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University of HUDDERSFIELD
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Contents

1. Introduction

Dipole antennas: A dipole antenna is a radio antenna consisting of a conductor rod or tube divided into two parts and fed at the centre.
Yagi-Uda antennas: Yagi-Uda antenna is a directional antenna consisting of a driving element (dipole) and one or more parasitic elements (usually a reflector and parameter one or more directors).
Return loss/S-parameter: The return loss is a measure of the amount of power reflected from an antenna due to an impedance mismatch. The S11-parameter is specifically designed to measure the reflection coefficient at the input port of a network and it corresponds to the return loss in an antenna system.
Gain: Gain is a measure of the directional performance of an antenna and is usually expressed in decibels (dBi).
Directivity: Directivity is a measure of an antenna's ability to focus radiated energy in a specific direction.
Front-to-back ratio: The front-to-back ratio (F/B ratio) is a measure of an antenna's ability to reject signals coming from behind it, compared to those coming from the front.
Bandwidth: The bandwidth in antenna performance refers to the frequency range over which the antenna operates effectively.
Radiation patterns: The radiation pattern is a graphical representation of the antenna's radiation characteristics, showing the spatial distribution of radiated energy in the far field region.

2. Section 1

a) A picture of a CAD model of the dipole antenna displaying the length and the diameter of the dipoles.

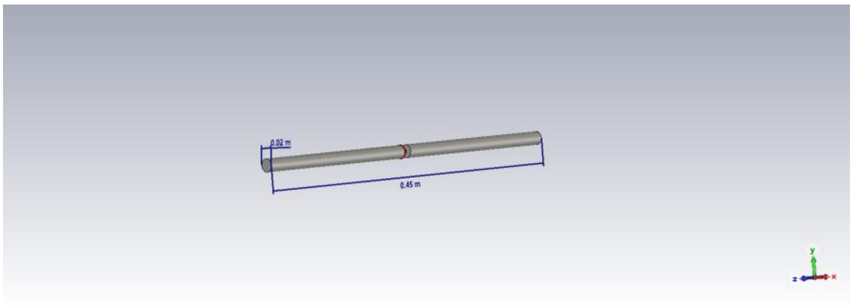

Figure 1 CAD model of dipole

The diameter and length of the dipole are set below.

Diameter	0.016 m
Dipole length	0.45 m

Table 1

Because CST will automatically change 0.016 to 0.02m, it shows 0.02m of dipole diameter in the CAD model.

b) S11-parameter sweep vs frequency, what is the dipole's -10dB bandwidth (BW)? What is the fractional BW (%)?

The one closest to 300 MHz was taken for observation based on a parametric sweep from 0.008 to 0.016m in diameter.

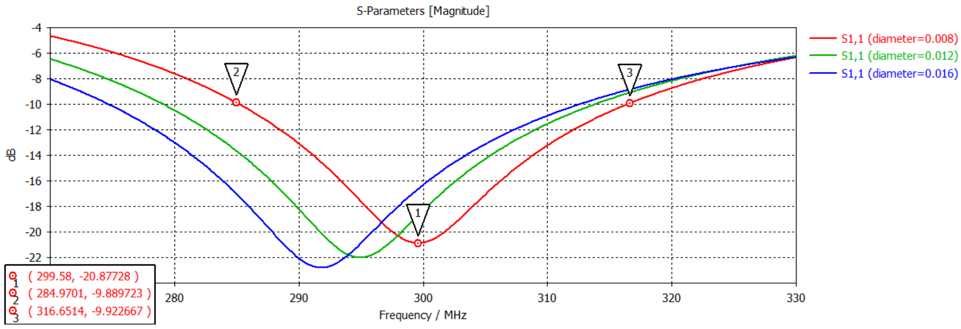

Figure 2 Bandwidth and centre frequency

Bandwidth:

$$BW = f_2 - f_1 = 316.65 - 284.97 = 31.68 \text{ MHz}$$

Fraction BW:

$$BW_F = \frac{BW}{f_c} = \frac{31.68}{299.58} = 0.1058 = 10.57\%$$

The result of fractional bandwidth showed the antenna can operate in a frequency range of 10.57% of its centre frequency while maintaining a reflection coefficient of less than or equal to -10dB. And I found the general fractional bandwidth of a half-wave dipole antenna is typically around 5% to 15%. Hence, this result was reasonable.

c) Realized gain (dBi) sweep vs frequency, what is the peak gain of the dipole?

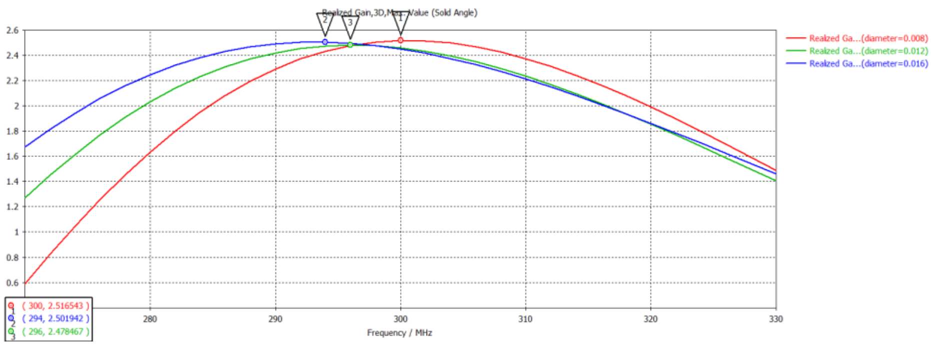

Figure 3 Realized gain

Also, when diameter = 0.008m, it showed the best-realized gain, which had a peak gain of 2.52 dBi.

d) Radiation pattern at 300 MHz (1D polar plot only-elevation pattern), what is the HPBW (Half Power Beam Width) of the dipole?

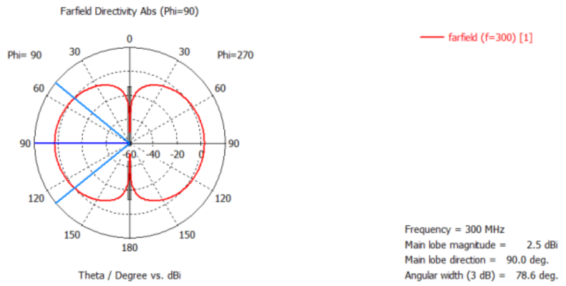

Figure 4 Radiation pattern at 300 MHz

A dipole antenna's half-power beamwidth (HPBW) is the angular width of the main flap of the radiation pattern measured at a power density of half its maximum value. The - 3 dB points on the major lobe of the antenna are the half-power points.
The graph showed the angular width(3 dB) was 78.6 degrees, which was also the HPBW of the dipole.

e) Explain how the dipole length and thickness are related to the operating frequency and bandwidth. Justify your explanations by showing a graph with a parametric sweep of realized gain vs dipole thickness. What do you observe regarding the resonance frequency and BW?

The length of the dipole is usually chosen to be half the wavelength of the desired operating frequency. As the operating frequency increases, the wavelength decreases and the length of the dipole must be reduced accordingly to maintain its resonance.

The thickness of the dipole also affects its bandwidth. A thin dipole (compared to its length) has a wider bandwidth than a thicker dipole because the thinner line has a lower self-resonant frequency and a lower Q-factor.

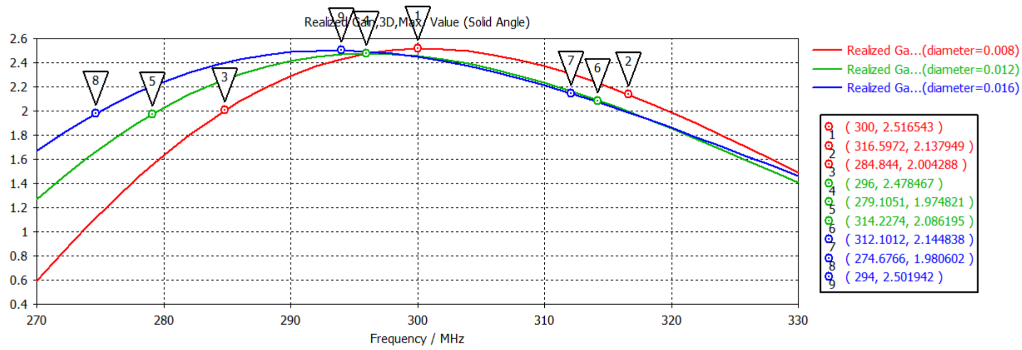

Figure 5 Realize gain vs thickness

It shows the thinner the dipole is, the higher realized gain it gets. Additionally, with the decline in thickness, the resonance frequency is rising, and the bandwidth is narrowing. (Below is the table showing the details) Generally, a wider bandwidth is associated with a lower realized gain, while a narrower bandwidth is associated with a higher realized gain, which justifies my previous explanations.

Thickness (m)	Resonant frequency (MHz)	Bandwidth (MHz)	Realized gain (dBi)
0.008	300	32	2.52
0.012	296	35	2.48
0.016	294	37	2.5

Table 2

2.52 - 2.52= 0 dBi

The realized gain of simpler antennas simulated was the best.

3. Section 2

a) A picture of a CAD model of the 2-element Yagi-Uda antenna displaying the length and the diameter of the dipoles.

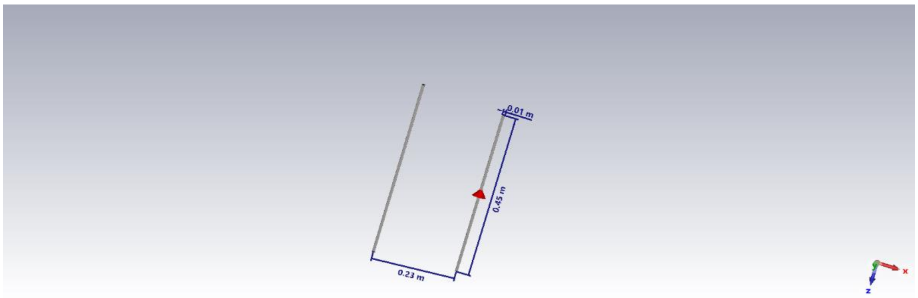

Figure 6 CAD model of 2-element Yagi-Uda

The diameter and dipole length are set below.

Diameter	0.01m
Dipole length	0.45m
Spacing	0.23m

Table 3

b) S11-parameter sweep vs frequency

Choose the best one to observe S11-parameter sweep vs frequency, when reflector length = 0.48m and reflector spacing = 0.23m.

Before choosing the best reflector length and spacing

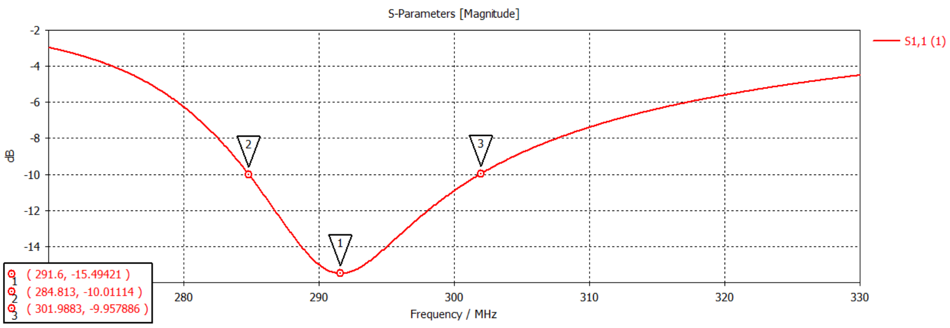

Figure 7 S-11 1st

It reaches its minimum point at -15.49dB when the frequency is 291.6MHz and its

value of s-11 is not low enough, which will result in lower efficiency and degraded antenna performance.
Additionally, its fractional bandwidth is only 5.89%, which can still be improved.
Bandwidth:

$$BW = f_2 - f_1 = 301.99 - 284.81 = 17.18 \text{ MHz}$$

Fraction BW:

$$BW_F = \frac{BW}{f_c} = \frac{17.18}{291.6} = 5.89\%$$

It means the effective working range of this antenna is not good enough.

After changing the length to 0.48 and spacing to 0.23.

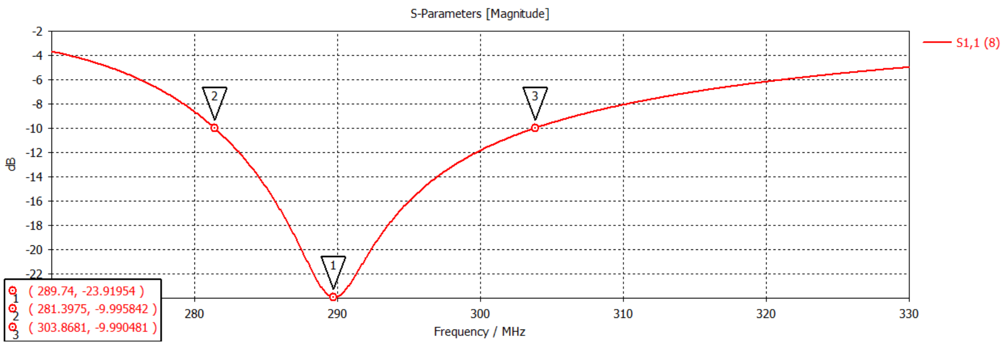

Figure 8 S-11 final

The magnitude of s-11 changes from around -4dB to -23.92dB and it reaches its minimum point (-23.92dB) when the frequency is 289.74 MHz.
This time, it has a lower magnitude and wider bandwidth, which means the antenna can perform better and has higher efficiency now.
Bandwidth:

$$BW = f_2 - f_1 = 303.87 - 281.4 = 22.47 \text{ MHz}$$

Fraction BW:

$$BW_F = \frac{BW}{f_c} = \frac{22.47}{289.74} = 7.76\%$$

c) Realized gain sweep vs frequency
Based on the best data when reflector length = 0.48m and reflector spacing = 0.23m.

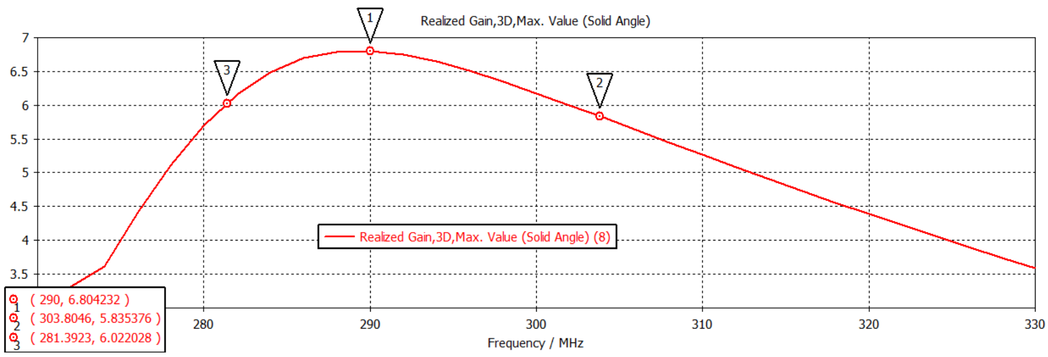

Figure 9 Realized gain (best)

The realized gain is between 3 to 7 dBi and it reaches its maximum realized gain at 6.80 dBi when the frequency is 290 MHz. Observed from the bandwidth, it shows the most effective operation range of this Yagi-Uda antenna has a realized gain of at least 5.84 dBi.

d) Radiation pattern at 300 MHz (polar plot: azimuth and elevation patterns)

Azimuth:

The azimuth angle is measured in the horizontal plane, with 0 degrees corresponding to the forward direction of the antenna and 180 degrees corresponding to the backward direction.

Here I choose Theta as a variable and set Phi = 0.

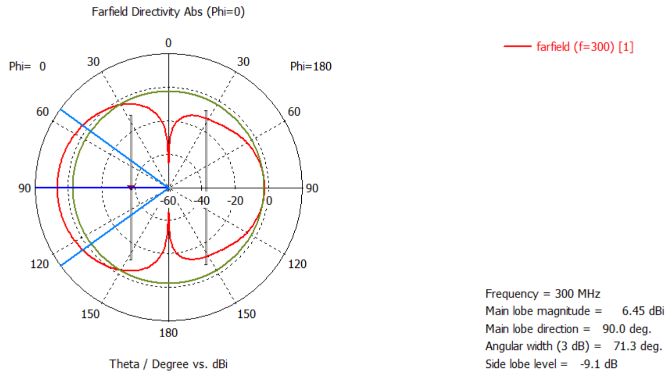

Figure 10 Azimuth

Elevation:

The elevation angle is measured in the vertical plane, with 0 degrees corresponding to the plane of the antenna and 90 degrees corresponding to the zenith direction.

Here I choose Phi as a variable and set Theta = 90

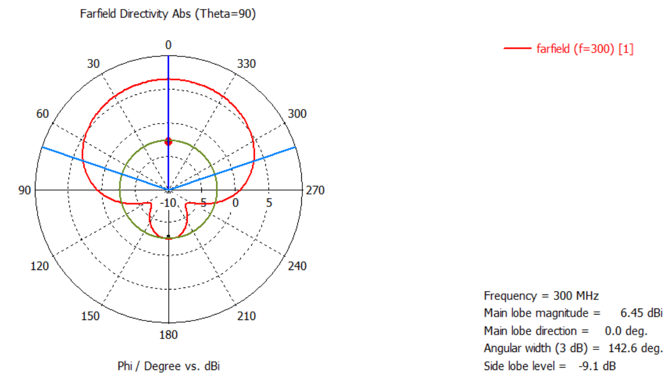

Figure 11 Elevation

e) Front-to-back ratio sweep vs frequency

Based on the best data when reflector length = 0.48m and reflector spacing = 0.23m. The graph shows the front-to-back ratio keeps rising to its maximum magnitude of 9.87 between about 274 MHz and 310 MHz and then keeps declining.

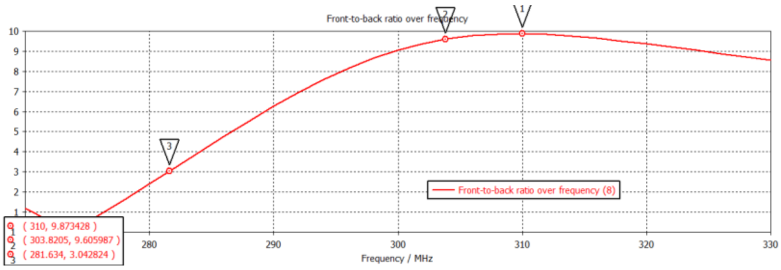

Figure 12 Front-to-back ratio

The bandwidth of the Front-to-back ratio is relatively large. A wider bandwidth in the Front-to-back ratio graph indicates that the antenna can maintain the directivity over a wider frequency range, making it suitable for use in a wider range of applications.

f) Realized gain vs reflector length sweep

There is a parametric sweep on reflector length from 0.45m to 0.52m. When reflector length = 0.48m, it gets the highest realized gain of 6.90 dBi.

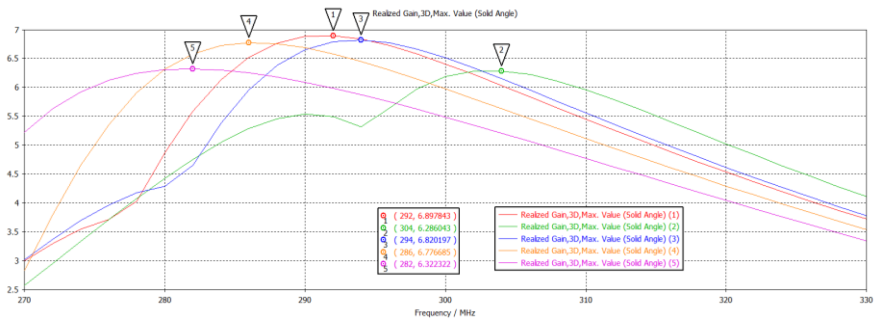

Figure 13 Realized gain vs length

Reflector length (m)	Resonant frequency (MHz)	Bandwidth (MHz) (-10dB)	Realized gain (dBi)
0.45	304	10	6.29
0.47	294	14	6.82
0.48	292	17	6.9
0.5	286	23	6.78
0.52	282	27	6.32

Table 4

With the increment in reflector length, the resonant frequency keeps decreasing and the bandwidth goes up. However, it reaches its peak realized gain at 0.48m and its realized gain declines from both sides of the peak gain, which means choosing the 0.48m as the best length is reasonable to get an effective antenna. The resonant frequency can be improved to get closer to the expected 300 MHz.

g) Realized gain vs reflector spacing sweep

Based on the previous settings and setting the reflector length to 0.48m, there is a parametric sweep on reflector spacing from 0.1m to 0.3m. When reflector spacing = 0.23, it gets its highest realized gain 6.80 dBi.

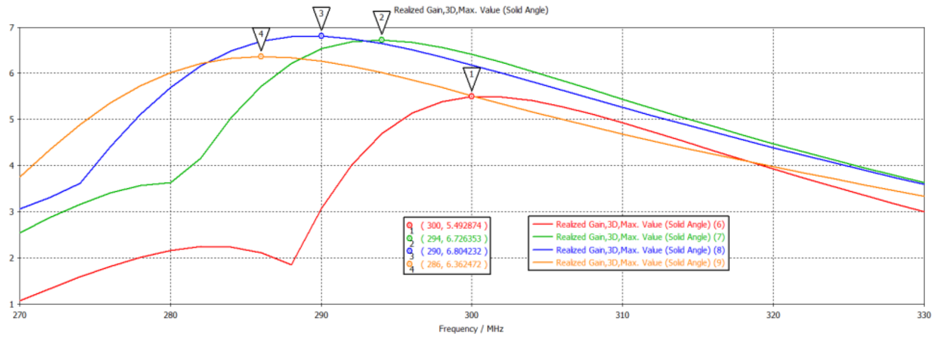

Figure 14 Realized gain vs spacing

Reflector spacing (m)	Resonant frequency (MHz)	Bandwidth (MHz) (-10dB)	Realized gain (dBi)
0.1	300	-	5.49
0.167	294	8	6.73
0.23	290	17	6.8
0.3	286	30	6.36

Table 5

With the increment in reflector spacing, the resonant frequency keeps decreasing and the bandwidth goes up. However, it reaches its peak realized gain at 0.23m and its realized gain declines from both sides of the peak gain, which means choosing the 0.23m as the best spacing is reasonable to get an effective antenna. The resonant frequency can be improved to get closer to the expected 300 MHz.

6.80 - 2.52= 4.28 dBi

It increased by 4.28 dBi than the simpler antennas simulated in Section 1.

4. Section 3

a) A picture of a CAD model of the optimized 1-director and 7-director Yagi-Uda antenna displaying the dipoles.
Dipole length = 0.45m, dipole diameter = 0.01m.

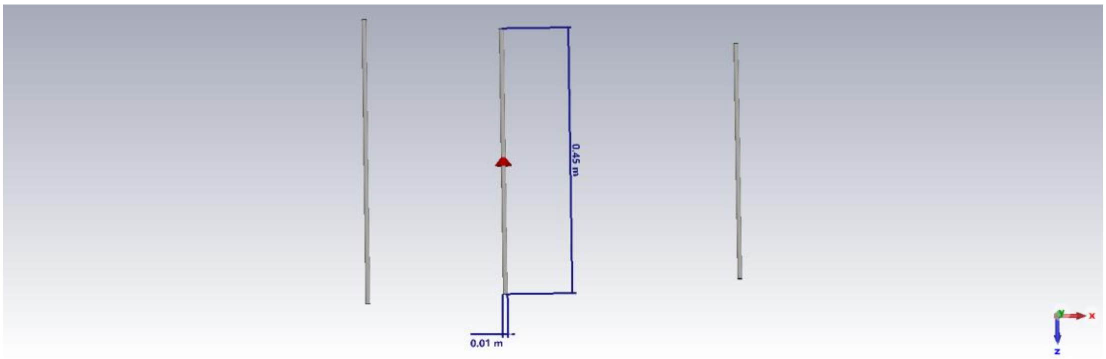

Figure 15 CAD model of 1-director Yagi-Uda antenna

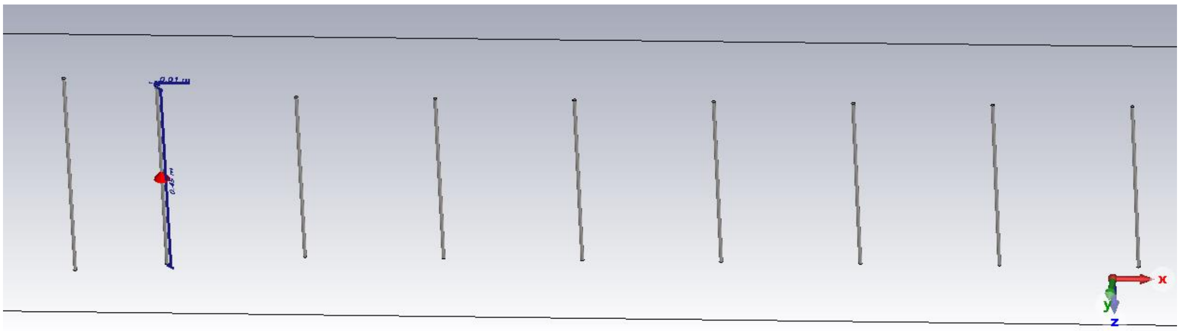

Figure 16 CAD model of 7-director Yagi-Uda antenna

b) S11-parameter sweep vs frequency

Below results were based on 3-elements Yagi-Uda antenna.

After the parametric sweep of director spacing, choose the best s11-parameter = -16.08dB when spacing = 0.25m.

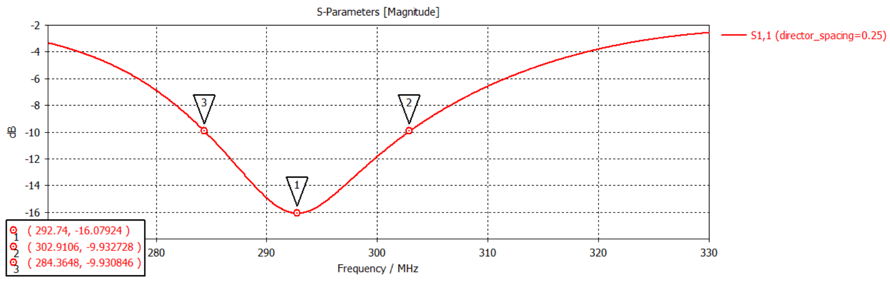

Figure 17 3-element Yagi-uda

Below results were based on 9-elements Yagi-Uda antenna.

After the parametric sweep of director spacing, choose the best s11-parameter when spacing = 0.2m.

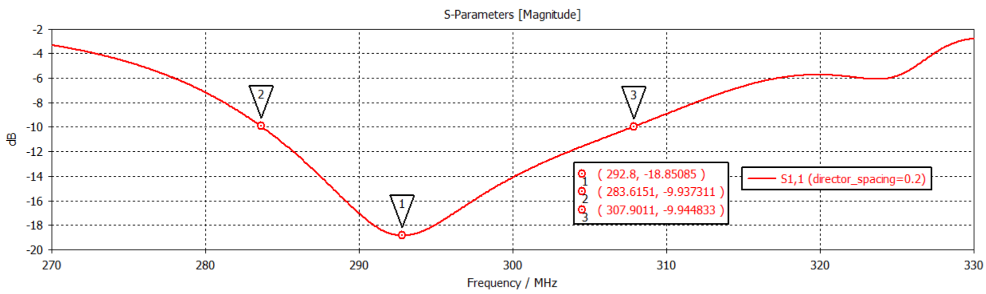

Figure 18 S11-parameter sweep vs frequency

Bandwidth:

$$BW = f_2 - f_1 = 307.90 - 283.62 = 24.28 \text{ MHz}$$

Fraction BW:

$$BW_F = \frac{BW}{f_c} = \frac{24.28}{292.8} = 8.29\%$$

It reaches its minimum point at -18.85dB when the frequency is 283.62MHz and its magnitude of s-11 is not low enough, which will result in lower efficiency and degraded antenna performance. Additionally, its fractional bandwidth is 8.3%, but it is relatively in higher efficiency than results in Section 2 and 3-elements antenna.

c) Realized gain sweep vs frequency

Below results were based on 3-elements Yagi-Uda antenna.

When spacing = 0.25m, it reached its highest gain at 8.17dBi.

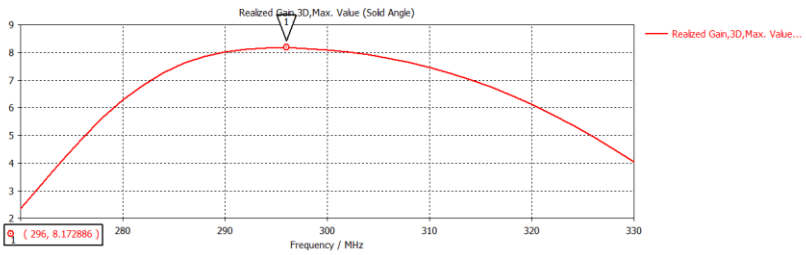

Figure 19 3-elements

Below results were based on 9-elements Yagi-Uda antenna.

When spacing = 0.2m.

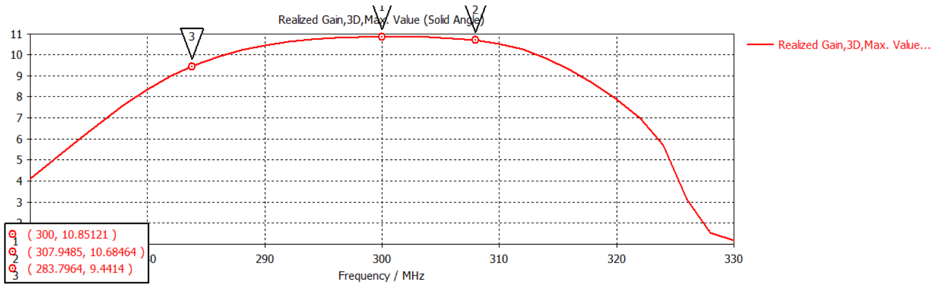

Figure 20 Realized gain sweep vs frequency

The realized gain is between 0 to 11 dBi and it reaches its maximum realized gain at 10.85 dBi when the frequency is 300 MHz. Observed from the bandwidth, it shows the most effective operation range of this Yagi-Uda antenna has a realized gain of at least 9.44 dBi. Compared with realized gain in section 2's antenna and 3-element antenna, this one is much more effective.

d) Radiation pattern at 300 MHz (polar plot: azimuth and elevation patterns)

Below results were based on 9-elements Yagi-Uda antenna.

Azimuth

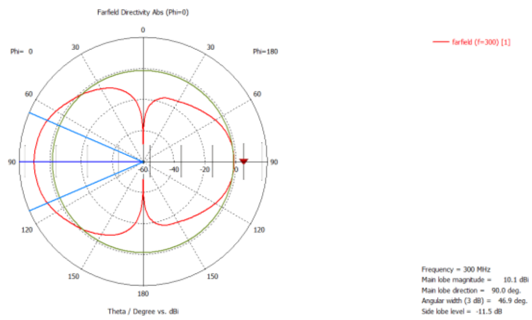

Figure 21 Azimuth

Elevation

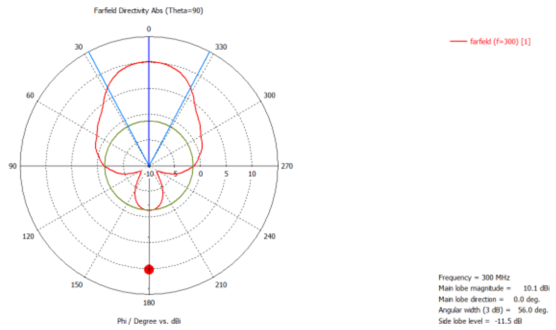

Figure 22 Elevation

e) Front-to-back ratio sweep vs frequency

Below results were based on 3-elements Yagi-Uda antenna.

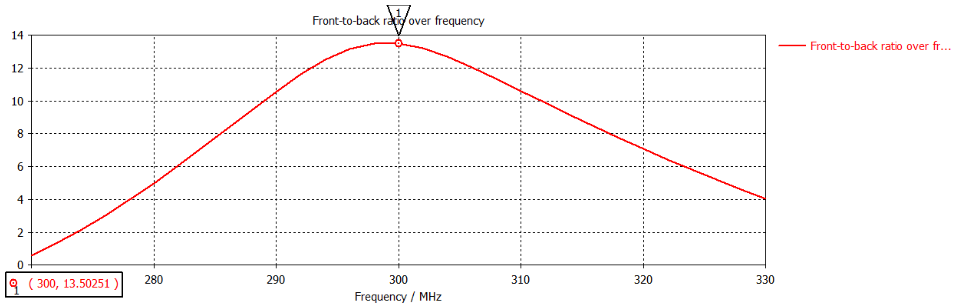

Figure 23 3-element

Below results were based on 9-elements Yagi-Uda antenna.

Based on the best data when director spacing = 0.2m. The graph shows the front-to-back ratio keeps rising to its maximum magnitude of 23.67 between about 270 MHz and 312 MHz and then keeps declining.

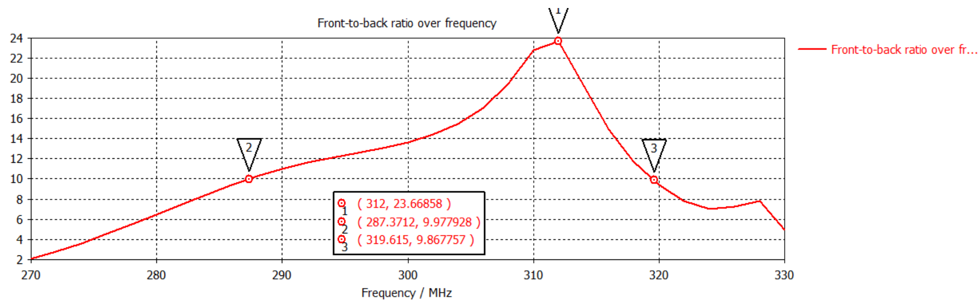

Figure 24 Front-to-back ratio sweep vs frequency

By comparison, the lowest magnitude of Front-to-back ratio between the bandwidth range (most effective range) of this antenna is higher than the peak ratio in section 2's antenna, which shows higher efficiency and makes it suitable for use in a wider range of applications.

f) Realized gain vs director spacing sweep

Below results were based on 3-elements Yagi-Uda antenna.

After parametric sweeps, the maximum realized gain was 8.17 dBi, which increased by 0.41 dBi (8.17-7.76).

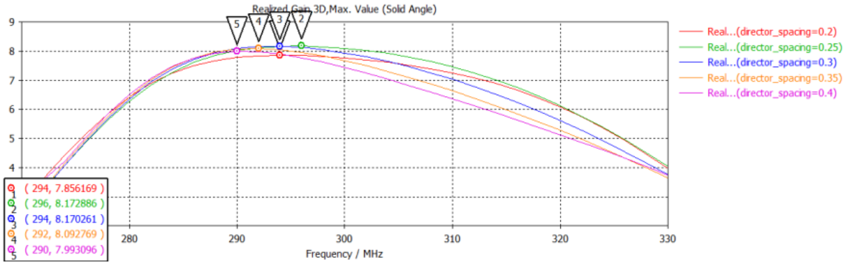

Figure 25 Realized gain 3-elements

Below results were based on 9-elements Yagi-Uda antenna.

Based on the previous setting, there is a parametric sweep on director spacing from 0.2m to 0.4m. When director spacing = 0.2, it gets its highest realized gain 10.85 dBi.

Reflector spacing (m)	Resonant frequency (MHz)	Bandwidth (MHz) (-10dB)	Realized gain (dBi)
0.2	300	24.28	10.85
0.25	300	20	10.71
0.3	300	18	10.42
0.35	298	17.5	10.2
0.4	294	9	9.71

Table 6

With the increment in director spacing, the resonant frequency and the bandwidth keep decreasing.

To find the better realized gain,

At first, I set the director spacing = 0.2, and then I tried to use a different reflector spacing sweep from 0.1 to 0.2 to get a better gain.

It shows that when reflector spacing is 0.2, the realized gain improves to 10.86 dBi.

Then I Changed the dipole gap to 0.001 and the reflector spacing to 0.18 and finally I get a realized gain of 11.14 dBi.

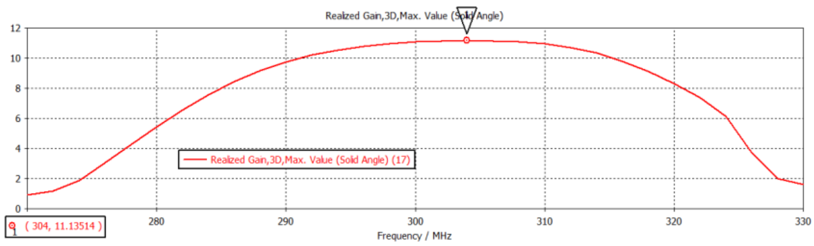

Figure 26 Realized gain 3rd

Realized gain vs director length sweep

There is a parametric sweep on director length from 0.35 to 0.45m, but it showed when the length = 0.4m (original setting), it got its highest realized gain, which means I don't need to change the value of director length.

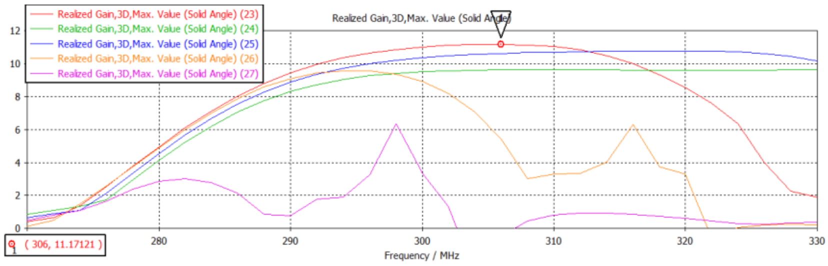

Figure 27 Director length sweep

Finally, I Set the dipole length to 0.445m, director spacing to 0.22m and reflector spacing to 0.23m and get the realized gain = **11.1934 dBi**, which is the best one I can find.

11.1934 – 2.52= 8.67 dBi

It increased by 8.67 dBi than the simpler antennas simulated in Section 1.

Compared with realized gain in 3-elements Yagi-Uda antenna, it got 3.02 dBi (11.1934-8.17) more after adding additional 6 directors.

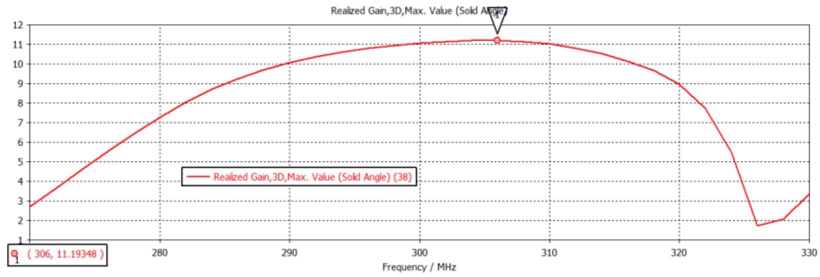

Figure 28 Realized gain (best)

a) Table with optimum values for spacing of the 7 directors.

Director length (m)	Director spacing (m)	Reflector spacing (m)	Dipole gap (m)	Dipole length (m)	Realized Gain (dBi)
0.4	0.2	0.23	0.01	0.4	10.85
0.4	0.25	0.23	0.01	0.4	10.71
0.4	0.3	0.23	0.01	0.4	10.42
0.4	0.35	0.23	0.01	0.4	10.2
0.4	0.4	0.23	0.01	0.4	9.71
0.4	0.2	0.1	0.001	0.4	10.26
0.4	0.2	0.12	0.001	0.4	10.65
0.4	0.2	0.14	0.001	0.4	10.94
0.4	0.2	0.16	0.001	0.4	11.08
0.4	0.2	0.18	0.001	0.4	11.14
0.4	0.2	0.2	0.001	0.4	11.13
0.4	0.2	0.18	0.001	0.445	11.17
0.4	0.22	0.18	0.001	0.445	11.1931
0.4	0.24	0.18	0.001	0.445	11.19
0.4	0.26	0.18	0.001	0.445	11.13
0.4	0.28	0.18	0.001	0.445	11.1
0.4	0.3	0.18	0.001	0.445	11.03
0.4	0.32	0.18	0.001	0.445	10.9
0.4	0.34	0.18	0.001	0.445	10.74
0.4	0.36	0.18	0.001	0.445	10.64
0.4	0.38	0.18	0.001	0.445	10.39
0.4	0.4	0.18	0.001	0.445	10.19
0.4	0.22	0.23	0.001	0.445	11.1934

Table 7

5. Conclusion

From Section 1, I have a basic understanding on the RF characteristics of antennas, including antenna's radiation pattern, realized gain, impedance, bandwidth, polarization, and efficiency. Realized gain and bandwidth are the most significant elements to judge if an antenna works with high efficiency, which can be adjusted by carrying out different kinds of parametric sweeps (dipole thickness and length in Section 1).

From Section 2, adding a reflector strongly improved the efficiency of antenna. By accessing parametric sweep of reflector length and spacing, it got its maximum realized gain when reflector length = 0.48m and reflector spacing = 0.2333m, which had an increment of 0.518189 dBi.

From Section 3, 7 more directors were added to get further improvement in efficiency of Yagi-Uda antenna. Both length and spacing of directors influence antenna performance. After doing different kinds of parametric sweeps, including director spacing, reflector length and spacing, and little changes in dipole length and gap, I found the best-realized gain I could get, 11.1934dBi.

Overall, I have a basic understanding of how the Yagi-Uda antenna works and how to make an effective one. However, though I explored different design parameters on antenna, to have better improvement in its efficiency, a lot of work can still be carried out in the future, including investigation of different materials and integration with other technologies.