Practical mmWave Filtering for 5G

Knowles Precision Devices
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Knowles Precision Devices is a division of Knowles focused on high performance components such as Microwave Devices (Filters, Power Dividers) and Capacitors (Multilayer and Single Layer)

Here today to discuss some practical considerations around selecting filter technology for mmWave applications

Takeaways to include
• Best current available solutions for RF filters at mmWave frequencies
• The impact of manufacturing tolerance
• The impact of temperature stability across wide temps
• The question of filter size at mmWave
Filtering in New Radios

Changing Approach To Phased Arrays Changes Filter Size Expectations

Plank or Brick Architecture

- Conventional Brick
  - Airborne AESA
    - TRU’s at 90° to array
    - TRU height limited by λ/2
    - TRU board not area constrained (can be long)

Flat Panel or Tile

- Flat Panel or Tile
  - 5G BTS
    - TRU’s on back side of array
    - Very dense spacing
    - TRU board Constrained by λ/2 in X and Y
    - Need High Temp Operation

Flat panel architecture requires very small and highly temperature stable filtering
Where can filters get placed?

Single ‘branch’ (beamforming has multiple such branches)

Single TR Path

- Behind the antenna element (F1)
  - Loss, size, cost and wide-band suppression important.
  - Suppress interference and emissions

- Behind first amplifiers (F2)
  - Size, cost and wide-band suppression important.
  - Suppress interference and emissions

- RF side of Mixer (F3)
  - Wide-band suppression important.
  - Suppress interference and emissions

- \(\lambda/2\) critical dimension in X and Y
5G Frequency Bands and Filter Technology

- **Rel 15 FR1 Mid-Band (3.3-5GHz)**
  - 2.6GHz, $\lambda/2 = 5.75\text{cm}$

- **Rel 15 FR2 (24.25-40GHz)**
  - 28GHz, $\lambda/2 = 5.35\text{mm}$
  - 39GHz, $\lambda/2 = 3.85\text{mm}$

- **Lumped LC, SAW, BAW, Ceramic Resonator, FBAR, Dielectric Waveguide, On-Chip, Transmission Line, Metal Waveguide**

- **Technologies And 5G Frequencies**

  - **Technologies**
    - Acoustic: small, but can’t reach FR2 range
    - Waveguide: high frequency, but not usually compact
    - Distributed element (On-Chip, Variations on Transmission Line) offer the best frequency range and footprint combination.
    - To-date on-chip is low performing for filters
    - We will look at some approaches factors to consider when building Transmission Line filters in the FR2 range
Microstrip on PCB at 26GHz

Design

Goals
• Center Frequency: 26GHz
• 3dB Bandwidth: 4x800MHz
• Insertion Loss: 2dB
• Stopband 1: -35 dB within DC-22 GHz
• Stopband 2: -35dB within 30-68 GHz

Implementation
• PCB Microstrip
• 6th Order
• Edge Coupled
• 10 mil of RO43503B
• 2 oz copper
• E.g. implemented on the TRU board
## Microstrip on PCB at 26GHz

### Tolerance Impact

<table>
<thead>
<tr>
<th>Tolerance</th>
<th>Microstrip on RO4350B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>10 mil ± 1 mil</td>
</tr>
<tr>
<td>Etching Tolerance</td>
<td>±2 mil</td>
</tr>
<tr>
<td>Dielectric Constant (Dk) Tolerance</td>
<td>3.66 ±0.05</td>
</tr>
</tbody>
</table>

35dB ~2GHz Shift
60% of 3.2GHz Bandwidth
Stripline on PCB at 26GHz

Design

Goals
• Center Frequency: 26GHz
• 3dB Bandwidth: 4x800MHz
• Insertion Loss: 2dB
• Stopband 1: -35 dB within DC-22 GHz
• Stopband 2: -35dB within 30-68 GHz

Implementation
• PCB Stripline
• 7th Order
• Hairpin
• 30 mil RO3003
• 0.5 oz copper
• E.g. implemented on the TRU board
Stripline PCB at 26GHz

Tolerance Impact

<table>
<thead>
<tr>
<th>Tolerance</th>
<th>Stripline on RO3003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>30 mil ± 1.5 mil</td>
</tr>
<tr>
<td>Etching Tolerance</td>
<td>±0.5 mil</td>
</tr>
<tr>
<td>Dielectric Constant (Dk) Tolerance</td>
<td>3 ±0.04</td>
</tr>
</tbody>
</table>

35dB ~1GHz Shift
30% of 3.2GHz Bandwidth
SMT Component Microstrip at 26GHz

Unscreened Tolerance

- KPD Catalog Devices
- B259MC1S
- Microstrip on KPD Custom Dielectric
- SMT Package
- Status: Production

35dB ~130MHz Shift
0.04% of 3.2GHz Bandwidth

- This is unscreened tolerance

- Discrete SMT Devices tested before they touch the board
The Size of 26GHz Filters

Size Impact

- 26GHz \( \lambda/2 = 5.75\) mm
- 5 mm — length of average red ant

Nominal Filter Comparison

Knowles B259MC1S, 5.5x2.3mm
Stripline, 14.2x4.0mm
Microstrip, 12.8x4.3mm

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Transmission Line Temperature Stability

Choice of material impacts temperature shift

S21 for 18 GHz Bandpass Filter On Alumina, -55°C to +125°C

35dB ~140MHz

S21 for 18GHz Bandpass Filter on CF Dielectric, -55°C to +125°C

35dB ~17MHz
Transmission Line is a good option for mmWave if you consider the following:

- **Size Constraints**
  - $\lambda/2$ at 26GHz is 5.75mm
  - Filter Choices narrowed
  - Distributed Element Transmission Line Implementations Promising for Small Form Factor

- **Impact of Manufacturing Tolerance**
  - Choice of implementation becomes critical

- **Impact of Temperature Stability**
  - Choice of implementation becomes critical

- **Guard Bands**
  - Allow for Tolerance + Temp Stability

- **More info at:**
  - www.knowlescapacitors.com/5G