ARM Scanning Cloud and Precipitation Radar

Nitin Bharadwaj and Kevin Widener
Outline

- ARM Radar Deployment
- Precipitation and Cloud Radars
- Polarization diversity
- Operational considerations
- Scan strategy
- Data Formats
C-Band Scanning ARM Precipitation Radar (C-SAPR)

- Advanced Radar Corporation
- TITAN Processing Environment

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### Transmitter
- **Type**: Magnetron
- **Center frequency**: 5625 ± 25 MHz
- **Peak power output**: 250 kW
- **Average power output**: 250 W
- **Pulse width**: 200 ns - 2 μs
- **Polarization**: Dual polarization, Simultaneous H and V
- **Max. Duty Cycle**: 0.1%
- **PRF**: 200 Hz - 5kHz

### Antenna and Pedestal
- **Type (diameter)**: Parabolic reflector (4.27 m)
- **3-dB Beam width**: 0.98°
- **Gain**: 45.0 dB
- **ICPR**: 32 dB
- **Two-way Radome loss**: 1 dB
- **Scan rate**: up to 36°/s
- **Acceleration**: up to 30°/s²

### Receiver
- **Type**: Dual-channel HiQ digital
- **Dynamic range**: > 80 dB
- **Noise figure**: 2.8 dB
- **Sampling rate**: 40 MHz
- **Decimation factor**: Adjustable
- **Video Bandwidth**: Adjustable

### Core Products
- **Spectral Moments**
  - Reflectivity
  - Mean Velocity
  - Spectrum Width

- **Polarimetric Variables**
  - ZDR
  - Differential Phase
  - Co-polar corr coeff

- **Attenuation Correction**
  - Corr Reflectivity
  - Corr ZDR
  - KDP

### Meta Data
X-Band Scanning ARM Precipitation Radar (X-SAPR)

- Radtec Engineering Inc
- RVP900 and IRIS Processing Environment

<table>
<thead>
<tr>
<th>Core Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spectral Moments</strong></td>
</tr>
<tr>
<td>- Reflectivity</td>
</tr>
<tr>
<td>- Mean Velocity</td>
</tr>
<tr>
<td>- Spectrum Width</td>
</tr>
<tr>
<td><strong>Polarimetric Variables</strong></td>
</tr>
<tr>
<td>- ZDR</td>
</tr>
<tr>
<td>- Differential Phase</td>
</tr>
<tr>
<td>- Co-polar corr coeff</td>
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<tr>
<td><strong>Attenuation Correction</strong></td>
</tr>
<tr>
<td>- Corr Reflectivity</td>
</tr>
<tr>
<td>- Corr ZDR</td>
</tr>
<tr>
<td>- KDP</td>
</tr>
</tbody>
</table>

| Meta Data |

### Transmitter

- **Type**: Magnetron
- **Center frequency**: 9500 ± 30 MHz
- **Peak power output**: 200 kW
- **Average power output**: 200 W
- **Pulse width**: 200 ns - 4.5 μs
- **Polarization**: Dual polarization, Simultaneous H and V
- **Max. Duty Cycle**: 0.1%
- **PRF**: 200 Hz - 5kHz

### Antenna and Pedestal

- **Type (diameter)**: 2.4 m offset feed
- **3-dB Beam width**: 0.9°
- **Gain**: 45.0 dB
- **Two-way Radome loss**: 0.6 dB
- **Azimuth scan rate**: up to 24°/s
- **Elevation scan rate**: up to 15°/s

### Receiver

- **Type**: Vaisala Sigmet RVP900
- **Dynamic range**: < 105 dB
- **Noise figure**: 3.0 dB
- **Sampling rate**: 80 MHz
- **Decimation factor**: Adjustable
- **Video Bandwidth**: Adjustable
W-Band Scanning ARM Cloud Radar (W-SACR)

- Prosensing Inc
- Prosensing Signal processor

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Extended Interaction Klystron Amplifier (EIKA)</td>
</tr>
<tr>
<td>Center frequency</td>
<td>94000 ± 10 MHz</td>
</tr>
<tr>
<td>Peak power output</td>
<td>1.7 kW</td>
</tr>
<tr>
<td>Pulse width</td>
<td>50 ns - 2 μs</td>
</tr>
<tr>
<td>Polarization</td>
<td>Transmit horizontal linear</td>
</tr>
<tr>
<td>Max. Duty Cycle</td>
<td>1%</td>
</tr>
<tr>
<td>PRF</td>
<td>Up to 20 kHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Antenna and Pedestal</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type (diameter)</td>
<td>Parabolic reflector (0.9 m)</td>
</tr>
<tr>
<td>3-dB Beam width</td>
<td>0.29°</td>
</tr>
<tr>
<td>Gain</td>
<td>54.5 dB</td>
</tr>
<tr>
<td>Cross polarization</td>
<td>-27 dB</td>
</tr>
<tr>
<td>Two-way Radome loss</td>
<td>2.0 dB</td>
</tr>
<tr>
<td>Azimuth scan rate</td>
<td>Up to 36°/s</td>
</tr>
<tr>
<td>Elevation scan rate</td>
<td>Up to 20°/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Dual polarization digital receiver</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>&gt; 80 dB</td>
</tr>
<tr>
<td>Noise figure</td>
<td>6.0 dB</td>
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<tr>
<td>Sampling rate</td>
<td>120 MHz</td>
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<tr>
<td>Decimation factor</td>
<td>Adjustable</td>
</tr>
<tr>
<td>Video Bandwidth</td>
<td>Adjustable</td>
</tr>
</tbody>
</table>

Core Products

- Spectral Moments
  - Reflectivity
  - Mean Velocity
  - Spectrum Width

- Polarimetric Variables
  - LDR
  - Co-to-cross corr coeff

Meta Data
### Core Products

- **Spectral Moments**
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### Spectral Moments

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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Transmitter Type</td>
<td>Extended Interaction Klystron Amplifier (EIKA)</td>
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<tr>
<td>Center frequency</td>
<td>35300 ± 10 MHz</td>
</tr>
<tr>
<td>Peak power output</td>
<td>1.7 kW</td>
</tr>
<tr>
<td>Pulse width</td>
<td>50 ns - 13 μs</td>
</tr>
<tr>
<td>Polarization</td>
<td>Transmit horizontal linear</td>
</tr>
<tr>
<td>Max. Duty Cycle</td>
<td>5%</td>
</tr>
<tr>
<td>PRF</td>
<td>Up to 10 kHz</td>
</tr>
<tr>
<td>Antenna and Pedestal Type</td>
<td>Parabolic reflector (1.82 m)</td>
</tr>
<tr>
<td>3-dB Beam width</td>
<td>0.33°</td>
</tr>
<tr>
<td>Gain</td>
<td>53.5.0 dB</td>
</tr>
<tr>
<td>Cross polarization</td>
<td>-27 dB</td>
</tr>
<tr>
<td>Two-way Radome loss</td>
<td>1.5 dB</td>
</tr>
<tr>
<td>Azimuth scan rate</td>
<td>Up to 36°/s</td>
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<td>Video Bandwidth</td>
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X-Band Scanning ARM Cloud Radar (X-SACR)

- Prosensing Inc
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### Core Products

#### Spectral Moments
- Reflectivity
- Mean Velocity
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#### Polarimetric Variables
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- Differential Phase
- Co-polar corr coeff

#### Attenuation Correction
- Corr Reflectivity
- Corr ZDR
- KDP

#### Meta Data
X-SAPR, X-SACR, C-SAPR Dual Polarization Operations: Simultaneous Transmit and Receive (STAR) mode

Transmitter → Splitter

H- Channel → To H-receiver

Duplexer

V- Channel → To V-receiver

Transmit state

Backscattered signal from horizontal polarization

\[ (S_{vh}) \]

Backscattered signal from vertical polarization

\[ (S_{hv}) \]

\[ (S_{hh}) \]

\[ (S_{vv}) \]

\[ \Sigma_{BSA} = \begin{bmatrix} \left| S_{hh} \right|^2 & \sqrt{2}S_{hh}S^*_{hv} & S_{hh}S^*_{vv} \\ \sqrt{2}S_{hv}S^*_{hh} & 2\left| S_{hv} \right|^2 & \sqrt{2}S_{hv}S^*_{vv} \\ S_{vv}S^*_{hh} & \sqrt{2}S_{vv}S^*_{hv} & \left| S_{vv} \right|^2 \end{bmatrix} \]
Ka-SACR and W-SACR Dual Polarization Operations: Horizontal Polarization Mode

Transmit state

Backscattered signal from horizontal polarization

\[ \begin{bmatrix} S_{vh} \\ S_{hh} \end{bmatrix} \]

\[ \Sigma_{BSA} = \begin{bmatrix} |S_{hh}|^2 & \sqrt{2}S_{hh}S_{hv}^* \\ \sqrt{2}S_{hv}S_{hh}^* & 2|S_{hv}|^2 & S_{hv}S_{vv}^* \\ S_{vv}S_{hv}^* & \sqrt{2}S_{hv}S_{vv}^* & |S_{vv}|^2 \end{bmatrix} \]
Consideration for operations

- Range velocity ambiguity
- Sensitivity
- Ground clutter suppression
- Calibration and verification
- Attenuation correction
Range-velocity ambiguity

- Maximum unambiguous range-velocity space is constrained by radar wavelength

\[ r_{\text{max}} v_{\text{max}} = \frac{c \lambda}{8} \]
Range-velocity ambiguity

- At higher frequencies a uniform PRF waveform generally does not meet requirements
- Dual-PRF waveform is suitable for operations
- Pulse width reduced on magnetrons for stable operation
Sensitivity of X-SAPR

![Graph showing minimum observable reflectivity vs. range with an attenuation margin of 20 dB at 20 km.]

-5 dBz at 20 km


- Range resolution: 60 m

Sensitivity of C-SAPR

![Graph showing minimum observable reflectivity vs. range with an attenuation margin of 20 dB at 20 km.]

-8.8 dBz at 20 km

- Range resolution: 90 m
Sensitivity of X-SACR

- Range resolution: 60 m
- SNR=0 dB
- Pulse compression waveform is being developed

Sensitivity of Ka-SACR

- -5.5 dBz at 5 km
- -19.8 dBz at 5 km

Sensitivity of W-SACR

- -27.25 dBz at 5 km
Ground clutter suppression

- **X-SAPR : Day 1 solution as provided by vendor**
  - Chebyshev filter
  - GMAP: spectral domain filtering from Vaisala Sigmet RVP900 processor
  - Clutter filter on/off can be selected based on elevation angle

- **C-SAPR : Day 1 solution as provided by vendor**
  - Notch filter
  - Spectral domain clutter suppression
  - Clutter filter on/on selection: Clutter Mitigation Decision (CMD) from a fuzzy logic algorithm
Calibration and verification

❖ Calibration
   ❑ Receiver calibration (dual channel)
   ❑ Solar calibration
   ❑ ZH calibration
   ❑ ZDR Calibration
     ➢ Using vertically pointing mode
     ➢ Using precipitation medium
     ➢ Self consistency approach

❖ Verification
   ❑ Cross-comparison between radars
   ❑ Verification with disdrometers
Attenuation Correction

- Attenuation correction product will be provided
- X-SAPR
  - Vaisala’s KDP estimation algorithm
  - Vaisala’s version of attenuation correction algorithm
  - Mostly for rain and not mixed phase precipitation
- C-SAPR
  - ARC’s KDP estimation algorithm
  - ARC’s version of attenuation correction algorithm
  - Mostly for rain and not mixed phase precipitation
- Attenuation Correction only applicable with no signal extinction
- Mixed phase precipitation is an active research area
### Scan Modes

#### Table 2.1: Radar operating modes

<table>
<thead>
<tr>
<th>Mode name</th>
<th>Mode number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPI</td>
<td>TBD</td>
<td>Plan position indicator</td>
</tr>
<tr>
<td>RHI</td>
<td>TBD</td>
<td>Range height indicator</td>
</tr>
<tr>
<td>HTH</td>
<td>TBD</td>
<td>Horizon to horizon scan (subset of RHI)</td>
</tr>
<tr>
<td>FIX</td>
<td>TBD</td>
<td>Fixed antenna or stare</td>
</tr>
<tr>
<td>VER</td>
<td>TBD</td>
<td>Vertically pointing antenna (subset of FIX)</td>
</tr>
<tr>
<td>SLR</td>
<td>TBD</td>
<td>Solar calibration</td>
</tr>
<tr>
<td>CAL</td>
<td>TBD</td>
<td>Calibration with blue sky or hard target</td>
</tr>
<tr>
<td>COP</td>
<td>TBD</td>
<td>Co-plane mode for dual-Doppler</td>
</tr>
<tr>
<td>VAD</td>
<td>TBD</td>
<td>Velocity azimuth display scan pattern</td>
</tr>
<tr>
<td>TST</td>
<td>TBD</td>
<td>Radar testing mode</td>
</tr>
<tr>
<td>IDL</td>
<td>TBD</td>
<td>Radar idle</td>
</tr>
</tbody>
</table>

**Diagram:**

- **PPI:**
  - Ground plane
  - Antenna Rotation
  - Elevation angle

- **RHI:**
  - Ground plane
  - Antenna Rotation
  - Elevation angle
  - Azimuth angle
Example: Volume scan for X-SAPR

- 17 tilts with PPI sweeps of 360 degree (including zenith)
- 24 cuts with RHI sweeps of 90 degree (15 deg interval in azimuth)
- One of the 24 RHI is over Central Facility
- “Bird bath” (Zenith sweep) for ZDR calibration
- Scan speed 22.5 deg/s
- ~7 min (PPI+RHI) volume update
- Dual-PRF waveform
- Unambiguous range: 60 km
- Unambiguous velocity: 39 m/s
- Range resolution: 60 m
- Azimuth resolution: 0.9 deg
Data Format

Core Products

Spectral Moments
- Reflectivity
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- Spectrum Width

Polarimetric Variables
- ZDR
- Differential Phase
- Co-polar corr coeff
- LDR

Attenuation Correction
- Corr Reflectivity
- Corr ZDR
- KDP

Meta Data
1. Version
2. Radar name
3. Latitude
4. Longitude
5. Altitude
6. Volume
7. Sweep
8. Scan mode
9. Time
10. Frequency
11. Antenna Gain
12. Beam width
13. Elevation
14. Azimuth
15. Number of gates
16. Number of radials
17. Start range
18. Pulse width
19. Transmit power
20. Radar constant
21. Gate spacing
22. Noise floor
23. Clutter filter state
24. More...

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<td>TBD</td>
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</tr>
<tr>
<td>SNR</td>
<td>TBD</td>
<td>Solar calibration</td>
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<tr>
<td>CAL</td>
<td>TBD</td>
<td>Calibration with blue sky or hard target</td>
</tr>
<tr>
<td>COP</td>
<td>TBD</td>
<td>Coplane mode for dual-Doppler</td>
</tr>
<tr>
<td>VAD</td>
<td>TBD</td>
<td>Velocity azimuth display scan pattern</td>
</tr>
<tr>
<td>TST</td>
<td>TBD</td>
<td>Radar testing mode</td>
</tr>
<tr>
<td>FDL</td>
<td>TBD</td>
<td>Radar idle</td>
</tr>
</tbody>
</table>
Data Format

- Radar data formats used
  - Universal Format (UF): CSU-CHILL, SIGMET, SPOL,
  - MDV: ARC, NCAR
  - NETCDF: NCAR, ARM, CASA, SIGMET
  - HDF: TRMM
  - Radar specific binary files

- NETCDF-4
  - NASA funded effort to unify features of NETCDF-3 and HDF-5
  - NETCDF-4 is freely available
  - MATLAB provides toolbox to read NETCDF and HDF files
  - C, C++, Fortran and JAVA interfaces are freely available

- Use standard NETCDF format
  (http://www.unidata.ucar.edu/software/netcdf/docs/BestPractices.html)
Data Format

- ARM radar data storage
  - Vertically pointing radar
  - NetCDF files
  - Stored as daily files
  - Spectra stored

- ARM Scanning radars
  - NetCDF files
  - Store files based on volumes and not daily files
  - Raw timeseries stored only on request (this may not be archived by ARM)
  - Raw timeseries stored for vertical pointing mode
Discussion ...