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


Originally from 1981, Reprinted in 1988


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
Major Topics

- Single Element, Truncated Corner, Circular Polarized Patch Antenna
- Feed Network
- 2x2 Sub Array
Truncated Corners create Circular Polarization (CP) in the Patch Antenna

Corner Truncation produces CP

Rogers 5880 $\varepsilon_r = 2.2$

Wavelength inside Substrate, $\lambda_d$

Substrate Thickness, $t$
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 ($\varepsilon_r = 2.2$)

Truncation Varied, 50Ω Microstrip Feed

Greater Truncation

Simulation * Under predicts Measured Resonant Frequency
10 mil, Rogers 5880 ($\varepsilon_r = 2.2$)
Truncation Varied, 50Ω Microstrip Feed

Simulation
* Under predicts Measured AR Bandwidth

<table>
<thead>
<tr>
<th>$a$ [mm]</th>
<th>3 dB Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>4.22 %</td>
</tr>
<tr>
<td>0.57</td>
<td>6.73 %</td>
</tr>
<tr>
<td>0.60</td>
<td>2.07 %</td>
</tr>
<tr>
<td>0.74</td>
<td>1.78 %</td>
</tr>
</tbody>
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<th>$a$ [mm]</th>
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<td>0.78 %</td>
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<td>-----</td>
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</tbody>
</table>
10 mil, Rogers 5880 ($\varepsilon_r = 2.2$) 
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)

<table>
<thead>
<tr>
<th>Substrate Thickness</th>
<th>L [mm]</th>
<th>a [mm]</th>
<th>$\lambda_d$ [mm]</th>
<th>t/$\lambda_d$</th>
<th>AR 3dB Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mil</td>
<td>3.83</td>
<td>0.34</td>
<td>7.8</td>
<td>0.016</td>
<td>0.47 %</td>
</tr>
<tr>
<td>10 mil</td>
<td>3.75</td>
<td>0.49</td>
<td>7.8</td>
<td>0.033</td>
<td>1.19 %</td>
</tr>
<tr>
<td>20 mil</td>
<td>3.56</td>
<td>0.68</td>
<td>7.8</td>
<td>0.065</td>
<td>2.47 %</td>
</tr>
</tbody>
</table>

**Design Choice**: 10 mil

Rogers 5880

AR & S11 Mismatch
Effect of

- Substrate Thickness
- Design Frequency
- Substrate Dielectric Constant
10 mil, Rogers 5880 ($\varepsilon_r = 2.2$)
Frequency Varied (Simulation)

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

All Antennas Fed with 50 $\Omega$
All Truncations designed for -10 dB
Surface Current at Center Frequency
10 mil, Rogers 5880

S Band
2.5 GHz

Kα 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)

Frequency [GHz]

\( S_{11} \)  

Best Axial Ratio

10 mil  
Rogers 5880

62 mil  
Rogers 5880
- Effect of
  - Substrate Thickness
  - Design Frequency
- Substrate Dielectric Constant
10 mil, Rogers 6006 ($\varepsilon_r = 6.15$)

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

All Antennas Fed with 50 Ω
All Truncations designed for -10 dB

![Graph showing S_11 and Best Axial Ratio](image-url)
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

$W = 3.374$ mm

$W = 3.749$ mm

$W = 4.124$ mm

3 dB Bandwidth

1.28 %

1.57 %

1.60 %
Asymmetric Patch Matched With $\lambda/4$ 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

Sequential Rotation, 90°
Sequential Phase, 90°
90° Electrical Length
K_{a} Band Feed Network Design

Footprint: 199 mm$^2$

Footprint: 375 mm$^2$

Clever Use of $\lambda$/4 Line Lengths Allows Uniform Line Width and Compact Design

Unwieldy Feed Lines and $\lambda$/4 Transformers Increase Footprint and may Restrict $n \times n$ Array Design

$K_a$ Band Feed Network Design

$\frac{3\lambda}{4}$ 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

\[ a = 0.530 \text{ mm} \]

**LHCP**

25.7 GHz

**RHCP**

25.7 GHz
2 x 2 Sub Array, 10 mil, Rogers 5880
\( a = 0.530 \text{ mm} \)

**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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