Multifunction Phased Array Radar (MPAR)

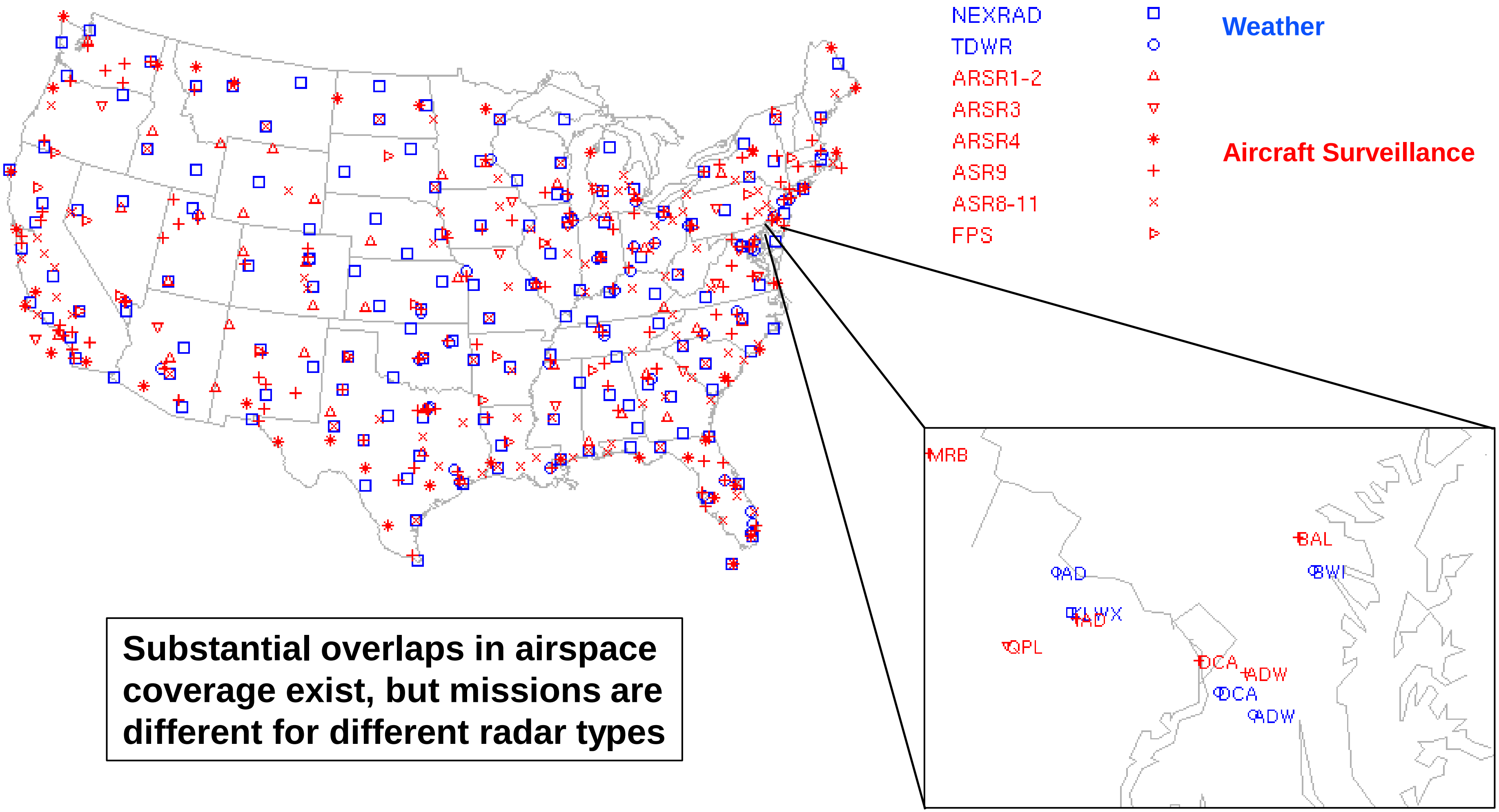
John Cho and Sean Duffy

28 July 2011

1951–2011
LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

This work was sponsored by the Federal Aviation Administration under Air Force Contract No. FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

Current Aircraft and Weather Surveillance Radars: Spatial Distribution



Substantial overlaps in airspace coverage exist, but missions are different for different radar types

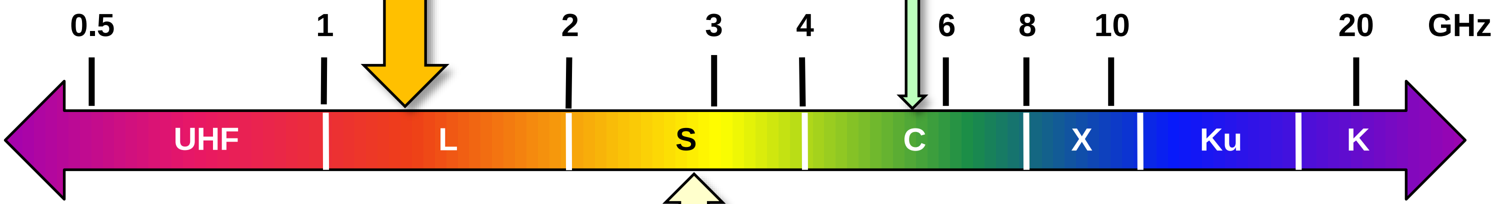
Current Aircraft and Weather Surveillance Radars: Spectral Usage

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

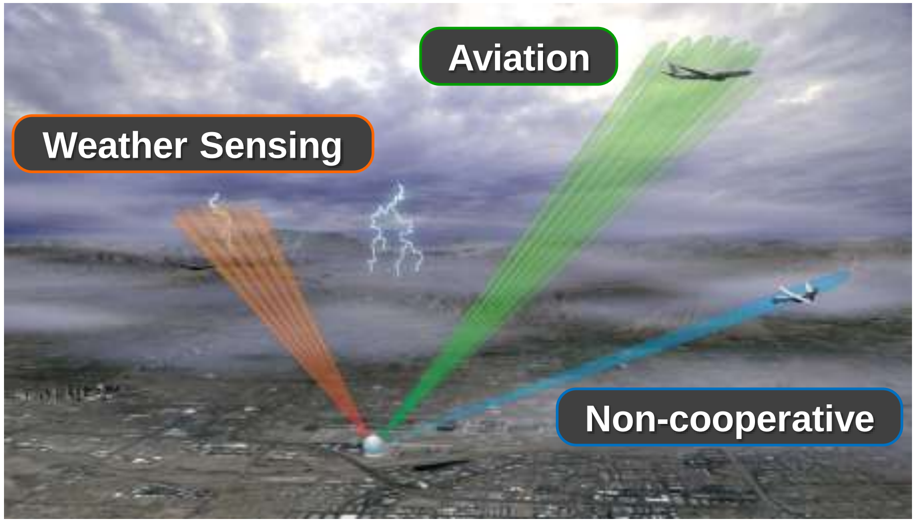
TDWR (FAA): 5.5–5.65 GHz



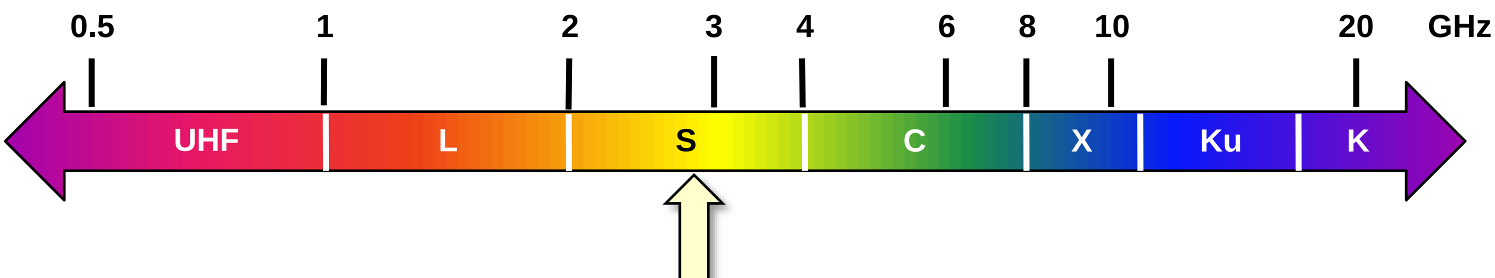
Terminal Air and National Weather Surveillance

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



<u>**All Aircraft and Weather Observation Missions**</u>

MPAR: 2.7–3.0 GHz

***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

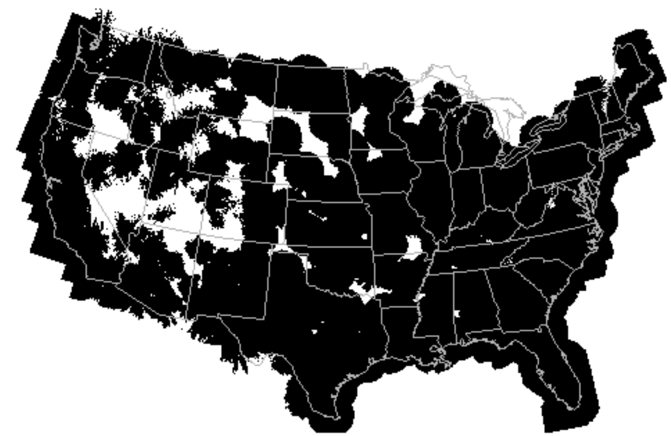
U.S. Airspace* Coverage

Current Coverage

Aircraft

Weather

Multifunction Radar Coverage



Improved coverage

***50 states + U.S. territories (only CONUS plots shown)**

Plots shown @ 5000 ft AGL

Potential Reduction in Radar Count

Replacement Scenario	Legacy	MPAR*	% Reduction
ASR and TDWR	276	228	17
ASR, TDWR, and NEXRAD	432	310	28
ASR, TDWR, NEXRAD, ARSR, and FPS	554	357	36

*Two tiered: Full-size MPARs and terminal-area MPARs

Cost Reduction Strategy

Multifunction radars exist—reducing cost is main challenge

Military S-Band Radars

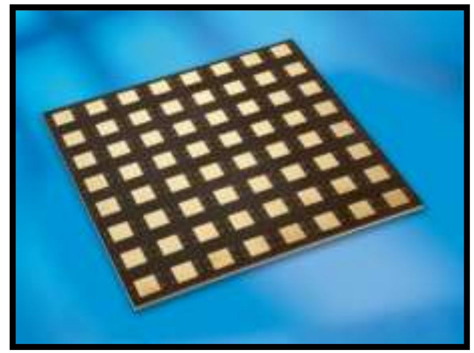
G/A-TOR

3DELRR

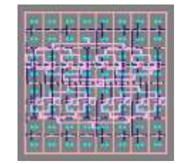
EQ-36

- Low production volume
- High power density
- Special purpose designs
- Fixed aperture sizes

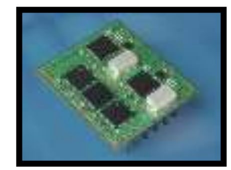
MPAR Panel Technology



MPAR Panel



Overlapped BF



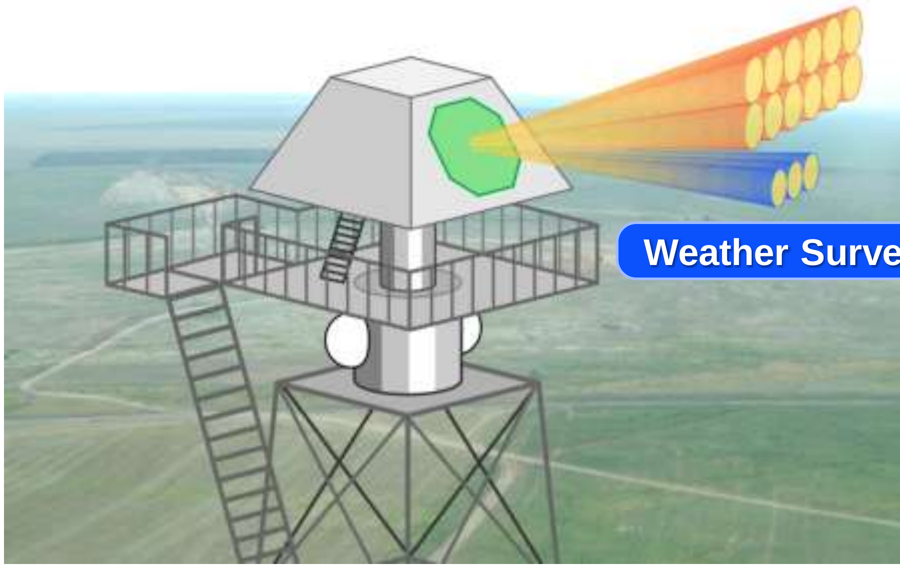
MPAR Module

- High production volume
- Modest power density
- General purpose design
- Scalable aperture sizes

Exploit wireless industry technology—leverage commercial manufacturing and test processes

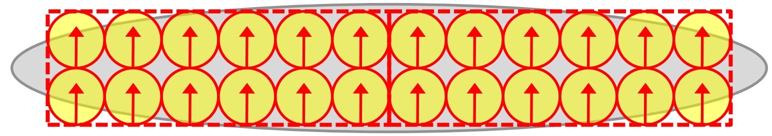
Terminal* MPAR Concept Design

Aircraft Surveillance



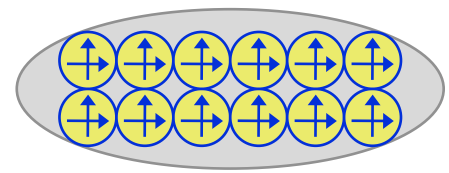
Weather Surveillance

Two 6 x 2 beam clusters



Aircraft

(Up to 24 single linear polarization beams)



Weather

(Up to 12 dual polarization beams)

Frequency:	2.7 – 3.0 GHz
Diameter:	4 m
T/R per face:	5,000
Beamwidth:	1.6° (broadside)
Array cost/m^2:	$50k
Polarization:	Dual linear/circular
Beam count:	> 10 beams
Duty Cycle:	8%
Peak power:	8 W/element

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

Challenging

Straightforward

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

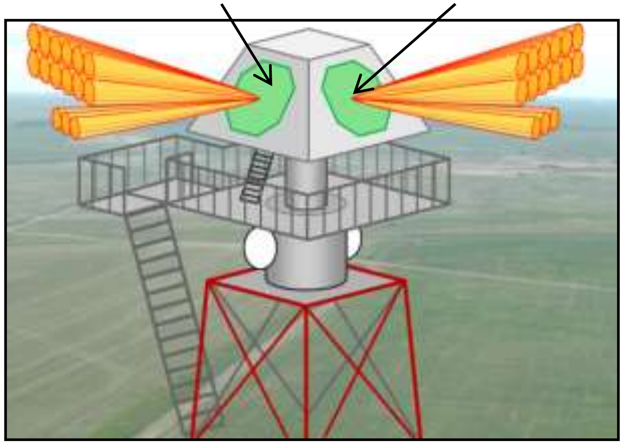
Spectral Usage Challenges

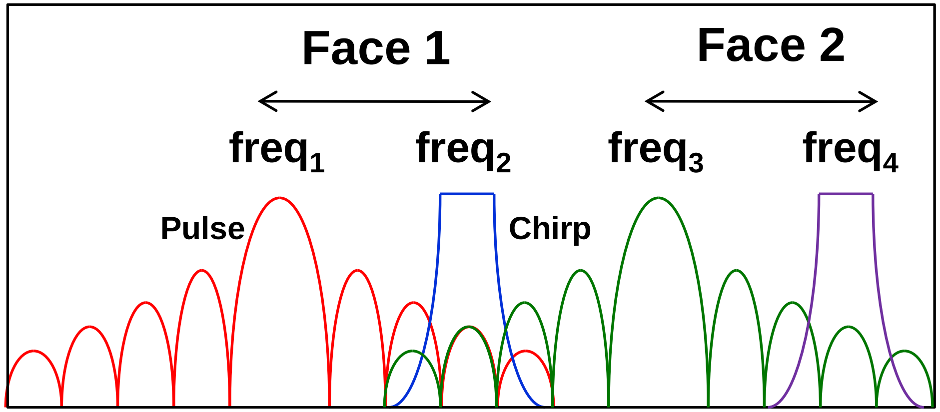
Factors that increase MPAR spectral usage

- **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

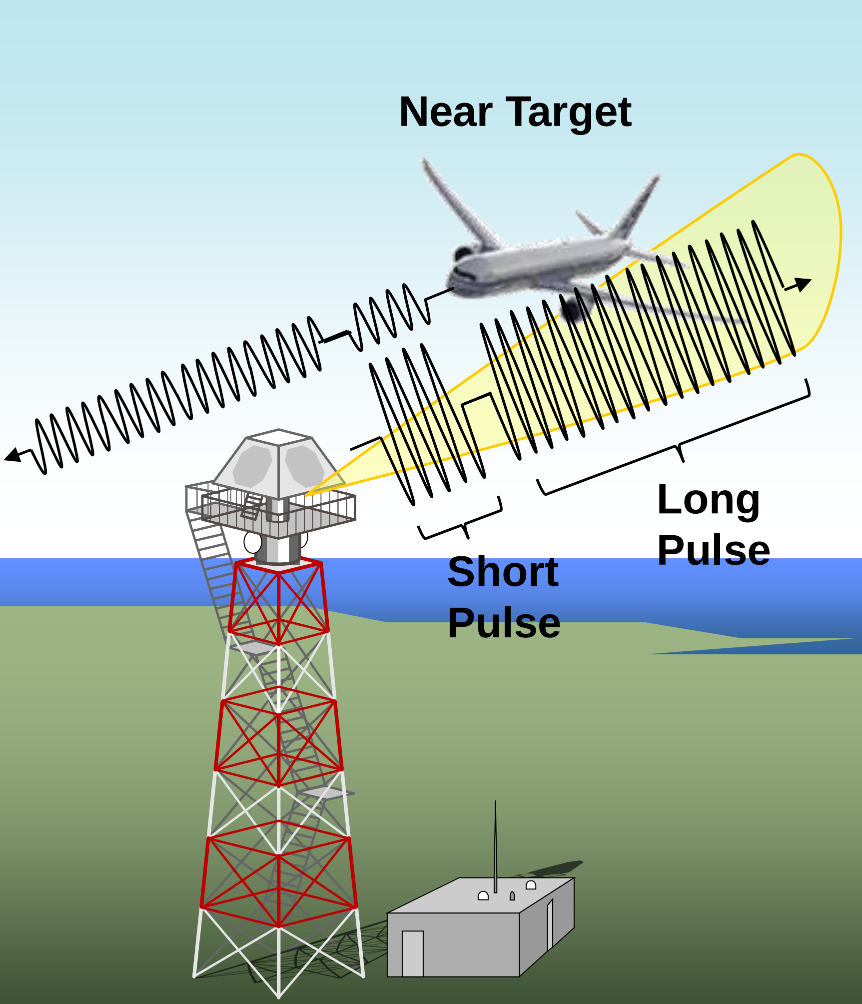




Scenario	Frequencies	Implications
All faces independent frequencies	8	Large spectral content at each site, most flexible
Front and back faces share frequencies	4	Front-to-back isolation is critical specification
All faces share frequencies	2	No adaptive operation allowed

Backup Slides

Near and Far Range Operation of Radar



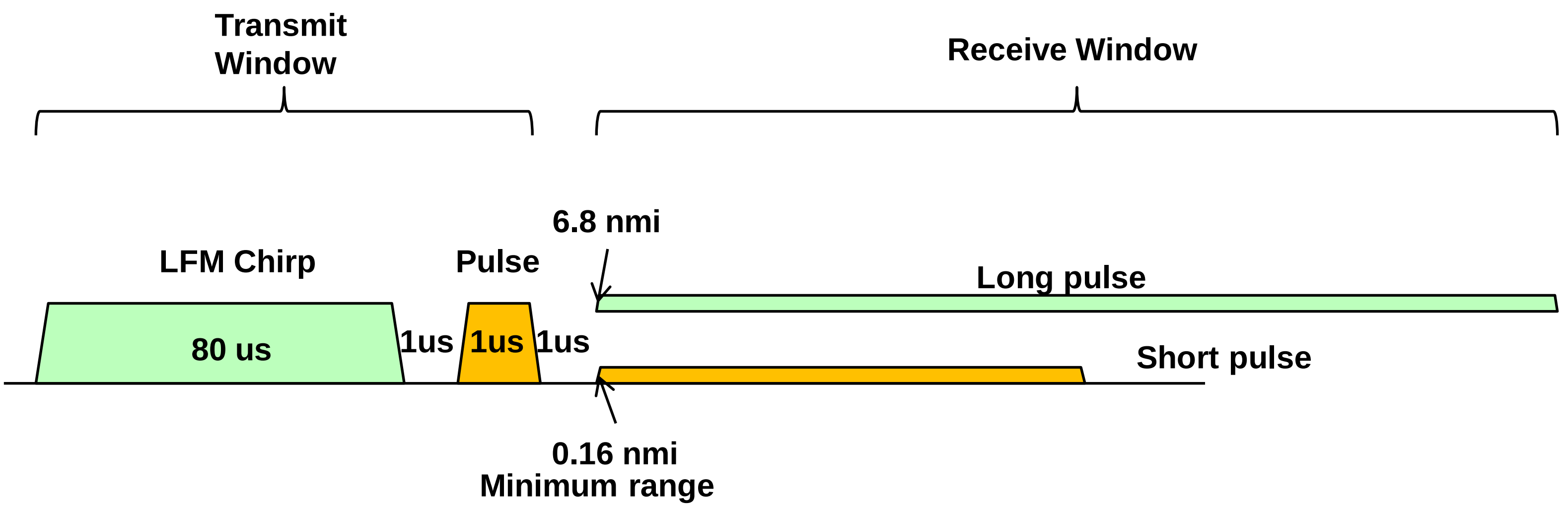
Close range
- Long pulse hits target and returns to radar before receive window

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

1951–2011
LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Timing Diagrams for Multiple Pulses

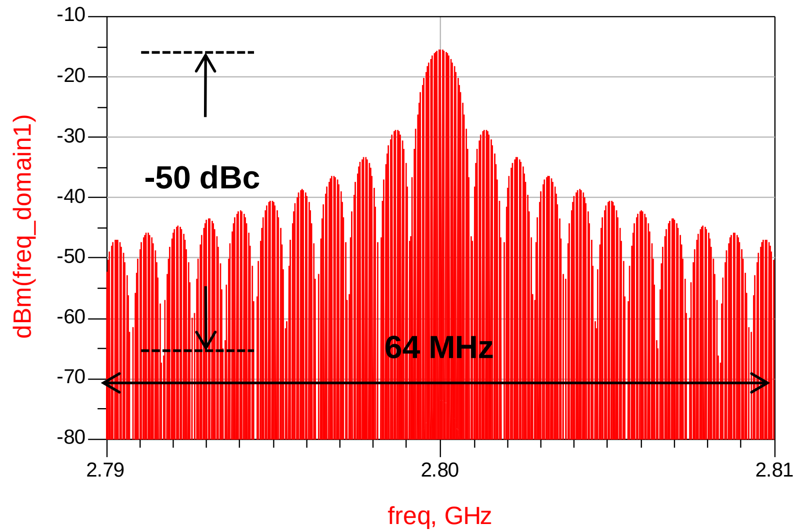


Minimum range: $R = cT_p/2$
c = speed of light
T_p = Start of pulse to beginning of receive window

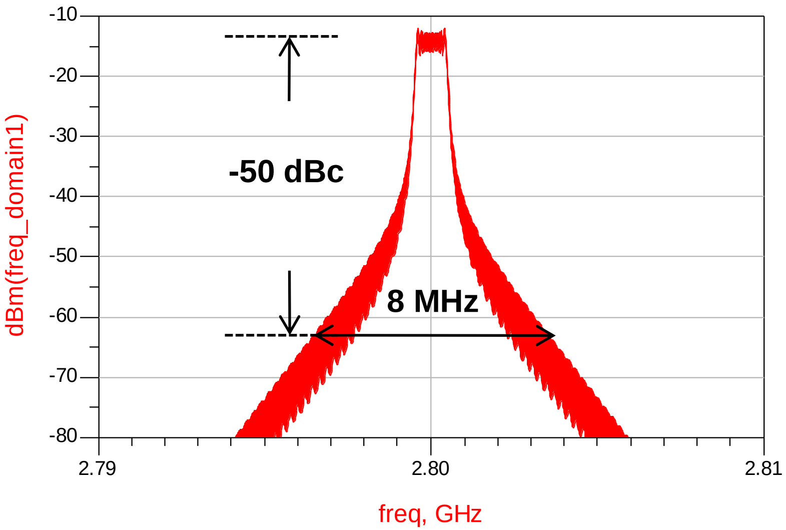
- Receive returns overlap in time with different ranges due to the different pulse start times
- Need a way to separate signals
  - Frequency offset is the standard method

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

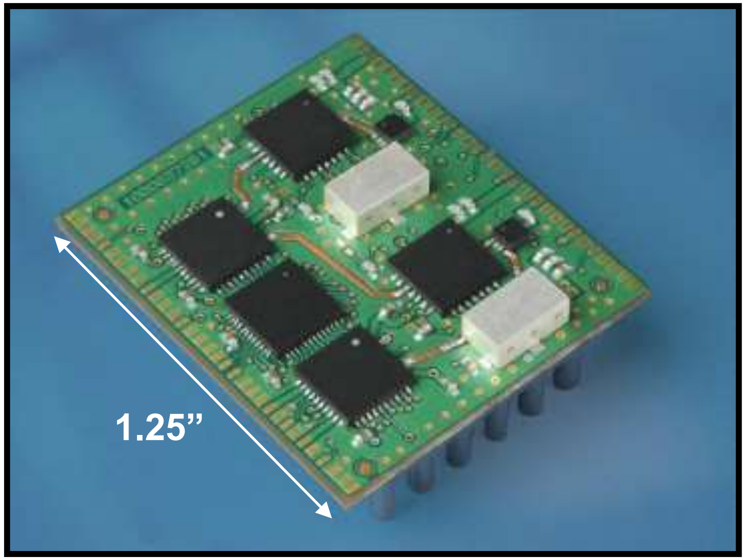
- **Detailed matched filter analysis for multiple pulse spectral separation**

- **Potential spectral improvements**
  - **Simultaneous transmit and receive for near range (lower power) operation**
  - **Sectored coded waveform**
  - **Other?**

Key Cost Reduction Strategies

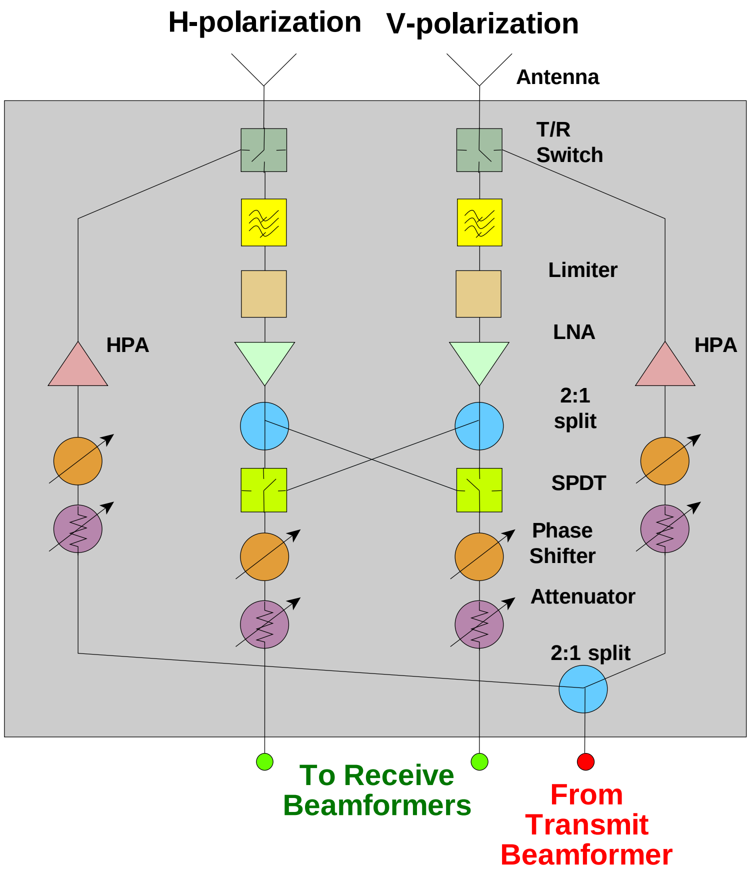
Approach	Impact
Low Peak Power	Allows standard surface mount package, air cooling
Custom T/R Chipset	Lowers T/R module cost
Tile Architecture	Reduces interconnects, simplifies assembly and test process
Scalable Array Size	Enables same array hardware for multiple aperture configurations
Exploit Wireless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

MPAR T/R Module

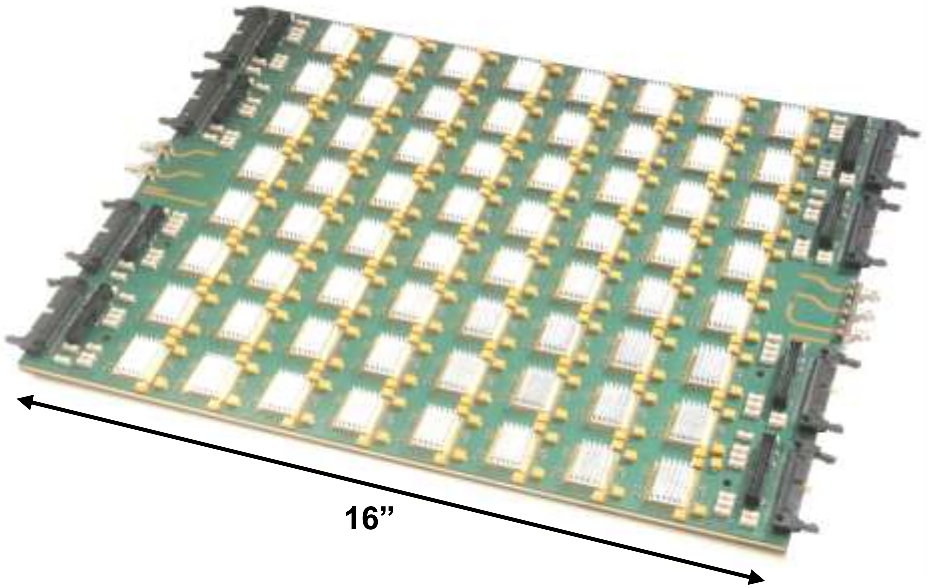


- **Polarization flexible**
  - **Single dual pol or two linear pol beams**
- **2.7 – 2.9 GHz operating band**
- **Plastic Quad Flat No-lead (QFN) RF packages for low cost**
- **Automated pick and place / assembly / test**
- **Low cost (< $25 ea)**
  - **Based on current high volume wafer costs and automated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

MIT LL MPAR T/R Module

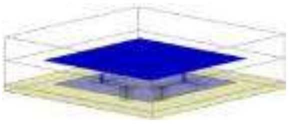


Panel Engineering Development Unit (EDU)



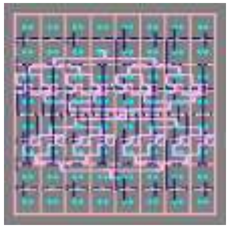
- **Fully populated 64 element Engineering Development Unit (EDU)**
  - **Dual simultaneous polarization**
  - **2.7 – 2.9 GHz operating band**
  - **Transmit and receive functionality**
- **Provides functional resource for RF performance assessment**

Critical Technologies



Dual Polarized Balance–feed Stacked Patch

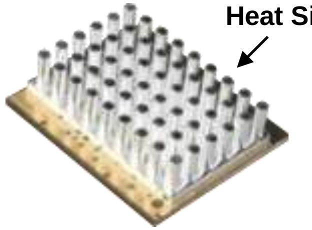
(MIT LL)



Overlapped Digital Subarray Beamformer

(MIT LL)

Top View



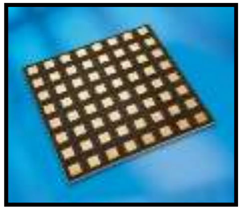
Bottom View

Polarization Flexible T/R Module

(MIT LL, M/A-COM)

Potential Risk Reduction Program FY11-FY14

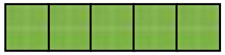
FY11



Line Replaceable Unit (LRU)

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

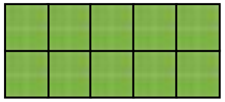
FY12



1D String Test 5 LRU

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

FY13



2D String Test 10 LRU's

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

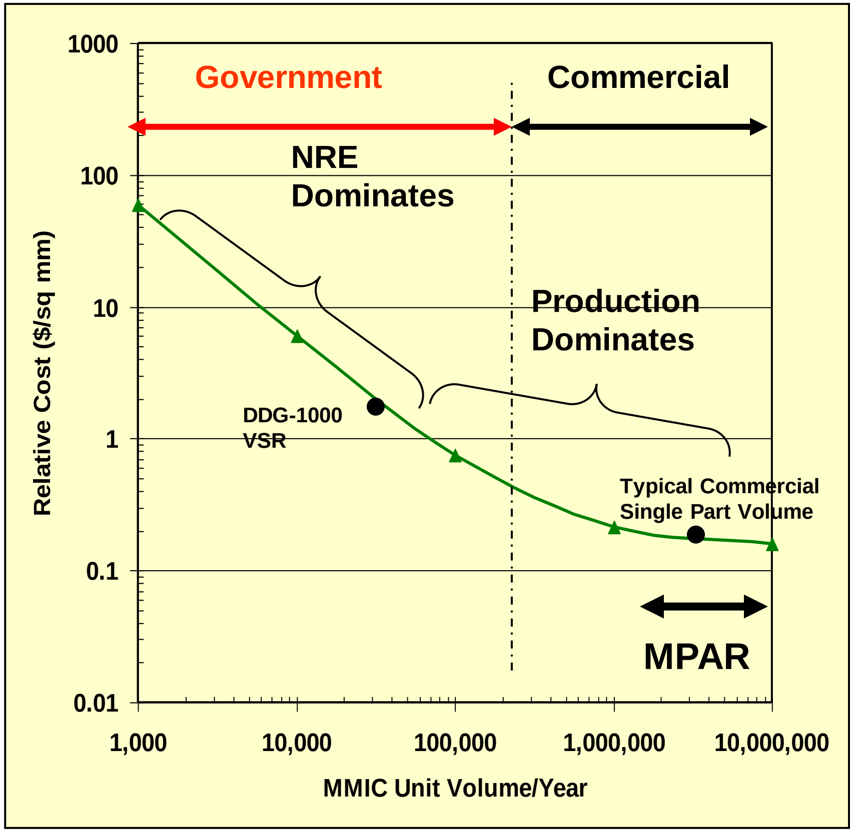
FY14

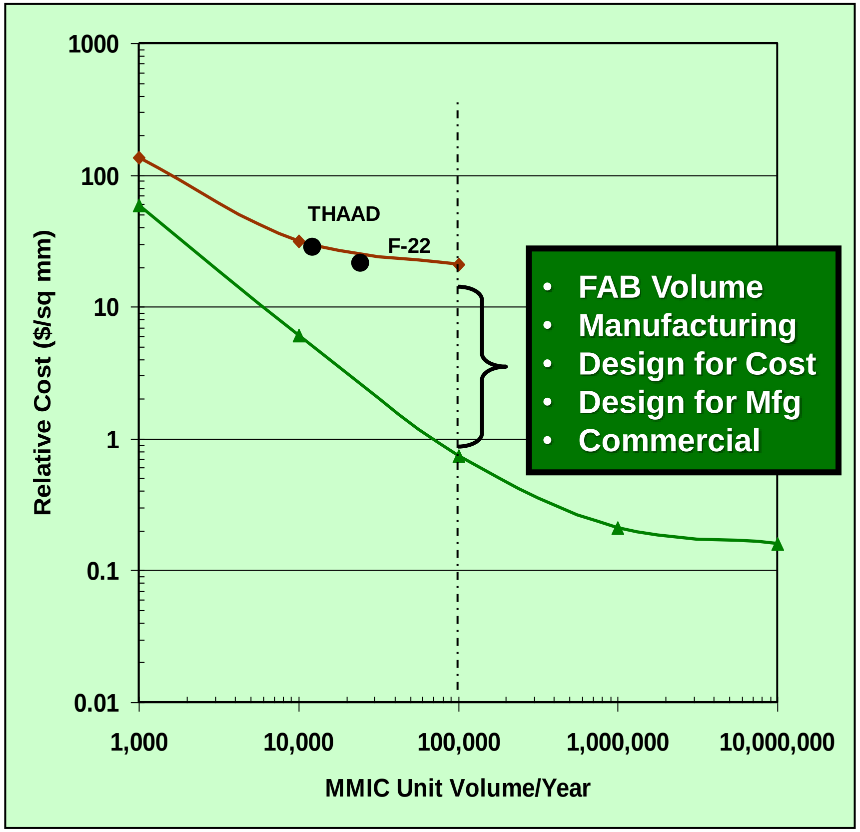
Initial Investment Decision

- 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**