Aalto University
School of Electrical
Engineering

ELEC-E4740 – Antenna Workshop

4-way Power Divider and Vivaldi Antenna Design

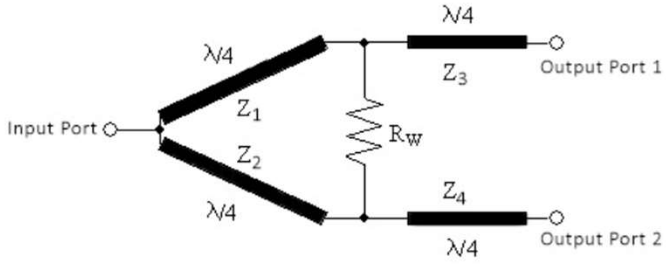
Group 1: Guo, Sihan & Zhenhan

Contents

Aalto University
School of Electrical
Engineering

1.1 Operational Principle of Power Divider

1. Formula for Wilkinson Power Divider



For output power ratio (P_A/ P_B =1):

$Z_1 = Z_2 = 70.71\Omega \quad Z_3 = Z_4 = 50\Omega \quad R_w = 100\Omega$

Physical characteristics of transmission line:

$L_1 = L_2 = 13.746\ mm \qquad W_1 = W_2 = 2.883mm$

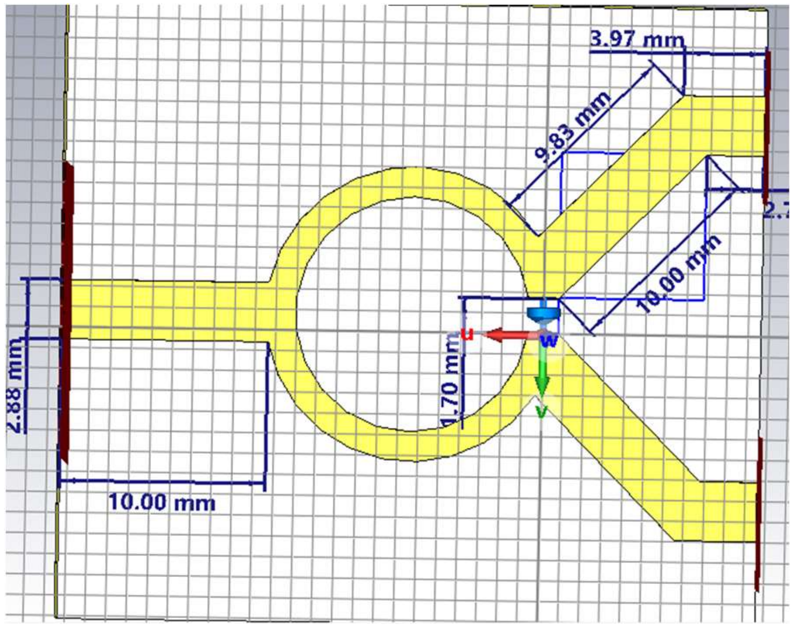
$L_3 = L_4 = 14.153\ mm \qquad W_4 = W_4 = 1.505mm$

2. Initial Design of Power Divider

a). Compact layout → Circle-shape line

$$W_1 = R_{out} - R_{in} = 2.883mm$$

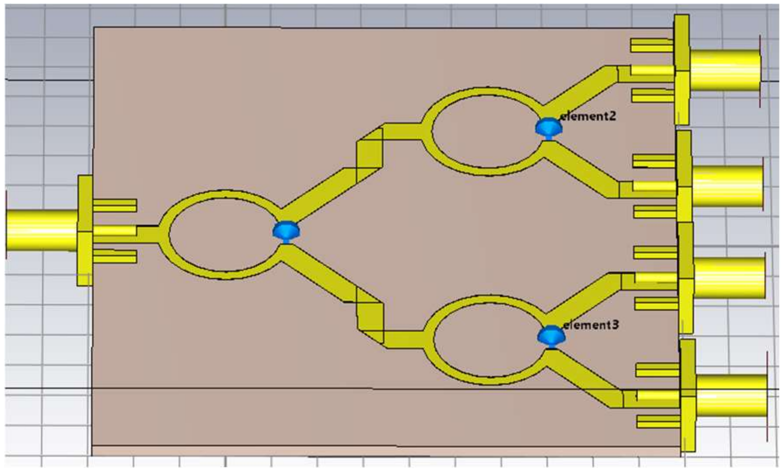
$$L_1 = \pi \cdot (R_{out} + R_{in}) - l_{gap} = 13.746mm$$

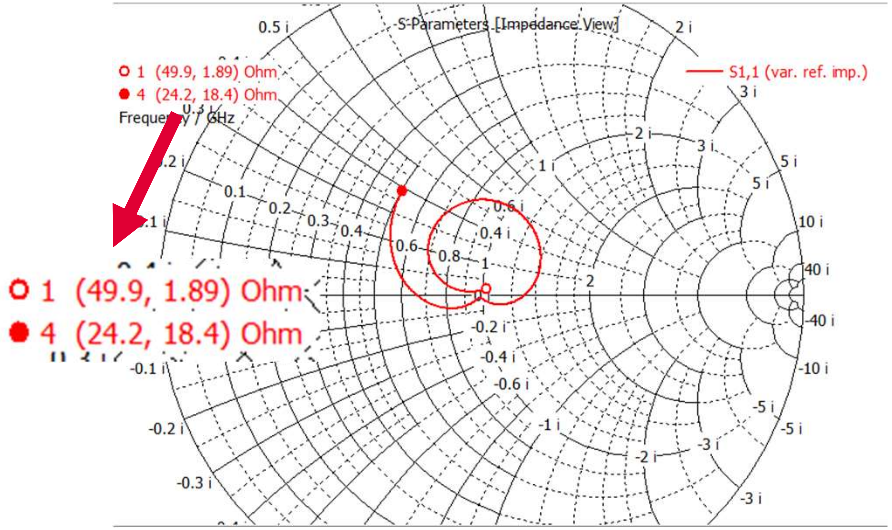


1.2 Four-Way Wilkinson Power Divider Design

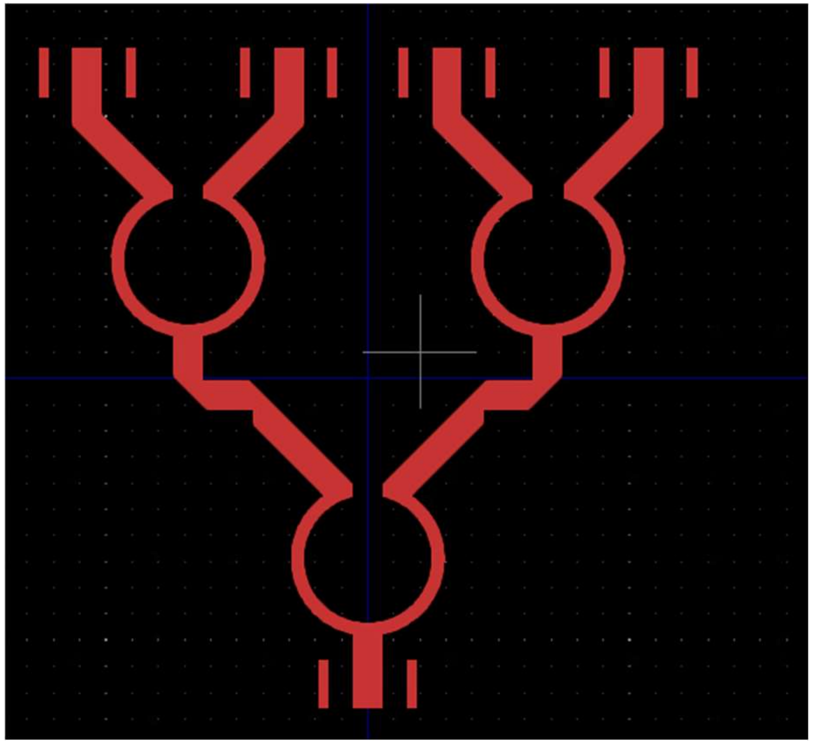
4-way Wilkinson power divider design:

- For 4 Vivaldi antenna arrays.
- Symmetric design for in-phase signal output.
- Y-shape transmission line to reduce mutual coupling in one divider.
- Extended transmission line to minimize the mutual coupling for cascaded two dividers.
- Mitered Bents to reduce the reflection and shunt capacitance in corners.

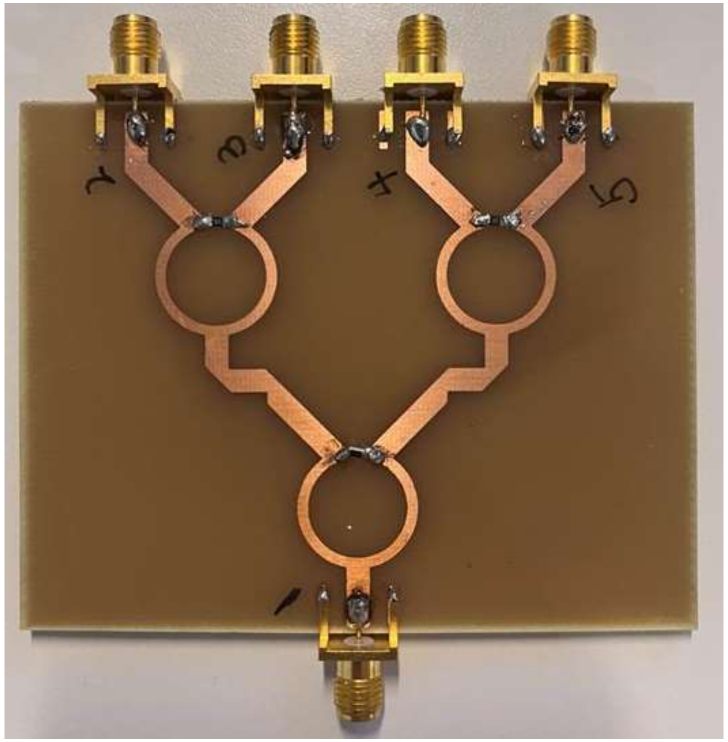




1.3 Final Layout and Fabricated Prototype



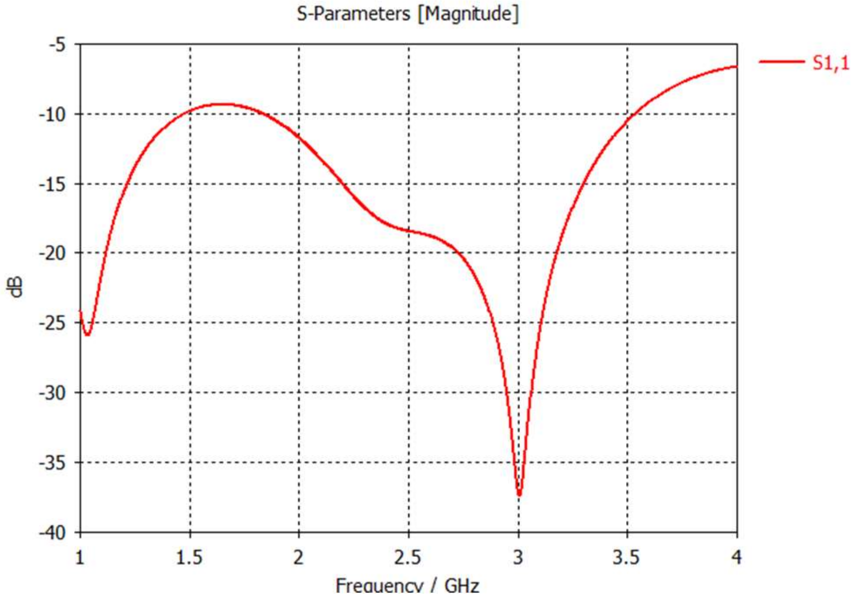
a) Final layout



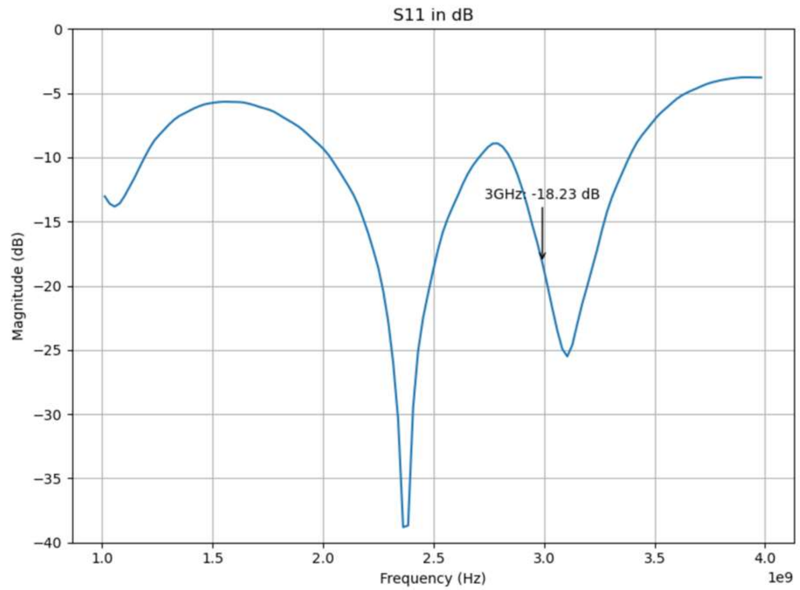
b) Fabricated Prototype

1.4 Comparisons (Simulation vs. Measurement)

a) Comparison of S_{11} in Simulated and Practical Divider



a) Simulation results

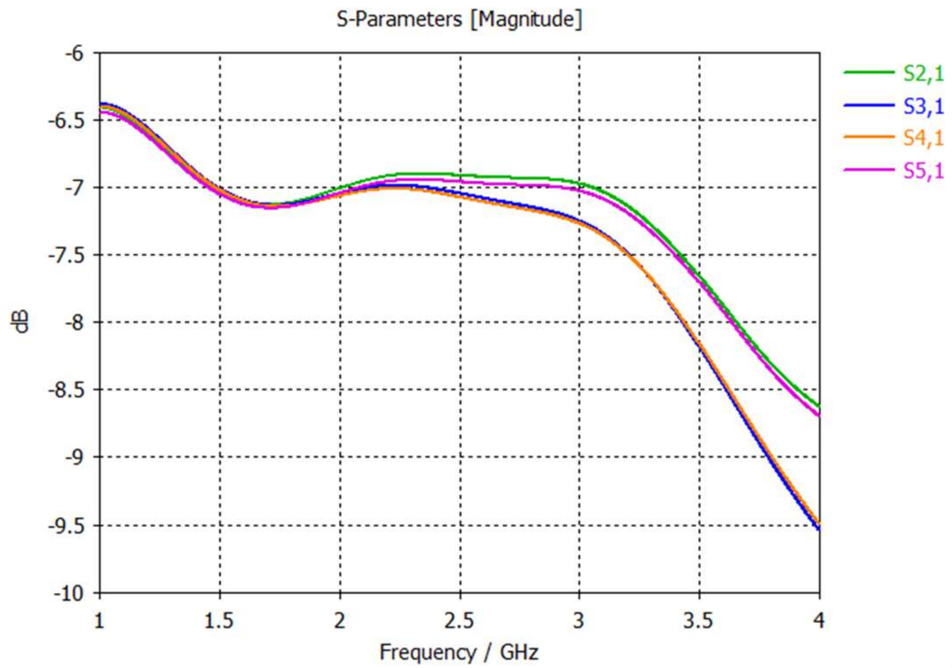


b) Measurement results

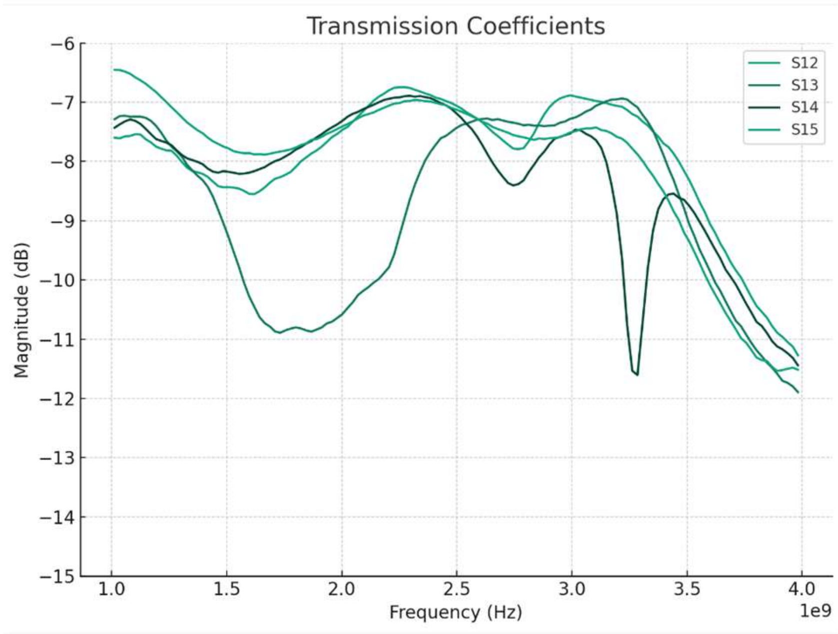
- Slight frequency shift observed.
- At 3GHz, practical divider's S_{11} < -15dB, indicating good performance.
- The actual power divider has two distinct minimum points. (Why?)
- The bandwidths of these two dividers are similar.

1.4 Comparisons (Simulation vs. Measurement)

b) Comparison of transmission coefficients.



a) Simulation results

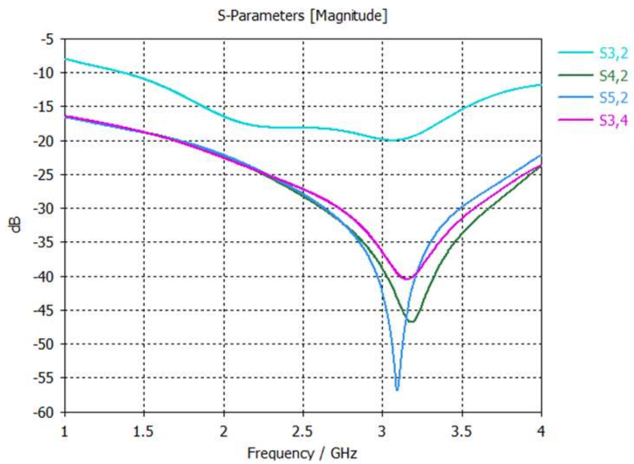


b) Measurement results

All transmission coefficients are above -7.5dB, which is quite similar to the simulated results.

1.4 Comparisons (Simulation vs. Measurement)

c) Comparison of isolation between each port.

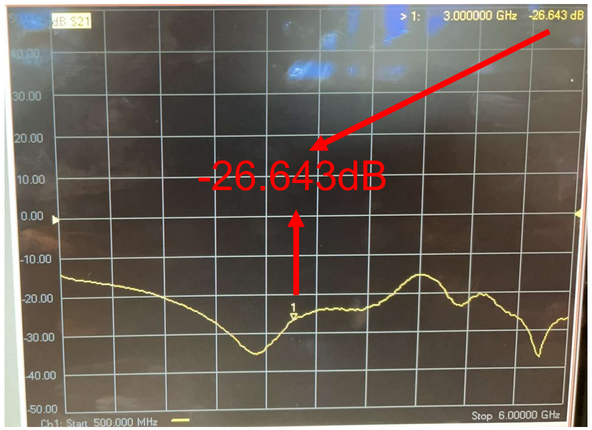


a) Simulation results

b) S_{32}

c) S_{34}

d) S_{42}

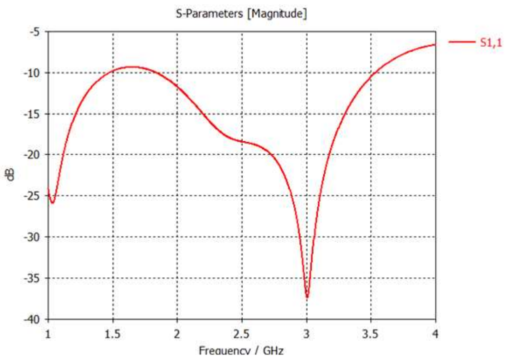


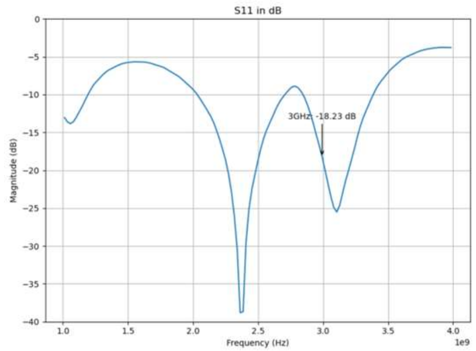
e) S_{52}

The results show all isolations are below -20dB

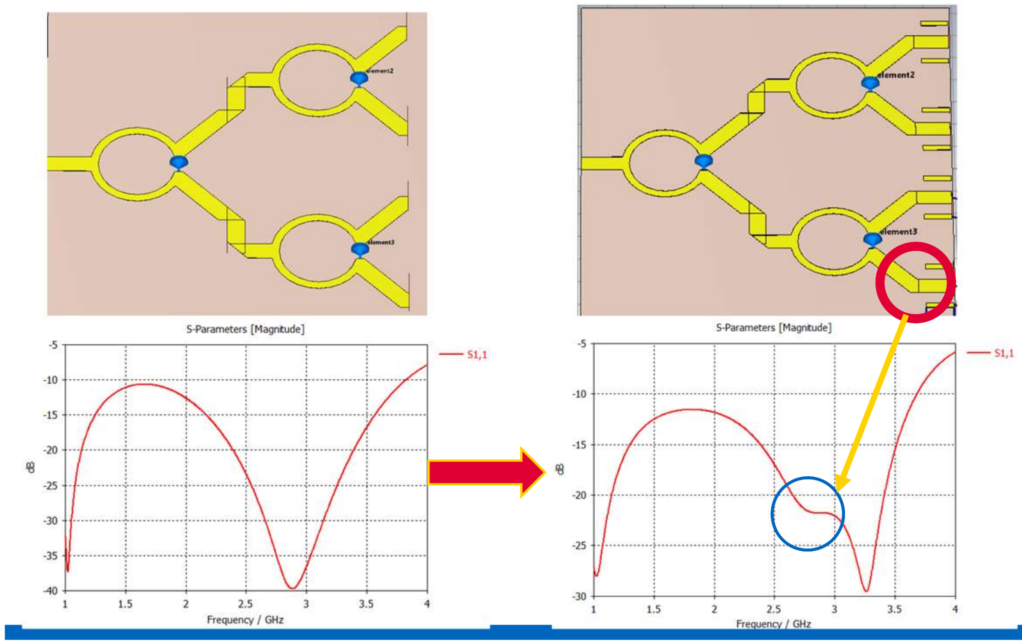
1.5 Discussion and Analysis

A) Why does S_{11} have two distinct minimum points in measurement?





- Potential reasons:

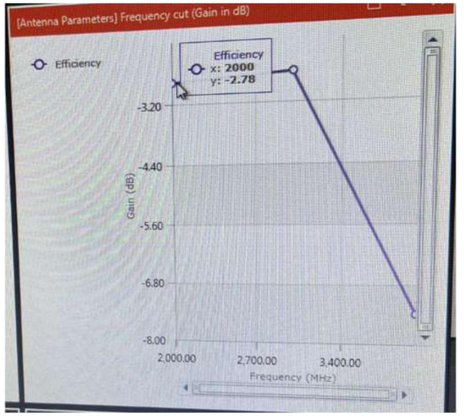


In the simulation, I find that non-mitered bents will bend S_{11} curve before 3GHz.

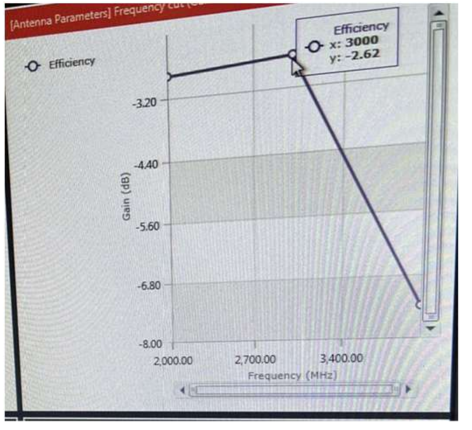
Thus, I guess that this effect may be enlarged in practice resulting in another minimum frequency point.

1.5 Discussion and Analysis

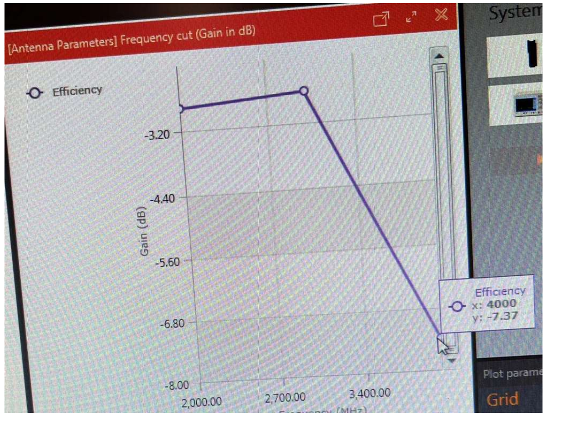
B) The relation between the bandwidth of the power divider and antenna radiation efficiency



a) 2GHz: -2.78dB



b) 3GHz: -2.62dB

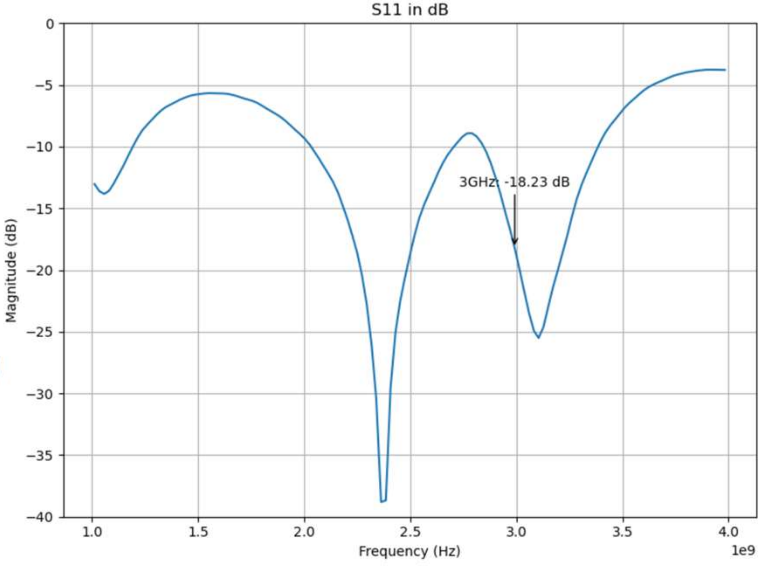


b) 4GHz: -7.37dB

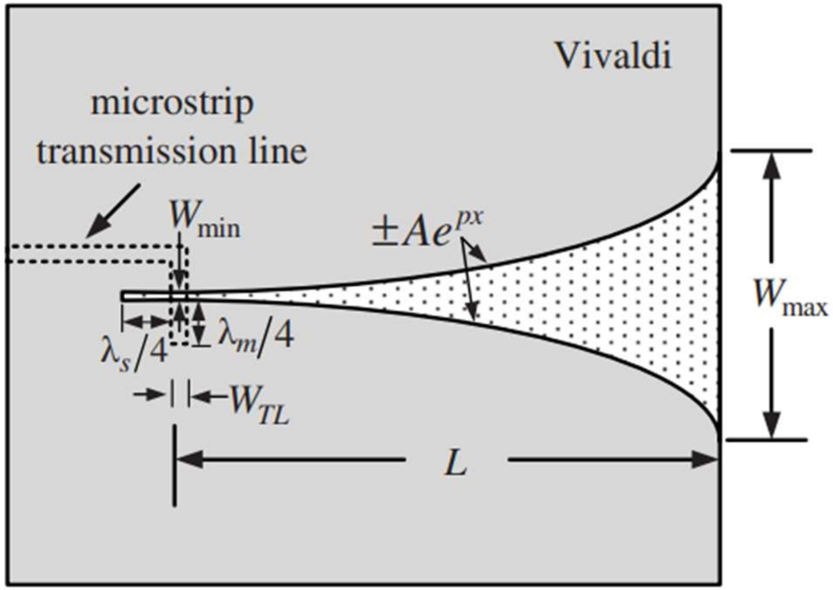
Fig. The radiation efficiency measured in StarLab.

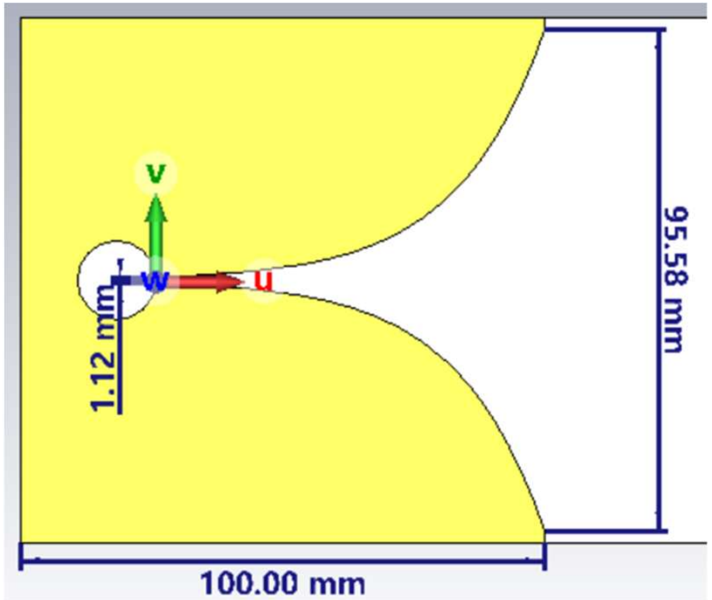
We have observed that the radiation efficiency of the antenna drops dramatically at 4GHz.

This is because the reflection coefficient of the power splitter is very large at 4GHz, and only a small amount of energy enters the antenna.



2.1 Operational Principle of Vivaldi Antenna





A typical Vivaldi antenna:

- Formed by a quarter-wavelength slot.
- Exponentially tapered slot connected.
- Fed by microstrip line.
- Slot can be circular or square resonant area.

Vivaldi Antenna Radiation Characteristics

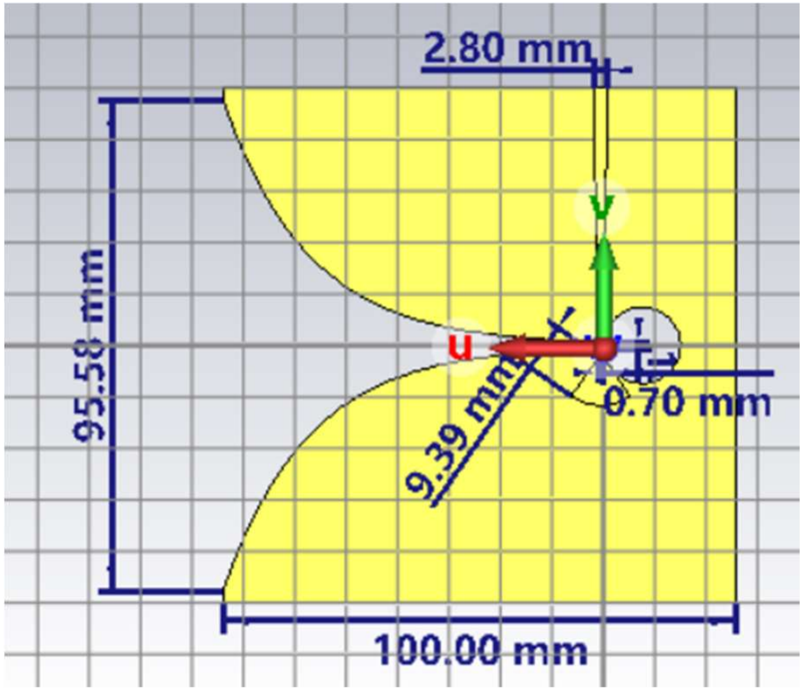
- Limited by W_{min} and W_{max}.
- End-fire direction when gap $\frac{\lambda}{2}$.

Design parameters:

$A = 0.5 \quad p = 0.06$

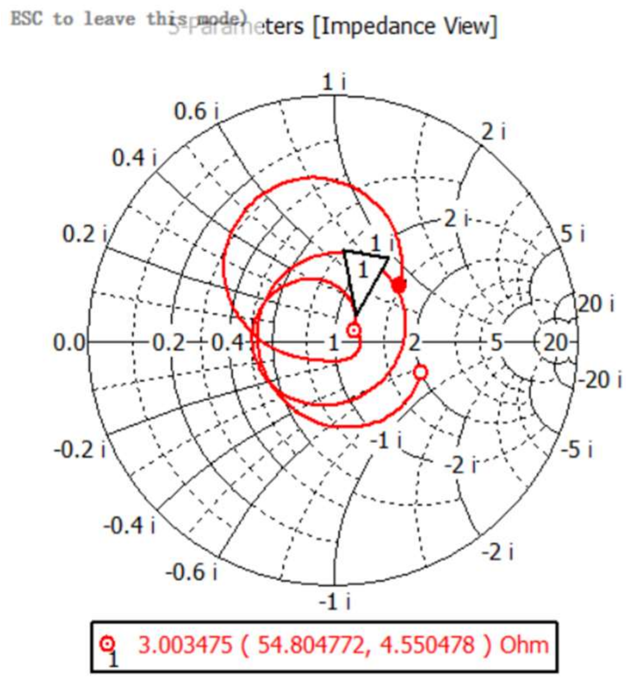
Circular radius: $R_1 = 7.5\ mm$

2.1 Design of the Feeding Structure



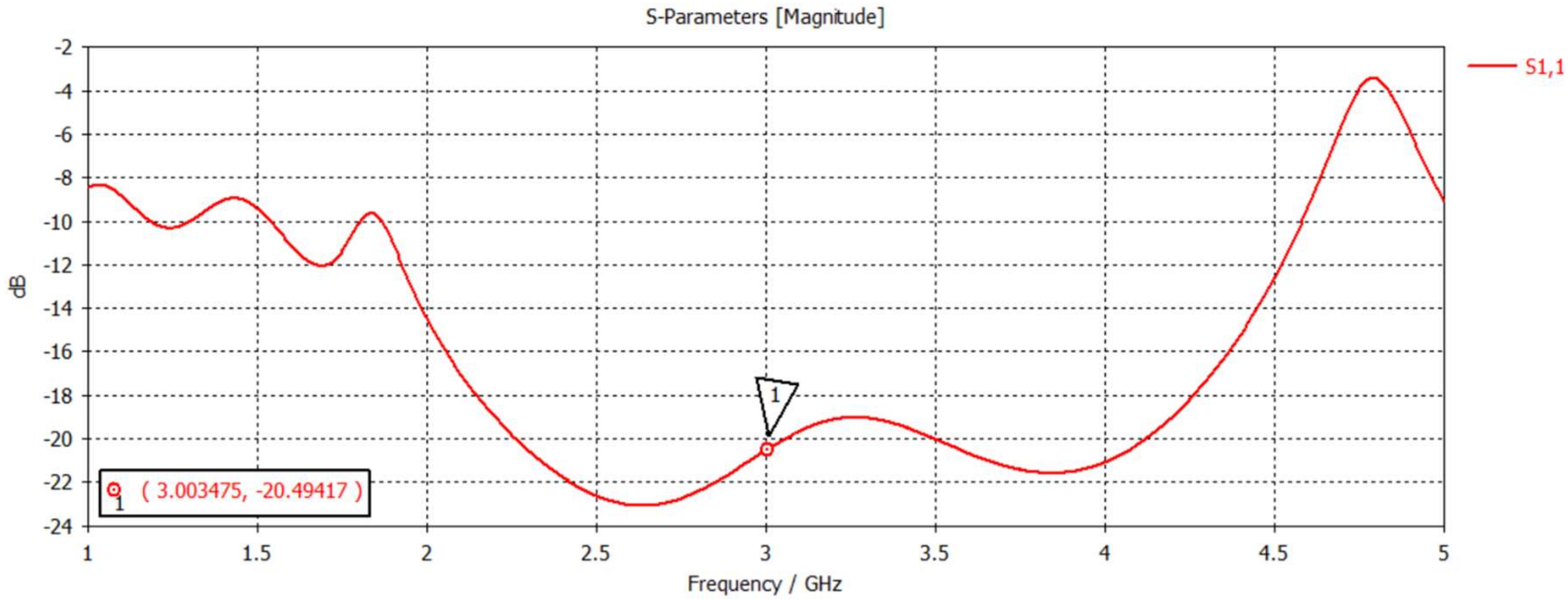
Feeding line design:

- Tapering microstrip line from 2.80mm to 0.70mm for wider impedance matching.
- Fan-shaped stub for impedance matching and better radiation efficiency.



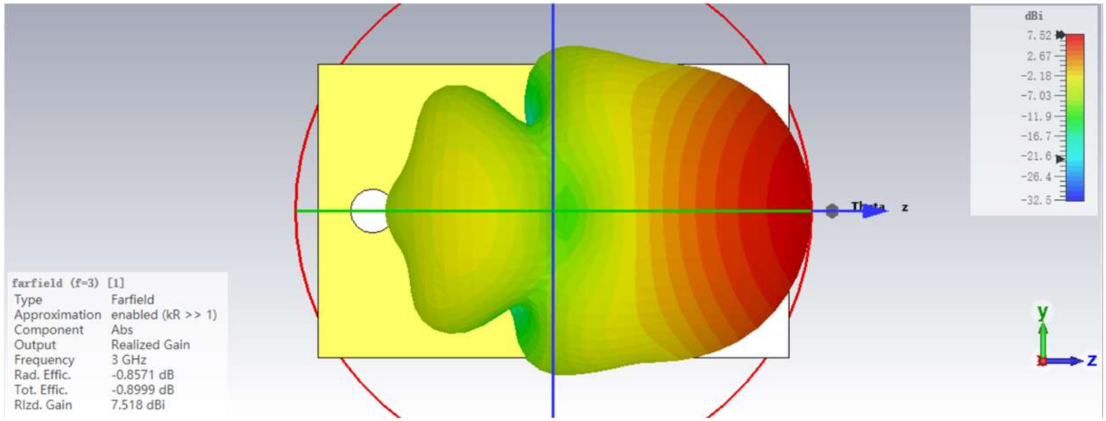
Due to the board bandwidth of Vivaldi antenna, the primary limitation is the matching of feeding line design.

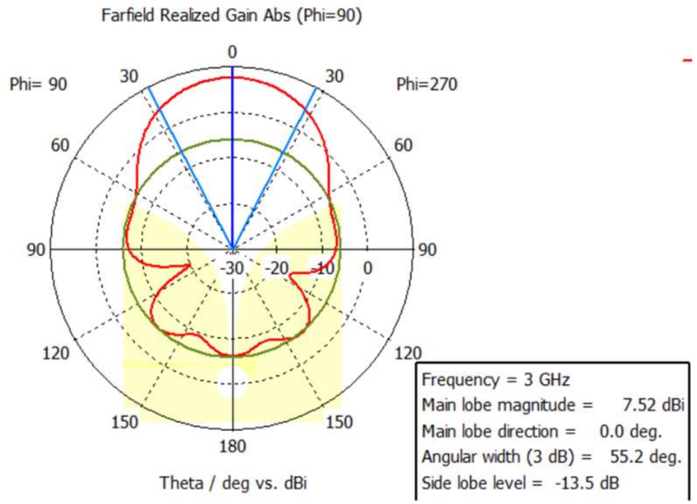
2.2 Simulation of a single Vivaldi antenna



The S_{11} parameter at 3GHz is below -20dB, and the -10dB bandwidth is over 2.5GHz, which is over 83%.

2.2 Simulation of a single Vivaldi antenna



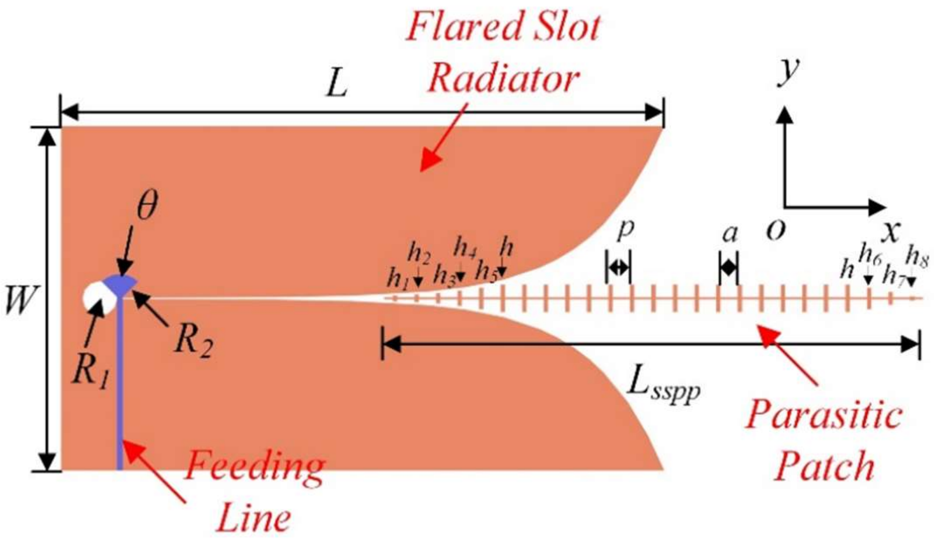


- The radiation efficiency: $-0.8571dB$.
- The maximum realized gain: $7.52dB$.

$$r_{max} = \left(\frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 S_{min}}\right)^{1/4}$$ =5.27m

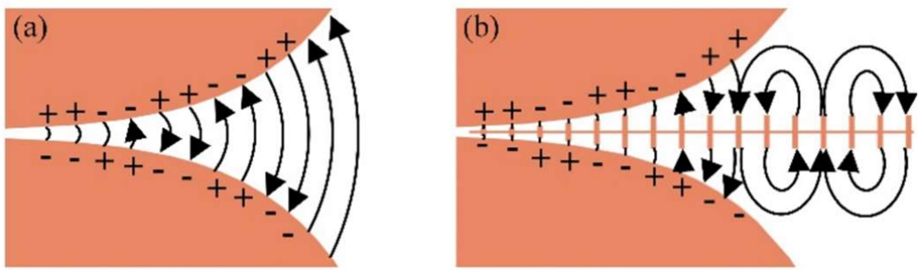
Although it is not perfectly symmetric due to the feeding line, it still radiates to the end-fire direction perfectly.

2.3 Parasitic Patch Design



Gain enhancement for Vivaldi Antenna:

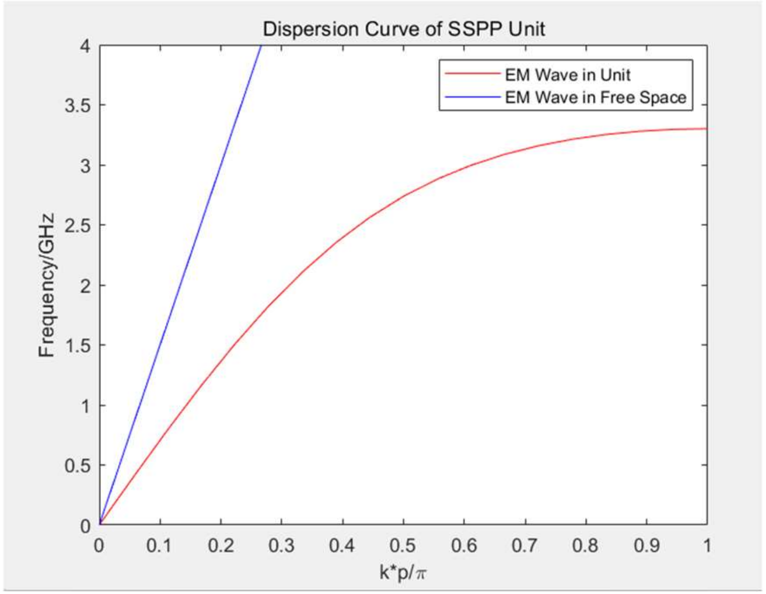
- Periodic structure with numerous small units.
- Parasitic structure coupled with Vivaldi antenna.
- Wave focuses on the middle region of slot aperture.



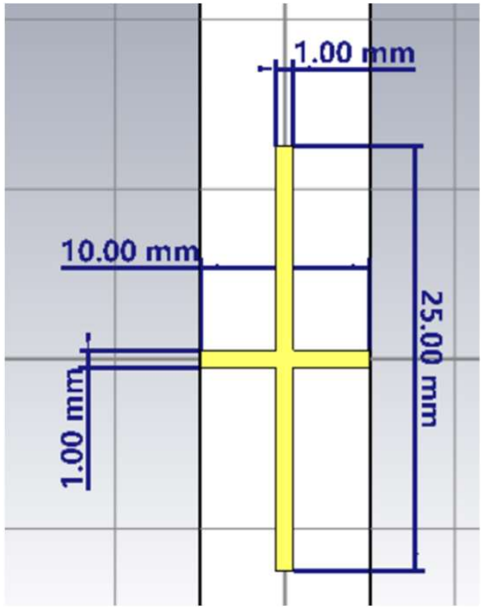
Ideally Condition

- Spoof Surface Plasmon Polaritons will be supported.
- Slow wave region-wavelength smaller than free space wavelength.

2.3 Parasitic Patch Design



a) Dispersion curve of the unit



b) Structure of Unit

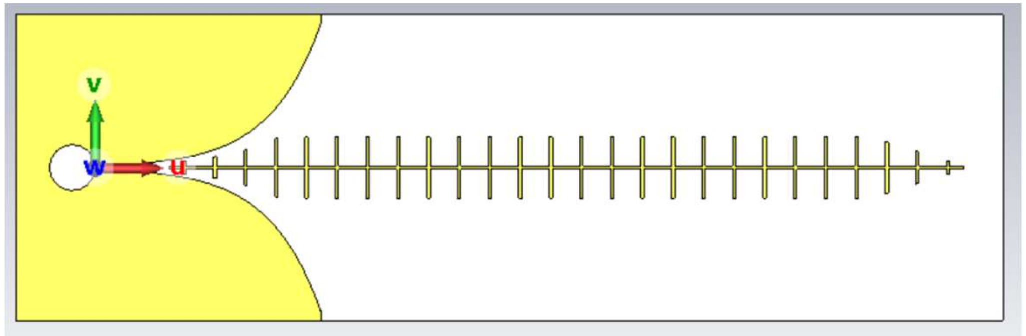
Dispersion curve: The relationship between the wavenumber and the frequency

Slow wave region-right area of the light wave

Fast wave region- left area of the light wave

Sommerfeld-Zenneck wave region- close to the light wave

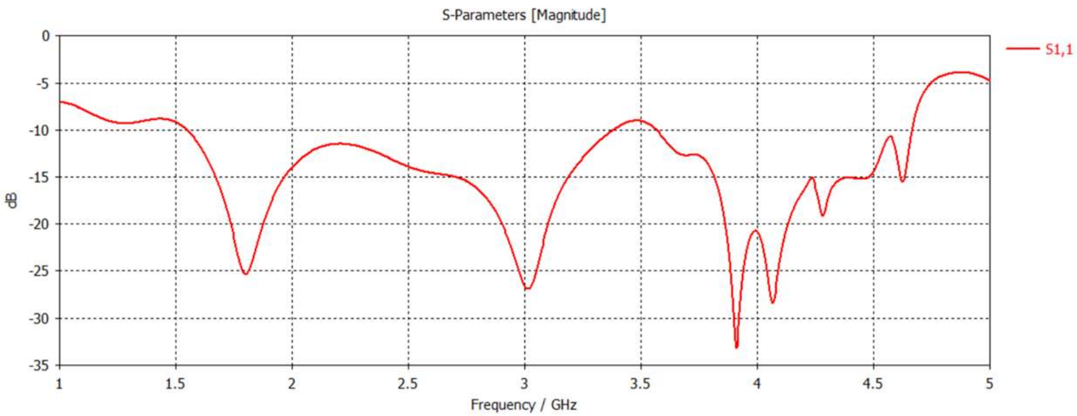
2.4 Antenna with Parasitic Patch Design



a) Final designed antenna with parasitic patch

Antenna size:

$W = 100mm \qquad H = 320mm$



b) S11 parameter

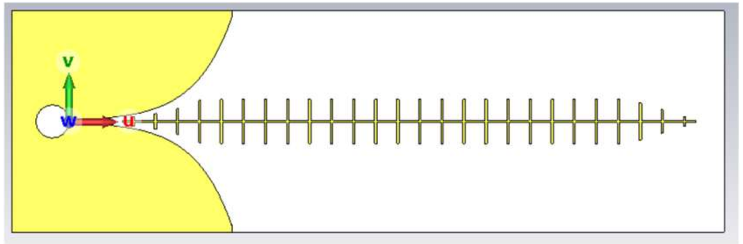
Comparison with Original Antenna:

- Improved matching at 3GHz.
- -10dB bandwidth reduced to <2GHz.

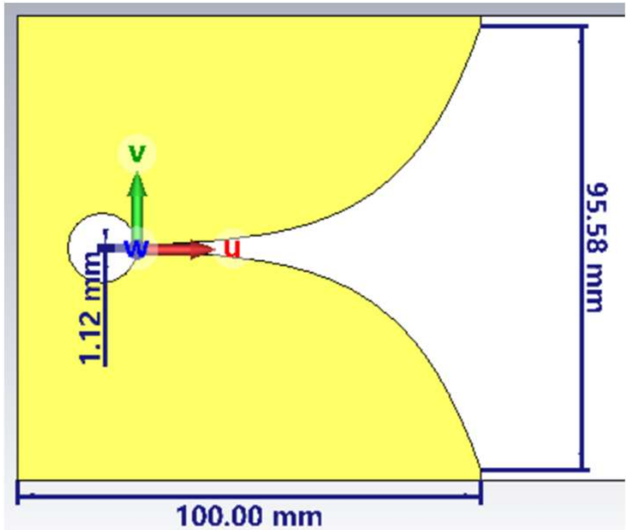
Question:

Are they a good *trade-off* between the ***performance*** (realized gain) and increased ***complexity***?

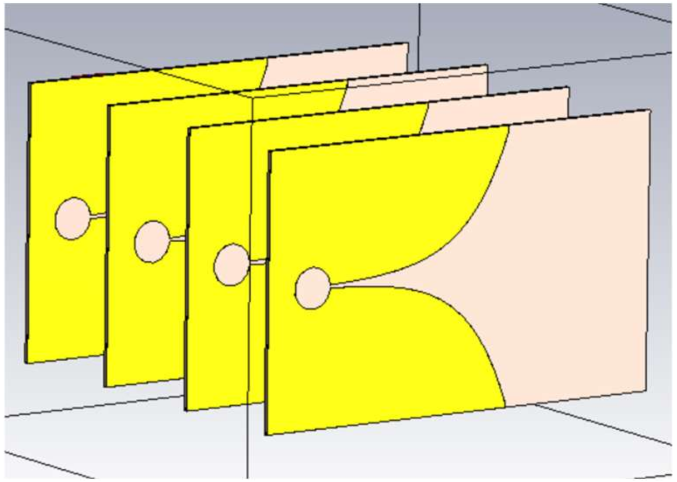
2.5 Comparison of Designed Antennas



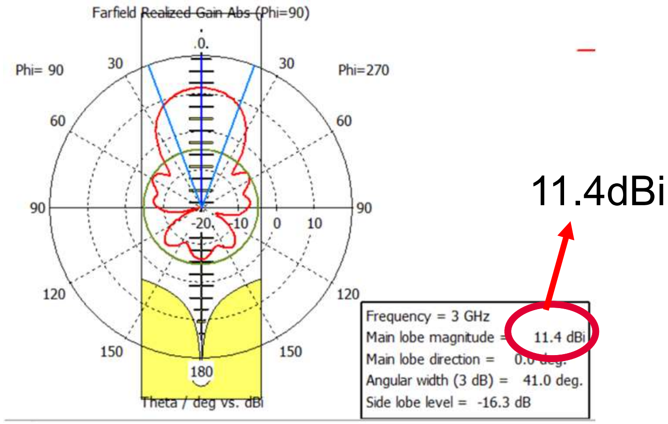
a) Antenna with parasitic patch

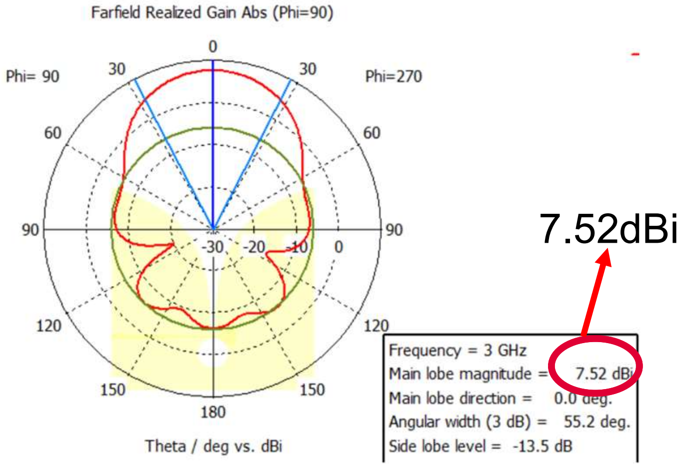


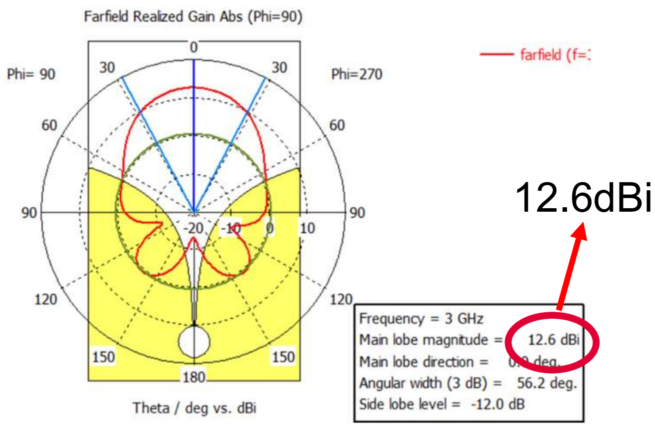
b) Single initial antenna



c) Initial array antenna

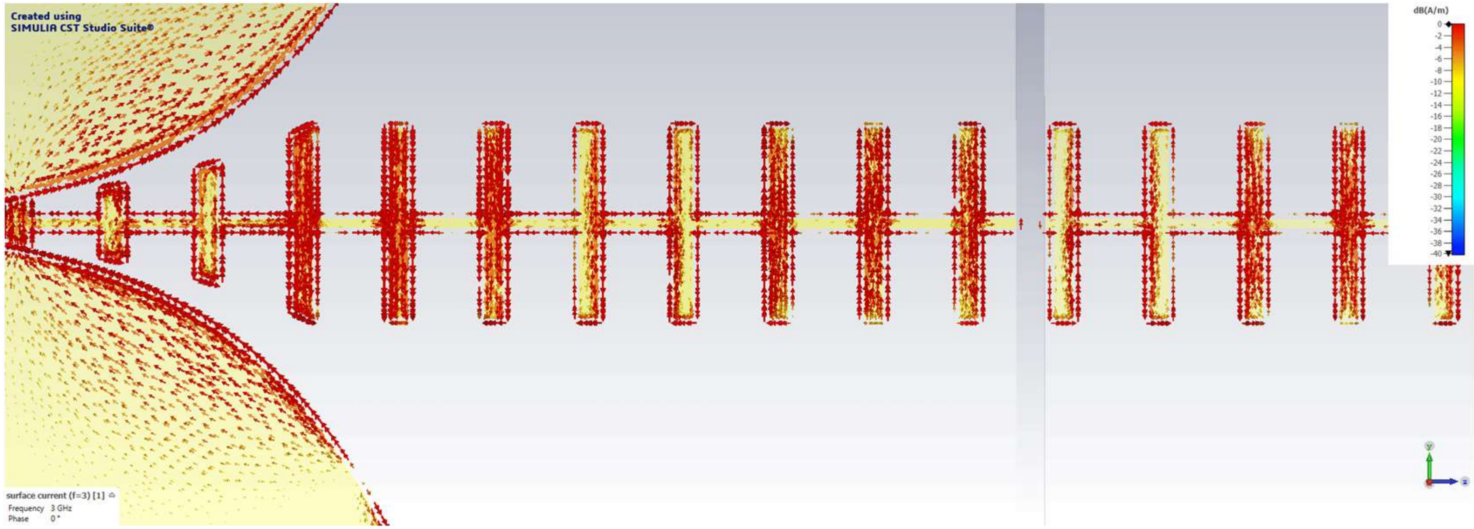






2.6 Another Perspective of Designed Antenna

1) Observation from Surface Current

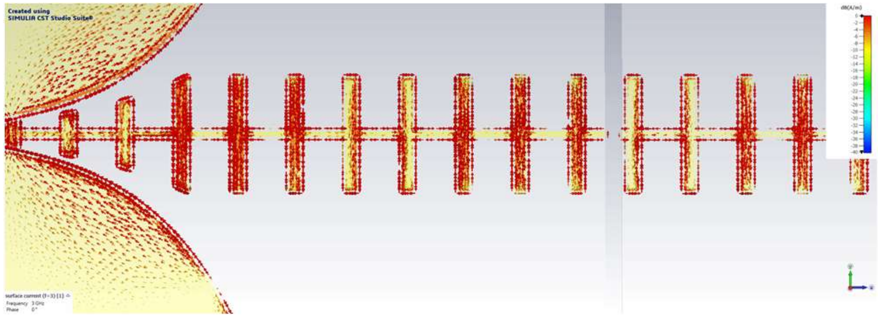


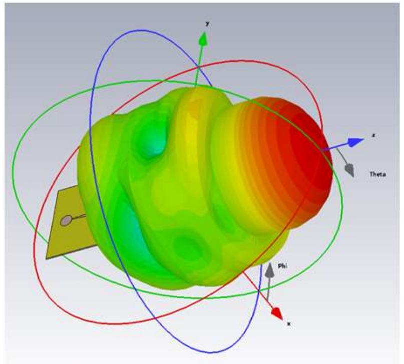
I found a few surface currents in these parts when I observed the animation of surface currents.

As we know surface current induces an electromagnetic field in an antenna.
So what will happen if we remove these parts?

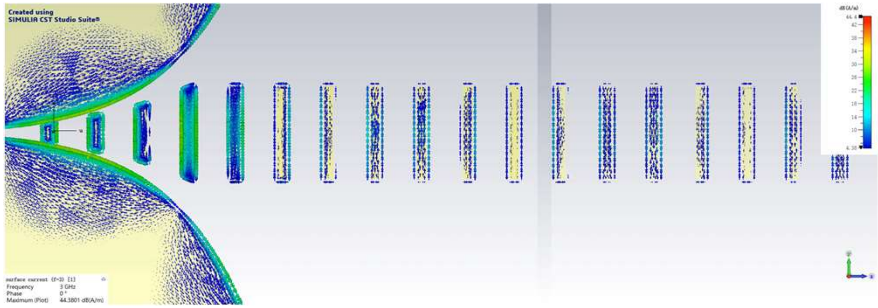
2.6 Another Perspective of Designed Antenna

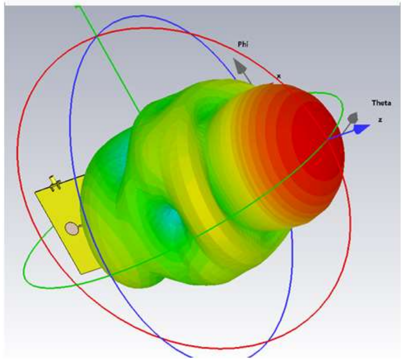
2) Comparison of Surface Current and Radiation Pattern





farfield (f=3) [1]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Realized Gain
Frequency	3 GHz
Tot. Effic.	-1.140 dB
Rlzd. Gain	11.52 dBi



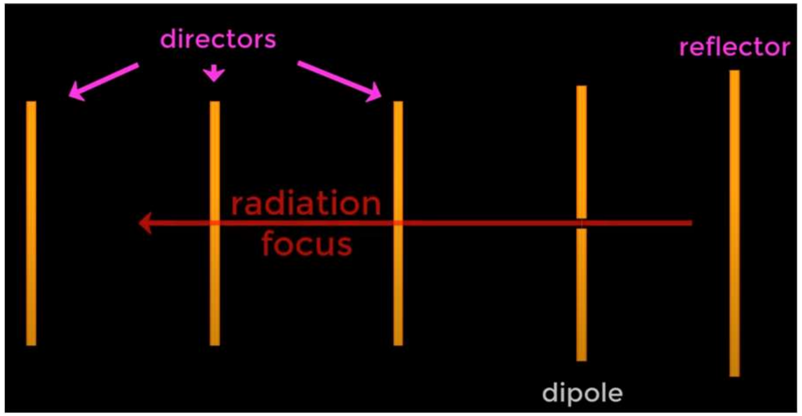


farfield (f=3) [1]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Realized Gain
Frequency	3 GHz
Rad. Effic.	-1.137 dB
Tot. Effic.	-1.458 dB
Rlzd. Gain	10.82 dBi

Finally, we prove that the radiation efficiency and realized gain are similar in these two structures.

2.6 Another Perspective of Designed Antenna

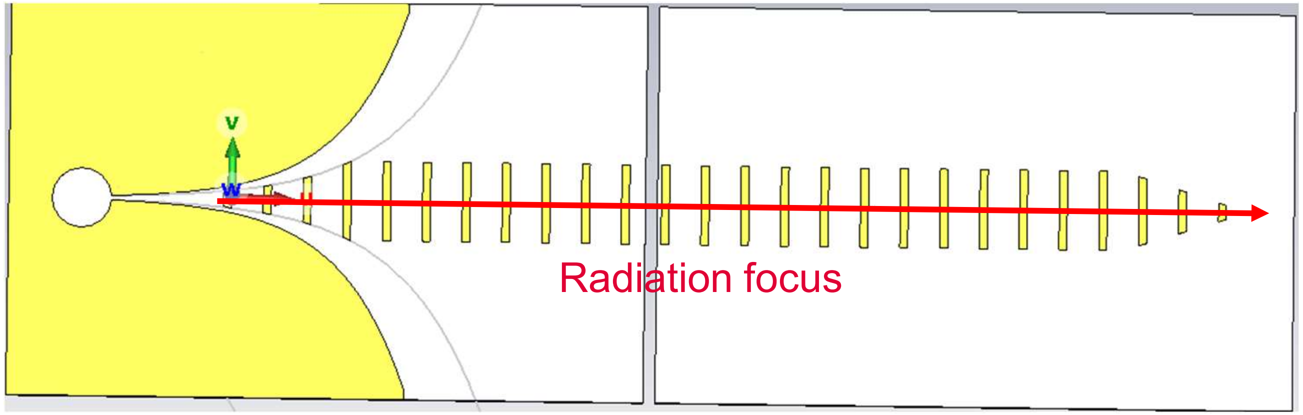
a) Yagi-Uda Antenna



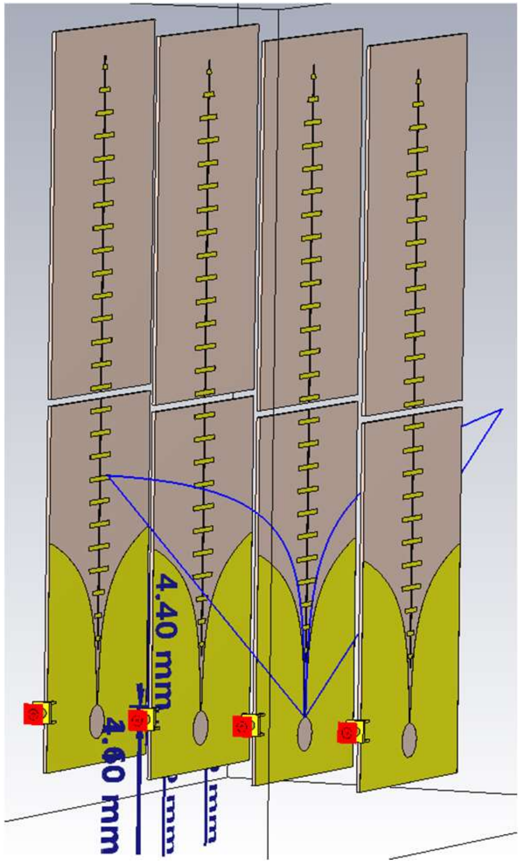
Vivaldi & director antenna system:

- **Vivaldi Antenna** as a main radiating element produces a directive radiation pattern.
- **Director** elements re-radiate energy from Vivaldi to focus waves in a specific direction.

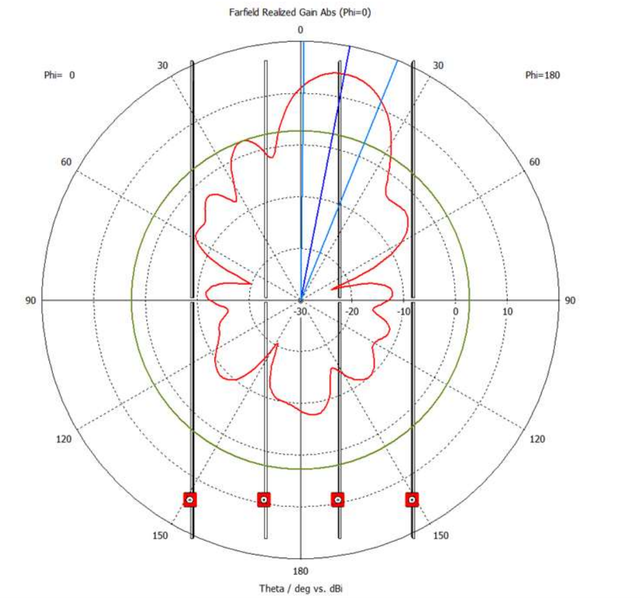
b) Vivaldi antenna with a series of directors



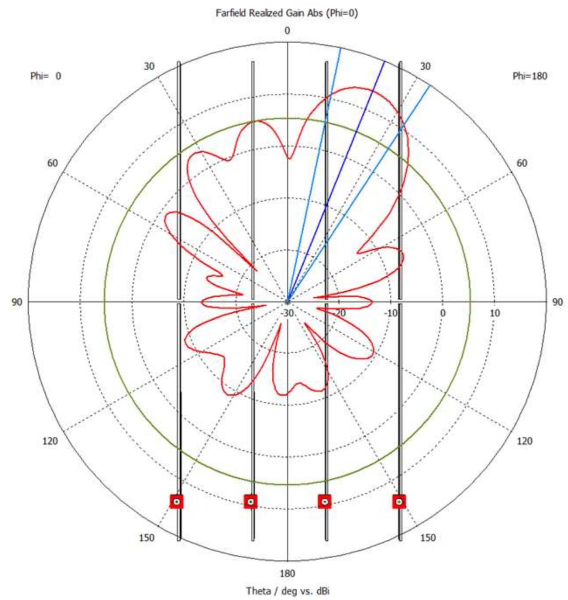
3.1 Array Design and Beam Steering



Element distance: 50mm



a) $45°$ phrase shift



b) $90°$ phrase shift

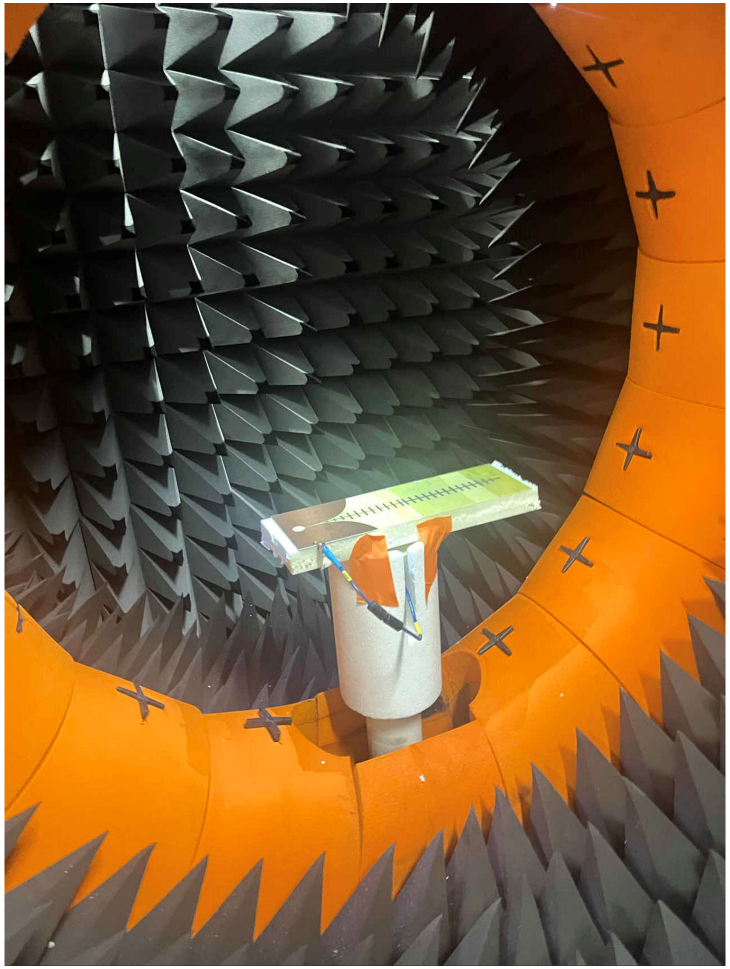
Beam with 90 degrees phase difference, the angle of main beam can be calculated as:

$$\frac{\pi}{2} + k * d * \cos(\theta) = 0$$

$$\cos(\theta) = -0.5$$

$$\theta \approx 120°$$

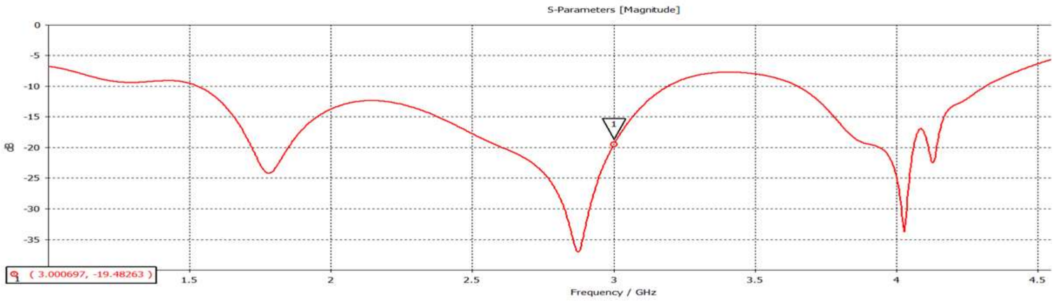
3.1 Measurement of Single Antenna



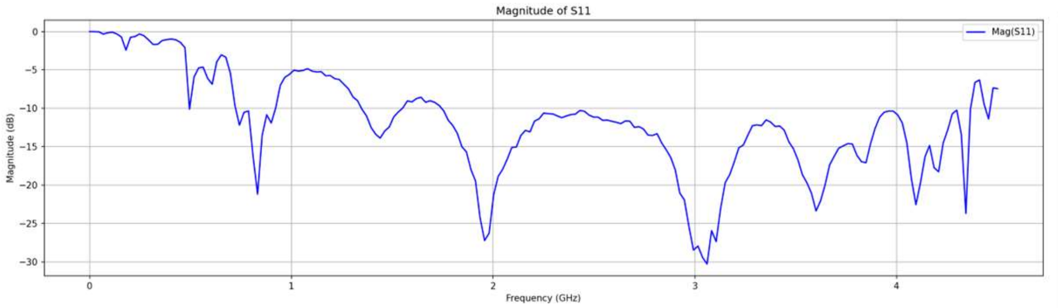
Compared with simulation, the measurement has many differences from it:

1. The realized gain has decreased from 12.5 to 12.2 dBi
2. The S11 parameter has a little shift, but the measurement result is better

3.1 Measurement of Single Antenna



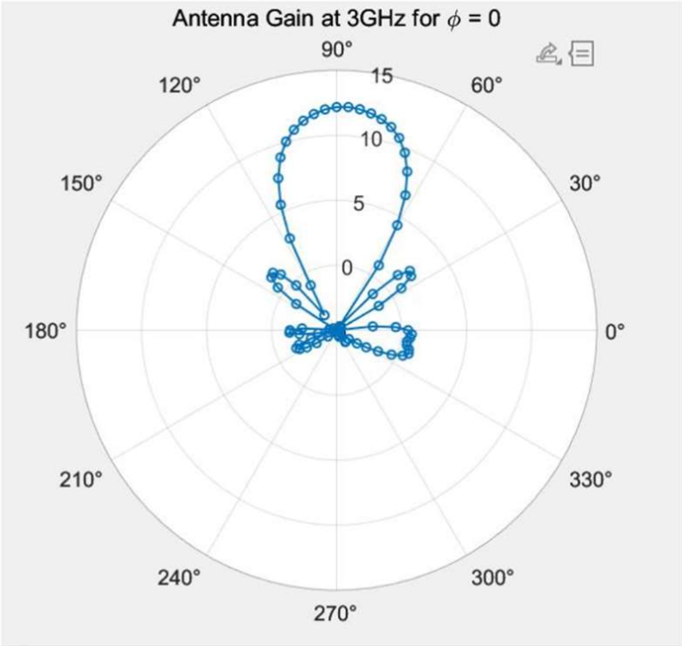
a) S-parameters of simulation

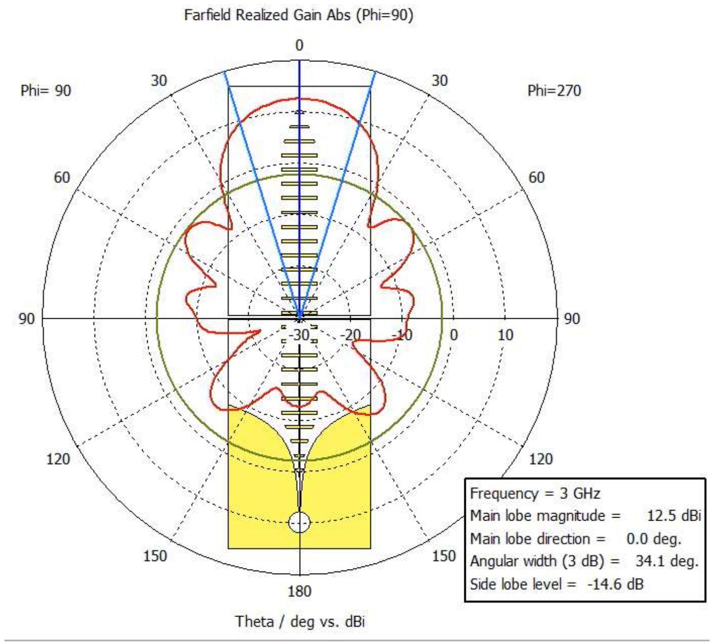


b) S-parameters of measurement

Parameter	Measurement	Simulation
S-parameter at 3 GHz	< -10 dB	< -15 dB
10 dB bandwidth	> 1 GHz	> 1 GHz

3.1 Measurement of Single Antenna

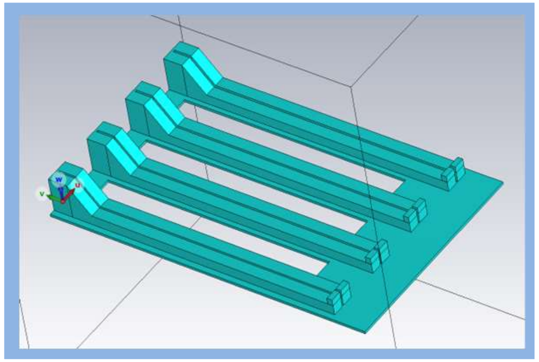
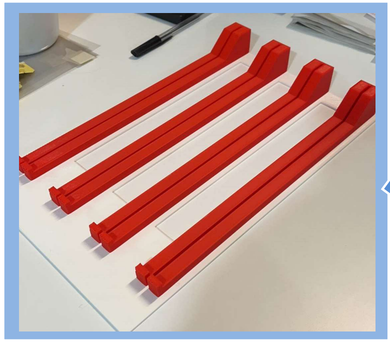
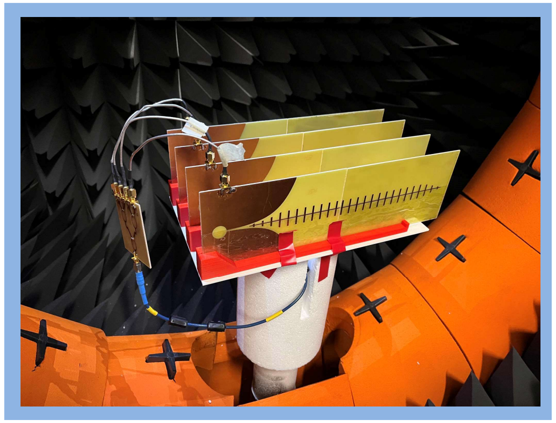
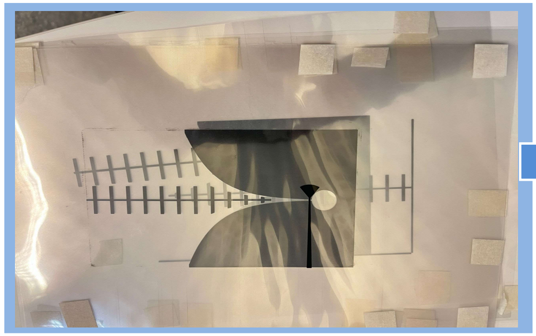
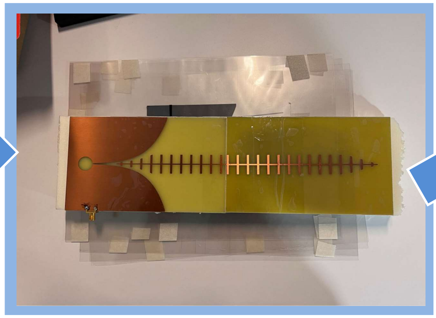




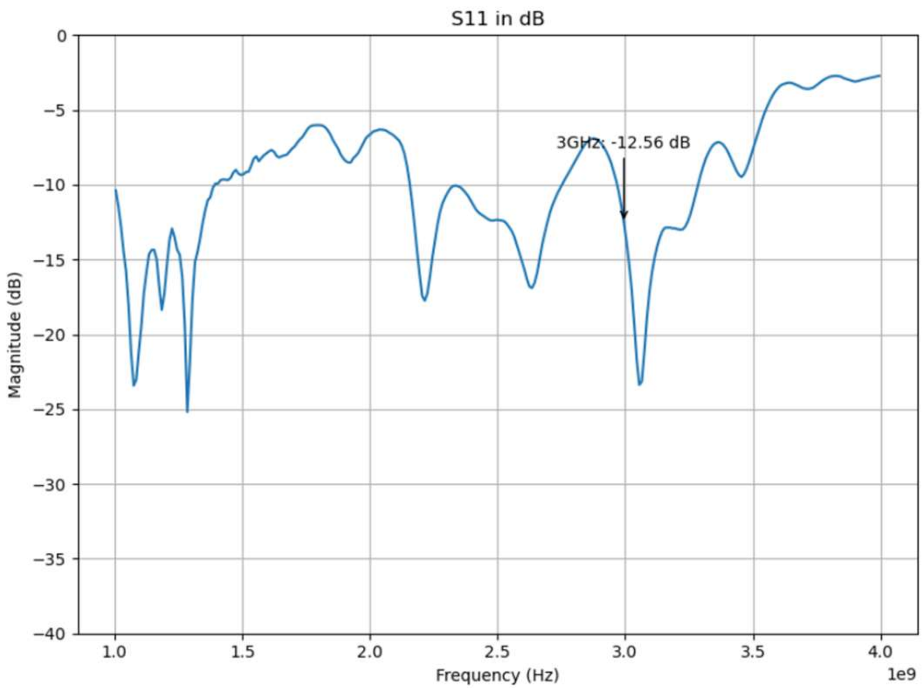
Parameter	Measurement	Simulation
Realize Gain at 3 GHz	12.2 dB	12.5 dB

The measured gain reaches to 12.2dB, which is similar with simulation result.

3.2 Antenna Array Manufacturing Process

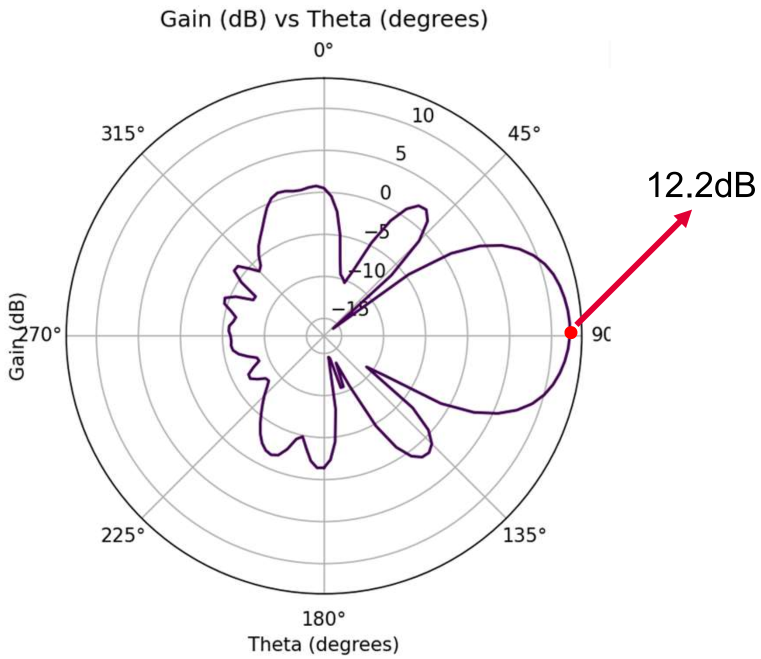
3.3.2 Antenna Array Measurement



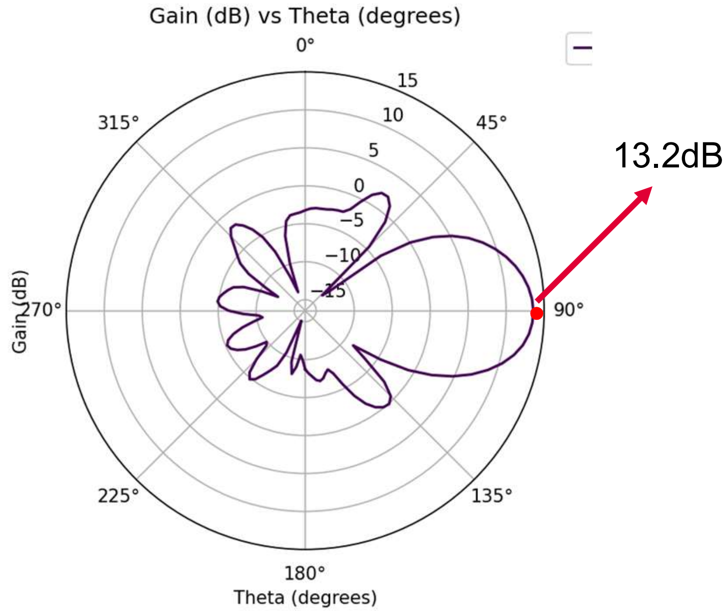
a) S11 of array antenna with power divider

The value of S11 is below -12.56, which means the most power can be transmitted into array antenna.

3.2 Gain Comparison of Single and Array Antenna



a) Realized gain of single antenna



b) Realized gain of array antenna

The realized gain of single antenna is 12.2dB, however the array antenna’s gain only has 13.2dB. The reason behind it may be **the coupling of each element.**

Thanks for your Attention!