Signal Processing Challenges for Phased-Array Radar Meteorology

Stephen J. Frasier

Microwave Remote Sensing Laboratory
University of Massachusetts
Amherst, MA 01003

ERAD 2012
Outline

- Motivation for Phased-Arrays
- Fundamentals
- Several Examples
- Issues for Radar Meteorology
  - Rapid scanning
  - Calibration
  - Polarization
- Outlook
Why Phased Arrays?

- Inertia-less scanning
- Multiple (simultaneous) beams
- No moving parts
- Improved ground clutter rejection & spectrum width
- Possibility to replace disparate systems with a single multi-function system
- Solid-state technology and manufacturing advances may permit cost reductions
Why not Phased-Arrays?

- Historically prohibitively expensive for civilian applications (~$1M/m²)
- Weather is a “slow-moving” target
- PAR is less sensitive than a comparably sized dish
- Rapid scanning is possible with mechanical systems
- PAR has more complications
  - Gain, Beamwidth, Polarization all vary with scan angle
- Uncertainty in the market. Is it large enough to reap economies of scale (yet)?
Phased Array Fundamentals

![Diagram of phased array fundamentals](image)
Arrays of Arrays

ROW / COLUMN
ARCHITECTURE
Passive Electronic Scanning Array (PESA)
• National Weather Radar Testbed (NWRT)
  • NOAA/NSSL, Norman, OK
  • SPY-1A (Aegis) radar panel w/WSR-88D transmitter & multi-channel receiver
  • S-band passive phased-array (4352 elements)
  • Single polarization
  • Ongoing experiments in rapid scanning, beam-multiplexing, spaced-antenna, sidelobe cancelling
Passive Electronic Scanning Array (PESA)

Varying the frequency can be used to scan.
Requires a large bandwidth.
EXAMPLE

- Rapid Doppler-on-Wheels
  - CSWR, Boulder, CO
  - X-band frequency-scan array of slotted waveguide antennas
  - 6-12 simultaneous beams
  - Single polarization
  - Frequency scan in elevation, mechanical in azimuth
Hybrid Electronic/Mechanical Systems

- To reduce cost, a combination of electronic and mechanical scanning is common
  - Rapid DOW
  - MWR-05XP
  - OU-AIR
  - CASA Phase-Tilt
  - Toshiba
  - Thales
MWR-05XP
(Naval Postgraduate School/CIRPAS)

X-band
Re-purposed military radar
Phase scan (elevation)
mechanical scan (azimuth)
Active Electronic Scanning Array (AESA)
CASA Phase-tilt

- CASA ERC, UMass
  - X-band dual-polarization
  - Solid-state 64-element AESA
  - ATAR waveform

see CASA booth
Digital Beamforming Array

- Digital Beamforming Array
- T/R Modules
- A/D
- T/R
- Scanned Beam Direction
- θ°
- Broadside
- Equiphase Front
- Δφ = \( \frac{2\pi}{\lambda} d \sin \theta_o \)
- Radiators
- Digital Beamformer
- Computer/FPGA
Digital beamforming allows simultaneous measurements within the field of view (FOV) of the radar with an infinite number of beams.

- X-band, 3.5 kW TWT, pulse compression, 1x25 degree FOV
- 36 independent I/Q receive channels, in-house design
- Clutter rejection via adaptive array processing

Development by Thales

Fig. 8 (at left) Radar Sensors deployment at XP1 Trials campaign scheduled in Sept. 2012, (at right) new Multi-Function (wake-vortex, weather, traffic) Electronic scanning X-band Radar for XP1 trials at CDG airport
2D Electronic-Scanning, Dual-Polarized Systems

- MPAR – S-band dual-pol prototyping underway by MIT-Lincoln Laboratories
- Raytheon – X-band dual-pol. 2D AESA for ground-based/airborne applications
Calibration Issues

- Beamwidth: $\Theta_1, \Phi_1 \sim 1/\cos(\Theta, \Phi)$

- Directivity (Gain): $G_D = \frac{4\pi}{\Theta_1 \Phi_1}$

- Polarization:
  - Biases in $Z_{DR}, \Phi_{DP}, \rho_{HV}, \text{LDR}$
Approaches to Polarization Correction

- **Projection correction**

- **Interleaved Sparse Arrays**

- **Cylindrical Array Architecture**
Multifunction Phased Array Radar Panel

RF Chip Set
- High Power Amplifier
- RF Transmit Chip
- RF Receive Chip

T/R Module
- 1.25”

Radiator

Beamformer

MPAR panel attributes:
- 2.7-2.9 GHz operating band
- 900 W peak RF transmit power
- Dual simultaneous receive polarization
- Low production cost (~$10K per panel)

Low cost and high performance met by:
- Design for manufacturability
- Low cost T/R modules
- Scalable aperture design
- Digital subarray architecture
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
Weather Radar Transceiver MMIC design optimized for low peak power high duty cycle Target, Weather, and Wake Vortex Radar requirements

- Building Block Panel PWB consists of 128 identical unit cells
  - 18 layer board
  - Slot fed single Patch Radiator
- Each unit cell contains single SiGe Flip Chip, Linear Regulator, and associated Caps / resistors
- 4 Power, 4 Logic connectors and 1 RF Connector
More Calibration Issues

- Amplitude and phase errors at each element elevate sidelobes and cross-pol
- Errors may drift with temperature, age, …
- Need careful characterization
- In-place re-calibration
Approaches to Calibration

- Beacons or reference targets
  - e.g. Illuminators on periphery of array
- Exploit element-to-element coupling
  
  
  - Approach under investigation for CASA phased array.

- Spatial correlation properties of clutter
  
  
  - Technique proven useful for digital beamforming systems
Outlook

- Phased-array weather radars have arrived.
- Low-cost rapid-scan systems incorporate mechanical scanning.
- Fully phased arrays in development at S-band and X-band (at least)
  - Technical challenges remain:
    - signal routing, heat dissipation, manufacturing cost
- Amplitude/Phase/Polarimetric calibration will continue to be a key research area.
Acknowledgement

The following kindly provided material for this presentation:

Paul Ackroyd, Raytheon
Jeffrey Herd, MIT-LL
Krzysztof Orzel, UMass
Bob Palmer, OU
Rob Palumbo, UMass
Josh Wurman, CSWR
Guifu Zhang, OU
Frederic Barbaresco, Thales
Thank You.
EWR Radar

Oct 2011

EMPAR™ series multifunction X-band phased array radar is unveiled at the Meteorological Technology World Expo in Brussels.