A Ka-Band (26 GHz) Circularly Polarized 2x2 Microstrip Patch Sub-Array with Compact Feed

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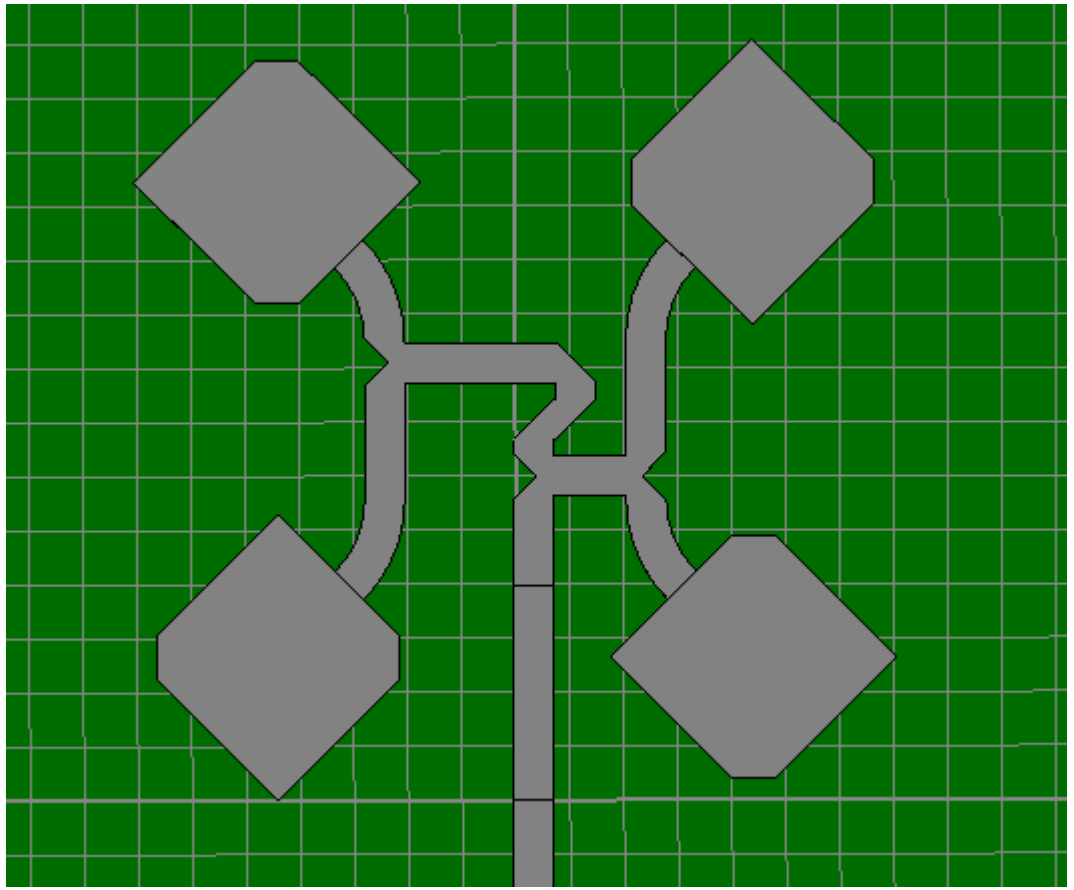
Motivation & Objective

- Design a 26 GHz, K_a band Reflector Antenna Feed to support next-generation SCaN architecture
  - Lightweight
  - Small
  - Durable
  - Circular Polarized

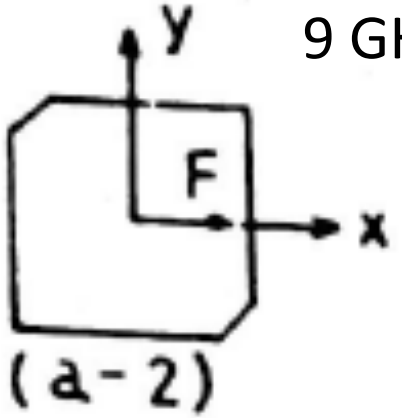


Circular Polarized (CP), Truncated Corner Patch Antennas

Haneishi, M. and S. Yoshida, "A Design Method of Circularly Polarized Rectangular Microstrip Antenna by One-Point Feed," in Microstrip Antenna Design, K.C. Gupta and A Benalla (Eds.), Artech House, Norwood, MA, 1988, pp. 313 -321

Originally from 1981, Reprinted in 1988

9 GHz



???

2017, Millimeter wave frequencies

P. Sharma and K. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 31, no. 6, pp. 949-955, November 1983.

3.1 GHz

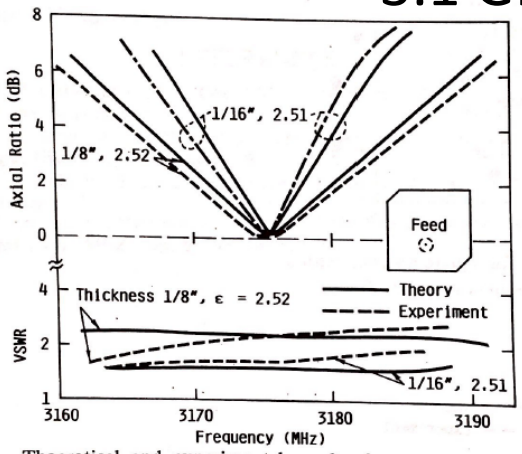


Fig. 7. Theoretical and experimental results for axial ratio and input VSWR for truncated-corners square antenna.

Explore changes that occur in the antenna design as the frequency is increased to 26 GHz

Major Topics

- Single Element, Truncated Corner, Circular Polarized Patch Antenna
- Feed Network
- 2x2 Sub Array

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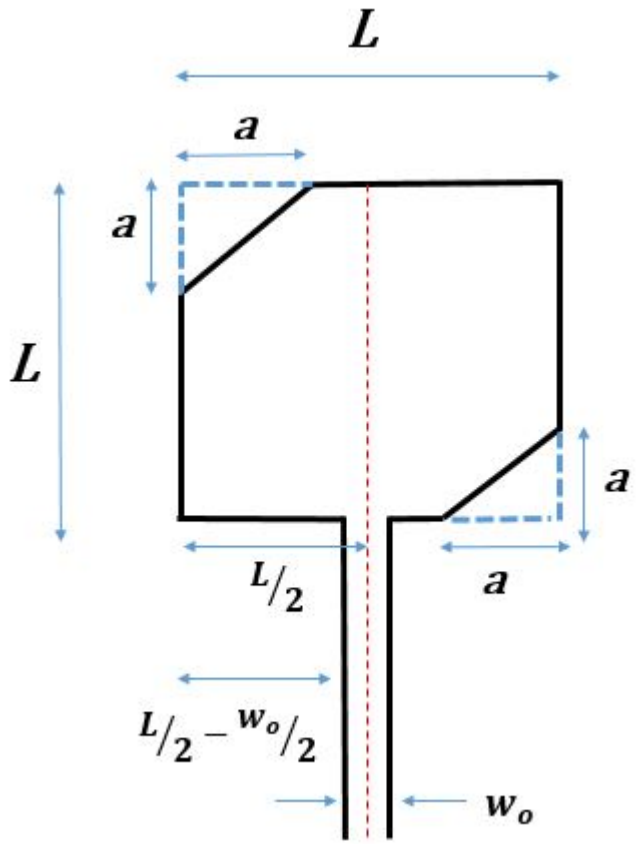
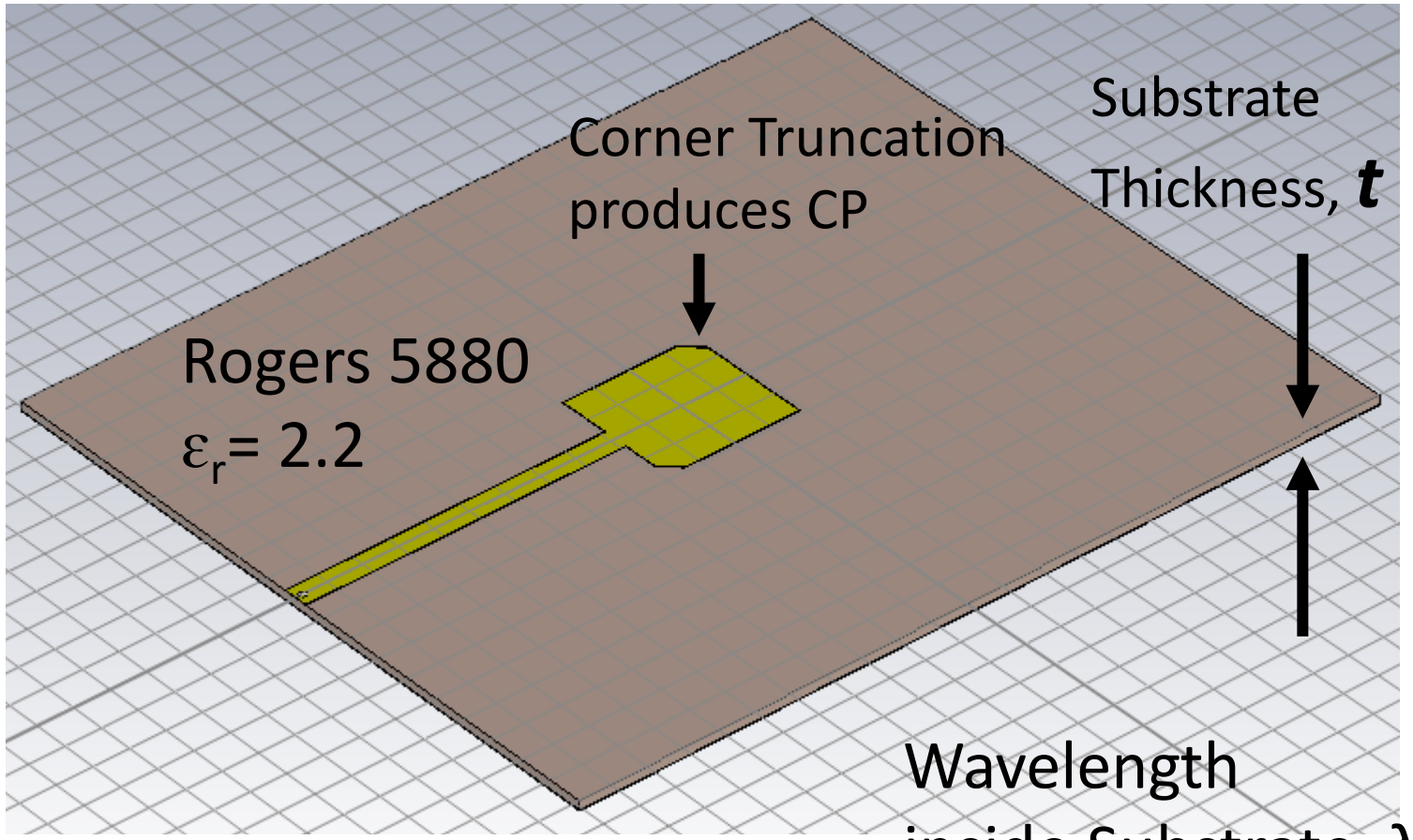
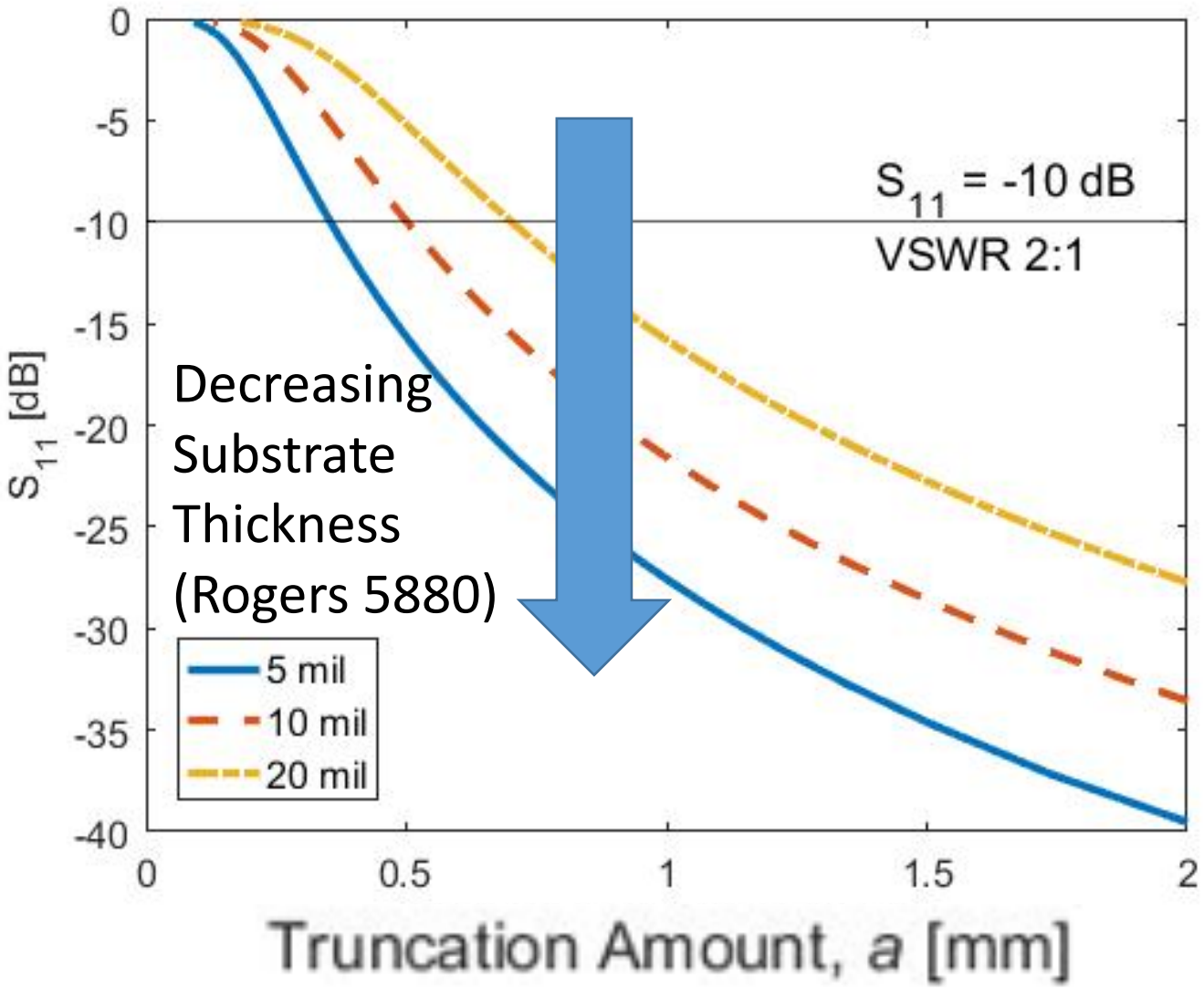
Truncated Corners create Circular Polarization (CP) in the Patch Antenna





Truncation and S_{11} Design



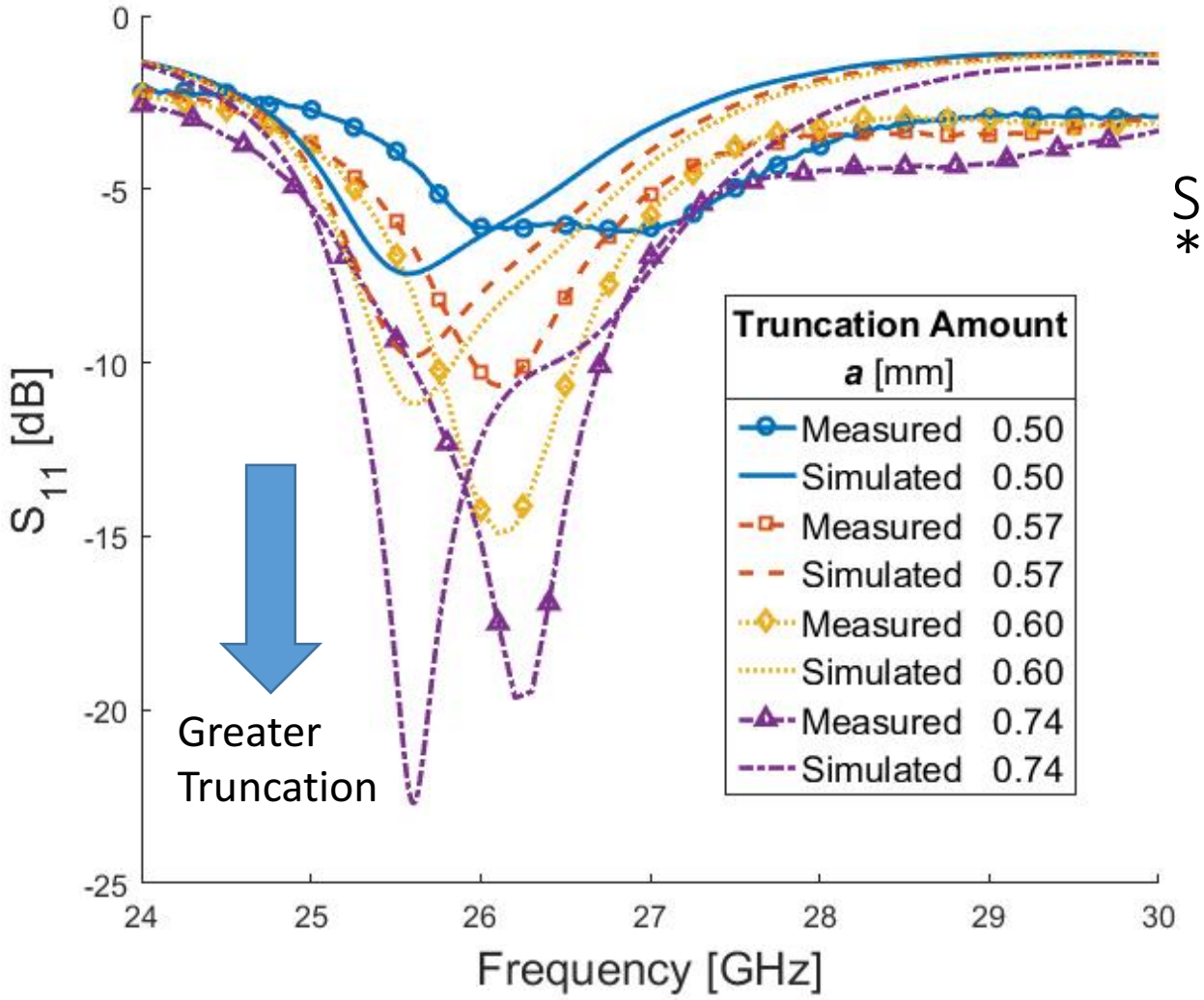
Rogers 5880

- Low Loss, $\varepsilon_r = 2.2$
- Many Thickness Available
- Common Substrate

Truncation Amount, *a*

- Known Relationship to S_{11}
- Unknown Relationship to Axial Ratio (AR)

10 mil, Rogers 5880 (ε_r = 2.2) Truncation Varied, 50Ω Microstrip Feed

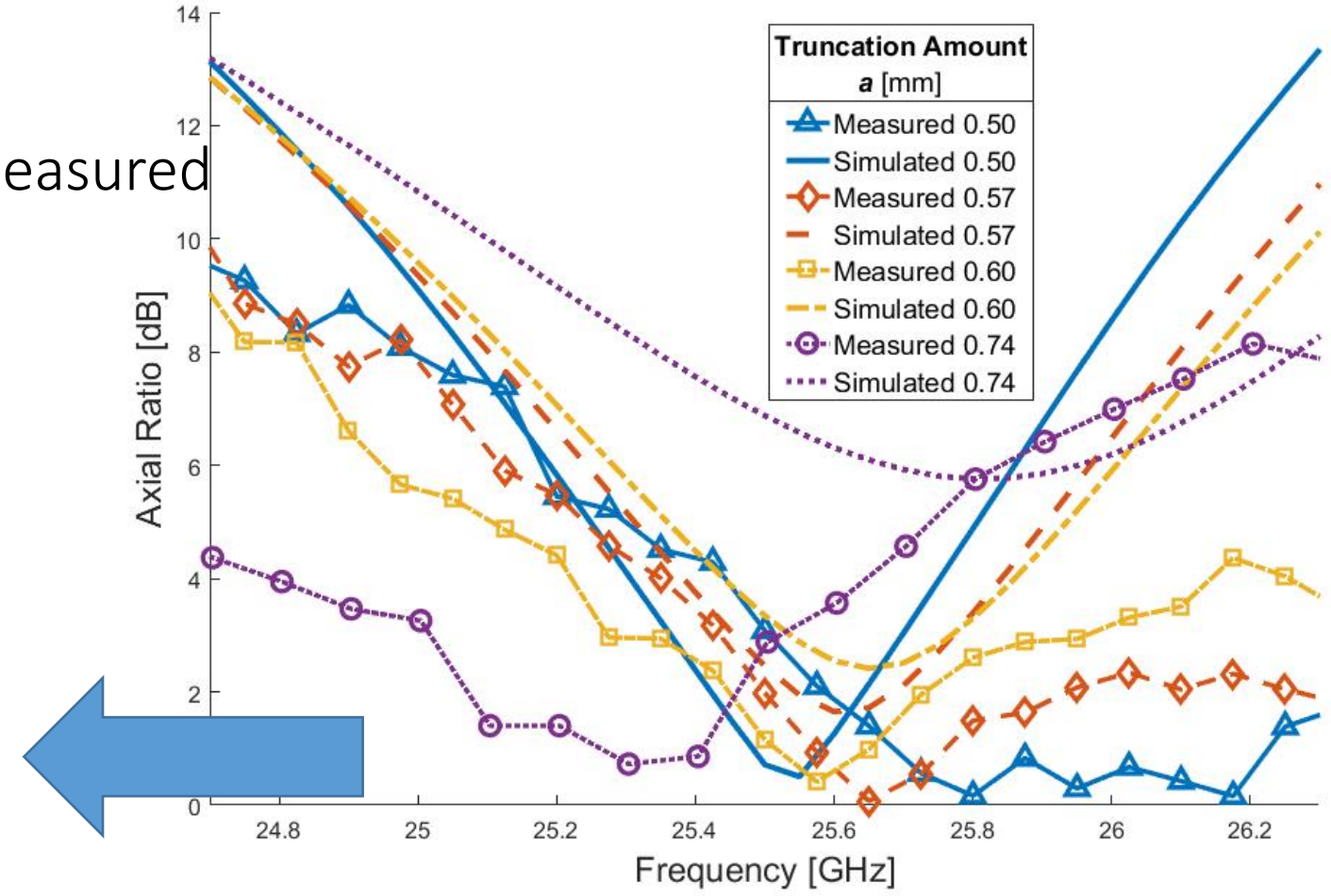


Simulation
* Under predicts Measured Resonant Frequency

10 mil, Rogers 5880 (ε_r = 2.2) Truncation Varied, 50Ω Microstrip Feed

ELECTRICAL AND COMPUTER ENGINEERING

Simulation
* Under predicts Measured AR Bandwidth



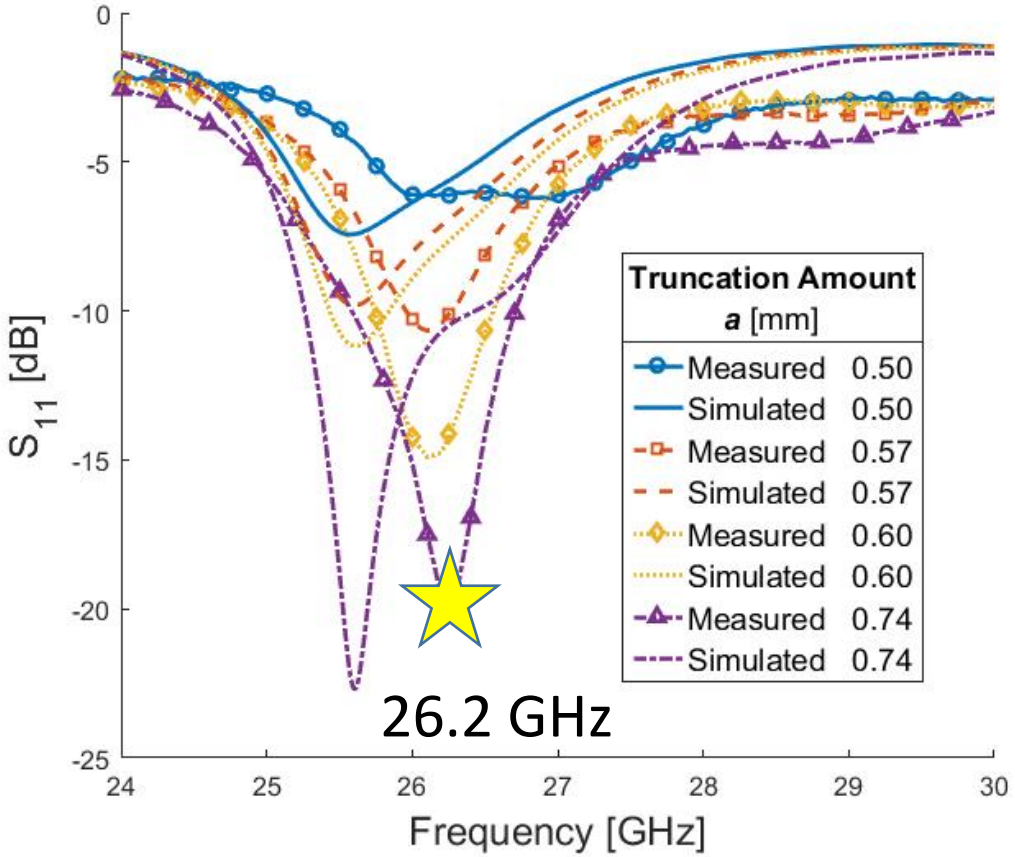
Measured AR

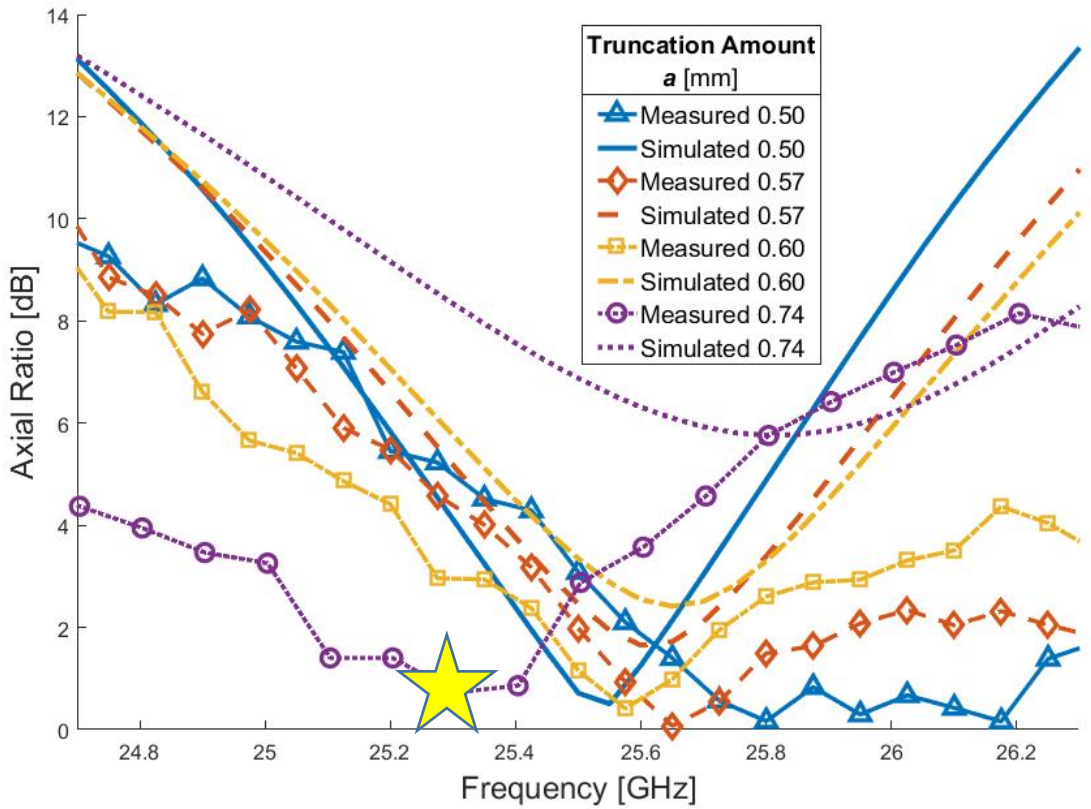
a [mm]	3 dB Bandwidth
0.50	4.22 %
0.57	6.73 %
0.60	2.07 %
0.74	1.78 %

Simulated AR

a [mm]	3 dB Bandwidth
0.50	1.37 %
0.57	1.37 %
0.60	0.78 %
0.74	-----

10 mil, Rogers 5880 (ε_r = 2.2) Truncation Varied, 50Ω Microstrip Feed

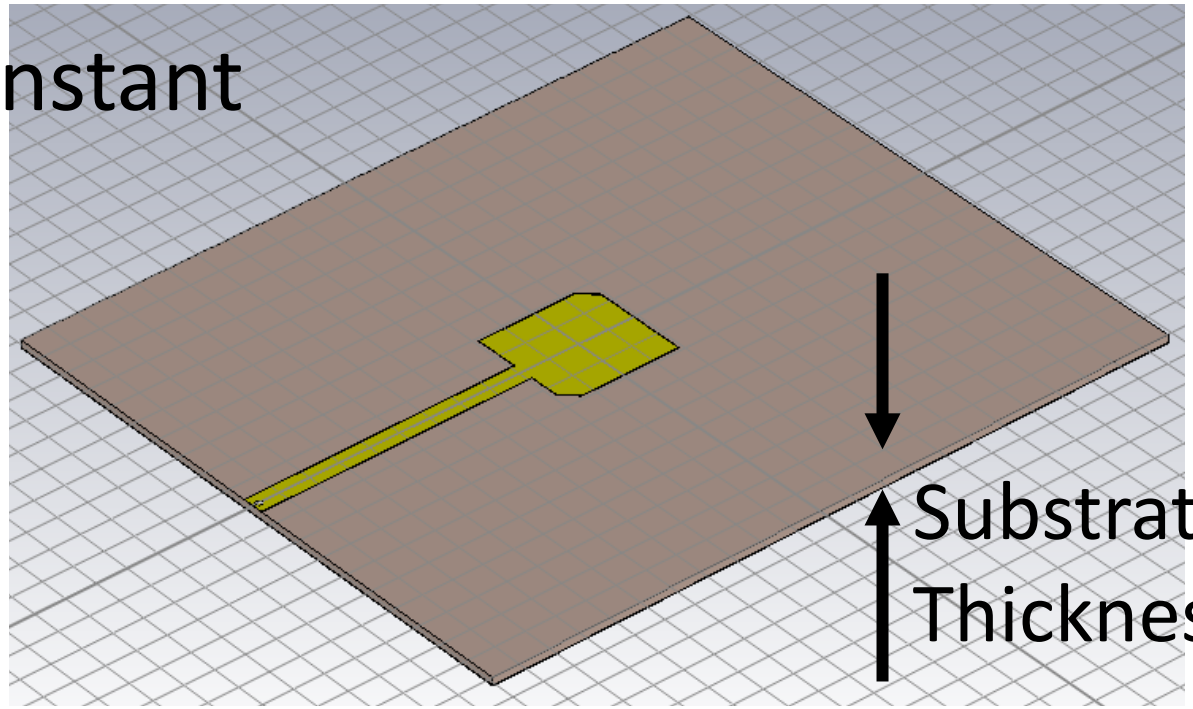




The Best AR and the Best S_{11} do not occur at the same frequency

- Effect of
  - Substrate Thickness
  - Substrate Dielectric Constant
  - Antenna Design Frequency

- Effect of
  - Substrate Thickness
    - Substrate Dielectric Constant
    - Design Frequency

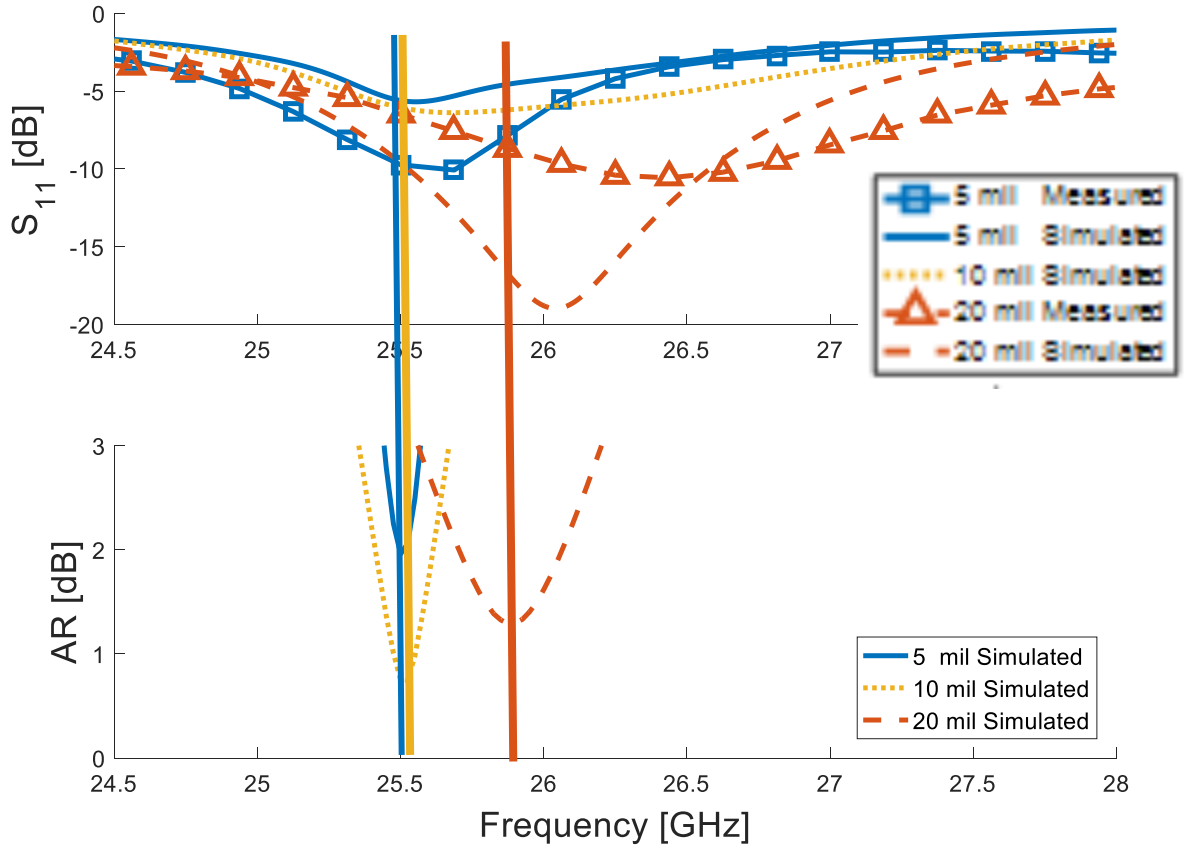


Substrate Thickness Variation at the K_a Band (26 GHz)

Substrate Thickness	L [mm]	a [mm]	λ_d [mm]	t/λ_d	AR 3dB Bandwidth
5 mil	3.83	0.34	7.8	0.016	0.47 %
10 mil	3.75	0.49	7.8	0.033	1.19 %
20 mil	3.56	0.68	7.8	0.065	2.47 %

Design Choice

Rogers 5880



AR & S11 Mismatch

- Effect of
  - Substrate Thickness
  - **Design Frequency**
  - Substrate Dielectric Constant

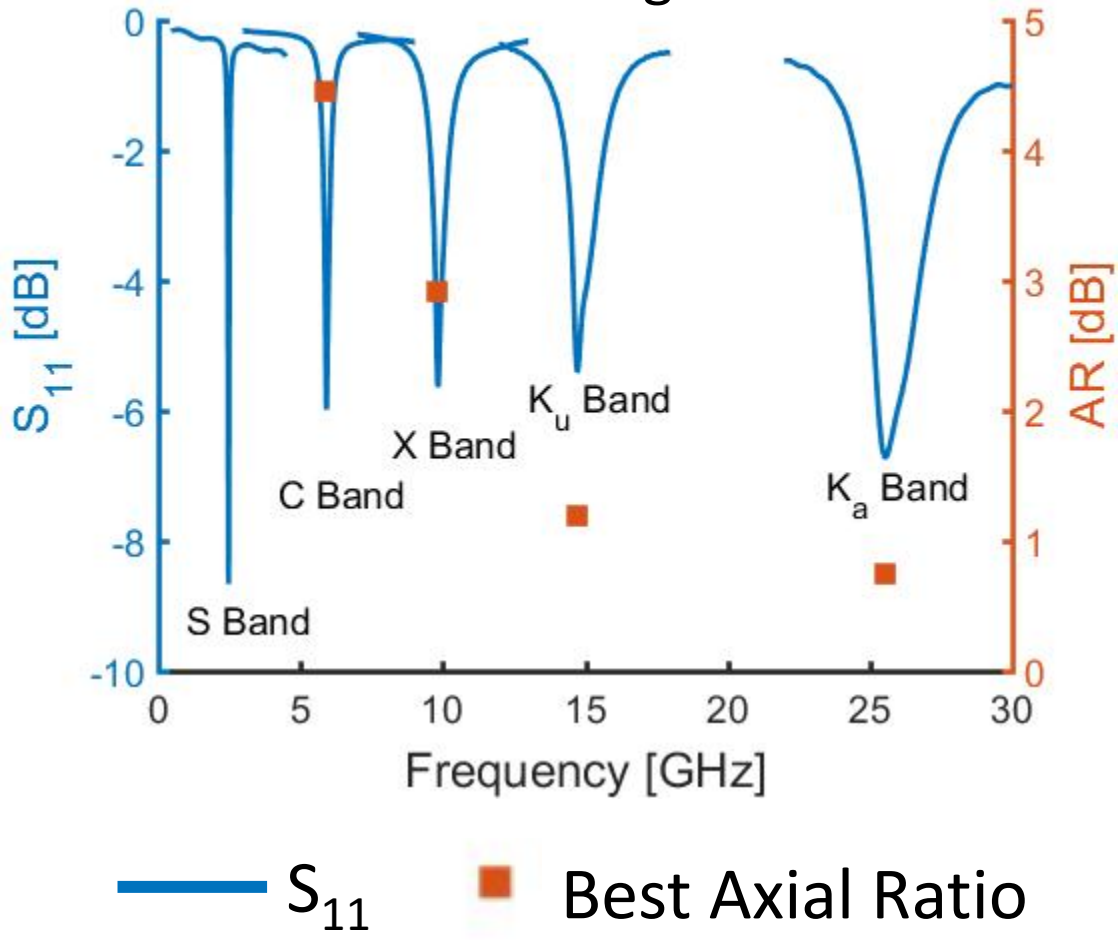
10 mil, Rogers 5880 (ε_r = 2.2) Frequency Varied (Simulation)

ELECTRICAL AND COMPUTER ENGINEERING

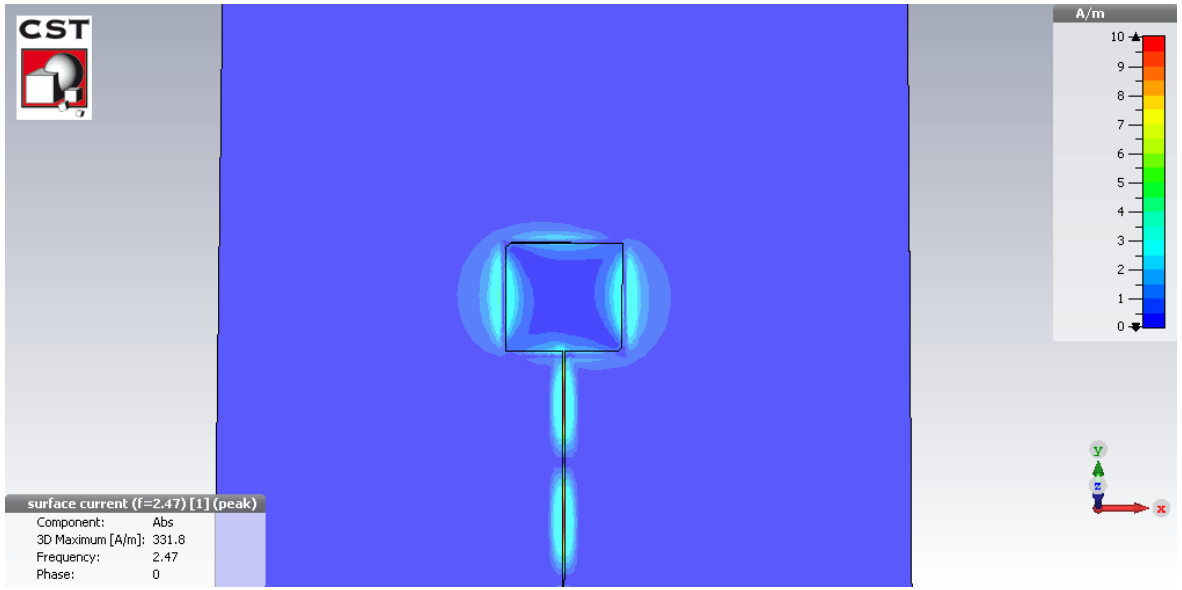
Frequency	L [mm]	a [mm]	λ_d [mm]	t/λ_d	AR 3dB Bandwidth
2.5 GHz (S Band)	40.4	1.563	80.9	0.12	--
6 GHz (C Band Center)	16.7	1.011	33.7	0.30	--
10 GHz (X Band Center)	10.0	0.784	20.2	0.50	0.05%
15 GHz (Ku Band Center)	6.6	0.641	13.5	0.74	0.66%
26 GHz (Ka Band)	3.7	0.487	7.8	0.87	1.19%

All Antennas Fed with 50 Ω

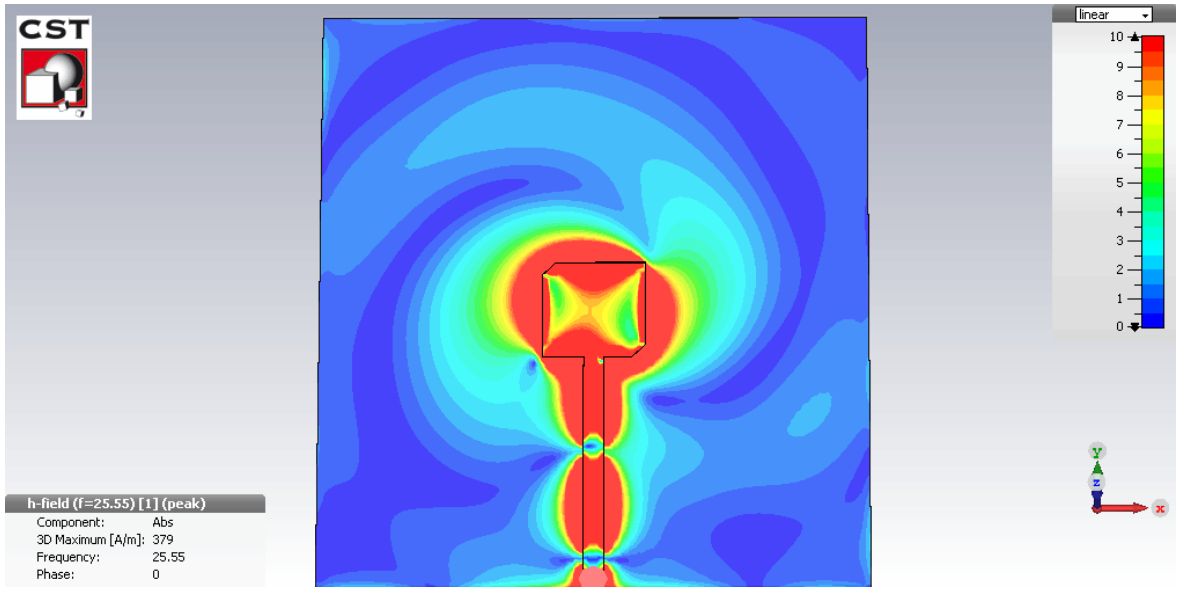
All Truncations designed for -10 dB



Surface Current at Center Frequency
10 mil, Rogers 5880

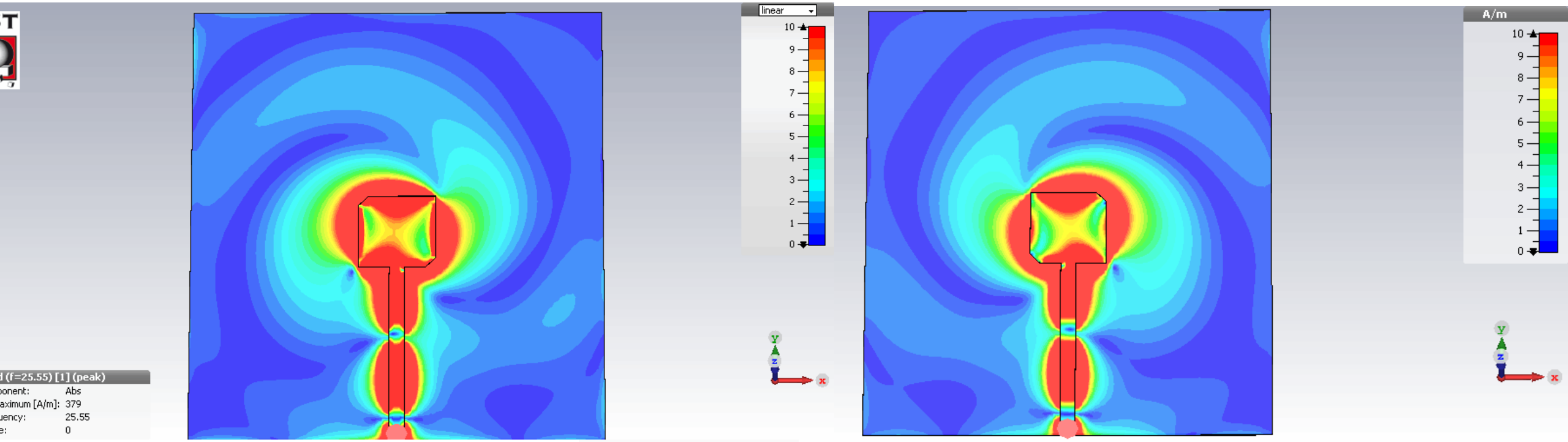


S Band
2.5 GHz



K_a Band
25.5 GHz
AR < 1 dB

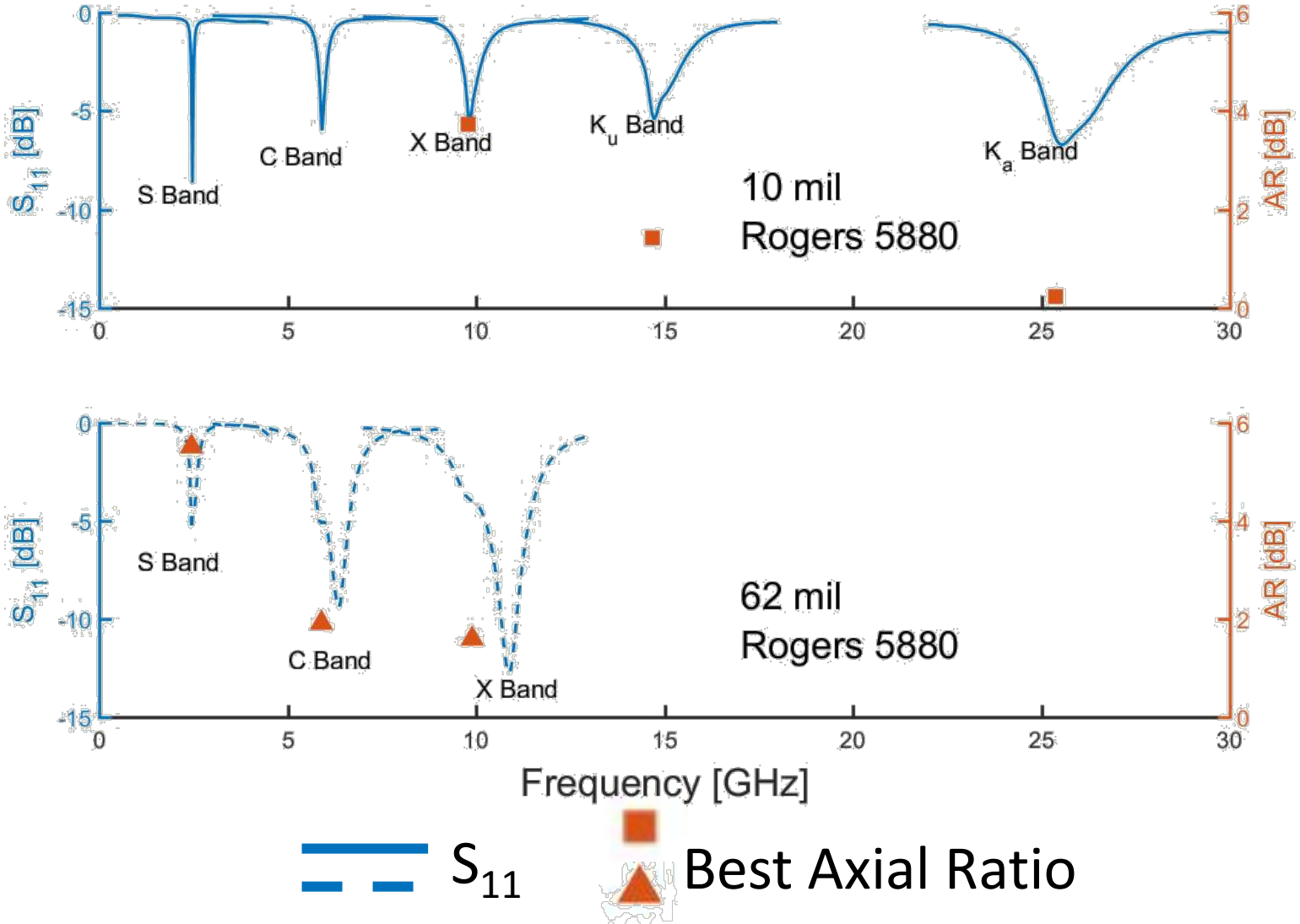
Left Hand and Right Hand CP K_a Band



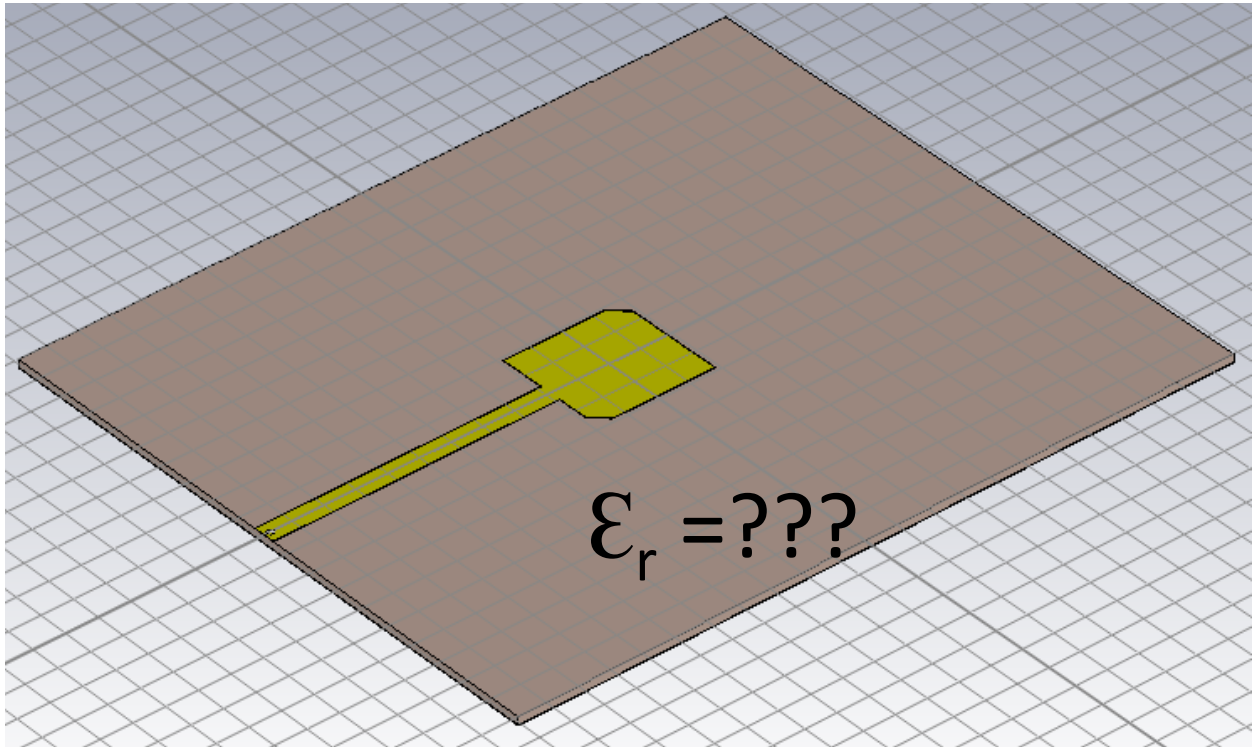
LHCP

RHCP

Substrate Thickness Variation Over Several Frequency Bands (Simulation)



- Effect of
  - Substrate Thickness
  - Design Frequency
  - Substrate Dielectric Constant

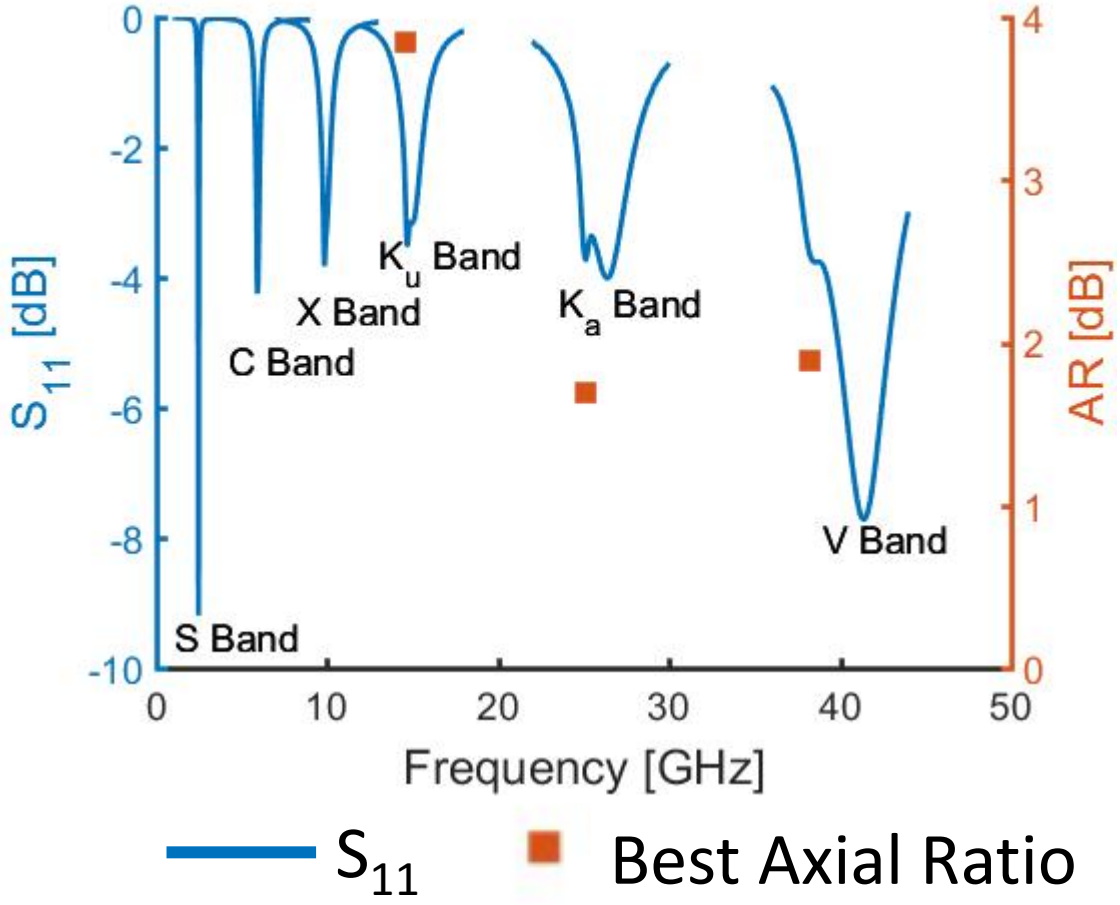


10 mil, Rogers 6006 (ε_r = 6.15)

Frequency [GHz]	L [mm]	a [mm]	λ_d [mm]	t/λ_d
2.5 (S Band)	24.2	0.67	48.4	0.0052
6 (C Band)	10.1	0.44	20.2	0.013
10 (X Band)	6.0	0.34	12.1	0.021
15 (Ku Band)	4.0	0.29	8.1	0.032
26 (Ka Band)	2.3	0.22	4.7	0.055
40 (V Band)	1.4	0.18	3.0	0.084

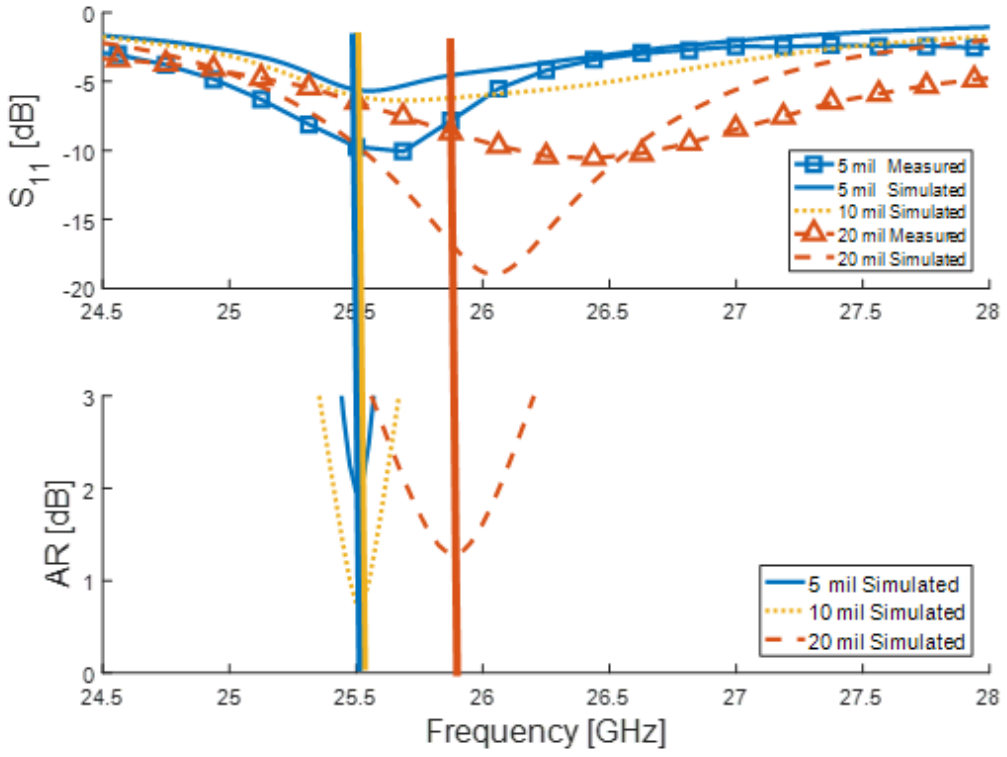
All Antennas Fed with 50 Ω

All Truncations designed for -10 dB



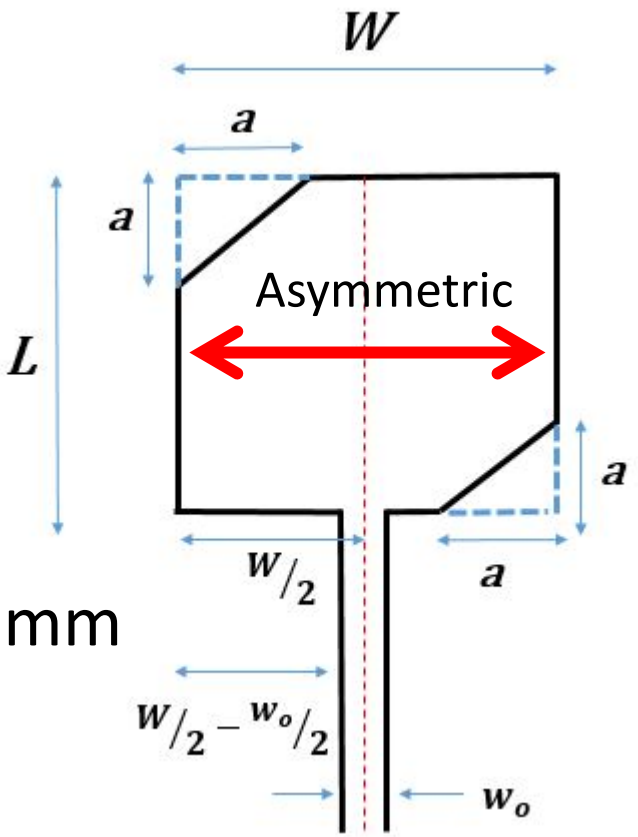
Sub-Topics

- Single Element, Truncated Corner Patch Antenna
  - Patch Design
  - Initial Measurements
  - Effect of:
    - Substrate Thickness
    - Substrate Dielectric Constant
    - Design Frequency
  - Design Suggestion to Eliminate S_{11} & AR Mismatch

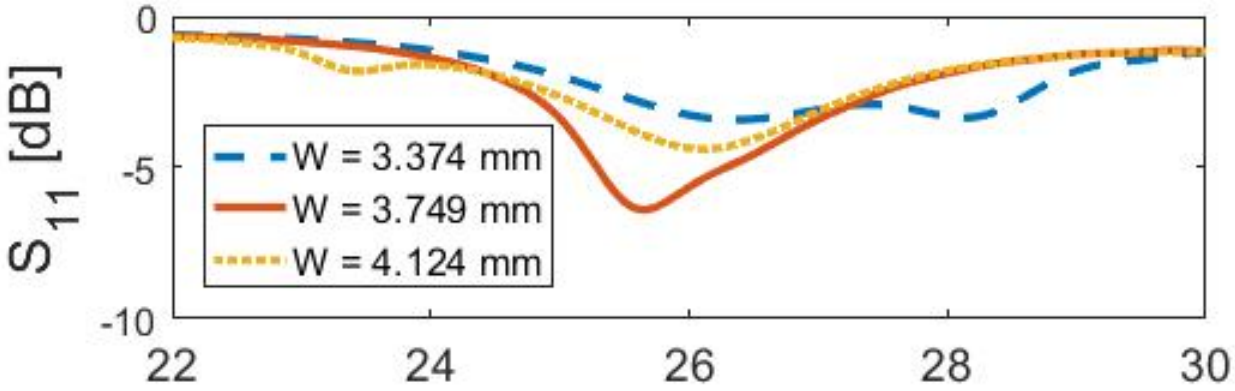


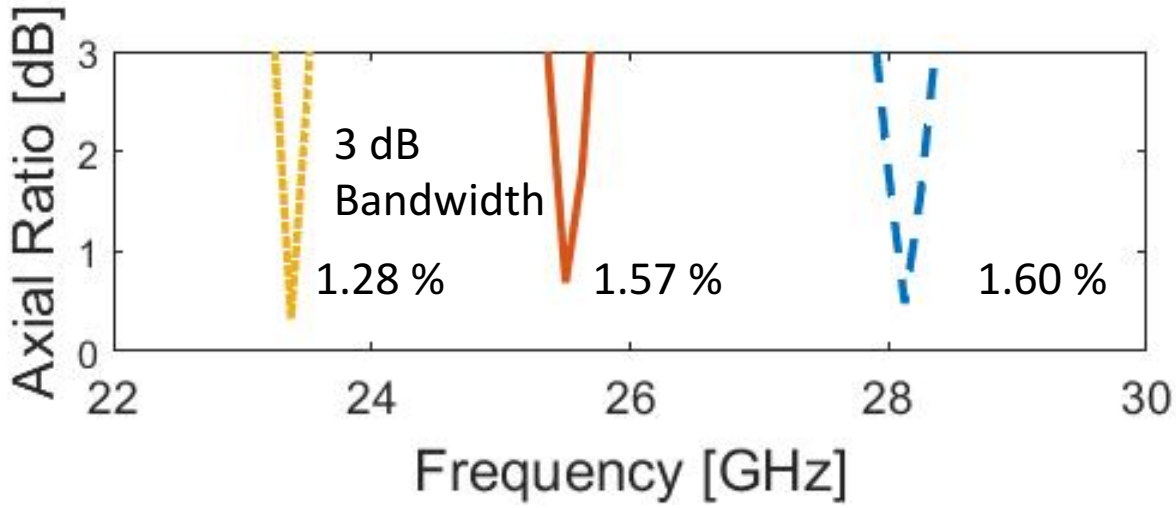
AR & S11 Mismatch

Possible Method for High Frequency S_{11} and AR Alignment

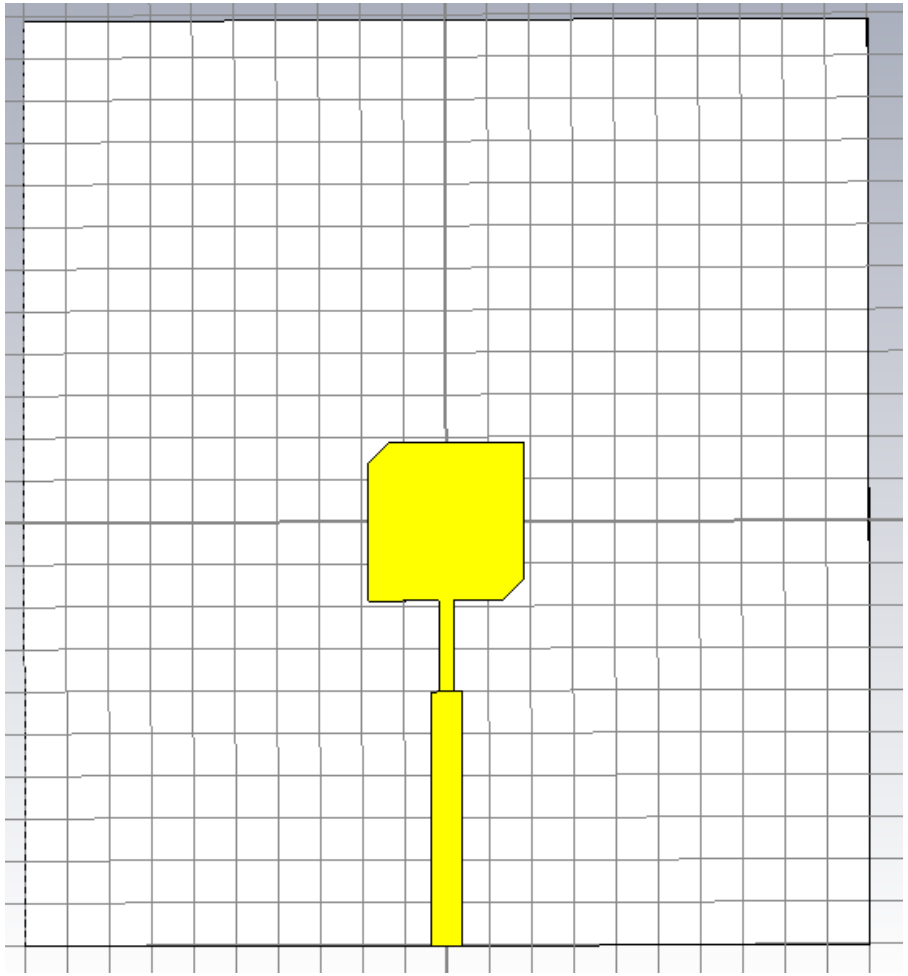


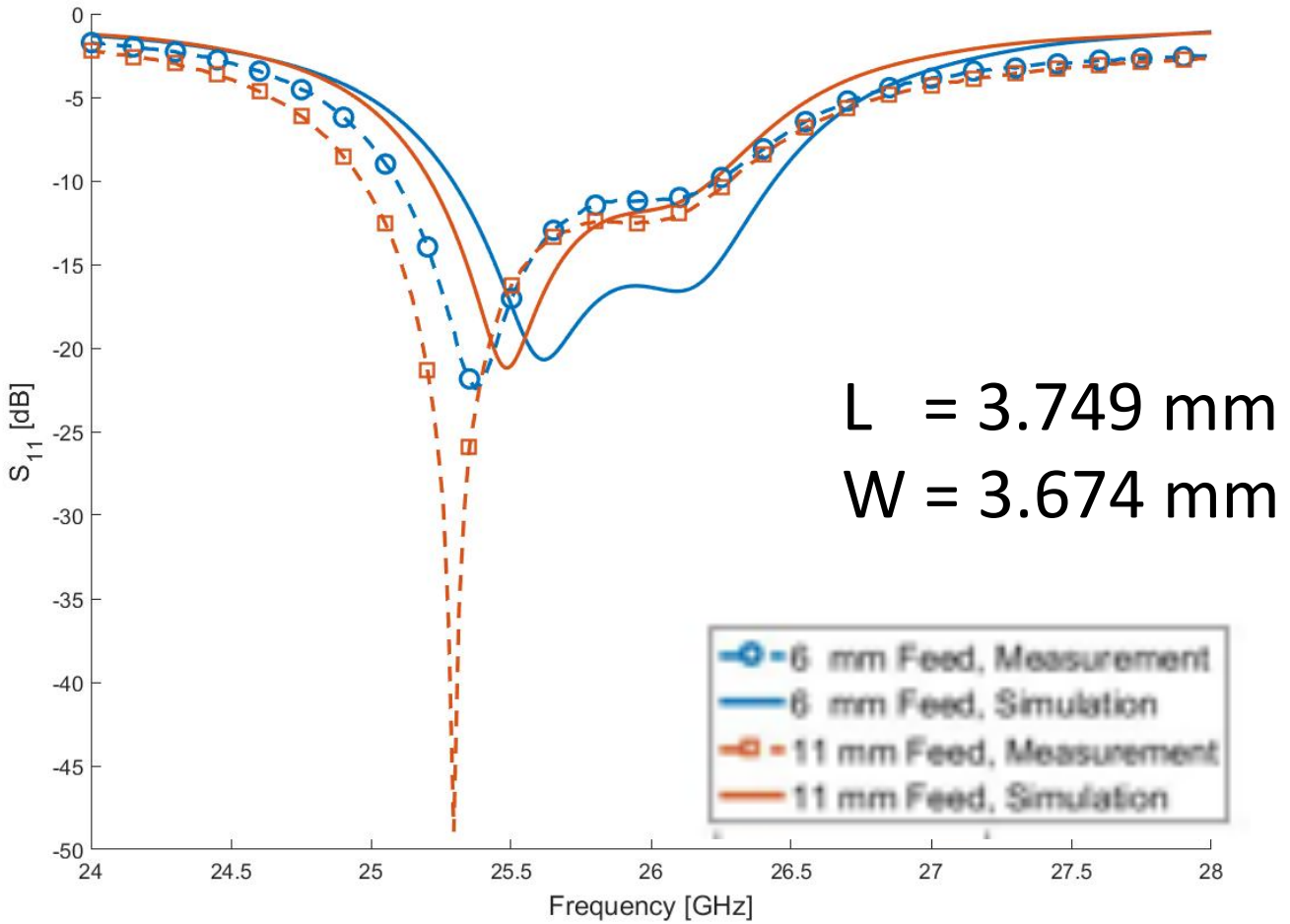
L = 3.749 mm





Asymmetric Patch Matched With λ/4 Transformer

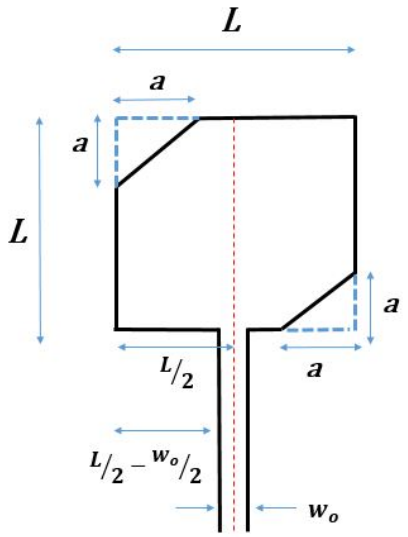


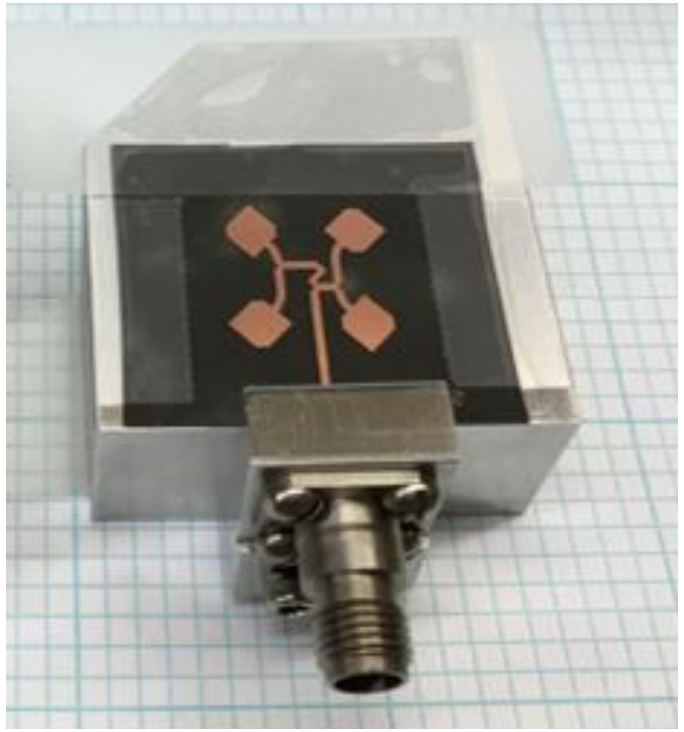


L = 3.749 mm

W = 3.674 mm

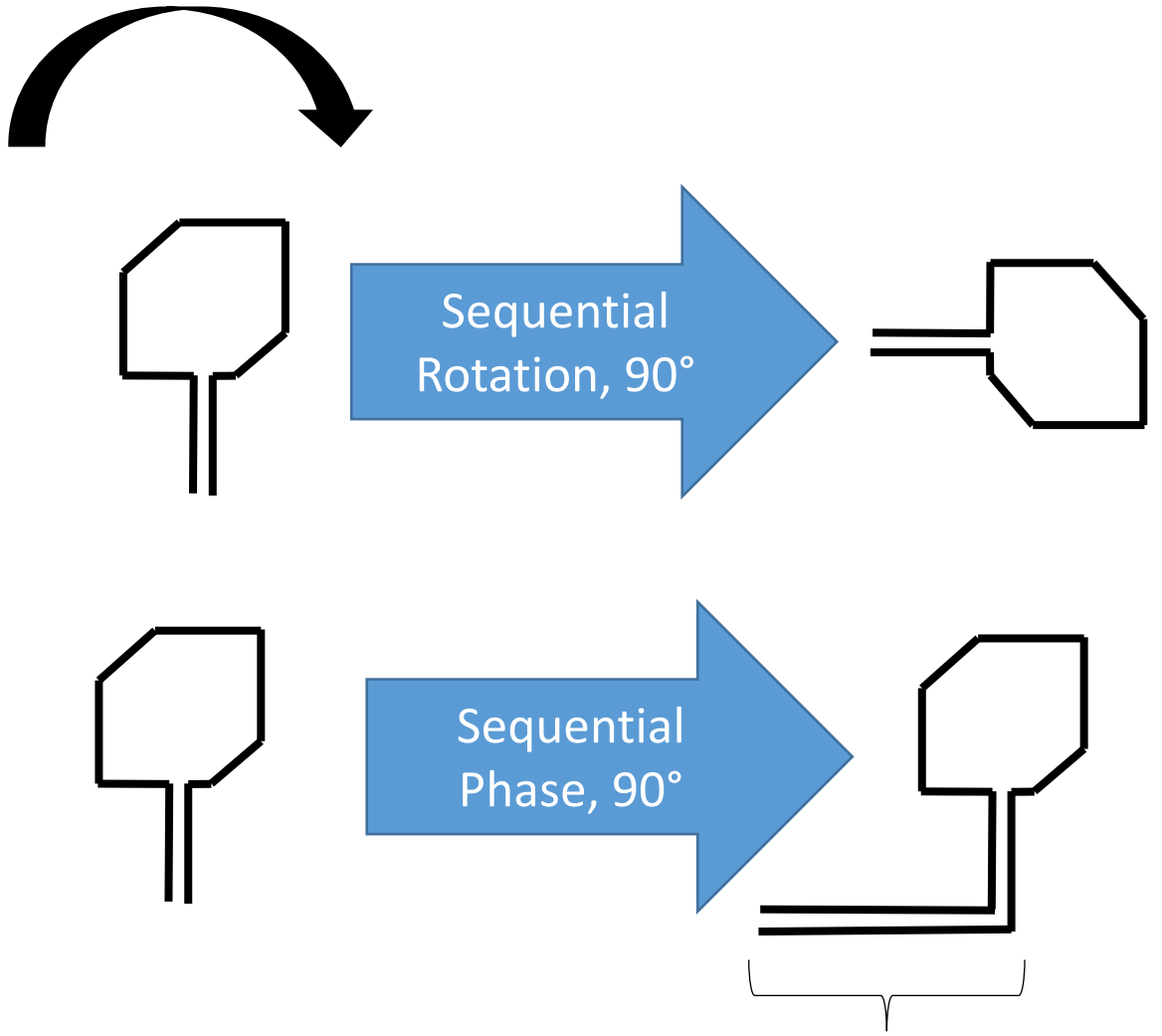
- Single Element, Truncated Corner Patch Antenna
- **Feed Network**
- 2x2 Sub Array





Feed Network Design

- Circular Polarization Improved
  - Sequential Rotation
    - A 90° Geometric Rotation
  - Sequential Phase
    - A 90° Phase Rotation

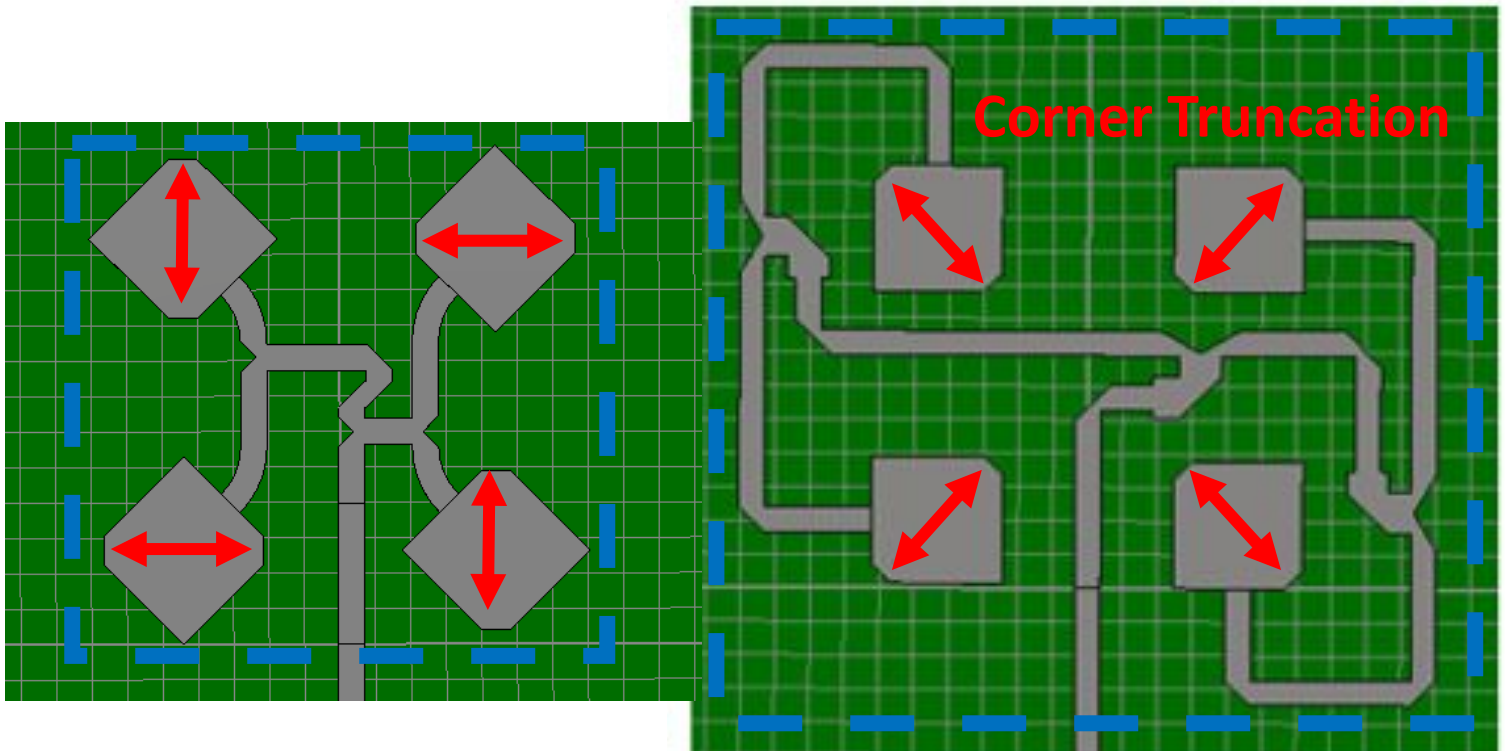


K_a Band Feed Network Design

Footprint: 199 mm²

Footprint: 375 mm²

Clever Use of λ/4 Line Lengths Allows Uniform Line Width and Compact Design



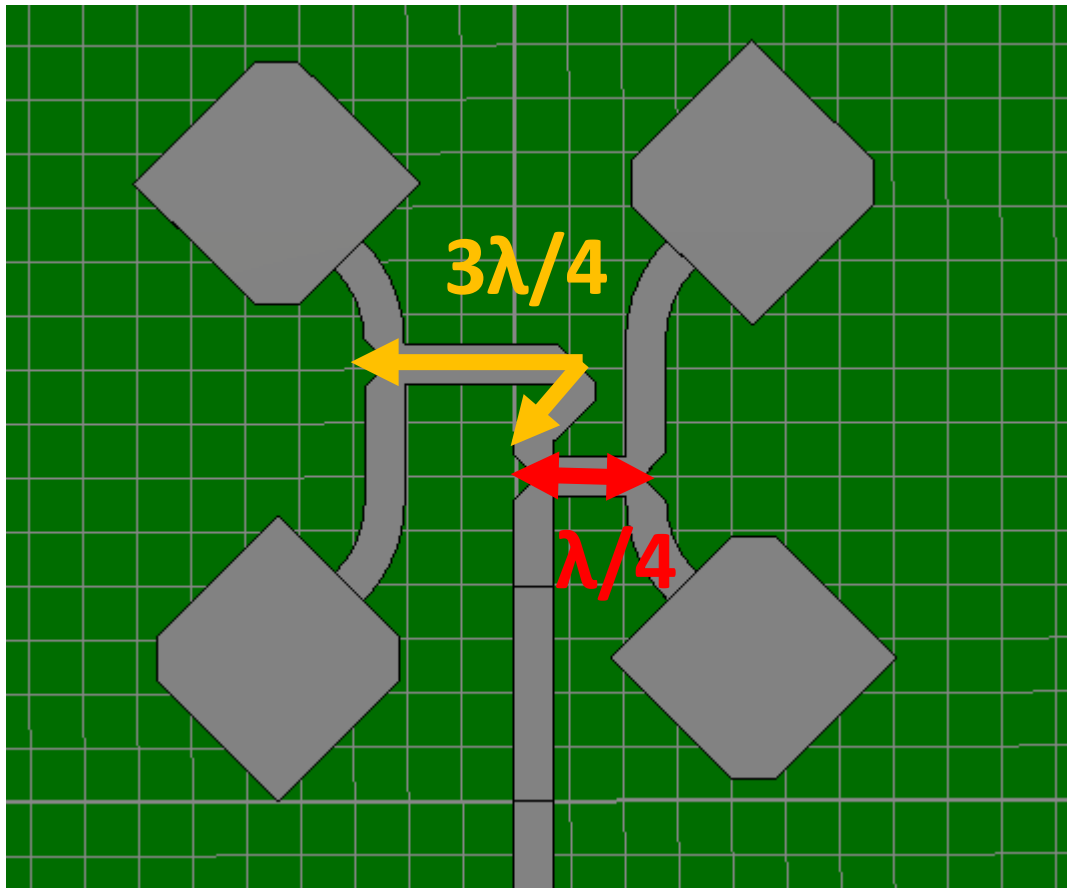
Unwieldy Feed Lines and λ/4 Transformers Increase Footprint and may Restrict *n* x *n* Array Design

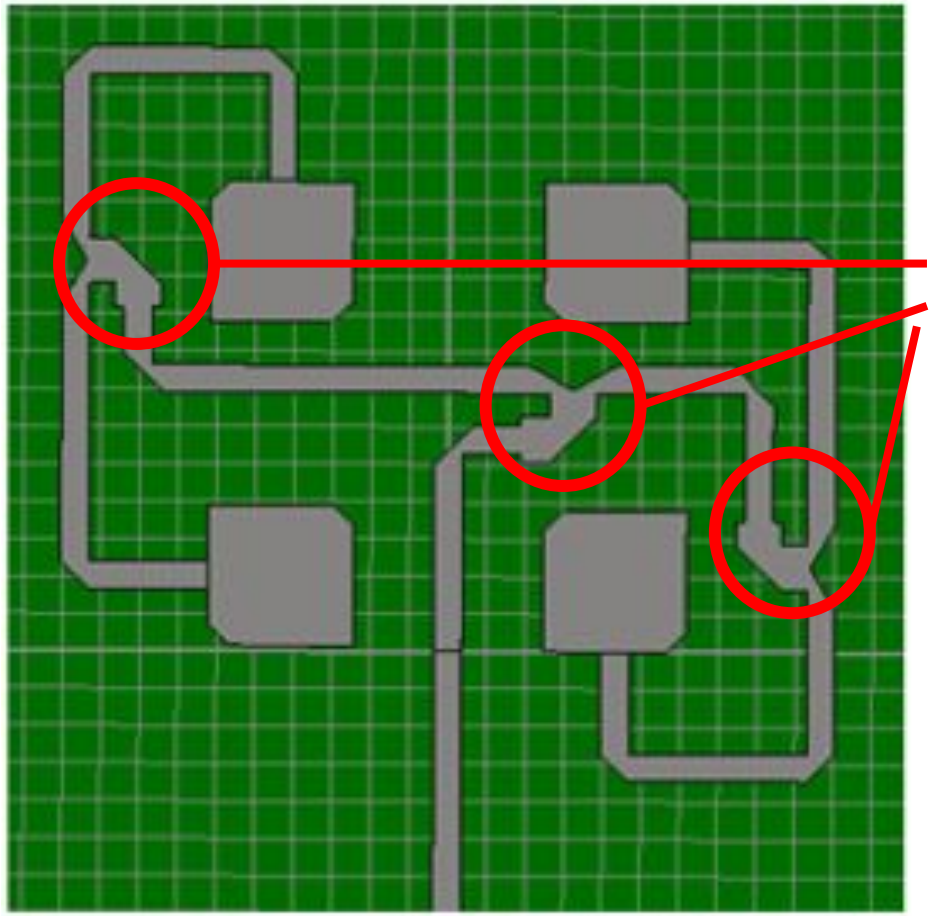
Compact Feed Network

Traditional Feed Network

S. K. Lin and Y. C. Lin, "A Compact Sequential-Phase Feed Using Uniform Transmission Lines for Circularly Polarized Sequential-Rotation Arrays," in *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 7, pp. 2721-2724, July 2011.

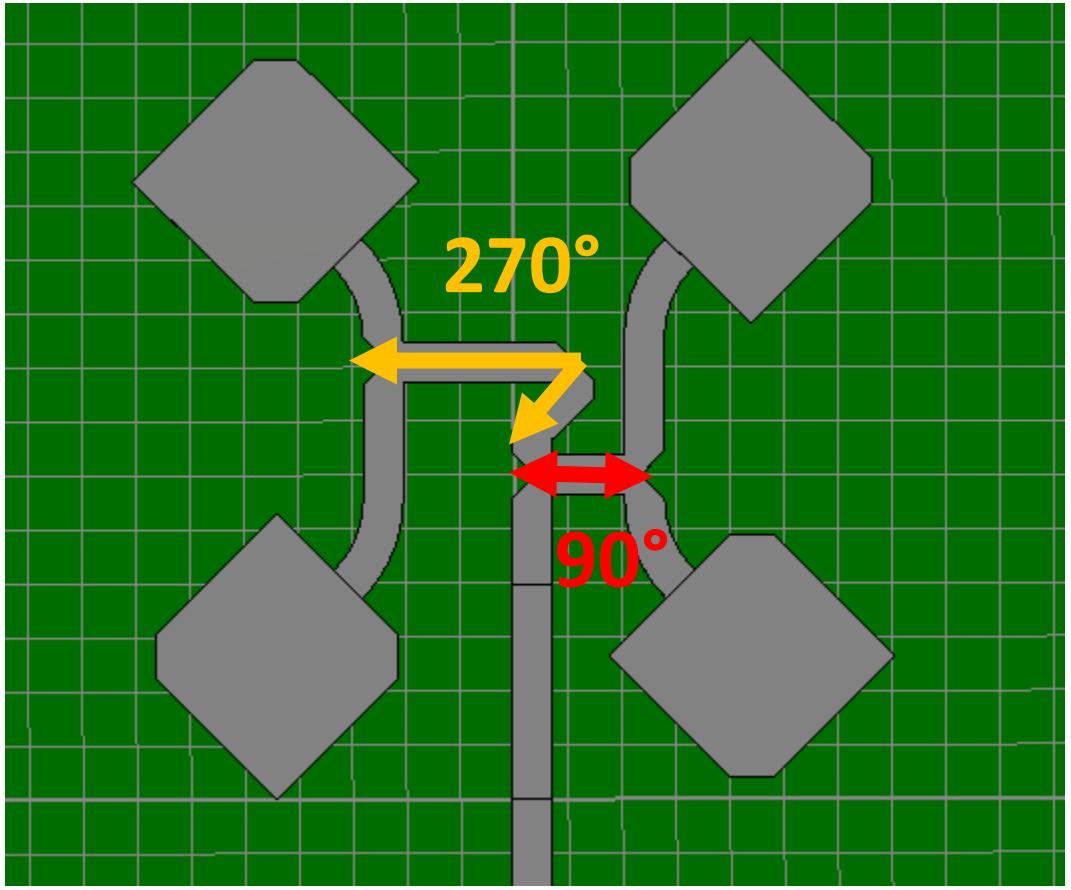
K_a Band Feed Network Design

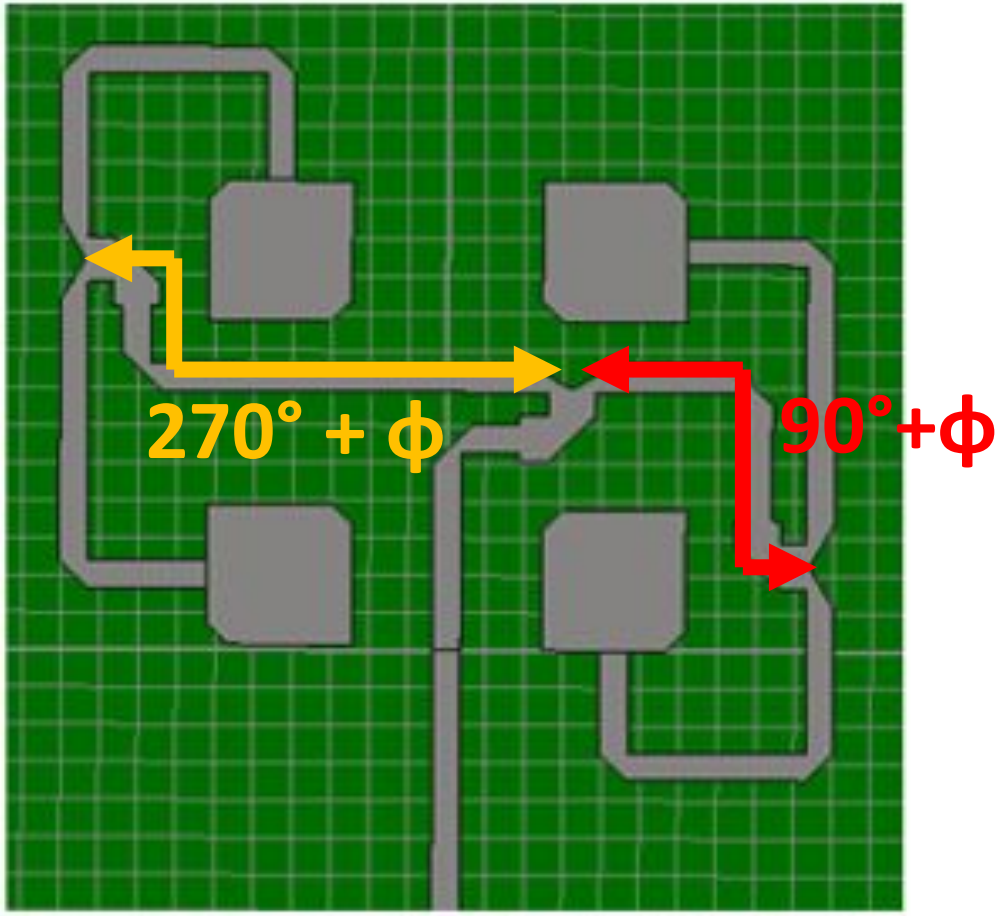




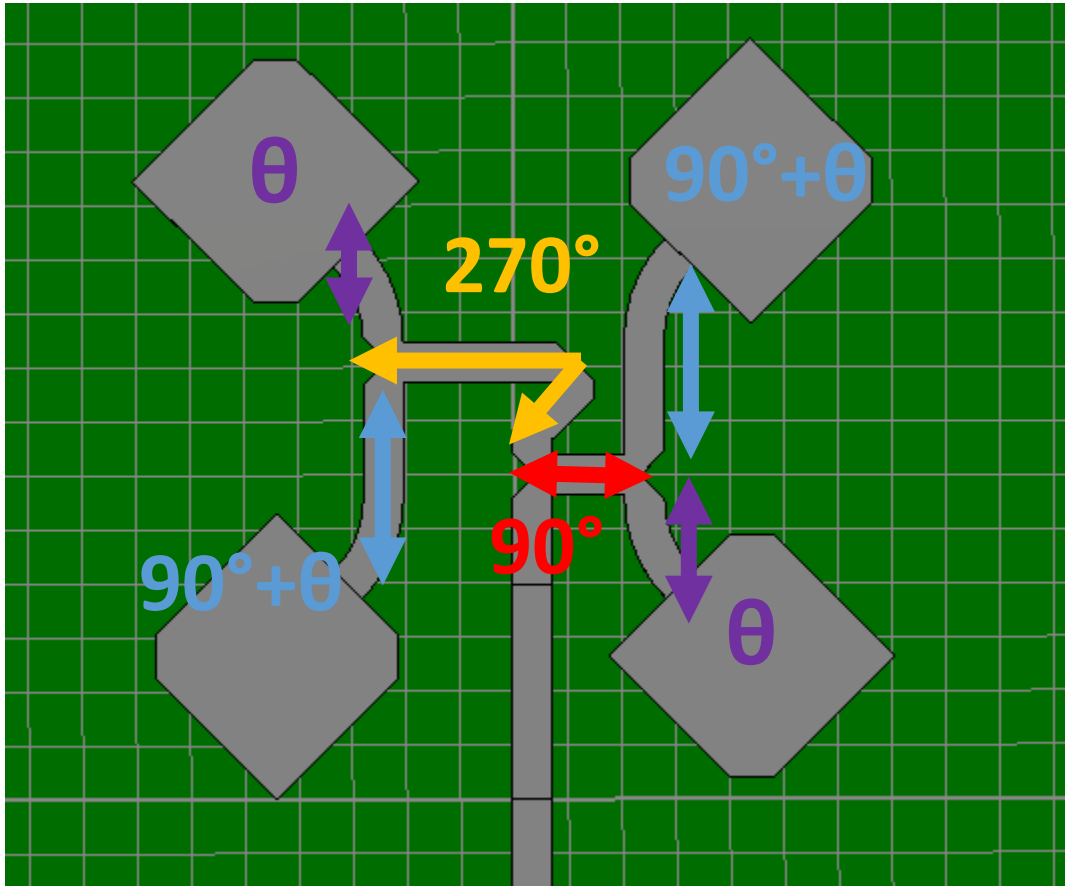
λ/4 transformers match impedance at branches

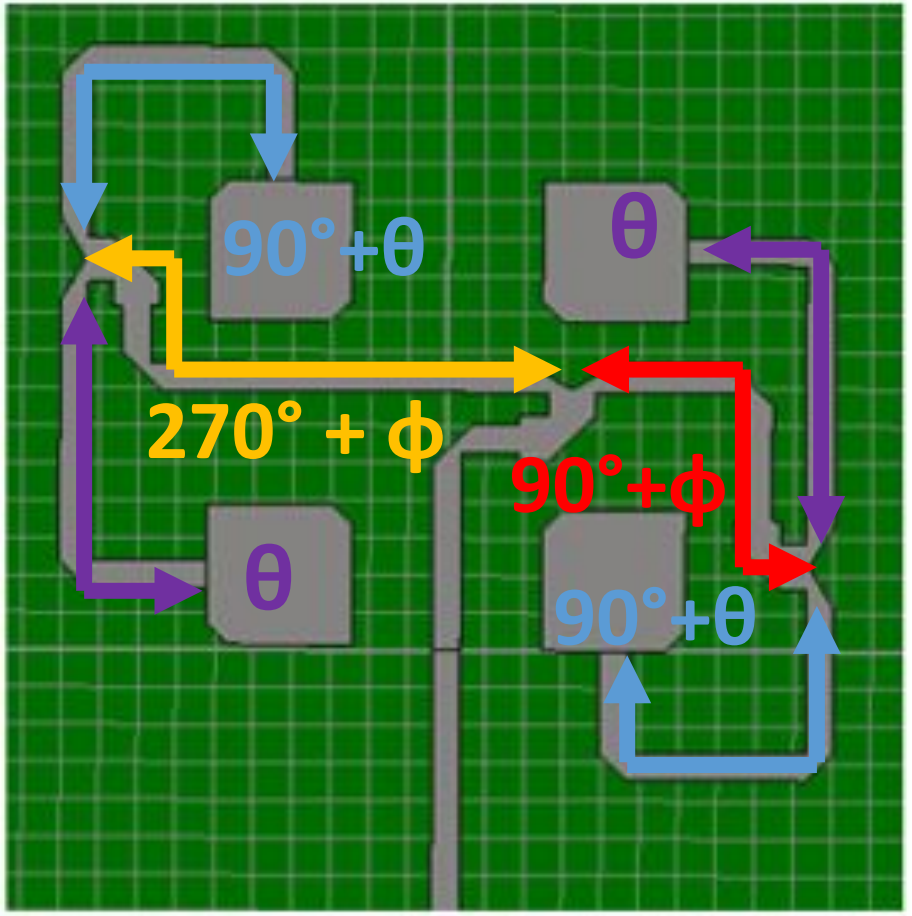
K_a Band Feed Network Design



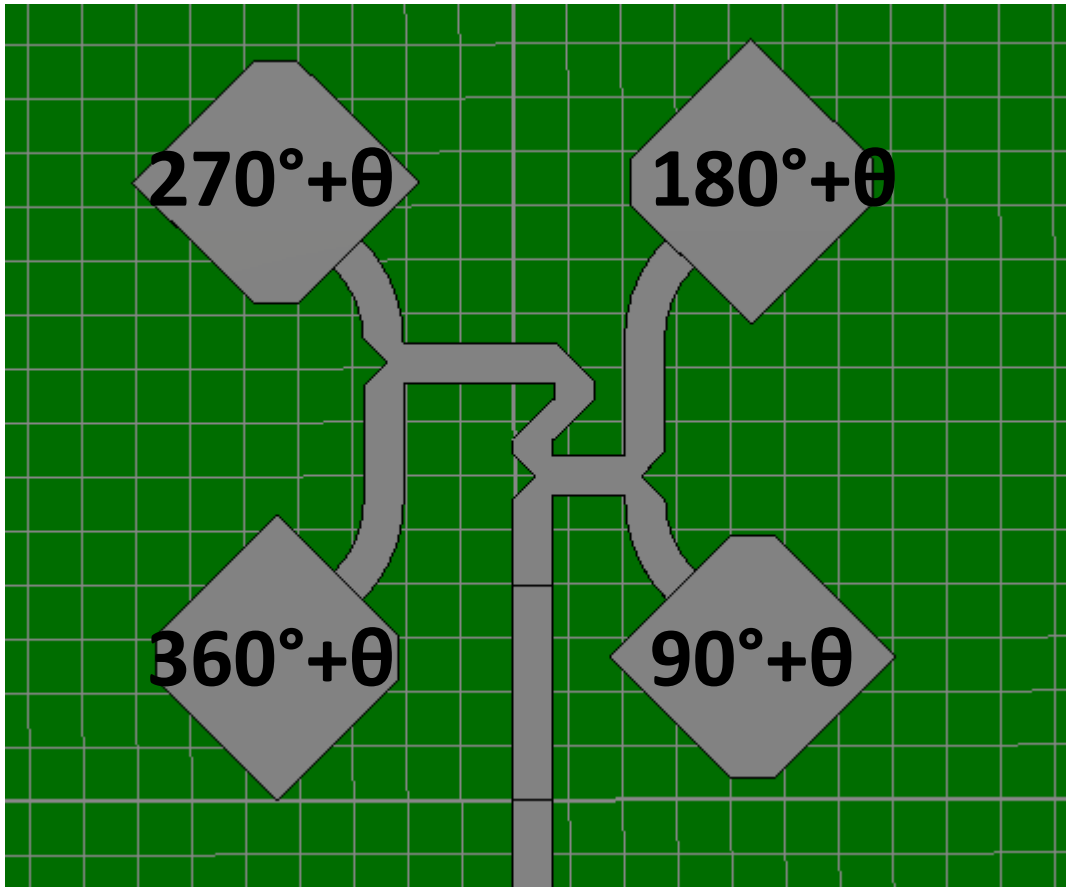


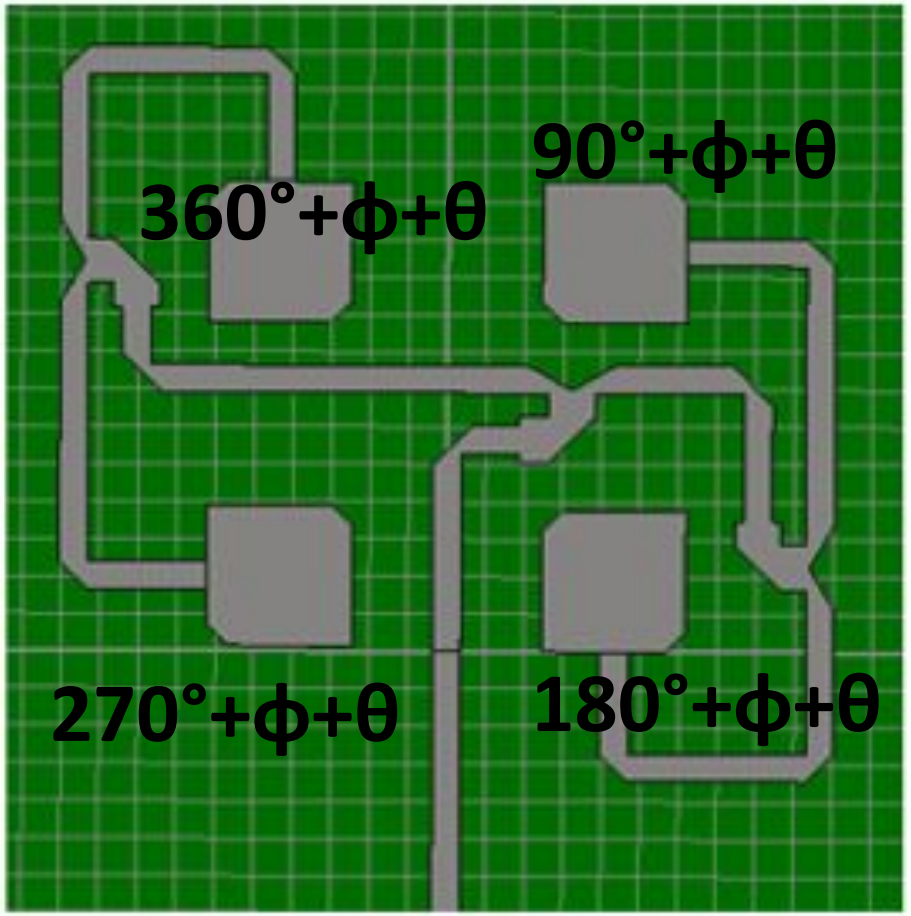
K_a Band Feed Network Design





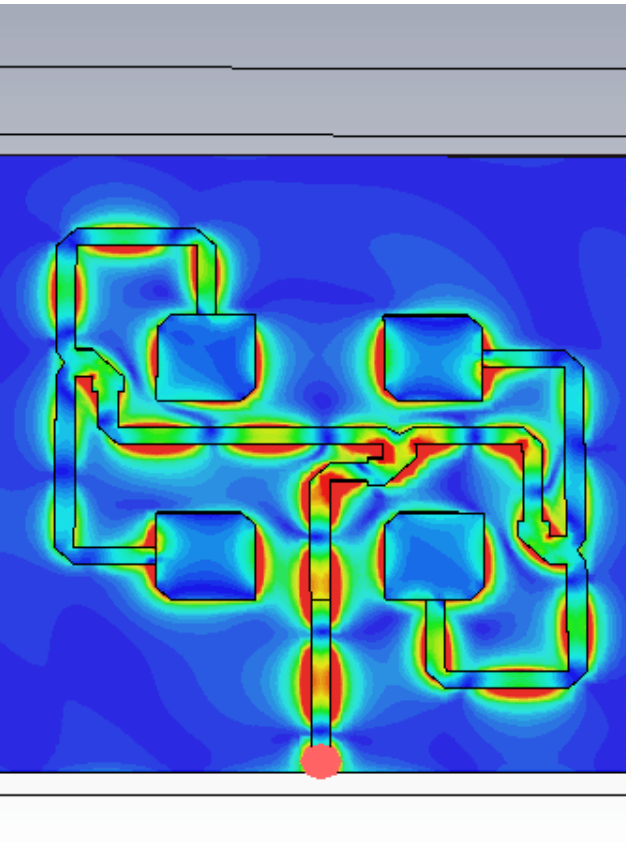
Electrical Distance From First Tee Junction



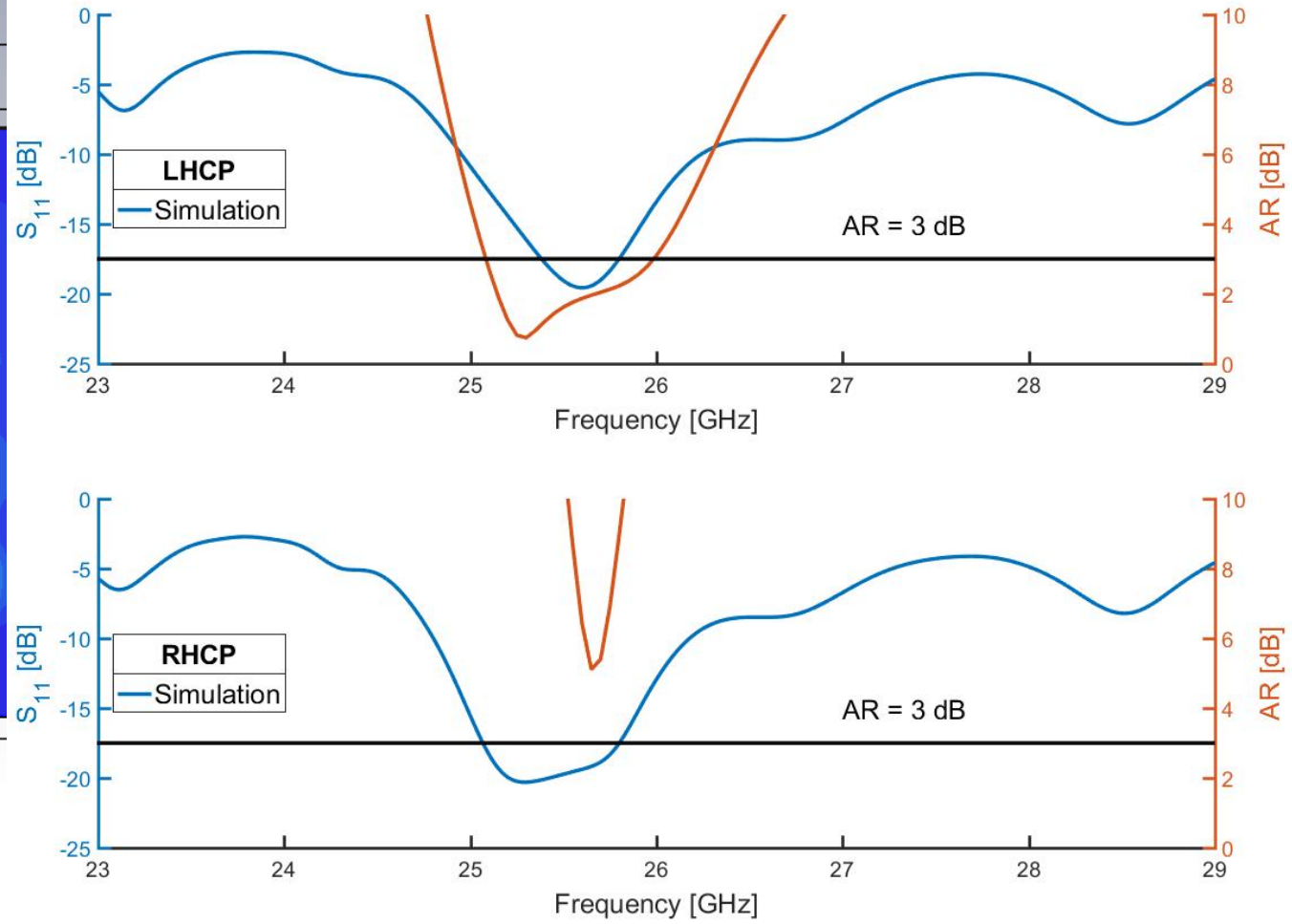


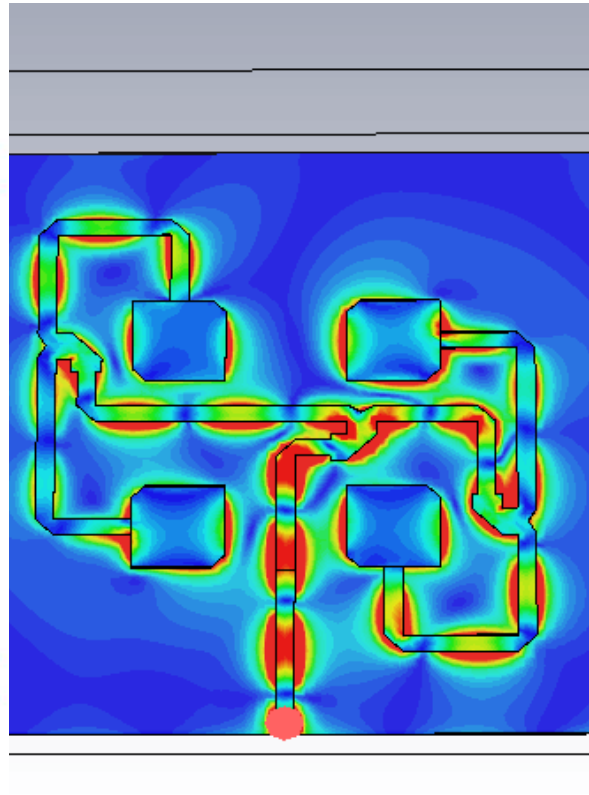
- Single Element, Truncated Corner Patch Antenna
- Feed Network
- 2x2 Sub Array

2 x 2 Sub Array, 10 mil, Rogers 5880
a = 0.530 mm



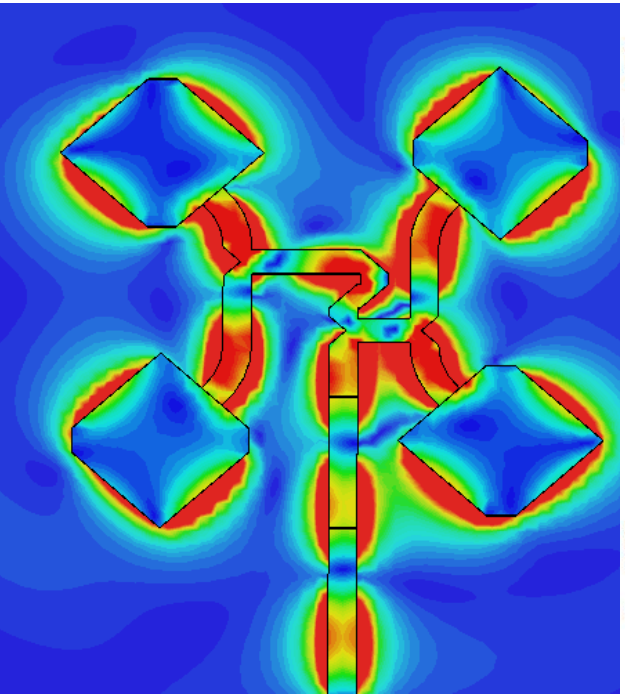
LHCP
25.7 GHz

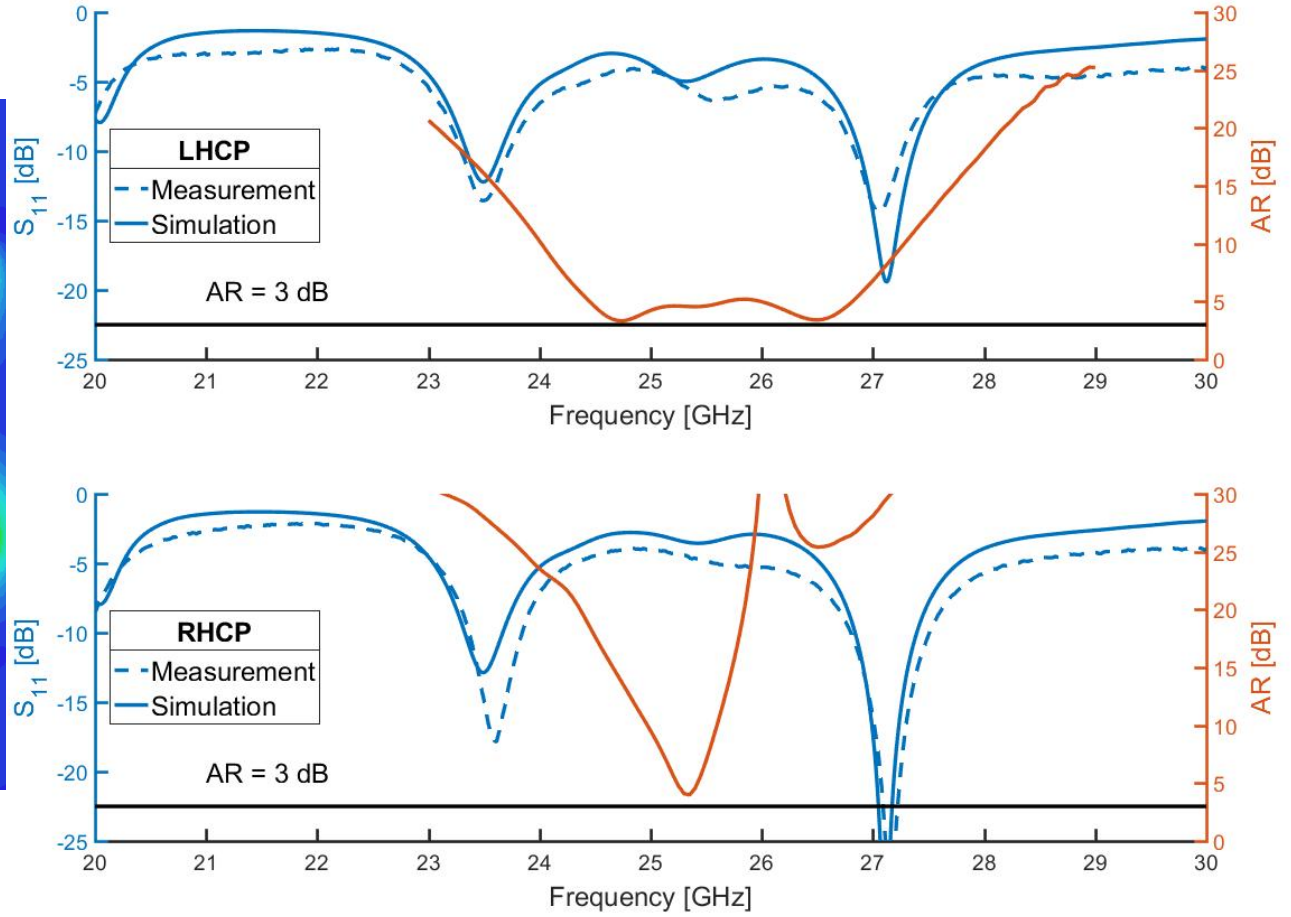


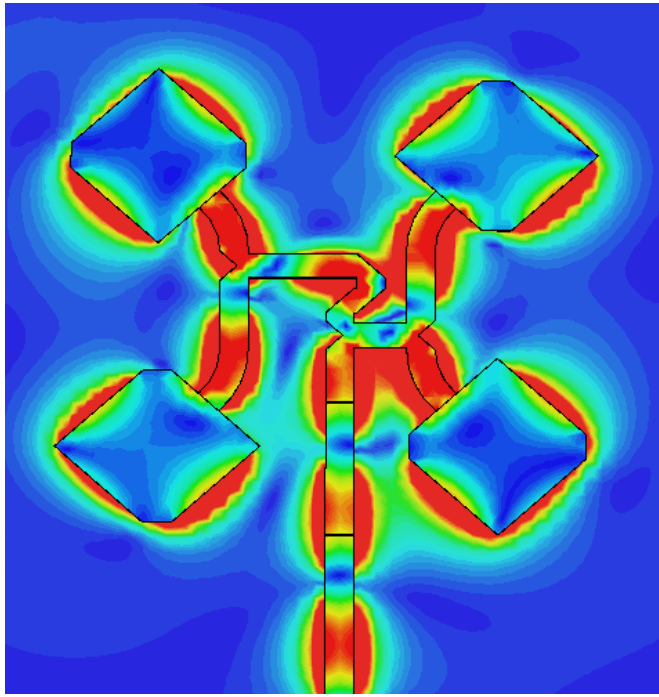


RHCP
25.7 GHz

2 x 2 Sub Array, 10 mil, Rogers 5880
a = 0.530 mm







LHCP
27.1 GHz

RHCP
27.1 GHz

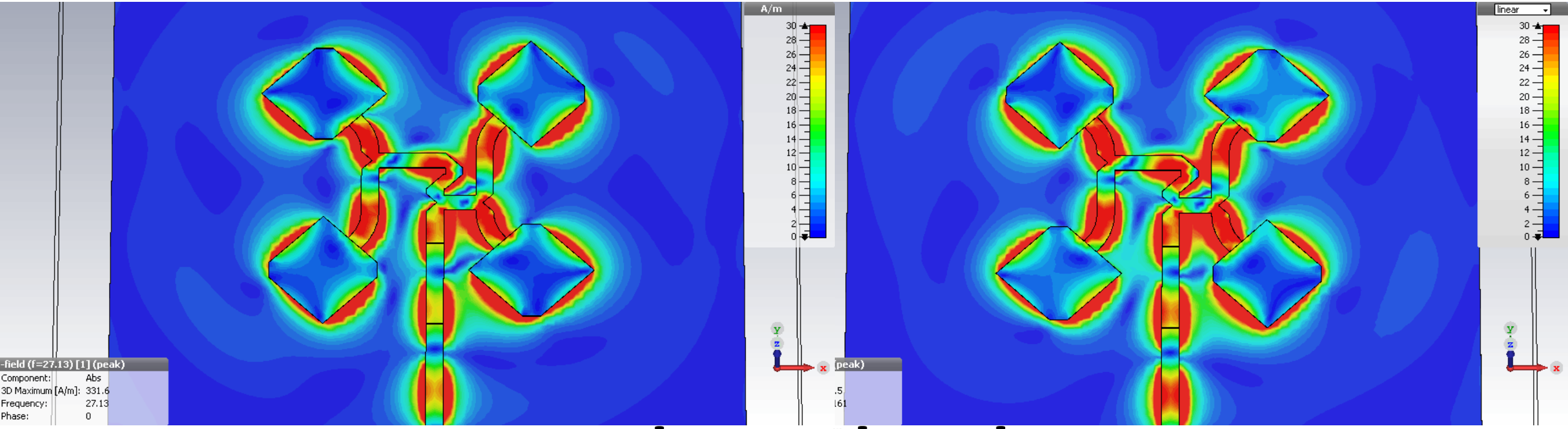
Conclusion & Future Works

- Ideal antennas will have good overlap in S_{11} and AR bandwidth
- In addition to the known design equations, good choice in substrate thickness and dielectric constant is required
- The compact sub-array offers a nice size reduction, but coupling may reduce the CP performance

Questions?

LHCP
27.1 GHz

RHCP
27.1 GHz



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