# Antenna Theory and Design

## PROJECT 3

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# Topic 1

## Introduction

Design a linear array of isotropic elements placed along the z-axis such that the zeros of the array factor occur at θ = 0°, 60°, and 120°. Assume that the elements are spaced λ/4 apart and the progressive phase shift between them is 0°. Find the required number of elements, determine their excitation coefficients, and plot 2D pattern.

## Simulation

The procedure of calculation is in the code given. The output is a matrix that gives the excitation of each element and 2D pattern of the array factor in linear scale. In this case, the parameter setting is as below:

```
A = [0 pi/3 2*pi/3];
%A is the nulls of the pattern
d = 1/4;
%d is the distance between each element
b = 0;
%b is the progressive phase shift of each element
iso(A,d,b)
```

The output gives:

```
M =

   1.0000 + 0.0000i  -1.4142 - 1.0000i   1.0000 + 1.4142i  -0.0000 - 1.0000i
```

Figure 1.1

Figure 1.1 gives the excitation of each element both in amplitude and phase. $A_1 = 1; A_2 = 1.73e^{j215}; A_3 = 1.73e^{j55};\ A_4 = e^{j270}$

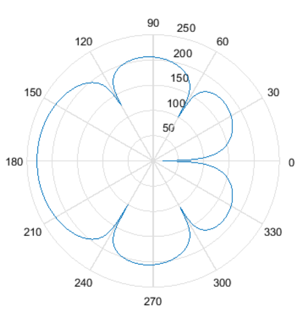



Figure 1.2

Figure 1.2 gives the 2D pattern of the array factor of the antenna array. It is clear there are three nulls at θ = 0°, 60°, and 120°.

# Topic 2

## Introduction

Use a half-wavelength dipole array directed along the x axis to implement your design in topic 1. Plot 2D pattern in two principle planes and 3D pattern.

## Simulation

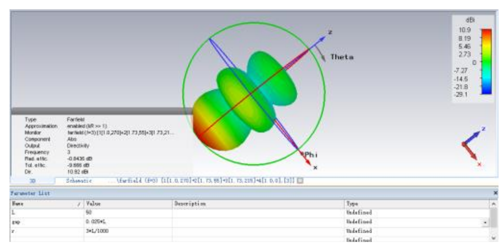



Figure 2.1

Figure 2.1 shows the 3D pattern of the simulation.

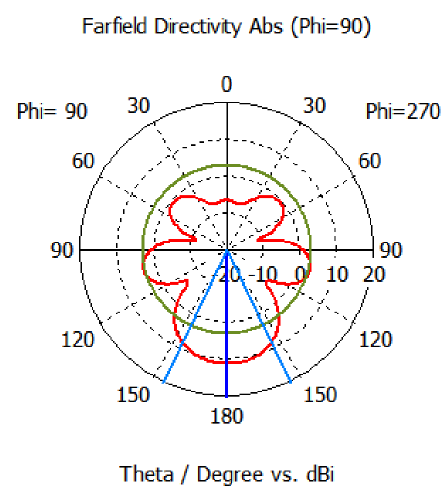



Figure 2.2

Figure 2.2 gives the 2D plot of the simulation at phi=90°.

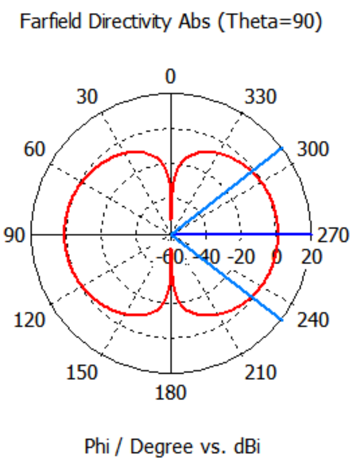



Figure 2.3

Figure 2.3 gives the 2D plot of the simulation at theta=90°.

## Conclusion

In real simulation results, the pattern with stimulation conditions calculated in topic 1 does not follow the theoretical pattern.

# Topic 3

## Introduction

Repeat topic 1 and 2 with a spacing of λ/8. Provide the same plots as topic 1 and 2.

## Simulation

```
A = [0 pi/3 2*pi/3];
%A is the nulls of the pattern
d = 1/8;
%d is the distance between each element
b = 0;
%b is the progressive phase shift of each element
iso(A,d,b)
```

The output gives:

```
M =

   1.0000 + 0.0000i  -2.5549 - 0.7071i   2.3066 + 1.3066i  -0.7071 - 0.7071i
```

Figure 3.1

Figure 3.1 gives the excitation of each element both in amplitude and phase.

$A_1 = 1; A_2 = 2.65e^{j196}; A_3 = 2.65e^{j30};\ A_4 = e^{j225}$

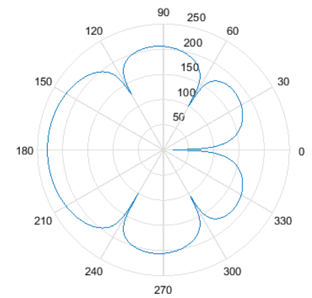



Figure 3.2

Figure 3.2 gives the 2D pattern of the array factor of the antenna array. It is clear there are three nulls at θ = 0°, 60°, and 120°.

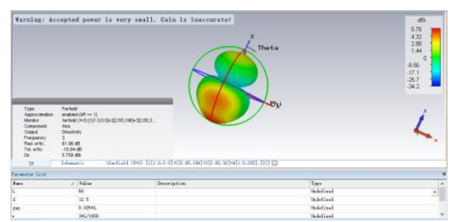



Figure 3.3

Figure 3.3 shows the 3D pattern of the simulation.

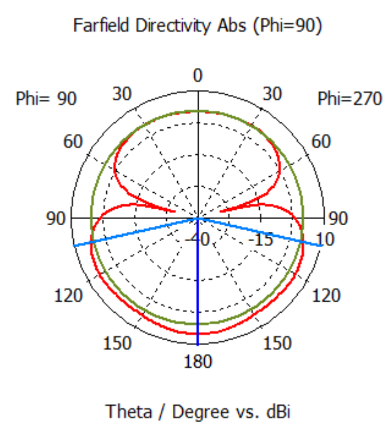



Figure 3.4

Figure 3.4 gives the 2D plot of the simulation at phi=90°.

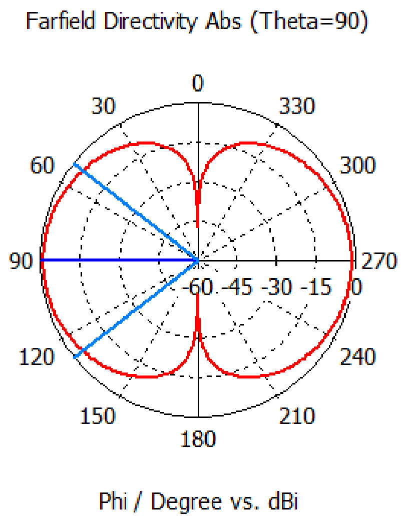



Figure 3.5

Figure 3.5 gives the 2D plot of the simulation at theta=90°.

## Conclusion

The real pattern has great difference with the one which is calculated theoretically. The reason is the real pattern of an antenna array does not fit the equation of

Total Field=Single Element*Array Factor

which only holds true for infinitesimal dipole array.

# Topic 4

## Introduction

Design a linear array of isotropic elements placed along the z-axis such that the zeros of the array factor occur at θ = 0°, 135°, and 180°. Assume that the elements are spaced λ/4 apart with a progressive phase shift between them as 0°.

## Simulation

```
A = [0 3*pi/4 pi];
%A is the nulls of the pattern
d = 1/4;
%d is the distance between each element
b = 0;
%b is the progressive phase shift of each element
iso(A,d,b)
```

The output gives:

```
M =

1.0000 + 0.0000i  -0.4440 + 0.8960i   1.0000 - 0.0000i  -0.4440 + 0.8960i
```

Figure 4.1

Figure 3.1 gives the excitation of each element both in amplitude and phase.

$A_1 = 1; A_2 = e^{j116}; A_3 = 1;\ A_4 = e^{j116}$

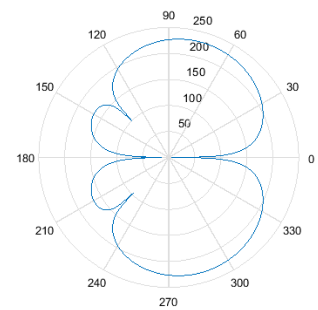



Figure 4.2

Figure 4.2 gives the 2D pattern of the array factor of the antenna array. It is clear there are three nulls at θ = 0°, 135°, and 180°.

# Topic 5

## Introduction

Use an infinitesimal dipole array directed along the z axis to implement your design in topic 4. Plot 2D pattern and 3D pattern.

## Simulation

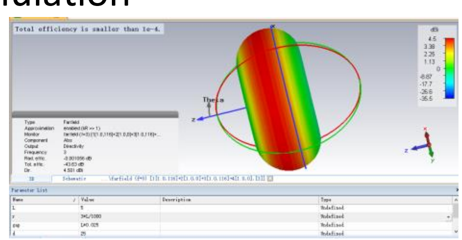



Figure 5.1

Figure 5.1 shows the 3D pattern of the simulation.

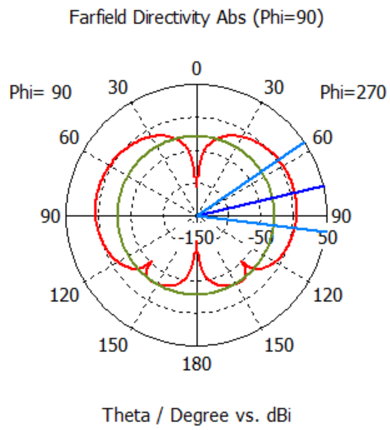



Figure 5.2

Figure 5.2 gives the 2D plot of the simulation at phi=90°.

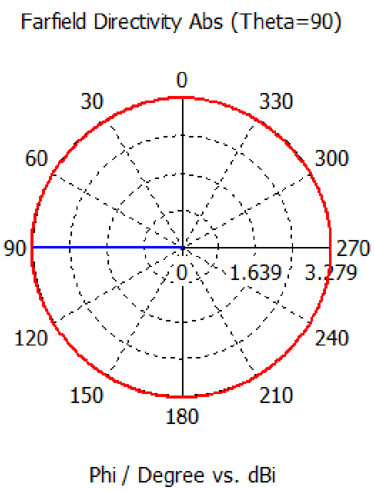



Figure 5.3

Figure 5.3 gives the 2D plot of the simulation at theta=90°.

## Conclusion

In this section, the real simulation result is similar with the pattern in calculation. It is because the single element of the antenna array is infinitesimal dipole.

# Topic 6

## Introduction

Design a linear array of infinitesimal dipoles directed and placed along the z-axis such that the zeros of the array factor occur at θ = 0°, 10°, 30°, 40°, 60°, 70°, 90°, 110°, 120°, 140°, 150°, 170°, and 180°. Assume that the elements are spaced λ/4 apart and that the progressive phase shift between them is 0°. Find the required number of elements, determine their excitation coefficients, and plot 2D pattern.

## Simulation

```
M =

   1.0e+02 *

  Columns 1 through 6

   0.0100 + 0.0000i  -0.0532 - 0.0000i   0.1681 + 0.0000i  -0.3808 - 0.0000i   0.6746 + 0.0000i  -0.9709 - 0.0000i

  Columns 7 through 12

   1.1598 + 0.0000i  -1.1598 - 0.0000i   0.9709 + 0.0000i  -0.6746 - 0.0000i   0.3808 + 0.0000i  -0.1681 - 0.0000i

  Columns 13 through 14

   0.0532 + 0.0000i  -0.0100 - 0.0000i
```

Figure 6.1

Figure 1.1 gives the excitation of each element both in amplitude and phase.

$$A_1 = 0.01;\ A_2 = 0.0532e^{180};$$
$$A_3 = 0.1681;\ A_4 = 0.3808e^{180};$$
$$A_5 = 0.6746;\ A_6 = 0.9709e^{180};$$
$$A_7 = 1.1598; A_8 = 1.1598e^{180};$$
$$A_9 = 0.9709;\ A_{10} = 0.6746e^{180};$$
$$A_{11} = 0.3808;\ A_{12} = 0.1681e^{180};$$
$$A_{13} = 0.0532;\ A_{14} = 0.01e^{180}$$

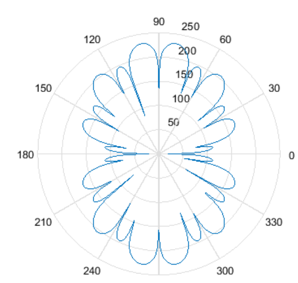



Figure 6.2

Figure 6.2 gives the 2D pattern of the array factor of the antenna array. It is clear there are three nulls at θ = 0°, 10°, 30°, 40°, 60°, 70°, 90°, 110°, 120°, 140°, 150°, 170° and 180°.

# Topic 7

## Introduction

Design the current distribution on a line-source placed along the z-axis whose desired radiation pattern is given by SF(θ) = 1 for π/4 ≤ θ ≤ 3π/4 and 0 elsewhere. Plot the desired current distribution. Truncate the current to 5λ, 10λ and 20λ long and plot the corresponding space factor together with the desired pattern.

## Simulation

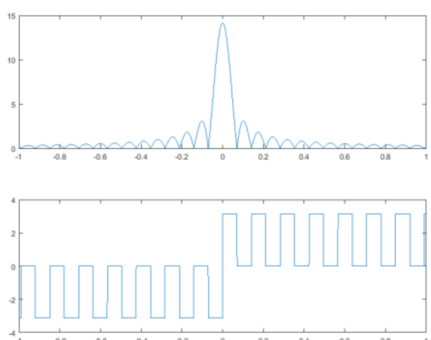


Figure 7.1

Figure 7.1 shows the current distribution by calculating Fourier Transform of the space factor in Matlab.

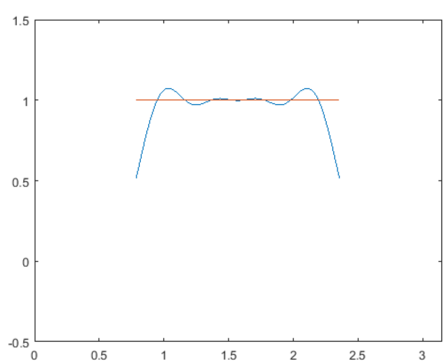


Figure 7.2

Figure 7.2 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 5λ in length. The red line is the ideal case.

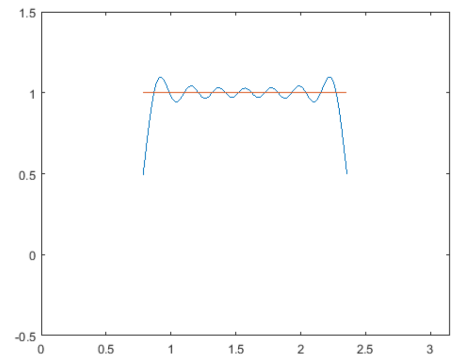


Figure7.3

Figure 7.3 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 10λ in length. The red line is the ideal case.

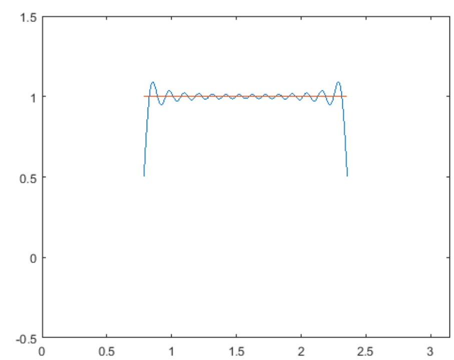


Figure7.4

Figure 7.4 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 20λ in length. The red line is the ideal case.

## Conclusion

In this section, it proves that the space factor and the current distribution has a relationship as a Fourier Transform pair. And when the current distribution is given, the synthesis of space factor has a better similarity compared with the ideal case.

# Topic 8

## Introduction

Repeat topic 7 with SF(θ) = 1 for $3\pi/8 \le \theta \le 5\pi/8$ and 0 elsewhere. Beside provide the same plots as topic 7, also compare the desired current distribution in this topic with that in topic 7.

## Simulation

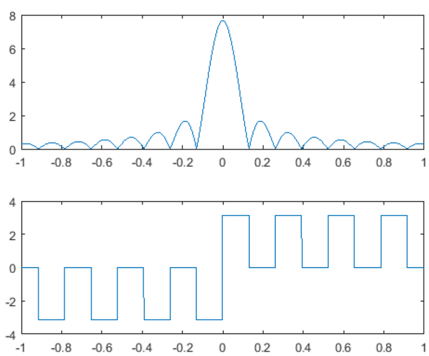


Figure 8.1

Figure 8.1 shows the current distribution by calculating Fourier Transform of the space factor in Matlab.

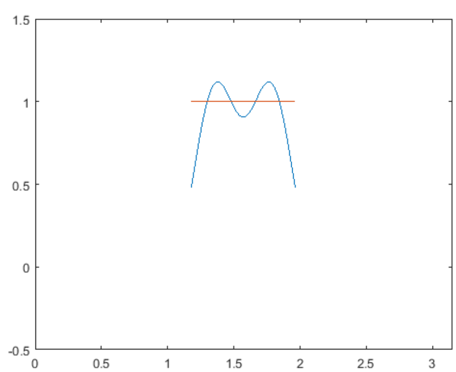


Figure 8.2

Figure 8.2 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 5λ in length. The red line is the ideal case.

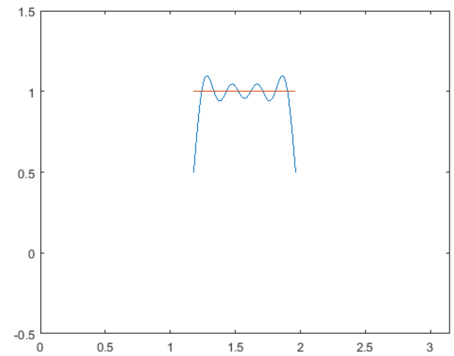


Figure 8.3

Figure 8.3 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 10λ in length. The red line is the ideal case.

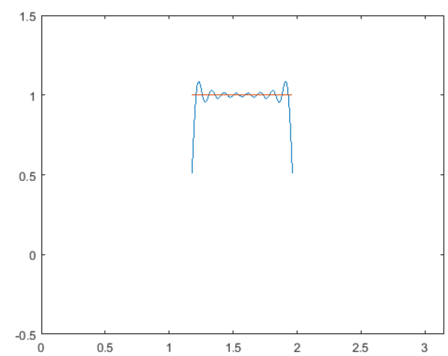


Figure8.4

Figure 8.4 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 20λ in length. The red line is the ideal case.

## Conclusion

When the width of SF is decreased, the amplitude of the sinc function as the current distribution would as be decreased, while the width of spread will be enhanced.

# Topic 9

## Introduction

Repeat topic 7 with SF(θ) = 1 for $\pi/3 \le \theta \le \pi/2$ and 0 elsewhere. Provide the same plots as topic 7.

## Simulation

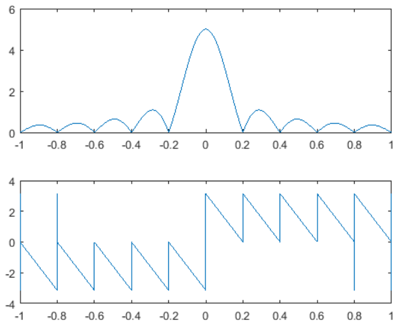


Figure 9.1

Figure 9.1 shows the current distribution by calculating Fourier Transform of the space factor in Matlab.

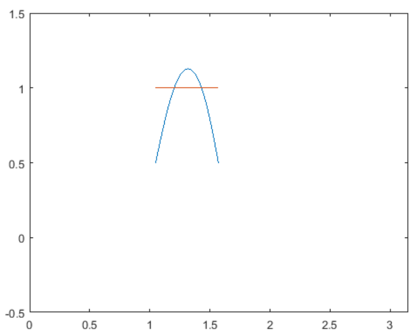


Figure 9.2

Figure 9.2 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 5λ in length. The red line is the ideal case.

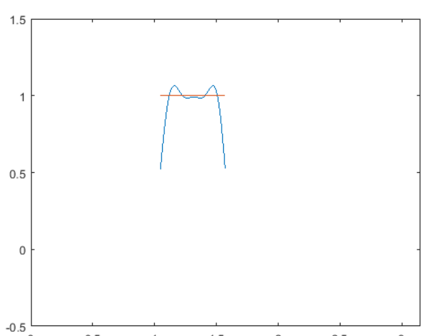


Figure 9.3

Figure 9.3 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 10λ in length. The red line is the ideal case.

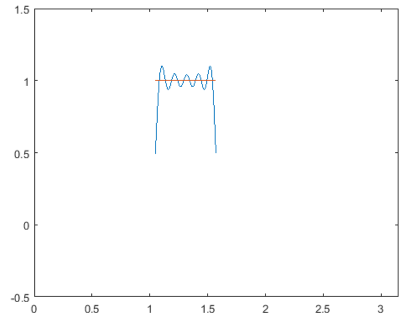


Figure9.4

Figure 9.4 is the space factor by calculating the inverse of Fourier Transform of the current which is truncated as 20λ in length. The red line is the ideal case.

## Conclusion

In Figure 9.1, it is clear the amplitude of the current distribution is symmetric while the phase isn’t. It is because the space factor is not symmetric to the pi/2 anymore. It also gives a intuition that the similarity of synthesis space factor is lower when the width of the origin one is decreased.

# Topic 10

## Introduction

Repeat topic 7 with a linear array of d = λ/2. Try 11 and 21 elements. Plot the array factor together with the desired pattern.

## Simulation

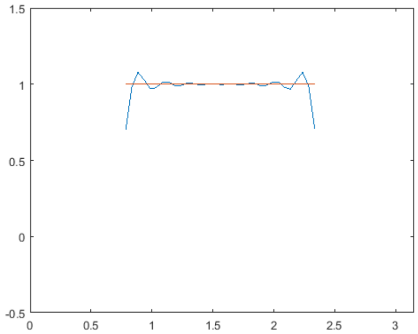



Figure 10.1

Figure 10.1 shows the synthesis of space factor with 11 elements.

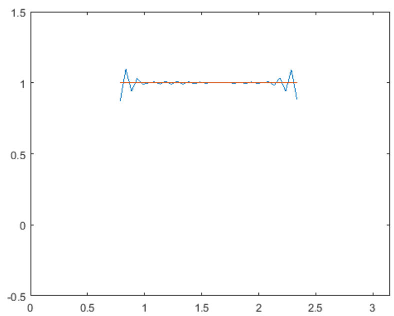



Figure 10.2

Figure 10.2 shows the synthesis of space factor with 21 elements.

## Conclusion

It is clear when the number of elements is increased, the similarity of space factor is higher compared with the origin pattern.

# Topic 11

## Introduction

Use an infinitesimal dipole array directed and placed along the z axis to implement your design in topic 10 for both 11 and 21 elements. Plot 2D pattern and 3D pattern.

## Simulation

1. 11 elements

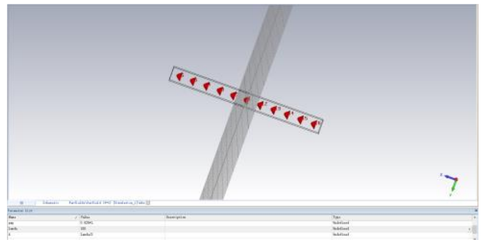
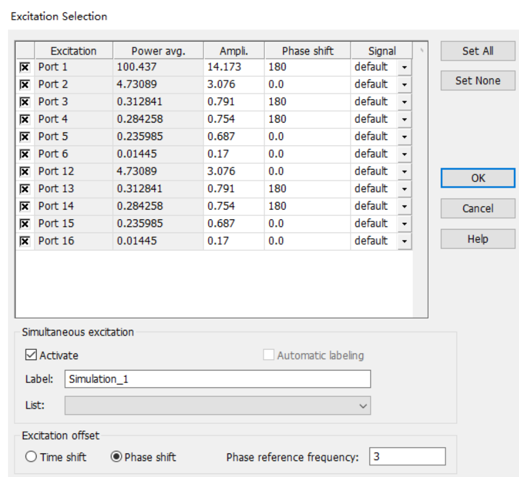


Figure 11.1.1

Figure 11.1.1 gives the schematic of simulation.


Excitation Selection

| Excitation | Power avg. | Ampl. | Phase shift | Signal |
|---|---|---|---|---|
| Port 1 | 100.437 | 14.173 | 180 | default |
| Port 2 | 4.73089 | 3.076 | 0.0 | default |
| Port 3 | 0.312841 | 0.791 | 180 | default |
| Port 4 | 0.284258 | 0.754 | 180 | default |
| Port 5 | 0.235985 | 0.687 | 0.0 | default |
| Port 6 | 0.01445 | 0.17 | 0.0 | default |
| Port 12 | 4.73089 | 3.076 | 0.0 | default |
| Port 13 | 0.312841 | 0.791 | 180 | default |
| Port 14 | 0.284258 | 0.754 | 180 | default |
| Port 15 | 0.235985 | 0.687 | 0.0 | default |
| Port 16 | 0.01445 | 0.17 | 0.0 | default |



Figure 11.1.2

Figure 11.1.2 shows the excitations of each ports showed in figure 11.1.1. Data is drawn from topic 7.

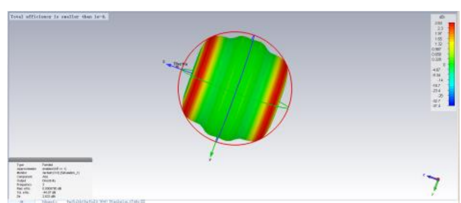


Figure 11.1.3

Figure 11.1.3 shows the 3D pattern of the simulation.

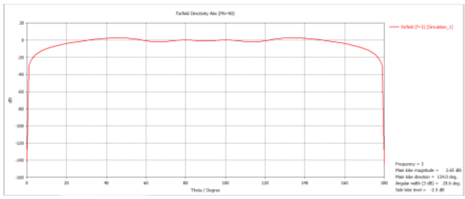


Figure 11.1.4

Figure 11.1.4 shows the 2D pattern of the simulation in Cartesian coordinate.

## 2. 21 elements

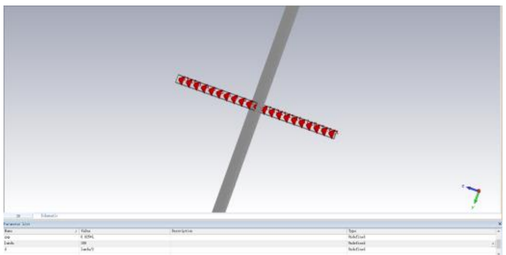
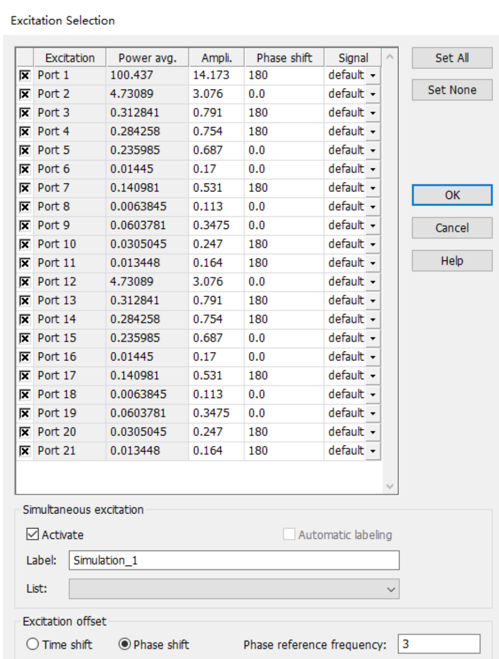


Figure 11.2.1

Figure 11.2.1 gives the schematic of simulation.




| Excitation | Power avg. | Ampl. | Phase shift | Signal |
|---|---|---|---|---|
| Port 1 | 100.437 | 14.173 | 180 | default |
| Port 2 | 4.73089 | 3.076 | 0.0 | default |
| Port 3 | 0.312841 | 0.791 | 180 | default |
| Port 4 | 0.284258 | 0.754 | 180 | default |
| Port 5 | 0.235985 | 0.687 | 0.0 | default |
| Port 6 | 0.01445 | 0.17 | 0.0 | default |
| Port 7 | 0.140981 | 0.531 | 180 | default |
| Port 8 | 0.0063845 | 0.113 | 0.0 | default |
| Port 9 | 0.0603781 | 0.3475 | 0.0 | default |
| Port 10 | 0.0305045 | 0.247 | 180 | default |
| Port 11 | 0.013448 | 0.164 | 180 | default |
| Port 12 | 4.73089 | 3.076 | 0.0 | default |
| Port 13 | 0.312841 | 0.791 | 180 | default |
| Port 14 | 0.284258 | 0.754 | 180 | default |
| Port 15 | 0.235985 | 0.687 | 0.0 | default |
| Port 16 | 0.01445 | 0.17 | 0.0 | default |
| Port 17 | 0.140981 | 0.531 | 180 | default |
| Port 18 | 0.0063845 | 0.113 | 0.0 | default |
| Port 19 | 0.0603781 | 0.3475 | 0.0 | default |
| Port 20 | 0.0305045 | 0.247 | 180 | default |
| Port 21 | 0.013448 | 0.164 | 180 | default |

Figure 11.2.2

Figure 11.2.2 shows the excitations of each ports showed in figure 11.2.1. Data is drawn from topic 7.

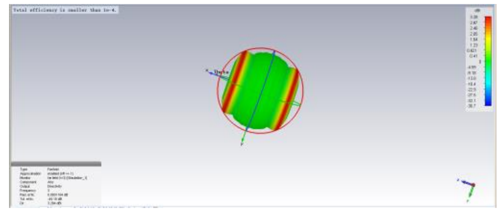


Figure 11.2.3

Figure 11.2.3 shows the 3D pattern of the simulation.

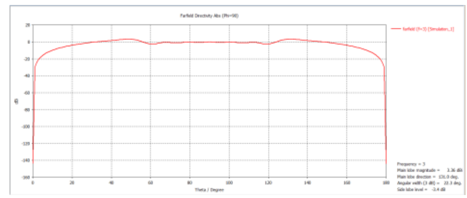


Figure 11.2.4

Figure 11.2.4 shows the 2D pattern of the simulation in Cartesian coordinate.

# Conclusion

In simulation, it is also true that with more elements which will produce a better perform space factor compared with the ideal case.

# Topic 12

## Introduction

Use an infinitesimal dipole array directed and placed along the z axis to synthesize a pattern given by the following expression. Use 31 elements and d = λ/2. Plot 2D pattern in Cartesian coordinate and 3D pattern.

$$\mathrm{SF} = \begin{cases} \frac{1}{30}\theta - 2, & 60^\circ \le \theta \le 90^\circ \\ 4 - \frac{1}{30}\theta, & 90^\circ \le \theta \le 120^\circ \\ 0 & \text{elsewhere} \end{cases}$$

## Simulation

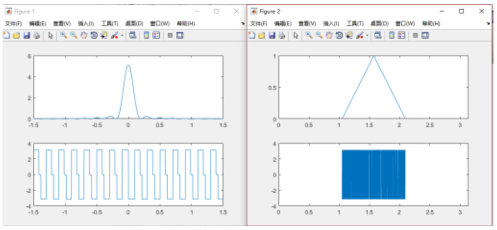


Figure 12.1

Figure 12.1 shows the current distribution and the synthesis of the space factor by calculating Fourier Transform in Matlab.

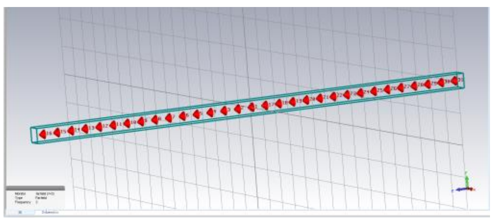
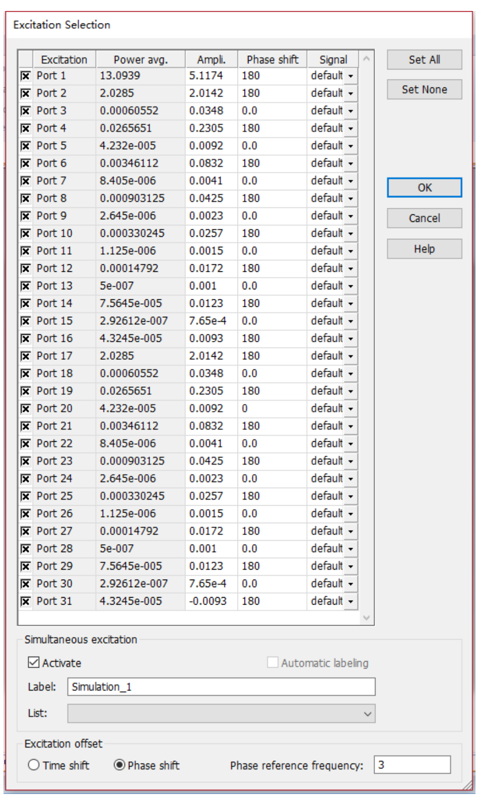


Figure 12.2

Figure 12.2 gives the schematic of simulation.



| | Excitation | Power avg. | Ampl. | Phase shift | Signal |
|---|---|---|---|---|---|
| ☒ | Port 1 | 13.0939 | 5.1174 | 180 | default |
| ☒ | Port 2 | 2.0285 | 2.0142 | 180 | default |
| ☒ | Port 3 | 0.00060552 | 0.0348 | 0.0 | default |
| ☒ | Port 4 | 0.0265651 | 0.2305 | 180 | default |
| ☒ | Port 5 | 4.232e-005 | 0.0092 | 0.0 | default |
| ☒ | Port 6 | 0.00346112 | 0.0832 | 180 | default |
| ☒ | Port 7 | 8.405e-006 | 0.0041 | 0.0 | default |
| ☒ | Port 8 | 0.000903125 | 0.0425 | 180 | default |
| ☒ | Port 9 | 2.645e-006 | 0.0023 | 0.0 | default |
| ☒ | Port 10 | 0.000330245 | 0.0257 | 180 | default |
| ☒ | Port 11 | 1.125e-006 | 0.0015 | 0.0 | default |
| ☒ | Port 12 | 0.00014792 | 0.0172 | 180 | default |
| ☒ | Port 13 | 5e-007 | 0.001 | 0.0 | default |
| ☒ | Port 14 | 7.5645e-005 | 0.0123 | 180 | default |
| ☒ | Port 15 | 2.92612e-007 | 7.65e-4 | 0.0 | default |
| ☒ | Port 16 | 4.3245e-005 | 0.0093 | 180 | default |
| ☒ | Port 17 | 2.0285 | 2.0142 | 180 | default |
| ☒ | Port 18 | 0.00060552 | 0.0348 | 0.0 | default |
| ☒ | Port 19 | 0.0265651 | 0.2305 | 180 | default |
| ☒ | Port 20 | 4.232e-005 | 0.0092 | 0 | default |
| ☒ | Port 21 | 0.00346112 | 0.0832 | 180 | default |
| ☒ | Port 22 | 8.405e-006 | 0.0041 | 0.0 | default |
| ☒ | Port 23 | 0.000903125 | 0.0425 | 180 | default |
| ☒ | Port 24 | 2.645e-006 | 0.0023 | 0.0 | default |
| ☒ | Port 25 | 0.000330245 | 0.0257 | 180 | default |
| ☒ | Port 26 | 1.125e-006 | 0.0015 | 0.0 | default |
| ☒ | Port 27 | 0.00014792 | 0.0172 | 180 | default |
| ☒ | Port 28 | 5e-007 | 0.001 | 0.0 | default |
| ☒ | Port 29 | 7.5645e-005 | 0.0123 | 180 | default |
| ☒ | Port 30 | 2.92612e-007 | 7.65e-4 | 0.0 | default |
| ☒ | Port 31 | 4.3245e-005 | -0.0093 | 180 | default |



Figure 12.3

Figure 12.3 shows the excitations of each ports showed in figure 12.2. Data is drawn from simulation in Matlab in previous section.

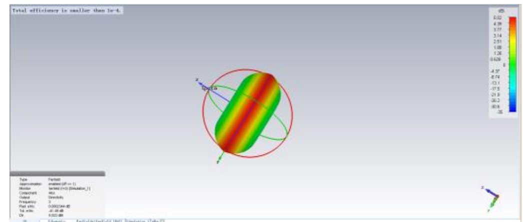


Figure 12.4

Figure 12.4 shows the 3D pattern of the simulation.

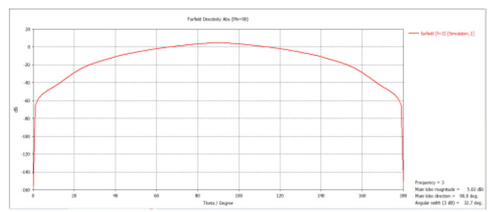


Figure 12.5

Figure 12.5 shows the 2D pattern of the simulation in Cartesian coordinate.

## Conclusion

In the case, the space factor is not uniform. From the result, we can figure out that the whole pattern has trend as a triangle though it is not very close to the origin space factor.