24–71 GHz PCB Array for 5G/ISM

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Outline

Motivation

Existing UWB mmW Arrays

PCB Limitations

Design for 24–71 GHz

Fabrication & Measurement
A Need for Ultra-Wideband in the Millimeter-Wave Spectrum

FCC proposed 5G bands: 28 GHz, 37 GHz, 39 GHz, and 64-71 GHz [1]
ISM allocations: 24 GHz, 60 GHz

- An Ultra-Wideband antenna allows us to consolidate these bands into one shared aperture
- Low-cost, low-loss PCB fabrication is desirable for mass-market acceptance

Are we going to integrate 6 separate phased arrays onto a cell phone?

Review of mmW UWB Arrays


[3] Demonstrate TCDAs with 6:1 BW, scalable up to 49 GHz on PCB.


Feeding Network is Critical to Wideband Operation

- Lower complexity
- Higher Frequency
- Lower bandwidth

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- Lower Frequency
- Higher bandwidth

• Improvements in size and performance of TCDAs comes as a result of more complex feed structures
• Wideband integrated balun requires a wide range (>10:1) of impedances
• These feeds do not easily scale, limiting designs to low frequencies
Eliminating vertical subarrays eliminates Vivaldi and slotline antennas

All mmW fabrication processes are inherently planar. Majority of feed must be designed from vias

Typical PCB process limits:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>μm</th>
<th>mil</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>76.2</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>76.2</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>152.4</td>
<td>6</td>
</tr>
<tr>
<td>D</td>
<td>152.4</td>
<td>6</td>
</tr>
<tr>
<td>E</td>
<td>304.8</td>
<td>12</td>
</tr>
<tr>
<td>F</td>
<td>254</td>
<td>10</td>
</tr>
</tbody>
</table>

Design should account for PCB fab limitations. Particularly challenging are via diameter and pitch limits.

6% of λ at 70GHz
Simplified 3-Pin Marchand Balun

Array of identical elements

Superstrate

Capacitive Coupling

Dipoles

Ground plane

Feed

H-wall

Input

Feed

Open Stub

Shorted Stub

Z_{ant}

Z_{open}

Z_{feed}

Z_{short}

Z_{in}
Impedance Analysis

**Coupled Dipoles with lumped port**

**Adding short circuit**
- Almost complete inversion
- Low frequencies at top of chart will be pulled down by added capacitance

**Adding open circuit**
- Very well matched at this stage (still lumped port near aperture), requires matched feed from source
Feed Via Placement

In-Line Feed Via

- Symmetrical layout reduces cross pol.
- Achievable via pitch in PCB bounds unit cell size
- Limited to < 75 GHz

Limited by via pitch requirements

Offset Feed Via

- Offset feed via allows unit cell miniaturization
- Enables operation up to 90 GHz
- Asymmetrical layout introduces high cross-polarized radiation

Polarization Ratio

Co Pol.
Cx Pol.
Elliptical pol.
Mitigating Common-Mode Resonance

- Resonant length can occur diagonally
- Thus, shorting pin only marginally effective
- High $\epsilon_r$ substrates can lower resonant frequency, but cause surface waves
- Can be resolved with continuous conducting wall along H-plane

![Graph showing VSWR vs Frequency](image)

- Unmodified path
- Alt. Substrate path
- Shorting Pins path
- H-Wall path

![Diagram of resonant structure](image)

- Resonant frequency $f_r = 46$ GHz
- 2.2 mm spacing
- Shorting Pin and “H Wall” notations
Coverage of the 5G/ISM Bands

Allocated 5G and ISM bands are highlighted:

<table>
<thead>
<tr>
<th>Allocation</th>
<th>Frequency (GHz)</th>
<th>Allocation</th>
<th>Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISM</td>
<td>24–25</td>
<td>5G</td>
<td>38.6–40</td>
</tr>
<tr>
<td>5G</td>
<td>27.5–28.35</td>
<td>ISM</td>
<td>57–64</td>
</tr>
<tr>
<td>5G</td>
<td>37–38.6</td>
<td>5G</td>
<td>64–71</td>
</tr>
</tbody>
</table>

Coverage of all 6 bands (24–71 GHz) with:
- VSWR < 2.2 - Broadside
- VSWR < 2.5 - 45° E-Plane
- VSWR < 3 - 45° H-Plane
- Radiation efficiency > 90%

(95% of grating lobe spacing)
Fabrication Layout

Layer M2

Layer M3

Stackup

Copper:
M2
M3
M4
M5

4 mil, Rogers 2929
36 mil, Duroid 5880
6 mil, Rogers 2929

Silkscreen

(blink)

via_2_5
via_2_4
via_3_4
Drill (unplated)
via_4_5

ENIG finish

all values in mil
Fabricated Samples

Application Samples

Measurement Samples

5x5 array

3x3 measurement coupons
Example Measurement Coupon

- Single active element per coupon
- All others terminated at matched load
- Groundplane extends to substrate edge
- Active element is not centered with respect to coax port
- Coupon size changes for different elements or array sizes, but always has 5mm groundplane surrounding array

1.85mm Coax connector
Or probe land
Measurement Coupon Diagrams

- “Defective” elements due to soldering failure, no connection at DC

**Coupon: H-Plane, Element 0**
- Defective Element
- Active Element
- Rotation Plane

**Coupon: H-Plane, Element 1**
- Active Element
- Rotation Plane

**Coupon: E-Plane, Element 0**
- Active Element
- Rotation Plane

**Coupon: E-Plane, Element 1**
- Defective Element
- Active Element
- Rotation Plane
Measurement Setup

Waveguide sources:
- 20-40 GHz
- 40-60 GHz

Horn source:
- 50-75GHz

- Coupon mounted on rotating post
- Measurements limited by frequency range of 1.85mm port (<70GHz)
- Horn source required at high band to increase dynamic range
3x3 Measured Results

- Measurements and simulation show good agreement
- 1x3 simulations were used to reduce computational burden, but some compromise in accuracy
- Reduced gain near 35GHz result of excess dielectric and groundplane surrounding the array
Conclusions

Motivation
• Multiple mmW communications bands
• Ideally, consolidate into a shared aperture

Design
• Simplified balun design overcomes limitations in PCB fabrication
• Cavity resonance is averted with a conducting wall perpendicular to dipole current

Fabrication
• 3x3 test articles were fabricated and measured
• Close agreement with simulations observed