RMIT UNIVERSITY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

EEET1131 Antennas for Mobile and Satellite Communications PG

Assignment No.1: Yagi-Uda antenna Design

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Due Time: *5pm Friday, 18th Sept 2009*

1. Problem:

Design a Yagi-Uda antenna, which can produce directivity of 9-10 dB. Use different software (search and find appropriate free software) to design and predict the performance of this antenna. You should discuss and compare the results (impedance, radiation patterns) from different software (minimum two). You can select the operating frequency (select any frequency from 2 to 5 GHz, e.g 2.8 GHz).

In your assignment you should include a plot of Return Loss (or S11) versus frequency and radiation pat terns for both principal planes (E & H).

2. Introduction and analysis:

Yagi-Uda antenna uses an array of linear dipole elements to increase antenna's directivity. In structure, it consists of three parts: a driver, a reflector and some directors. The outer source feed the driver element, other elements in the antennas are excited by electromagnetic coupling. The maximum radiation gain could get at the direction of the director elements. Adjusting the elements number, length, diameter and the distance could get different radiation pattern and directivity. Because the non-linear relation between the antenna performance and the antenna physical parameters, the design could use the software or experimental design curve. In this design, we will use software simulation to design Yagi-Uda antenna.

The requirements of this design is to design a Yagi-Uda antenna with the directivity about 9-10 dBd, the operating frequency could be between 2 to 5 GHz. Based on this requirement, the frequency of 2.8GHz is selected as the operating frequency of antenna. Because this design is based on the software simulation, the first step is to find suitable design software. After large time search and compare, two freeware software were selected as the main design software: 4NEC2X and MMANA-GAL. As a supplementary, the third small computation software YaGi is selected to compute the initial antenna parameters.

The design will follow the following procedures:

- Determine the init physical parameters with experimental design table and the parameter computation software Yagi.
- Using 4NEC2X simulating and optimizing the design
- Input the optimization results from 4NEC2X into MMANA-GAL make further simulation and comparison.

3. The determination of the initial parameters:

The requirement directivity of this antenna is 9-10dBd. Checking the design table in text-book, could find the 5 elements antennas has an ideal directivity of 9.2 dBd. So we could choose 5-elemets Yagi-Uda antenna as a start.

As a roughly estimation, we need estimate the size of the antenna. The wavelength at 2.8Ghz is about 107 mm. From the design table in text-book, for five-elements antenna, the antenna length is about 0.8 λ , which is about 86mm. The length of the reflector is 0.482 λ , which is 52 mm. So we could get the roughly size of the antenna as 86*52 mm*mm. From this size, we could choose initial antenna wire diameter as 2mm, the boom diameter initial value as 5mm.

The next step is to determine the initial physical parameters of the antenna. This could be performed with a computation software Yagi. Inputting the frequency of 2800 MHz and wire diameter = 2 mm, we could get the following initial antenna parameters result:

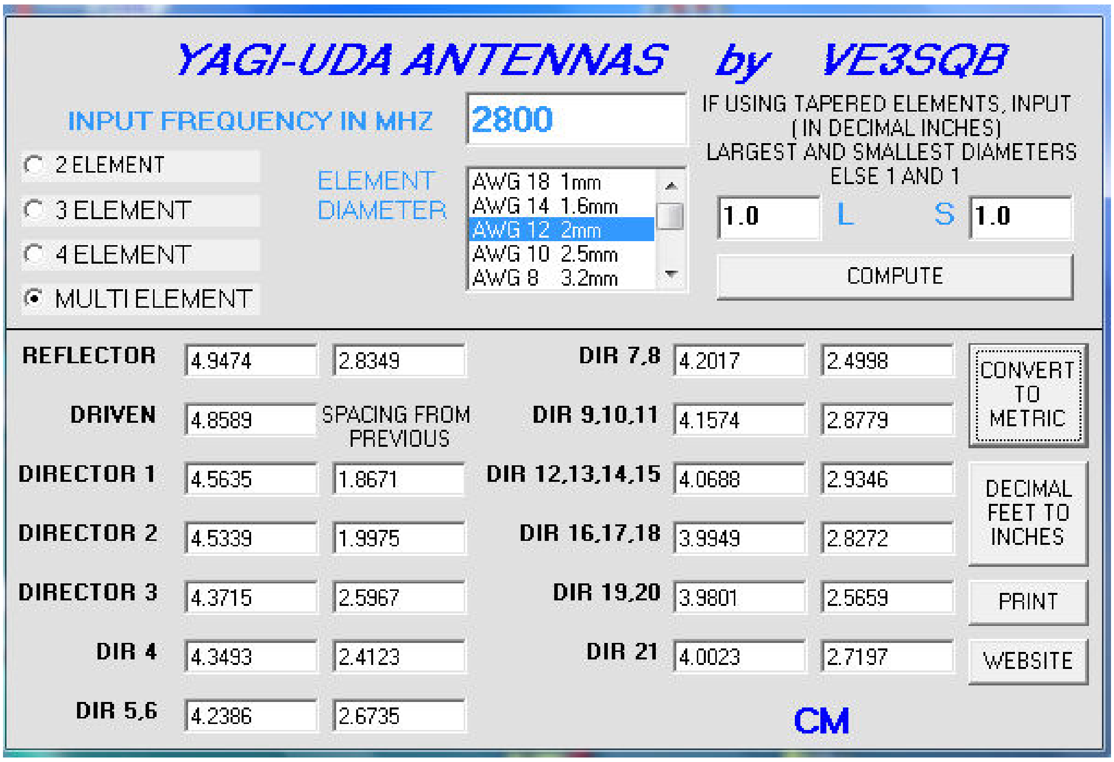


Fig.1 YaGi Main Window and Output

Above are the multi-elements dimensions. For 5-elements case, could choose first 5-elements dimension as the initial design dimensions, which is:

Table 1. Initial Physical Parameters

Reflector Length(m)	0.049474
Driver Length(m)	0.048589
Distance between driver and reflector(m)	0.028349
Director 1 length (m)	0.045635
Distance between director1 and driver(m)	0.018671
Director 2 length (m)	0.045339
Distance between director 2 and director 1(m)	0.019975
Director 3 length (m)	0.043715
Distance between director 3 and director 2(m)	0.025967
Wire radius (mm)	1.0
Boom radius (mm)	2.5
Boom length (m)	0.092962

Because we will use the simulation software to optimize these parameters, so we could make this approximation.

4. Simulation and optimization with 4NEC2X software:

1) 4Nec2x introduction:

The first simulation software is 4Nex2x. NEC is the abbreviation of Numerical Electromagnetic Code, which was developed at Lawrence Livermore Laboratory. It could analyze the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. The analysis is accomplished by the numerical solution of the integral equations for induced currents. The interface of the 4nec2x is following:

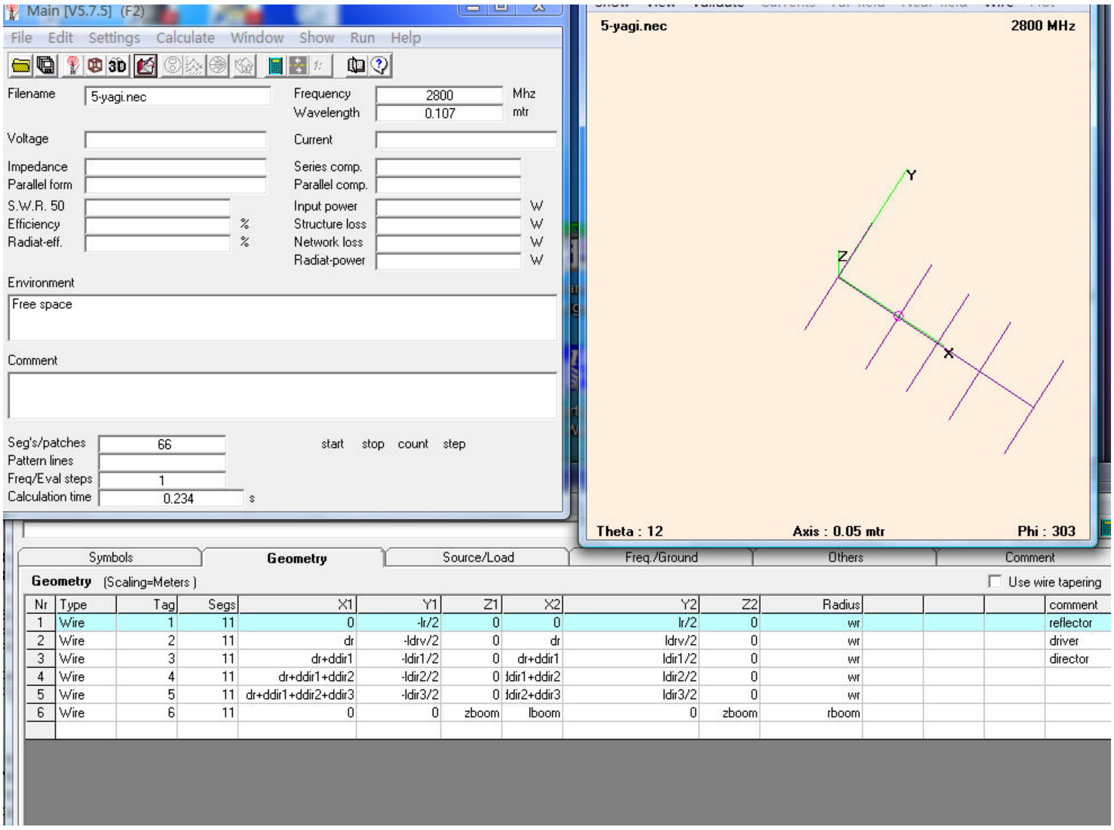


Fig.2 4Nec2x Main Window and Input Editor

In above graph, the above half is the software main window and the antenna shape, the below half is the input editor. The initial parameters which get from section 3 have input into the editor and antenna shape is displayed in the right-upper window.

2) Initial Simulation:

Input the initial parameters which get from section 3, we could get following initial radiation pattern simulation results:

a. E-Plane(Horizontal-plane) Radiation pattern:

In above section, we put the elements in the x-y plane (Horizontal plane). So the E-plane is horizontal plane. The radiation pattern in horizontal plane could get as:

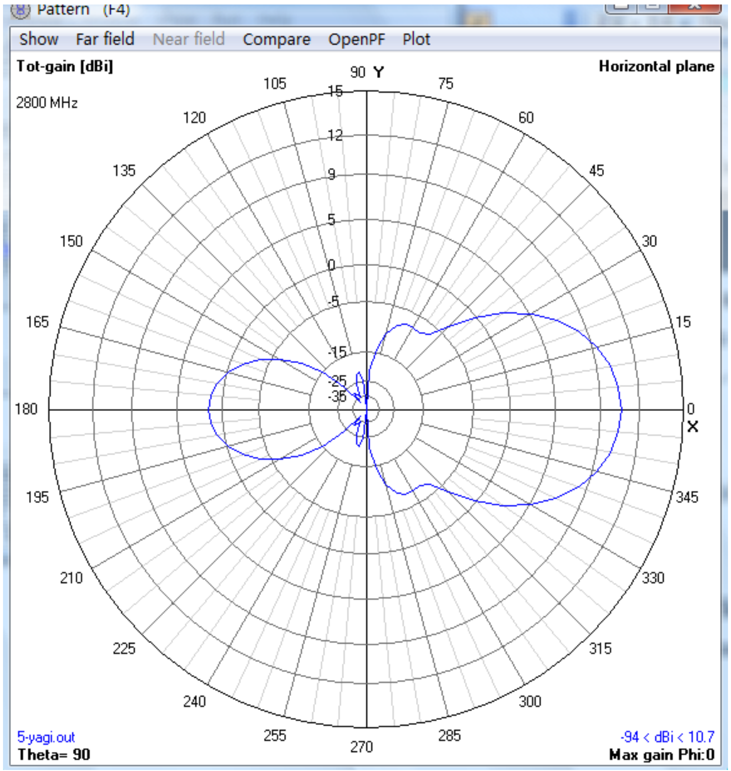


Fig.3 Initial parameters E-Plane Radiation Pattern

b. H-Plane Radiation pattern:

As the horizontal plane is E-plane, the Vertical plane is H plane. The H-Plane radiation pattern is:

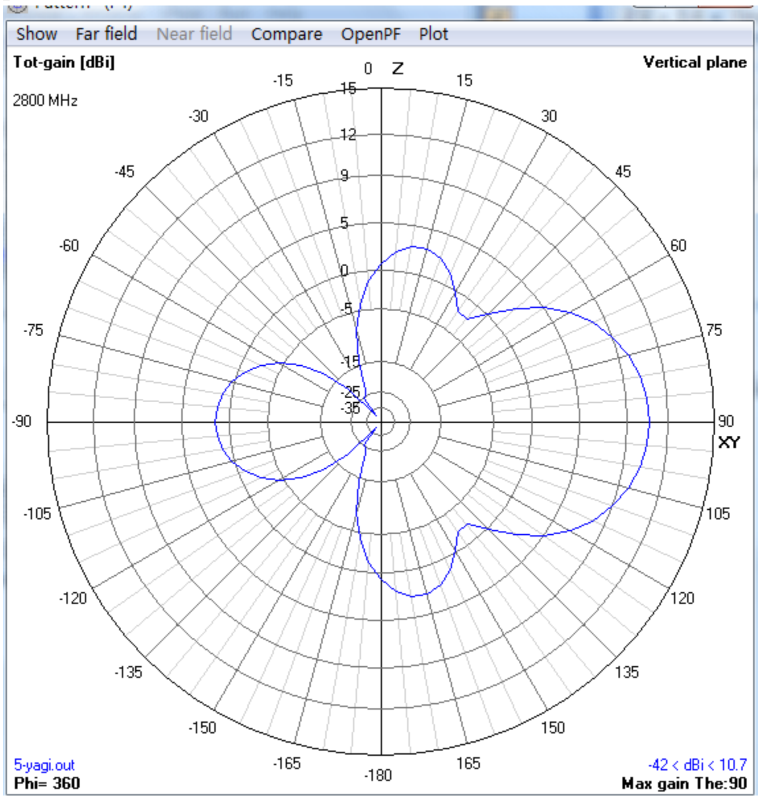


Fig.4 Initial parameters H-Plane Radiation Pattern

From above E plane and H plane radiation pattern, we could get that for initial parameters, antenna's maximum gain is 10.7dBi, which is 8.6 dBd.

3) Optimization:

From above section, the initial design cannot meet the requirements. So we need optimize design. This optimization could be performed with 4Nec2X. After optimization, antenna maximum gain become to 11.29dBi, which is 9.1dBd. This maximum gain is very near the antenna ideal maximum gain value 9.2dBd and could satisfy the requirement.

After optimization, antenna physical parameters become to:

Table 2. Optimization Physical Parameters

Reflector Length(m)	0.050349
Driver Length(m)	0.047646
Distance between driver and reflector(m)	0.026543
Director 1 length (m)	0.045931
Distance between director1 and driver(m)	0.018417
Director 2 length (m)	0.038932
Distance between director 2 and director 1(m)	0.021893
Director 3 length (m)	0.041927
Distance between director 3 and director 2(m)	0.026564
Wire radius (mm)	1.066
Boom radius (mm)	2.5
Boom length (m)	0.093417

We could further get the simulation results for optimization parameters:

a. Radiation pattern:

E-Plane (Horizontal Plane):

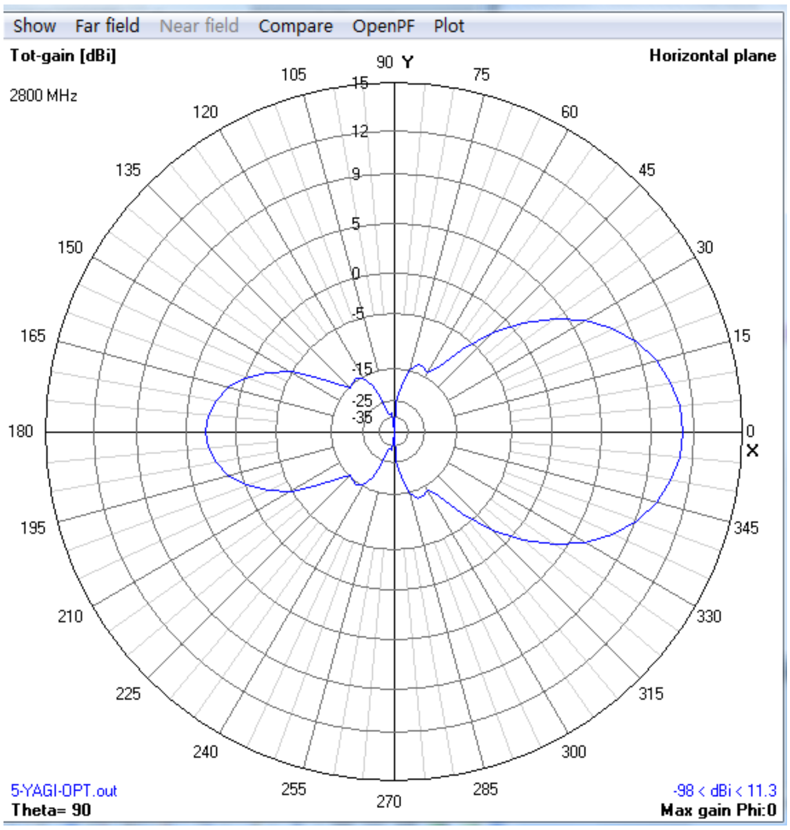


Fig.5 Optimization parameters E-Plane Radiation Pattern

H-plane (Vertical Plane):

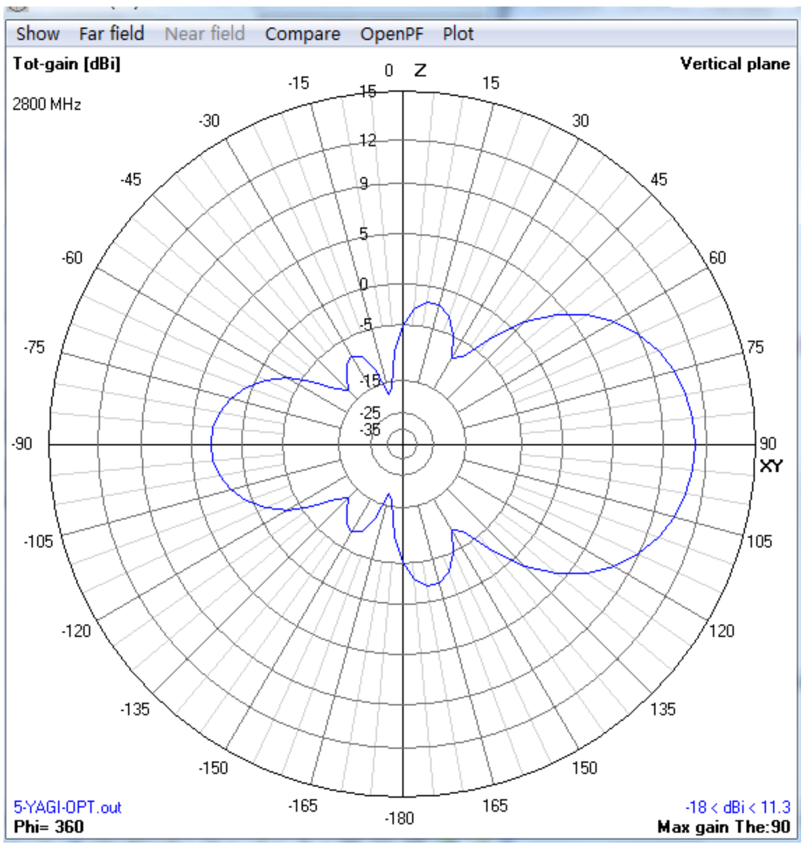


Fig.6 Optimization parameters H-Plane Radiation Pattern

From above radiation pattern, we could get that the maximum gain of the antenna has increased to **11.3dBi**, which is 9.1dBd.

b. SWR and return-loss vs. frequency:

The SWR and return-loss v.s. frequency is following:

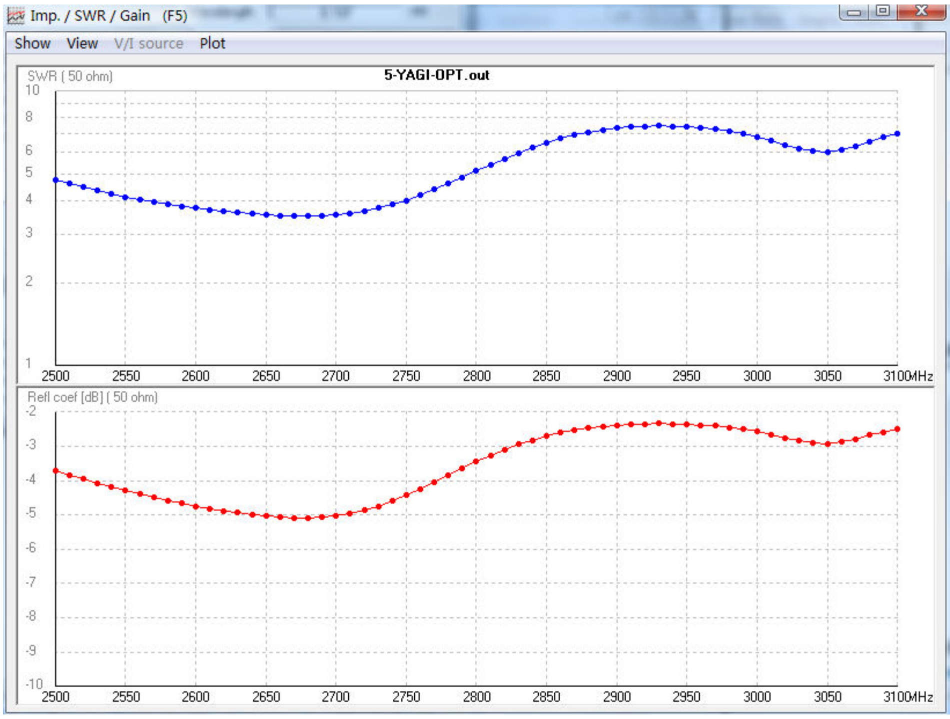


Fig.7 The SWR and Reflection Coefficient V.S. Frequency Plot

From above graph, the reflection coefficient at 2.8GHz is -3.44dB. SWR is 5.11.

S11 Smith chart from 2500MHz to 3100Mhz is:

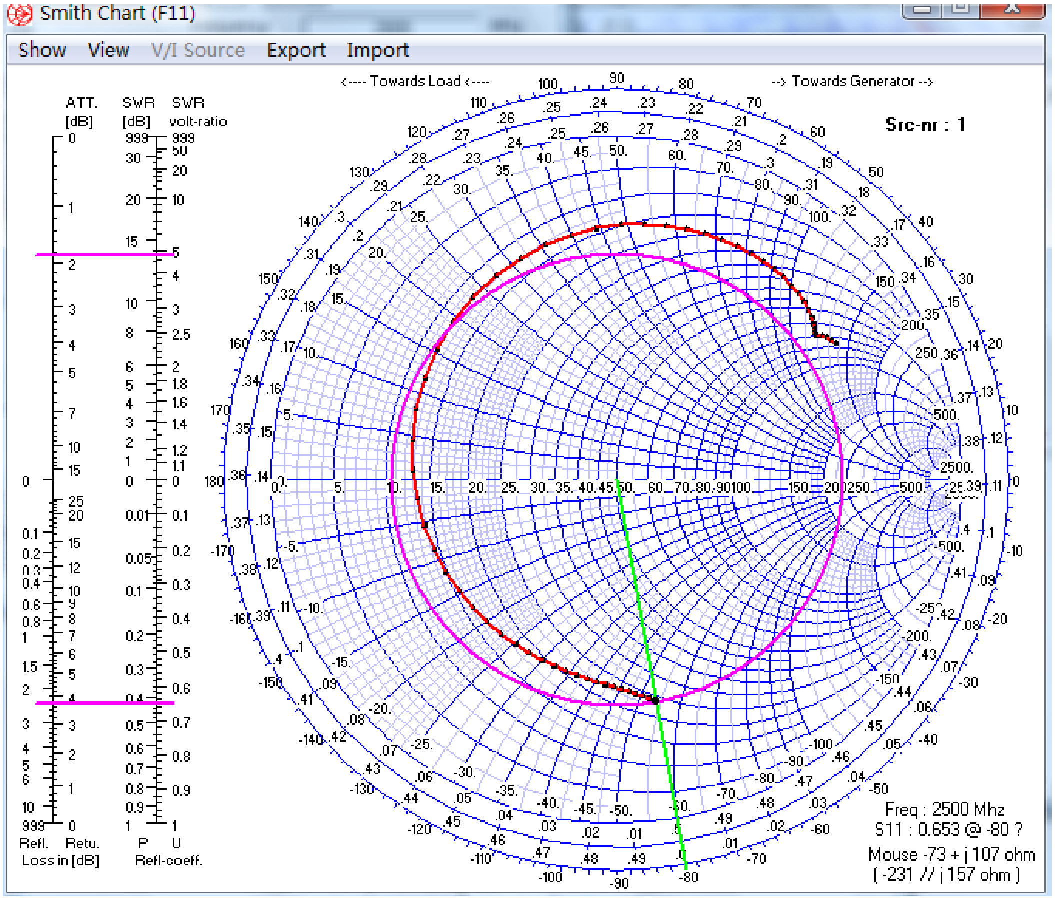


Fig.8 The S11 Smith Chart

In above graph, the red line is S11 plot which from 2500MHz to 3100MHz. At 2500MHz, the S11 is 0.653@-89.

c. Impedance:

The impedance changed to 12+j23.3 Ω. Making the similar calculation as initial parameters, could get S11 value at 2.8GHz as:

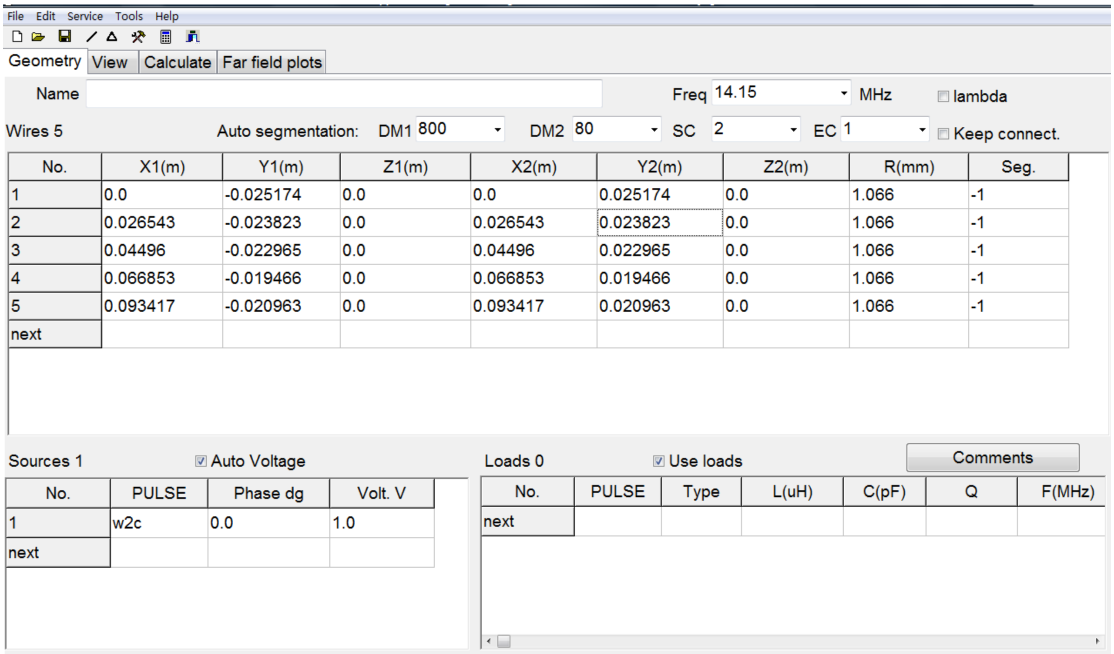
$$S_{11} = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{12 + j23.3 - 50}{12 + j23.3 + 50} = 0.6722\angle 128^0,$$

$|\Gamma| = |S_{11}|$ = 0.6722 = -3.45 dB, could match the reflection coefficient value from part b.

5. Simulation with MMANA-GAL software:

1) MMANA-GAL introduction:

The second used software is MMANA-GAL. MMANA-GAL is an antenna-analyzing tool based on the moment method, its computation source engine is based on MINNEC. The interface of MMANA-GAL is following:



No.	X1(m)	Y1(m)	Z1(m)	X2(m)	Y2(m)	Z2(m)	R(mm)	Seg.
1	0.0	-0.025174	0.0	0.0	0.025174	0.0	1.066	-1
2	0.026543	-0.023823	0.0	0.026543	0.023823	0.0	1.066	-1
3	0.04496	-0.022965	0.0	0.04496	0.022965	0.0	1.066	-1
4	0.066853	-0.019466	0.0	0.066853	0.019466	0.0	1.066	-1
5	0.093417	-0.020963	0.0	0.093417	0.020963	0.0	1.066	-1
next								

No.	PULSE	Phase dg	Volt. V
1	w2c	0.0	1.0
next			

No.	PULSE	Type	L(uH)	C(pF)	Q	F(MHz)
next						

Fig.9 MMANA-GAL Main Window and input parameters

The input parameters are the optimization results from 4NEC2X.

2) Simulation Results:

a. Radiation Pattern:

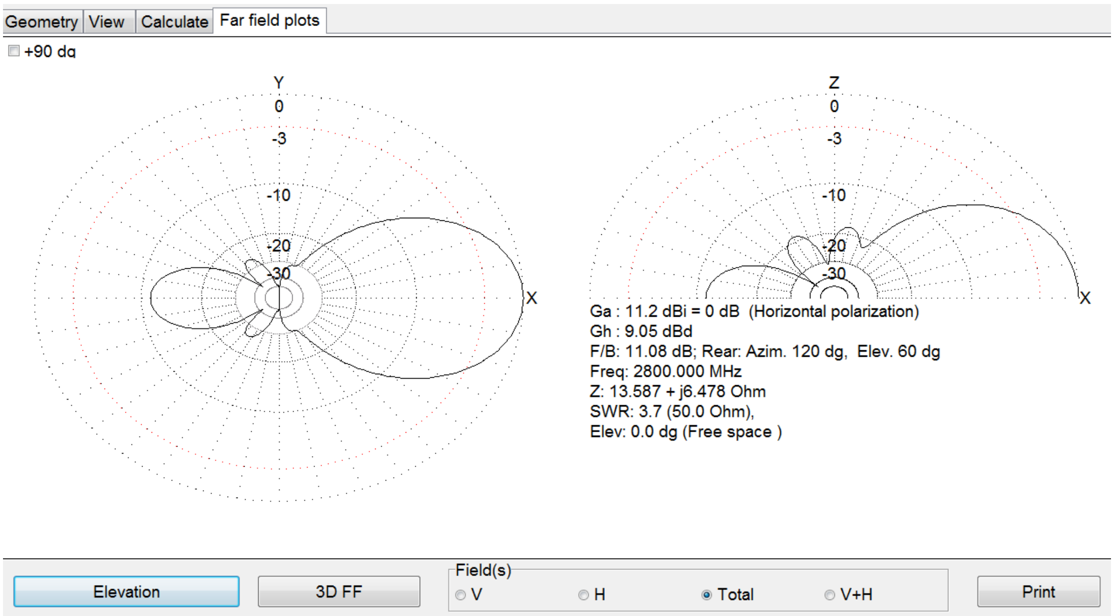


Fig.10 MMANA-GAL Radiation Pattern

Above is the radiation pattern from MMANA-GAL. The left is the radiation pattern in horizontal plane, from previous analysis, this is E-plane radiation pattern. The right is the radiation pattern in vertical plane, which is H-plane radiation pattern.

From above radiation pattern graph, we could get the maximum gain of this antenna with MMANA-GAL is 9.05dBd, which is close to the 9.1dBd value from 4NEC2x. The radiation patterns in MMANA-GAL are also similar to 4NEC2X.

b. SWR:

The SWR plot around 2800MHz is following:

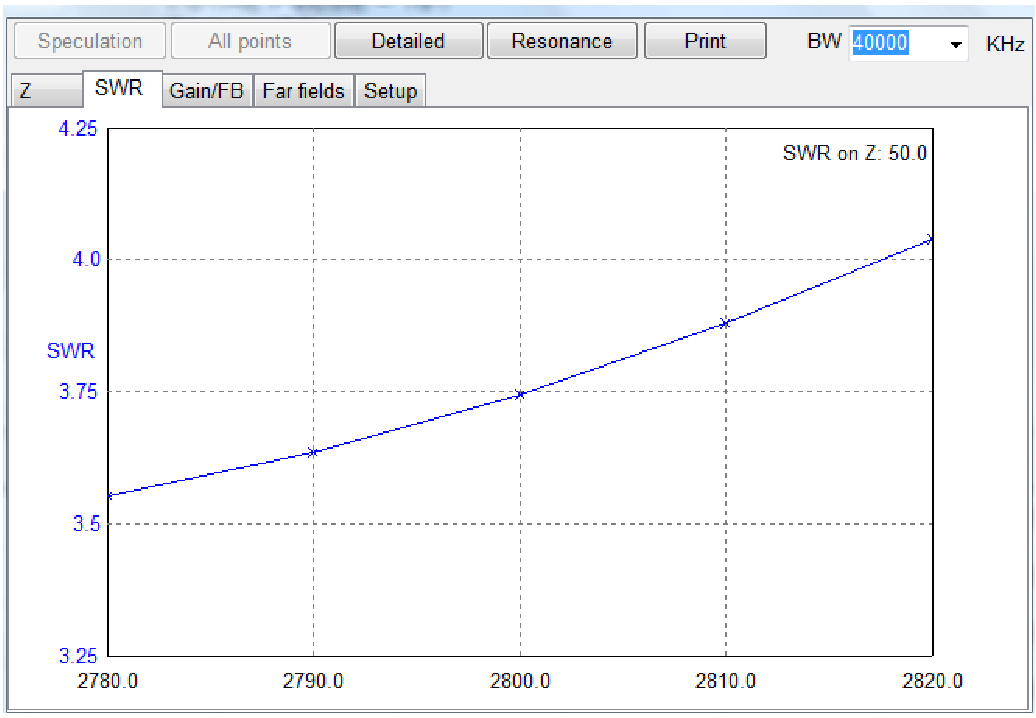


Fig.11 MMANA-GAL SWR v.s. Frequency Plot

From the above graph, could get that SWR at 2800MHz is about 3.75. From this value, could get the reflection coefficient at the 2.8GHz as:

$$|\Gamma| = \frac{SWR-1}{SWR+1} = \frac{3.75-1}{3.75+1} = 0.579$$

c. Impedance:

MMANA-GAL could get impedance v.s. frequency graph. The impedance plot around 2800MHz is:

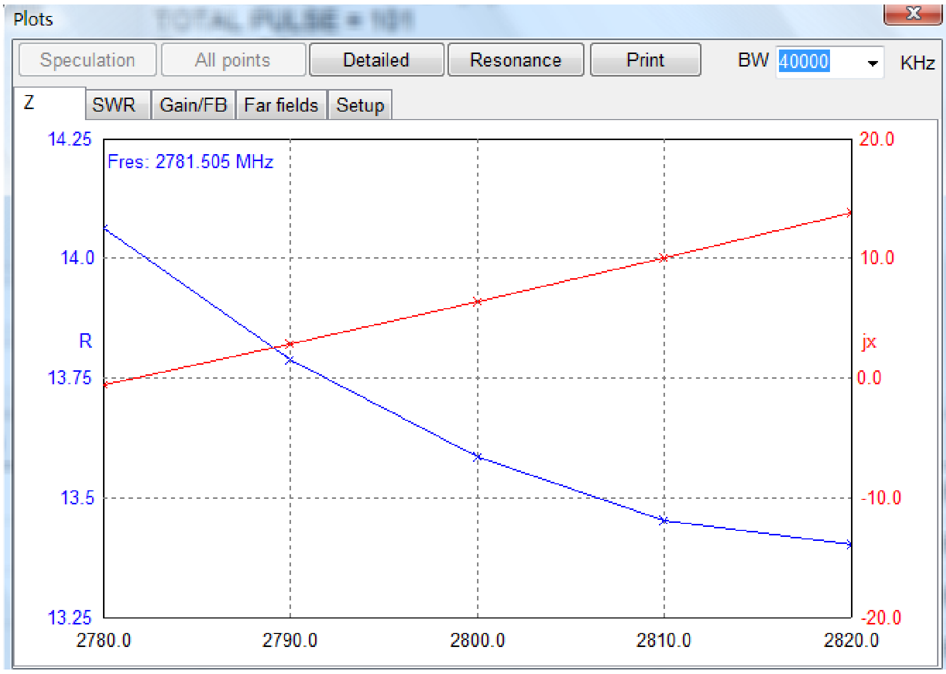


Fig.12 MMANA-GAL Impedance v.s. Frequency Plot

The impedance at 2800MHz is: 13.59-j6.48 Ω. From this value, could get S11 value at 2.8GHz as:

$$S_{11} = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{13.59 - j6.48 - 50}{13.59 - j6.48 + 50} = 0.5785\angle -164.1^0,$$

$|\Gamma| = |S_{11}|$ = 0.5785, could match the reflection coefficient value 0.579 from graph in part b.

d. Comparison with results from 4NEC2X:

In this section, we made the simulation with MMANA-GAL for the optimization results from 4nec2x. From the simulation result, the directivity from two software are close. The 4nec2x is 9.1dBd, and the MMANA-GAL is 9.05 dBd at 2.8GHz. The radiation pattern are also similar.

But the impedance and the reflection loss have some notable difference. At 2.8GHz, the impedance from 4NEC2X is 12+j23.3 Ω, corresponding reflection coefficient is 0.6722. The impedance from MMANA-GAL is 13.59-j6.48 Ω, the reflection coefficients is 0.5785. Given both software use the similar numerical method, this difference may come from the concrete algorithm and coding implementation. Because we don't have experimental data, so cannot determine which software has a higher accuracy.

6. Final design:

From above sections' design and simulation, although there are some difference between two simulation, the most important target, maximum gain, are very close. So we could get the following final design parameters

1) Antenna Physical Parameters:

Table 3. Final Design Antenna Physical Parameters

Reflector Length(m)	0.050349
Driver Length(m)	0.047646
Distance between driver and reflector(m)	0.026543
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Wire radius (mm)	1.066
Boom radius (mm)	2.5
Boom length (m)	0.093417

2) 3-D shape and radiation pattern:

Antenna 3-D shape and 3-D radiation pattern also could get as following:

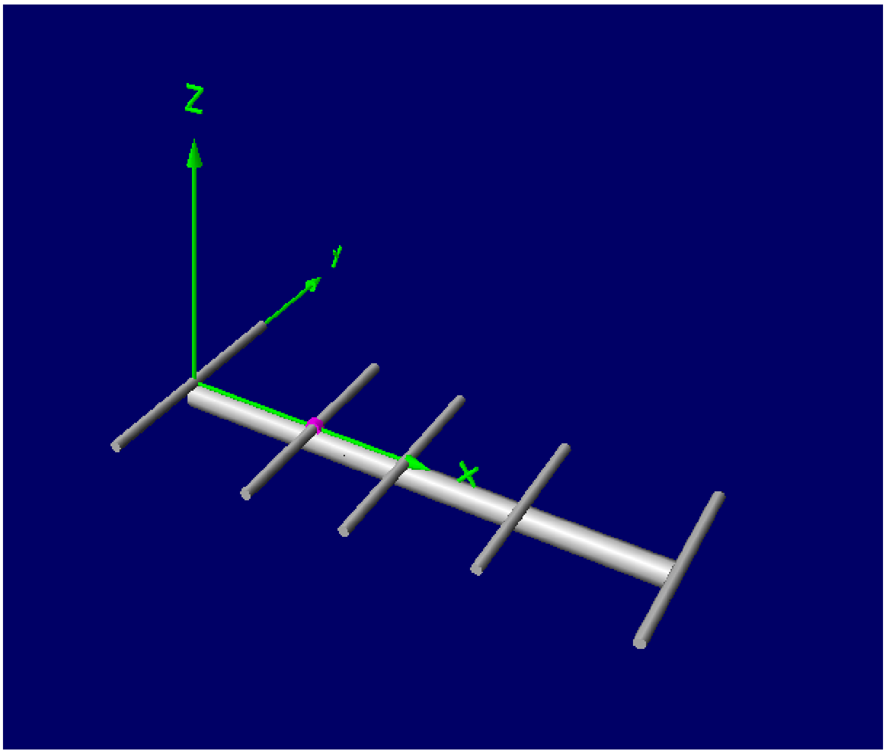

Fig.13 Final Design Antenna 3-D Shape (From 4Nec2x)

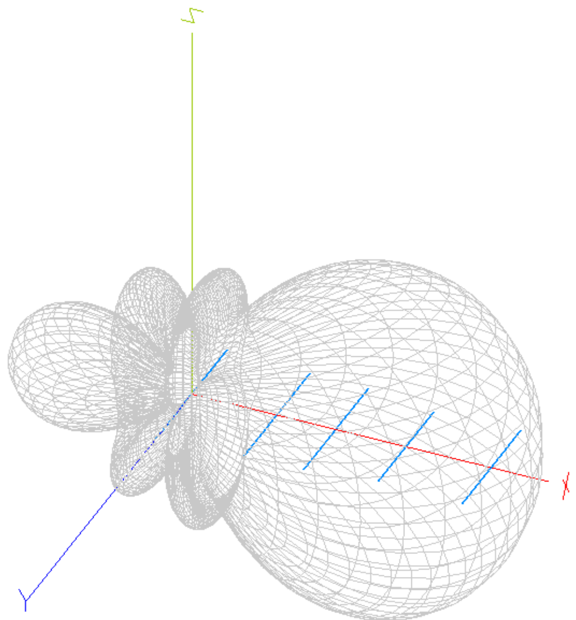

Fig.14 Final Design Antenna 3-D Radiation Pattern (From MMANA-GAL)

7. Conclusion:

A five-elements Yagi-Uda antenna has been designed with the method of software computation and simulation. The directivity of antenna is 9.1dBd (from 4NEC2x). The operating frequency is 2.8GHz.

The simulation are with two software—4Nec2X and MMANA-GAL. The directivity from two antenna is very close, 9.1dBd from 4Nec2X and 9.05dBd from MMANA-GAL. Radiation pattern are also similar. But the antenna impedance has some difference, from 4NEC2X is 12+j23.3Ω and MMANA-GAL is 13.59-j6.48Ω. This difference may come from two software's different specific implementation. Because don't have experimental data, I cannot determine which software's result is more accuracy.

8. Reference:

[1] Antenna Theory and Design, C. A. Balanis.

[2] 4Nec2x Online Help.

[3] MMANA-GAL Online Help