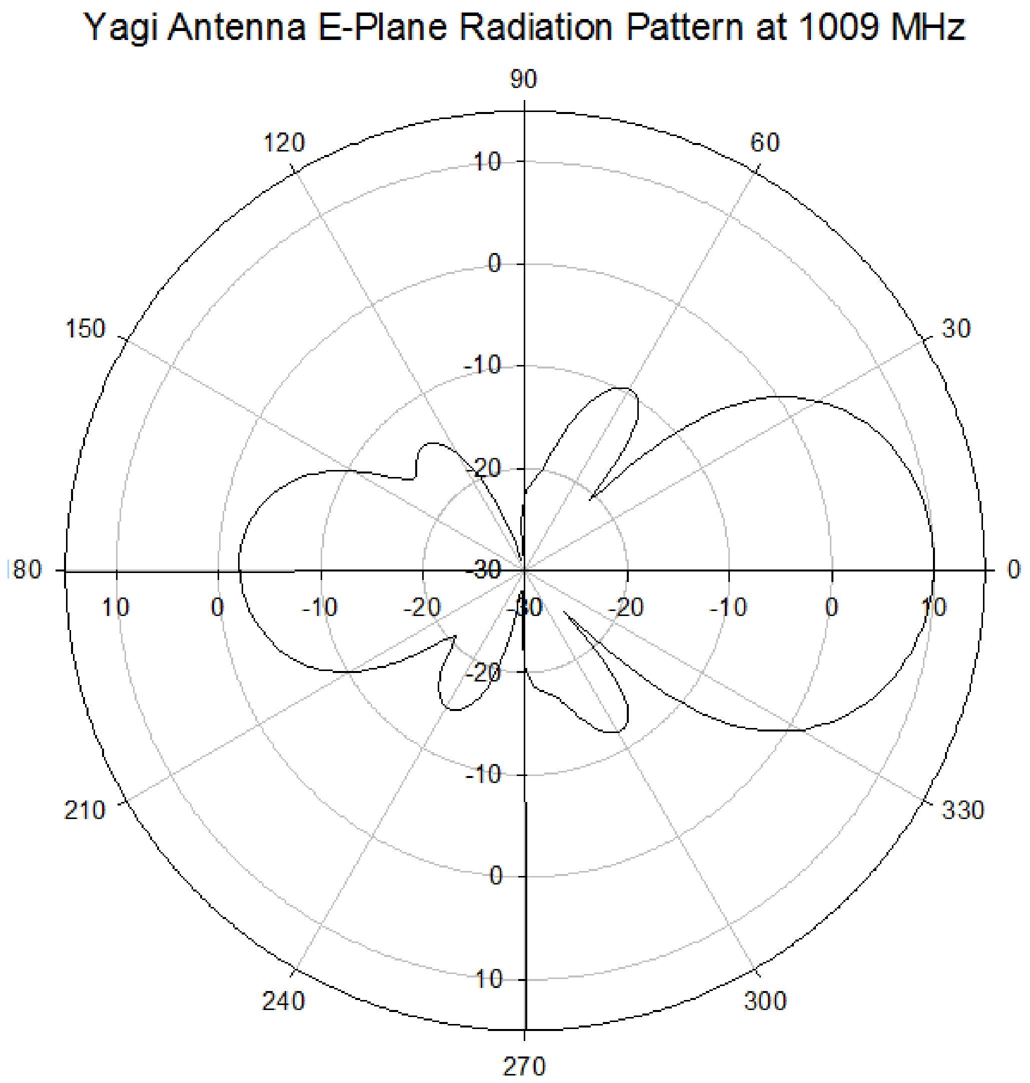

Figure 14 – E-Plane Radiation Pattern from Anechoic Chamber

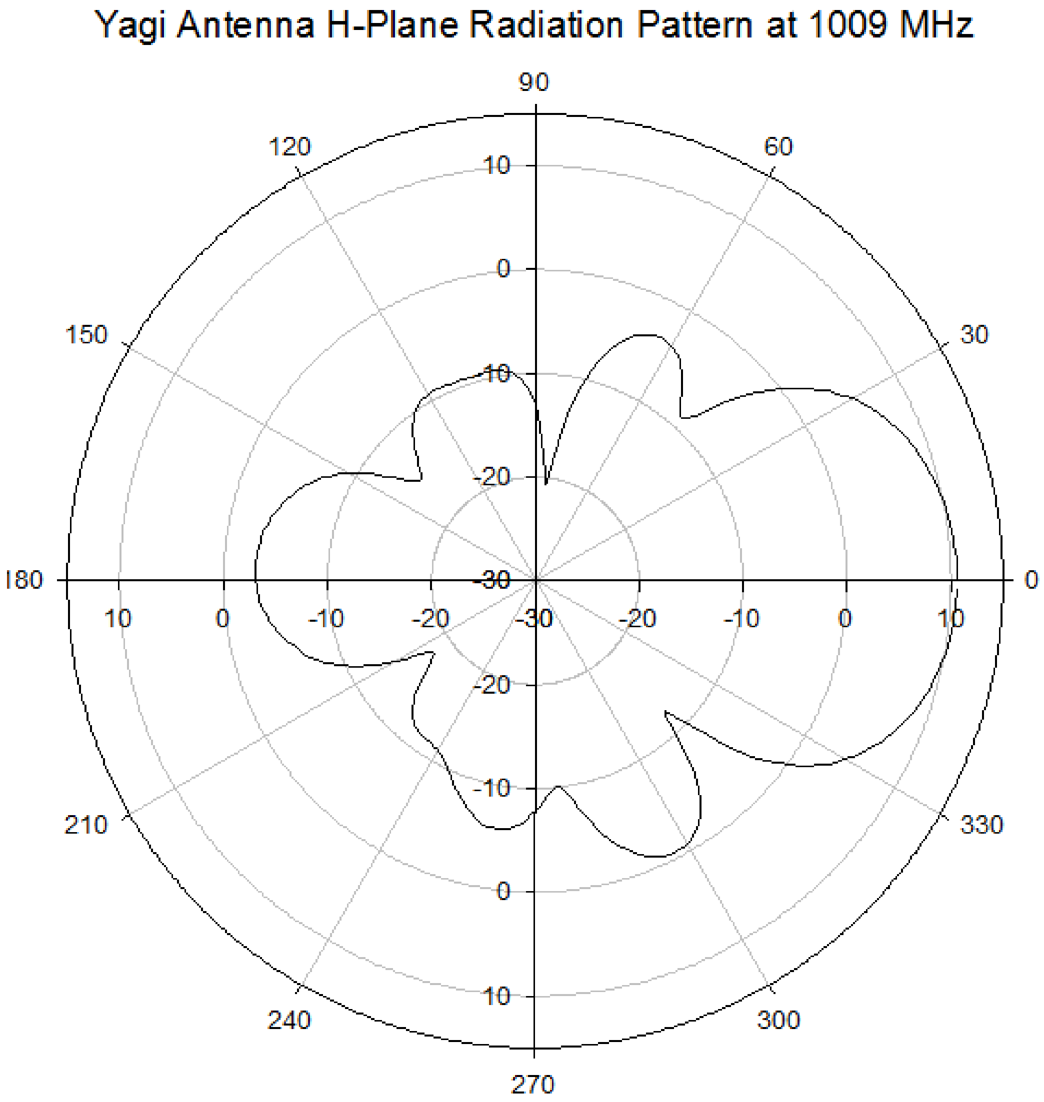

Figure 15 – H-Plane Radiation Pattern from Anechoic Chamber

7 - Discussion and Results Analysis

7.1 - Discussion and Results Analysis – PUFF

PUFF originally calculated the value of S_{11} in a perfectly matched system to be -76.42 dB at 1 GHz. The value of S_{11} calculated for the simulated Yagi was -42.27 dB at 1 GHz, with the optimal value of around -55 dB to be around 1.014 GHz. This could be explained due to the Yagi Antenna not being a perfect matching circuit and having a reactive part to it. This would give rise to some reflection within the BALUN and thus reduce its efficiency. However, it is low enough to be considered a successful result and perfect matching is near impossible to achieve in reality.

7.2 - Discussion and Results Analysis – VNA Results

The first Yagi Antenna structure created had poor results during the VNA testing. The VNA was expected to read an impedance value of 50 Ω, as this was only connected to port 1, yet the initial measurement was 68 + j24 Ω with a value of S_{11} of -12 dB. The impedance was far from the desired value and the S_{11} was only just under the minimum, meaning that there would be a large amount of reflection. The Yagi was altered in order to improve results. After iterative design was carried out, the results from the VNA were vastly improved. The impedance was now 49.5 – j0.5 Ω and the S_{11} was -32 dB, however this was at a frequency of 1009 MHz, not the desired frequency of 1 GHz.

The reason for the measured results differing from the simulated values can be explained by a number of reasons. First, the construction of the Yagi. Even though great care was taken to ensure the Yagi was built to the exact dimensions of the simulated design, it proved difficult to obtain the amount of accuracy required with the tools provided. This meant that the measurements on the built Yagi were either longer or shorter than desired. Due to the number of elements, a large amount of small differences would build up to create a large overall difference between the simulated and measured result.

Secondly, the orientation of the elements. It was difficult to guarantee the elements were perfectly level and in the simulated structure, the folded dipole is perfectly rectangular, while in reality it was difficult to ensure the angles were formed perfectly. Also, the elements on the simulated Yagi go through the boom, while in the constructed Yagi they sit on top of the boom after being soldered and screwed in place.

Finally, the environment the VNA was tested in. The simulated Yagi was created in 'free space' conditions in order to give the best results. In reality it is difficult to create 'free space' conditions. The Yagi emits radiation in a 3D space around itself, however when carrying out the VNA measurements it was situated on a desk. Therefore the desk, and other nearby objects, had an effect on the measurements.

The problems faced with measurements and orientation could be solved using computer aided manufacturing techniques to built the Yagi Antenna. This would ensure improved accuracy of the measurements, ensuring they are closer to the desired values, and that the folded dipole would be created better. The problems with the environment could have been solved by carrying out the measurements within an anechoic chamber, as it more accurately emulates 'free space' conditions by reducing external interference on the Yagi.

7.3 - Discussion and Results Analysis – Anechoic Chamber Results

Figures 16 and 17 show the E-plane and H-plane radiation patterns for both the simulated and measured resuls on the same graph. The simulated radiation pattern is in blue, while the measured radiation pattern, from the anechoic chamber, is in black.

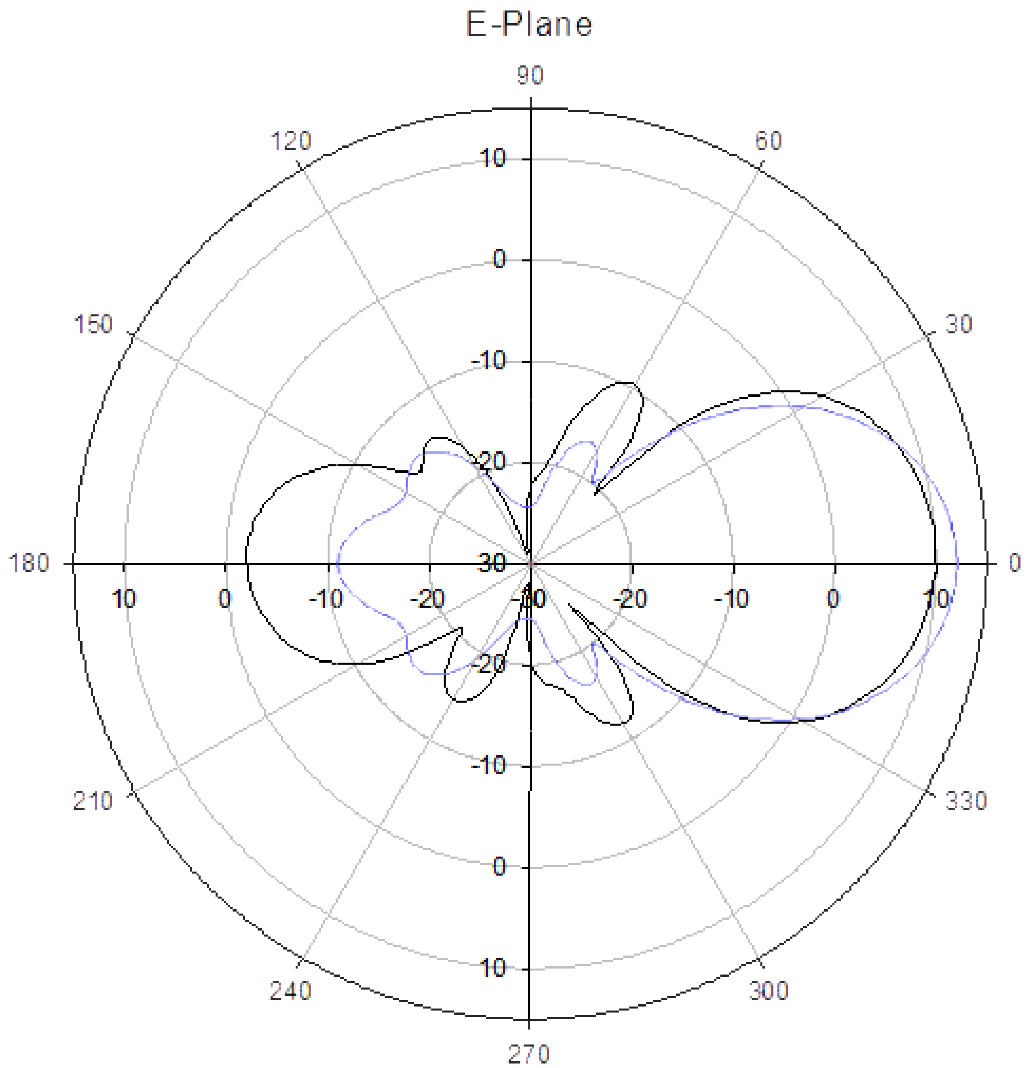

Figure 16 – E-Plane Radiation Pattern Comparing Simulated (Blue) and Measured (Black)

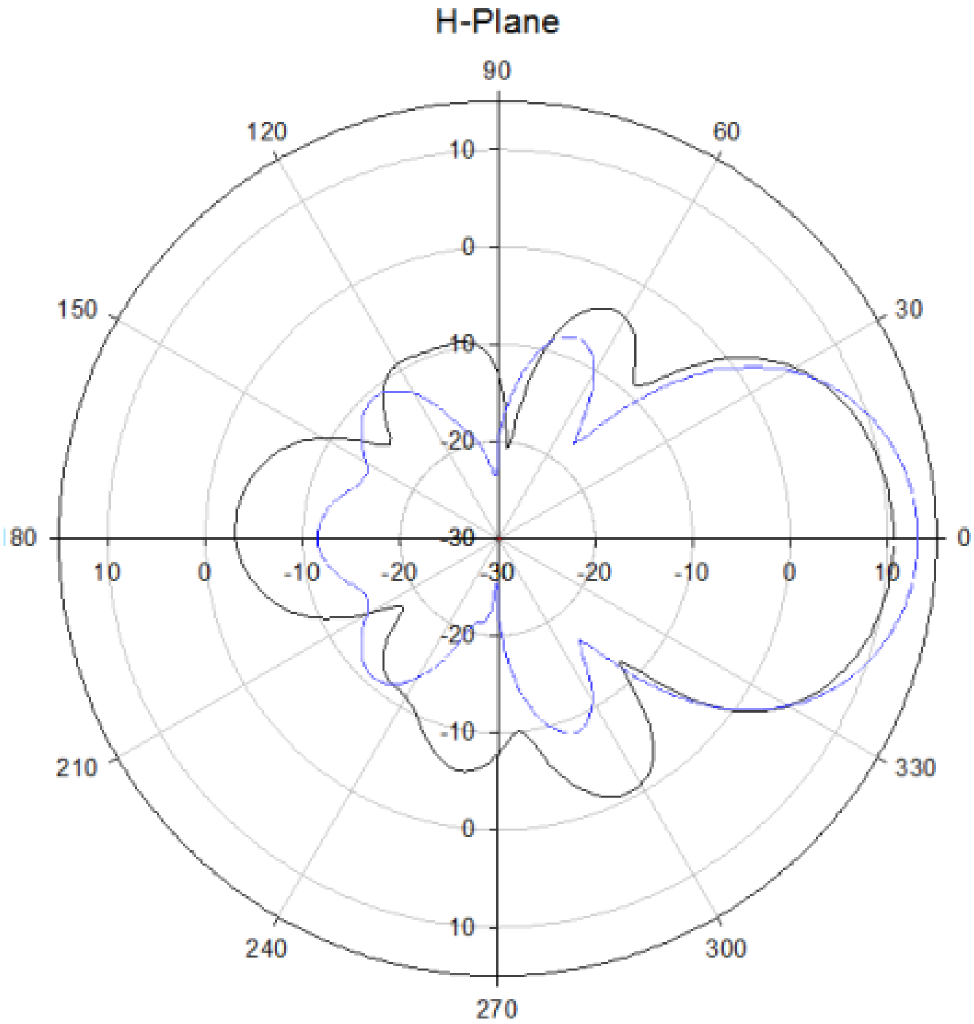

Figure 17 – H-Plane Radiation Pattern Comparing Simulated (Blue) and Measured (Black)

It can be seen that even though the patterns are not identical, they do have similar patterns. In both the E-plane and the H-plane the frontal lobe of the simulated radiation pattern are greater than that of the measured radiation pattern and the back and side lobes of the measured radiation pattern are greater than the simulated. This shows that the constructed Yagi Antenna radiates less power forward and loses more power in the rear and side. However, despite these differences, the general pattern in both planes are very similar.

For the measured and simulated the value of beamwidth for the E-plane is less than H-plane, this is to be expected as there is more of the structure of the Yagi present in the E-plane. The peak gain of the measured is different in the E-plane and H-plane by about 1 dBi, this should not be the case as the peak gain should be at the same point in both planes. Both of the gains are approx. 2 dBi less than the simulated gain.

The problems faced with the construction of an accurate replication of the simulated Yagi also apply to the radiation patterns. Obviously if the antenna structure is different then the results will be different. This could explain the 2 dBi different between the simulated gain and the measured gains.

The problem of replicating ‘free space’ conditions still applies. The anechoic chamber attempts to simulate ‘free space’ conditions. Even though it is vastly improved over the conditions where the VNA results were taken, it is still not a perfect replication of ‘free space’. This may be due to the polystyrene interfering with the radiation pattern or the quality of the anechoic chamber.

The reason for the difference in peak gain between the E-plane and the H-plane could be due to the positioning of the Yagi in the anechoic chamber. When the Yagi must be moved from on its side to upright the measurements of height from the ground and distance from the Yagi to the receiver must remain the same. However it is difficult keep these measurements exactly the same, which would give rise to different results in the planes. This could be solved by some sort of device that would not only rotate the Yagi through 360 degrees, but also tilt it in the position for E-plane and H-plane so it does not to be moved by hand.

8 - Conclusion

The results of a simulated and measured constructed Yagi Antenna vary in many parameters. This is due to a mixture of human error during construction and measurement error due to the equipment and environment required to perfectly replicated simulated conditions. Even then it may be difficult to achieve the same results. Transmission line theory, NEC theory and iterative design techniques all need to be utilised to achieve successful results and understanding.

Even so, the measured results detailed in this report do come close to simulated results. The measured impedance is very similar to the desired impedance, with a very small reactive part. However this is at a different frequency than required. The results from the anechoic chamber are more closer than simulated, especially the radiation patterns, which have a very similar shape even though they do differ in amplitude. This may be due to the anechoic chamber more accurately simulating 'free space' conditions than where the VNA measurements were taken

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9 - References

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