Switchable Array Antennas for 24 GHz Radar Applications

Master Thesis
By Bo Zhou
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Outline

→ Basic Theory and Concepts
→ Phased Array Antennas
→ Switching Concept
→ Network Distribution and Components
→ Final Design and Analysis
→ Conclusion
Radar System Requirements

Radar systems

transmitter → duplexer → receiver → display

antennas
Radar System Requirements

Automotive or security applications

High resolution
Not only range, speed
But also angular position

Small size
Low cost
flexible

4 beams
Narrowbeam
High directivity
(more than 20dB)

........
Good isolation between beams
(at least 3dB)
Network Concepts

Feeding Networks

Constrained Feeds
  - Series
  - Parallel

Semi-constrained Feeds

Unconstrained Feeds

Beam Forming Network
  - Series
  - Parallel
    - Blass Matrix
    - Butler Matrix
Network Concepts

Matched corporate feed

Parallel constraind feeds

Wilkison power divider
Phased Array Antennas

Equal phase array

Phase increase by \( \Delta \phi \)

\[
\Delta \phi = \frac{360^\circ \cdot d \cdot \sin \Theta_s}{\lambda}
\]
Phased Array Antennas

Azimuth distribution

Elevation distribution (column design)

Empire model of single column

Directivity

Angular distribution
Phased Array Antennas

Determination of the number of columns

Azimuth distribution

8 elements
Phased Array Antennas

Azimuth distribution

16 elements

Gain in dB

Angle in degree

scan angle=4
scan angle=12
scan angle=-4
scan angle=-12

16 elements
Phased Array Antennas

Azimuth distribution

Network Distribution
Phased Array Antennas

Double use of the antenna separated with Wilkison power divider

Design of the whole network
Phased Array Antennas

Simulation of the antenna array

Only with ports
**Phased Array Antennas**

<table>
<thead>
<tr>
<th>Port</th>
<th>Amplitude</th>
<th>Phase 1 in degree</th>
<th>Phase 2 in degree</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.19</td>
<td>0</td>
<td>0</td>
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<td>0.67</td>
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<td>96</td>
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<td>0.9</td>
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<td>312</td>
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<tr>
<td>11</td>
<td>0.9</td>
<td>120</td>
<td>360/0</td>
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<td>12</td>
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<td>144</td>
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</tr>
<tr>
<td>13</td>
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<td>168</td>
</tr>
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</table>

Simulated farfield patterns

Amplitude and phase distribution of the ports

Grating lobes

![Graph showing simulated farfield patterns](image-url)
Switching Concepts

Phase shifters

90° Hybrid

LNA/PA

$\Phi/2$

Hybrid coupled phase shifter

<table>
<thead>
<tr>
<th></th>
<th>MEMS</th>
<th>electronic Switching</th>
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</thead>
<tbody>
<tr>
<td>Absorption</td>
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<td>✓</td>
</tr>
<tr>
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<td>✓</td>
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<tr>
<td>Operating Voltage</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Switching Speed</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Life Circle</td>
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<td>✓</td>
</tr>
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</table>
Switching Concepts

Phase shifters

90° hybrid coupler

EMPIRE model of phase shifter
Switching Concepts

Phase shifters
Network implementation

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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.38</td>
<td>30</td>
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<td>0.38</td>
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Simulation of antenna array
Only with ports definition
Network implementation
Network implementation
Network implementation
Final Design
Final Design

Graphs showing the directivity in dB vs. angle in degree for different scenarios:
- Blue line: Excited port 1 diode off
- Red line: Excited port 1 diode on
- Green line: Excited port 2 diode off
- Purple line: Excited port 2 diode on

Right graph:
- Blue line: Antenna array simulated with network
- Cyan line: Antenna array simulated with ports
Conclusion

→ Different network concepts and switching concept are discussed

→ Phase shifters with PIN diode are simulated, fabricated and measured

→ The whole RF circuit is simulated

→ The radar system requirements are fulfilled

→ The PIN-diodes switching circuits will more detailed analyzed in near future
Reference

Balanis 2005

Bhattacharyya 2006
BHATTACHARYYA, Arun K.: Phased Array Antennas. 2006

Brookner 1991

Hansen 1998

Johnson 1998

Kraus 2009

Mailloux 1994

Pozar 1998
POZAR, David M.: Microwave Engineering. 1998

radartutorial8
Radar tutorial: Phased Array Antenna. www.radartutorial.eu

Skolnik 2008

Solbach 2009
SOLBACH: Antennas for Communication. 2009
Thank you for attention!
Network Concepts

Unconstrained Feeds

Lens array

Reflect array
Network Concepts

Beam Forming Network

- Series
  - Blass Matrix
- Parallel
  - Butler Matrix

Butler Matrix

Schematic of Butler matrix
Network Concepts

Butler Matrix

90° Hybrid couplers

Phase shifts in unit $\pi/8$
Network Concepts

Blass Matrix
Phased Array Antennas

Condition for appearance of grating lobes

\[ \frac{d}{\lambda} = \frac{1}{1 + |\cos \theta_0|} \]
Switching Concepts

Components of phase shifters

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Switching Concepts

Phase shifters

- **MA200 Silicon FlipChip PIN Diode**
  - Frequency in GHz
  - S-Parameters in dB
  - Simulated S21 with diode on
  - Simulated S21 with diode off
  - Measured S21 with diode off
  - Measured S21 with diode on

- **MA200 (Phase shift between diode on and off)**
  - Phase shift in degree
  - Frequency in GHz
  - Measurement
  - Simulation
Switching Concepts

Phase shifters
Final Design
Network Concepts

Constrained Feeds

Series constrained feeds

Figure 2.1: Series Feed [Skolnik (2008)]
Switching Concepts