Multifunction Phased Array Radar (MPAR)

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Substantial overlaps in airspace coverage exist, but missions are different for different radar types.
Current Aircraft and Weather Surveillance Radars: Spectral Usage

**Long-Range Air Surveillance**
- ARSR-1, 2, 3, 4 (FAA, USAF): 1.2–1.4 GHz
- FPS-20, 66, 67 (USAF): 1.25–1.35 GHz

**Terminal Weather Surveillance**
- TDWR (FAA): 5.5–5.65 GHz

**Terminal Air and National Weather Surveillance**
- ASR-8, 9, 11 (FAA, USAF): 2.7–2.9 GHz
- NEXRAD (NOAA, FAA, USAF): 2.7–3.0 GHz
Multifunction Phased Array Radar (MPAR)

- Consolidates all functions to S band
- Eliminates 122 L-band and 45 C-band* radars

*Commercial weather radars remain in C band (~350 TV stations)
Operational Wavelength Trade-offs

- **Long-range aircraft surveillance: L band ⇒ S band**
  - Increased atmospheric attenuation
    Compensate by increasing power on target

- **Terminal weather: C band ⇒ S band**
  - Improved range-velocity ambiguity
  - Less attenuation through severe weather
  - Worse angular resolution for same size antenna
    Put radar closer to airport
  - Decrease in signal-to-clutter ratio
    Phased array capability to form nulls and lack of scan-smearing can improve clutter suppression overall

One of the main reasons that TDWR was assigned to C band was potential conflict with existing terminal-area S-band radars
U.S. Airspace* Coverage

Current Coverage

Multifunction Radar Coverage

Aircraft

Weather

Plots shown @ 5000 ft AGL

*50 states + U.S. territories (only CONUS plots shown)
Potential Reduction in Radar Count

<table>
<thead>
<tr>
<th>Replacement Scenario</th>
<th>Legacy</th>
<th>MPAR*</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASR and TDWR</td>
<td>276</td>
<td>228</td>
<td>17</td>
</tr>
<tr>
<td>ASR, TDWR, and NEXRAD</td>
<td>432</td>
<td>310</td>
<td>28</td>
</tr>
<tr>
<td>ASR, TDWR, NEXRAD, ARSR, and FPS</td>
<td>554</td>
<td>357</td>
<td>36</td>
</tr>
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*Two tiered: Full-size MPARs and terminal-area MPARs
Cost Reduction Strategy

Multifunction radars exist—reducing cost is main challenge

**Military S-Band Radars**
- Low production volume
- High power density
- Special purpose designs
- Fixed aperture sizes

**MPAR Panel Technology**
- High production volume
- Modest power density
- General purpose design
- Scalable aperture sizes

Exploit wireless industry technology—leverage commercial manufacturing and test processes
Terminal* MPAR Concept Design

- Weather drives power-aperture requirements
- Aircraft drives volume update rate requirements

*Full-size MPAR antenna would be 8-m diameter, 20,000 elements per face

- Aircraft Surveillance
  - Two 6 x 2 beam clusters
  - (Up to 24 single linear polarization beams)

- Weather Surveillance
  - (Up to 12 dual polarization beams)

### Technical Specifications
- **Frequency:** 2.7 – 3.0 GHz
- **Diameter:** 4 m
- **T/R per face:** 5,000
- **Beamwidth:** 1.6° (broadside)
- **Array cost/m²:** $50k
- **Polarization:** Dual linear/circular
- **Beam count:** > 10 beams
- **Duty Cycle:** 8%
- **Peak power:** 8 W/element
Spectral Usage Challenges

Factors that increase MPAR spectral usage

• Asynchronous, independent operation on multiple (4) antenna faces
  – Frequency isolation between (at least) adjacent faces
• Low cost ⇒ low peak-power per module ⇒ pulse compression
  – Frequency separation between long pulse and fill pulse(s)
  – Strict range sidelobe requirement for weather widens pulse compression bandwidth
• If multifunction volume update rate cannot be met with one frequency band per face, multiple bands per face may be needed
• During deployment MPAR has to coexist with legacy radars
  – Interference with legacy radar mission cannot be tolerated
• If DHS becomes MPAR stakeholder and requires ultra-high bandwidth for target ID, spectral occupancy could explode

Spectral occupancy of 2.7-3.0 GHz band will increase with MPAR
Multi-Face Trade Space

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Frequencies</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>All faces independent frequencies</td>
<td>8</td>
<td>Large spectral content at each site, most flexible</td>
</tr>
<tr>
<td>Front and back faces share frequencies</td>
<td>4</td>
<td>Front-to-back isolation is critical specification</td>
</tr>
<tr>
<td>All faces share frequencies</td>
<td>2</td>
<td>No adaptive operation allowed</td>
</tr>
</tbody>
</table>
Near and Far Range Operation of Radar

**Close range**
- Long pulse hits target and returns to radar before receive window

**Medium range**
- Short and long pulse both hit target and return at different times in receiver
- Need to identify waveforms to know the range

**Long range**
- Short-pulse energy is too low for operation
Receive returns overlap in time with different ranges due to the different pulse start times.

Need a way to separate signals
  - Frequency offset is the standard method.

Minimum range: \( R = \frac{c T_p}{2} \)
\( c \) = speed of light
\( T_p \) = Start of pulse to beginning of receive window
Spectral Width of Standard Pulse Scheme

Rectangular pulse
Pulse width: 1 μs
Pulse bandwidth: 1 MHz

Linear Chirp
Pulse width: 80 μs
Pulse bandwidth: 1 MHz

- Near-range operation drives spectral width
- Range sidelobes of linear chirp are poor
  - Common mitigation strategies are amplitude tapering and/or additional spectrum with non-linear chirp
Ongoing RF Spectral Analysis

- Detailed matched filter analysis for multiple pulse spectral separation

- Potential spectral improvements
  - Simultaneous transmit and receive for near range (lower power) operation
  - Sectored coded waveform
  - Other?
## Key Cost Reduction Strategies

<table>
<thead>
<tr>
<th>Approach</th>
<th>Impact</th>
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<tbody>
<tr>
<td>Low Peak Power</td>
<td>Allows standard surface mount package, air cooling</td>
</tr>
<tr>
<td>Custom T/R Chipset</td>
<td>Lowers T/R module cost</td>
</tr>
<tr>
<td>Tile Architecture</td>
<td>Reduces interconnects, simplifies assembly and test process</td>
</tr>
<tr>
<td>Scalable Array Size</td>
<td>Enables same array hardware for multiple aperture configurations</td>
</tr>
<tr>
<td>Exploit Wireless Industry Technology</td>
<td>Leverages commercial manufacturing and test processes</td>
</tr>
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</table>
MPAR T/R Module

- Polarization flexible
  - Single dual pol or two linear pol beams
- 2.7 – 2.9 GHz operating band
- Plastic Quad Flat No-lead (QFN) RF packages for low cost
- Automated pick and place / assembly / test
- Low cost (< $25 ea)
  - Based on current high volume wafer costs and automated assembly / test
Panel Engineering Development Unit (EDU)

- Fully populated 64 element Engineering Development Unit (EDU)
  - Dual simultaneous polarization
  - 2.7 – 2.9 GHz operating band
  - Transmit and receive functionality
- Provides functional resource for RF performance assessment

Critical Technologies

- Dual Polarized Balance-feed Stacked Patch (MIT LL)
- Overlapped Digital Subarray Beamformer (MIT LL)
- Polarization Flexible T/R Module (MIT LL, M/A-COM)
- Heat Sink

Top View

Bottom View
Potential Risk Reduction Program FY11-FY14

FY11
- Systems analysis of MPAR EDM
- Build and test Gen 1 panel
- Build and test LRU (Gen 2) panel
- Mechanical / structural / thermal analysis

FY12
- MPAR algorithm development
- Build and calibrate 5 LRU panels
- Test 5 panel string as radar

FY13
- Develop real time processing code
- Build and calibrate 10 LRU panels
- Build enclosure and install at LL
- Test partially filled aperture (10 panels)

FY14
- Demonstrate multiple modes
- Develop and test polarimetric calibration techniques
- Support initial field testing
What are the Cost Drivers?

Is NRE the Issue?  
OR  
Is Manufacturing the Issue?

- High volume for MPAR brings commercial pricing
- Design for manufacturing critical to riding commodity curve