ARM Scanning Cloud and Precipitation Radar

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ARM
CLIMATE RESEARCH FACILITY

U.S. DEPARTMENT OF ENERGY

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

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°/s^2
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

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

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

W-Band Scanning ARM Cloud Radar (W-SACR)

- Prosensing Inc
- Prosensing Signal processor

Transmitter	
Type	Extended Interaction Klystron Amplifier (EIKA)
Center frequency	94000 ± 10 MHz
Peak power output	1.7 kW
Pulse width	50 ns - 2 μs
Polarization	Transmit horizontal linear
Max. Duty Cycle	1%
PRF	Up to 20 kHz
Antenna and Pedestal	
Type (diameter)	Parabolic reflector (0.9 m)
3-dB Beam width	0.29°
Gain	54.5 dB
Cross polarization	-27 dB
Two-way Radome loss	2.0 dB
Azimuth scan rate	Up to $36°/s$
Elevation scan rate	Up to $20°/s$
Receiver	
Type	Dual polarization digital receiver
Dynamic range	> 80 dB
Noise figure	6.0 dB
Sampling rate	120 MHz
Decimation factor	Adjustable
Video Bandwidth	Adjustable

Core Products

Spectral Moments

- Reflectivity
- Mean Velocity
- Spectrum Width

Polarimetric Variables

- LDR
- Co-to-cross corr coeff

Meta Data

Ka-Band Scanning ARM Cloud Radar (Ka-SACR)

- Prosensing Inc
- Prosensing Signal processor

Transmitter	
Type	Extended Interaction Klystron Amplifier (EIKA)
Center frequency	35300 ± 10 MHz
Peak power output	1.7 kW
Pulse width	50 ns - 13 μs
Polarization	Transmit horizontal linear
Max. Duty Cycle	5%
PRF	Up to- 10 kHz
Antenna and Pedestal	
Type (diameter)	Parabolic reflector (1.82 m)
3-dB Beam width	0.33°
Gain	53.5.0 dB
Cross polarization	-27 dB
Two-way Radome loss	1.5 dB
Azimuth scan rate	Up to 36°/s
Elevation scan rate	Up to 20°/s
Receiver	
Type	Dual polarization digital receiver
Dynamic range	> 80 dB
Noise figure	3.5 dB
Sampling rate	120 MHz
Decimation factor	Adjustable
Video Bandwidth	Adjustable

Core Products

Spectral Moments

- Reflectivity
- Mean Velocity
- Spectrum Width

Polarimetric Variables

- LDR
- Co-to-cross corr coeff

Meta Data

X-Band Scanning ARM Cloud Radar (X-SACR)

- Prosensing Inc
- Prosensing Signal processor

Transmitter	
Type	Traveling Wave Tube Amplifier (TWTA)
Center frequency	9510 ± 50 MHz
Peak power output	20.0 kW
Average power output	200 W
Pulse width	100 ns - 40 μs
Polarization	Dual polarization, Simultaneous H and V
Max. Duty Cycle	1%
PRF	Up to- 10 kHz
Antenna and Pedestal	
Type (diameter)	Parabolic reflector (1.82 m)
3-dB Beam width	1.40°
Gain	42.0 dB
Cross polarization	-30 dB
Azimuth scan rate	Up to 36°/s
Elevation scan rate	Up to 20°/s
Receiver	
Type	Dual-channel digital
Dynamic range	> 80 dB
Noise figure	4.5 dB
Sampling rate	120 MHz
Decimation factor	Adjustable
Video Bandwidth	Adjustable

Core Products

Spectral Moments

- Reflectivity
- Mean Velocity
- Spectrum Width

Polarimetric Variables

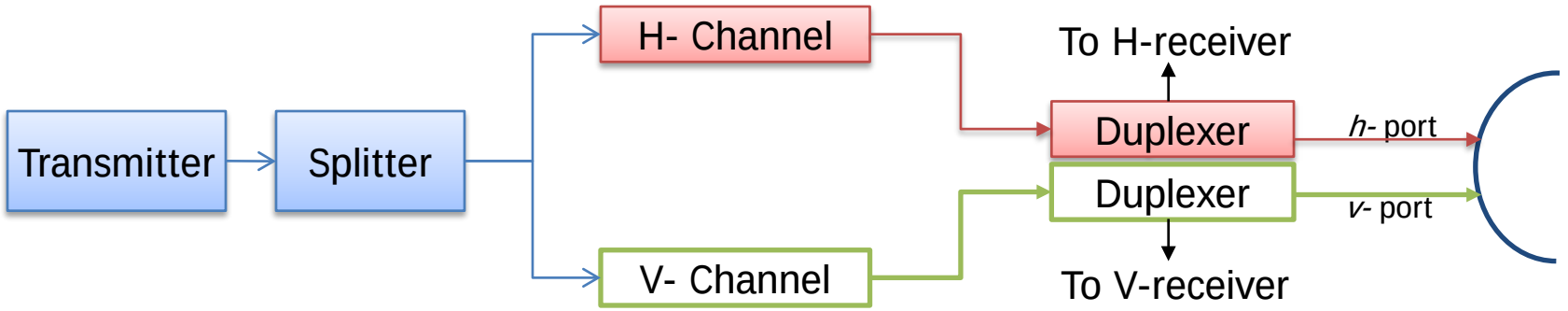
- ZDR
- Differential Phase
- Co-polar corr coeff

Attenuation Correction

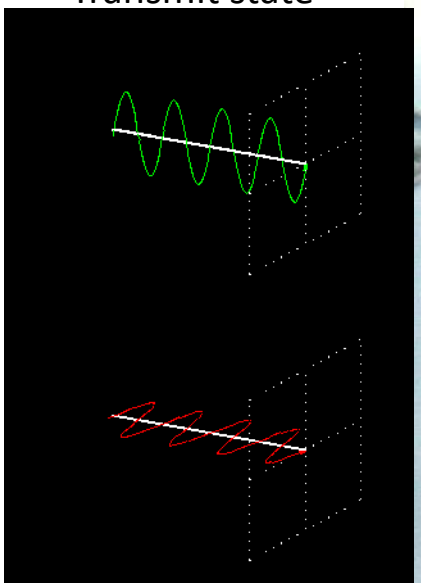
- Corr Reflectivity
- Corr ZDR
- KDP

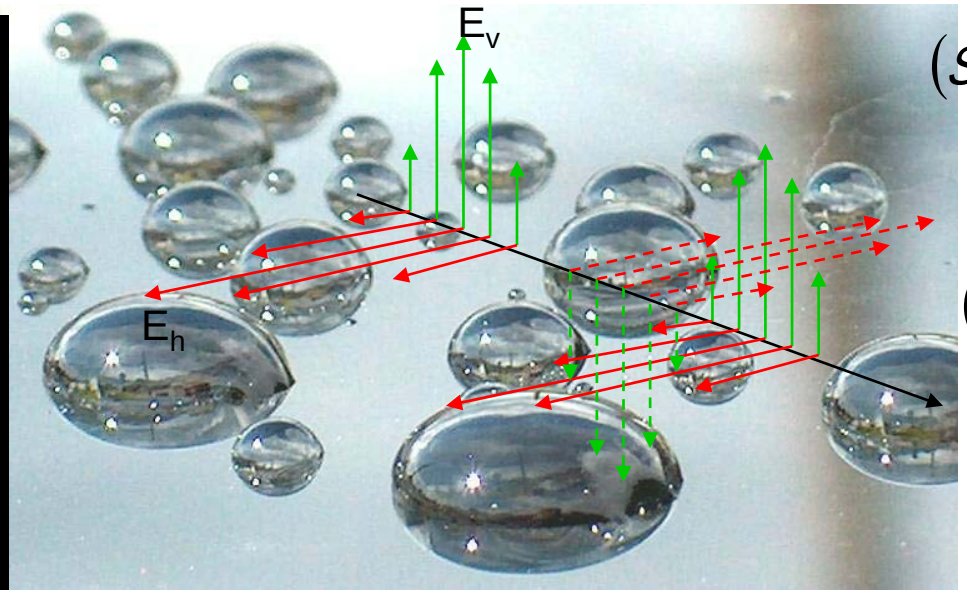
Meta Data

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



Transmit state





Backscattered signal from horizontal polarization

(S_{vh})

(S_{hh})

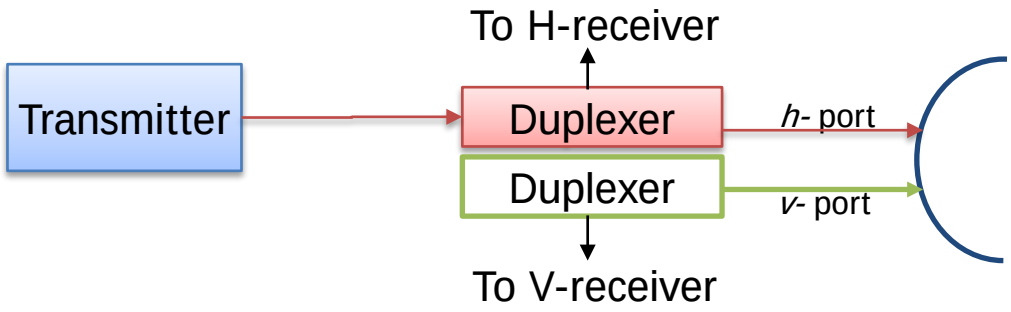
(S_{vv})

Backscattered signal from vertical polarization

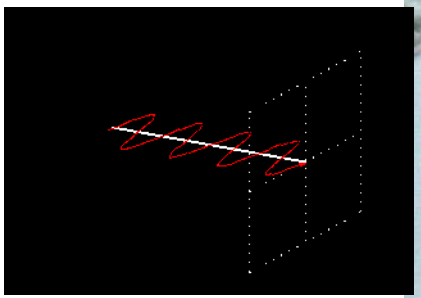
(S_{hv})

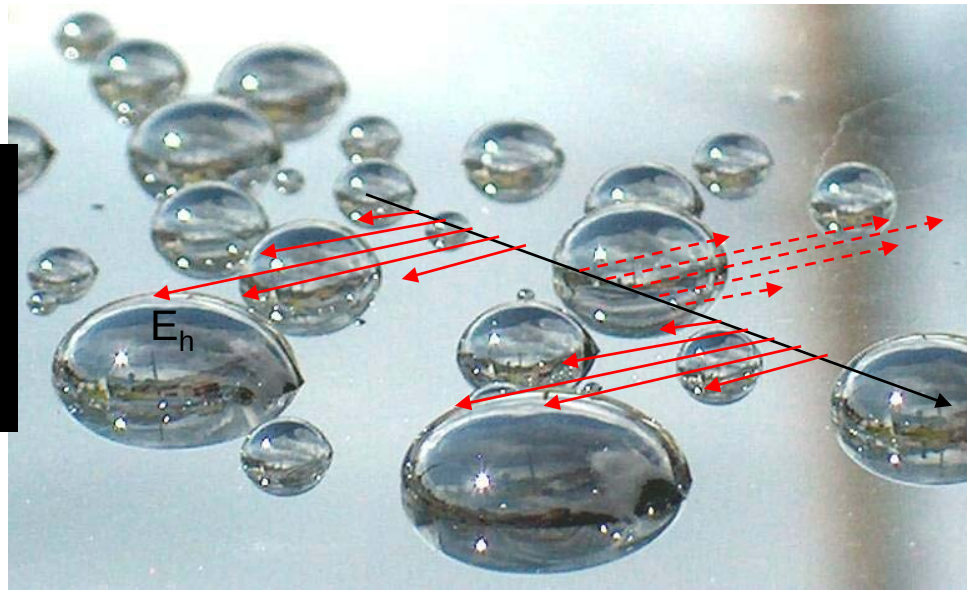
$$\Sigma_{BSA} = \left\langle \begin{bmatrix} |S_{hh}|^2 & \sqrt{2}S_{hh}S_{hv}^* & S_{hh}S_{vv}^* \\ \sqrt{2}S_{hv}S_{hh}^* & 2|S_{hv}|^2 & \sqrt{2}S_{hv}S_{vv}^* \\ S_{vv}S_{hh}^* & \sqrt{2}S_{vv}S_{hv}^* & |S_{vv}|^2 \end{bmatrix} \right\rangle$$

Ka-SACR and W-SACR Dual Polarization Operations: Horizontal Polarization Mode



Transmit state





(S_{vh})

Backscattered signal from horizontal polarization

(S_{hh})

$$\Sigma_{BSA} = \left\langle \begin{bmatrix} |S_{hh}|^2 & \sqrt{2}S_{hh}S_{hv}^* & S_{hh}S_{vv}^* \\ \sqrt{2}S_{hv}S_{hh}^* & 2|S_{hv}|^2 & \sqrt{2}S_{hv}S_{vv}^* \\ S_{vv}S_{hh}^* & \sqrt{2}S_{vv}S_{hv}^* & |S_{vv}|^2 \end{bmatrix} \right\rangle$$

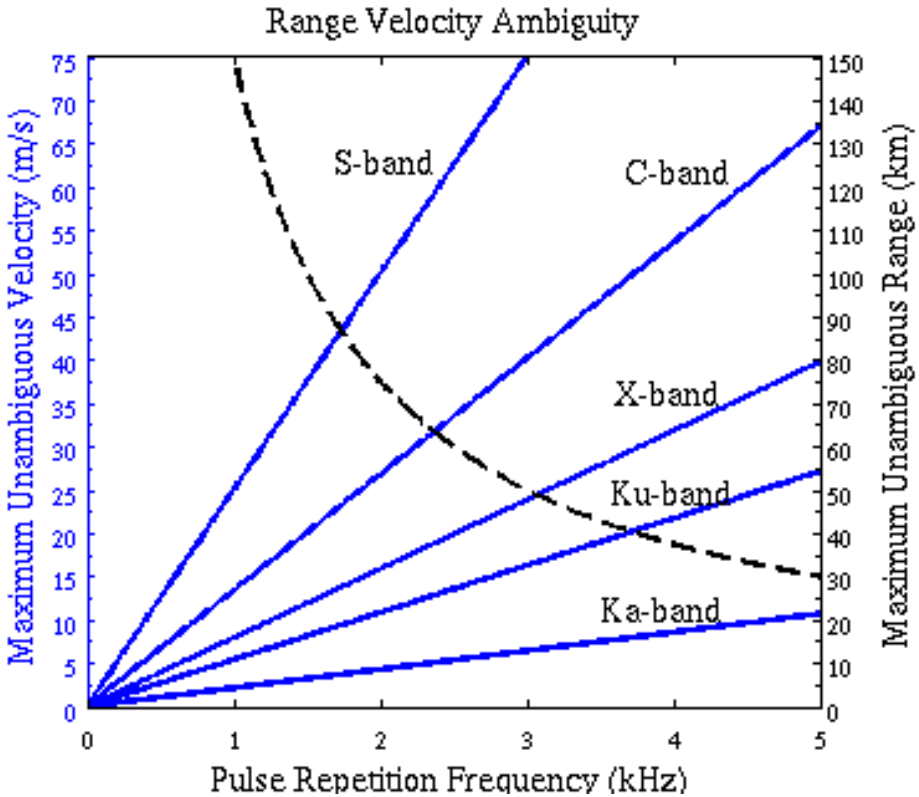
Consideration for operations

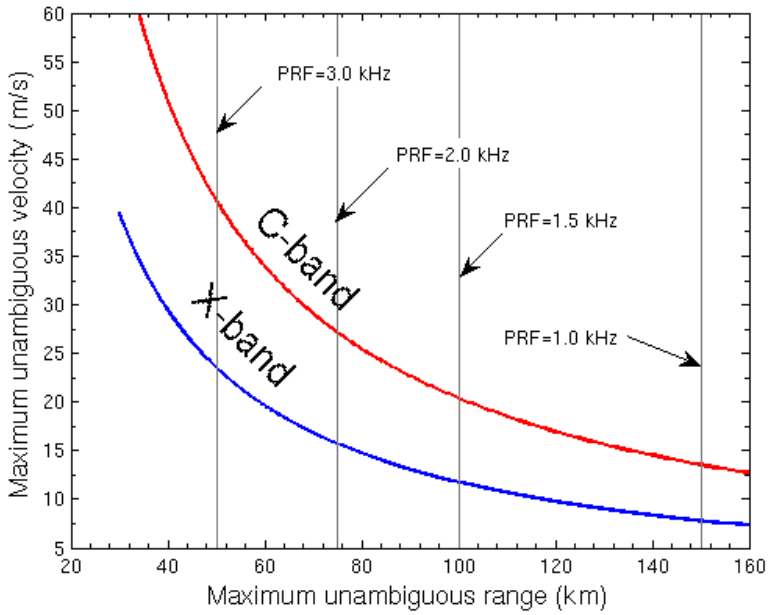
- Range velocity ambiguity
- Sensitivity
- Ground clutter suppression
- Calibration and verification
- Attenuation correction

Range-velocity ambiguity

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

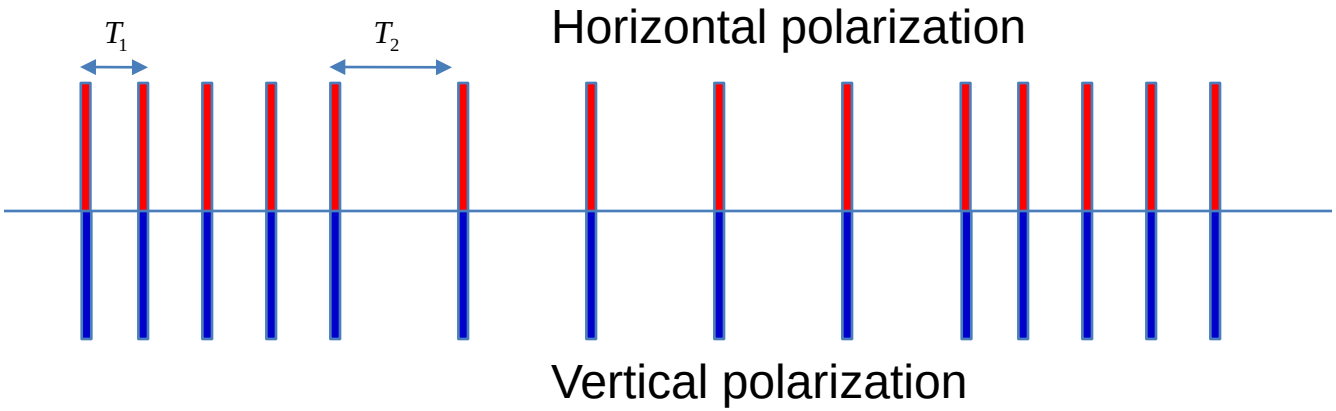
$$r_{\max} v_{\max} = \frac{c\lambda}{8}$$





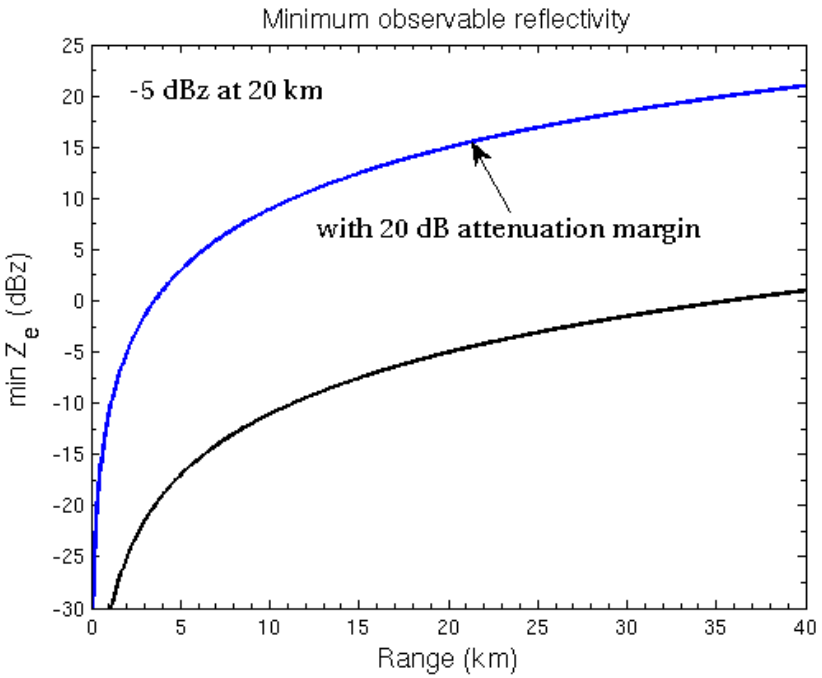
Range-velocity ambiguity

- 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

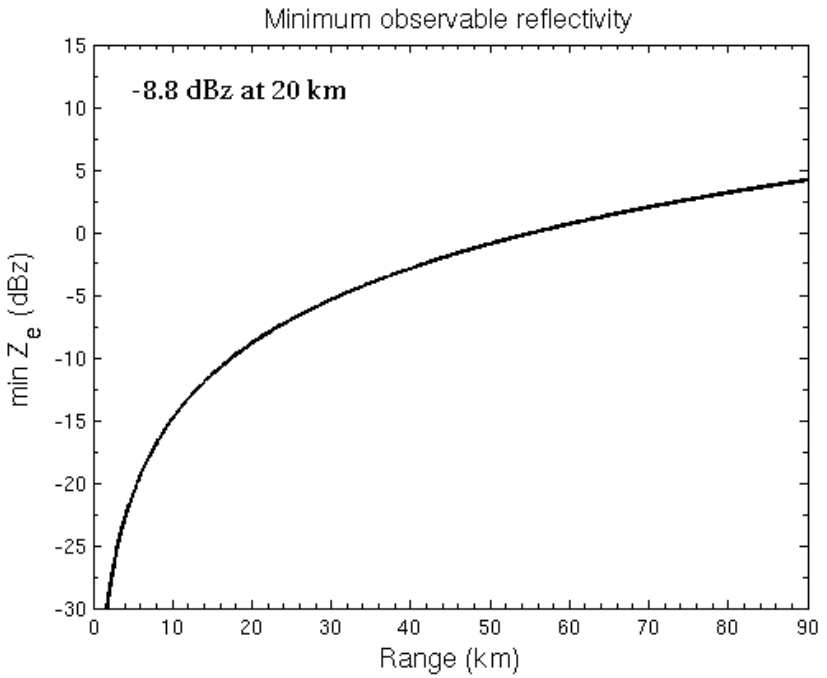
Sensitivity of X-SAPR



* Attenuation margin based on Li et al 2005 and Chandrasekar et al 2009.

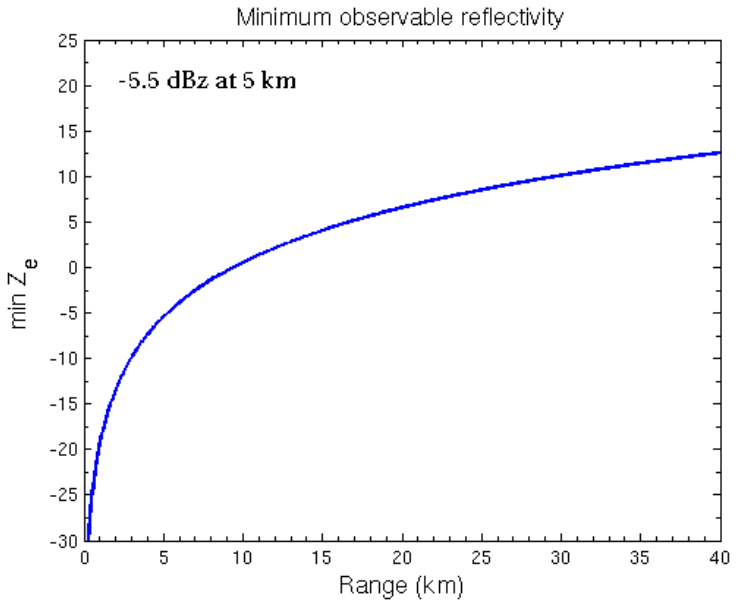
❖ Range resolution: 60 m

Sensitivity of C-SAPR

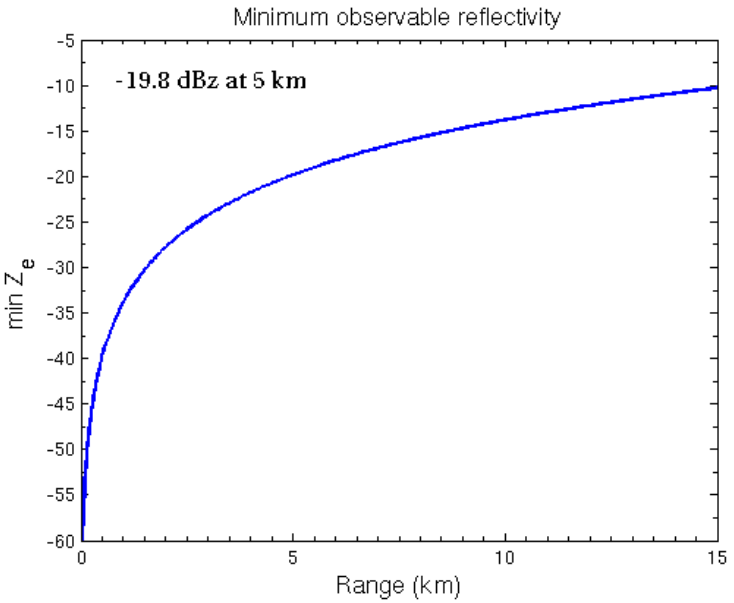


❖ Range resolution: 90 m

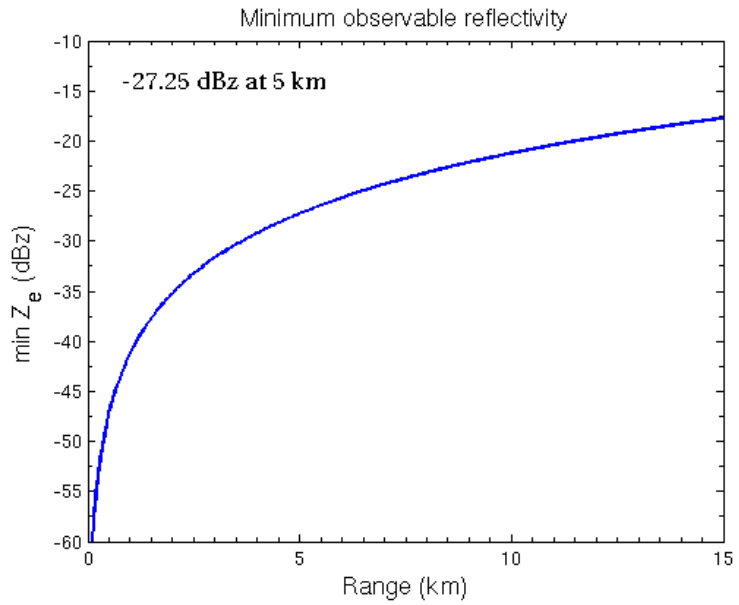
Sensitivity of X-SACR



Sensitivity of Ka-SACR



Sensitivity of W-SACR



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

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

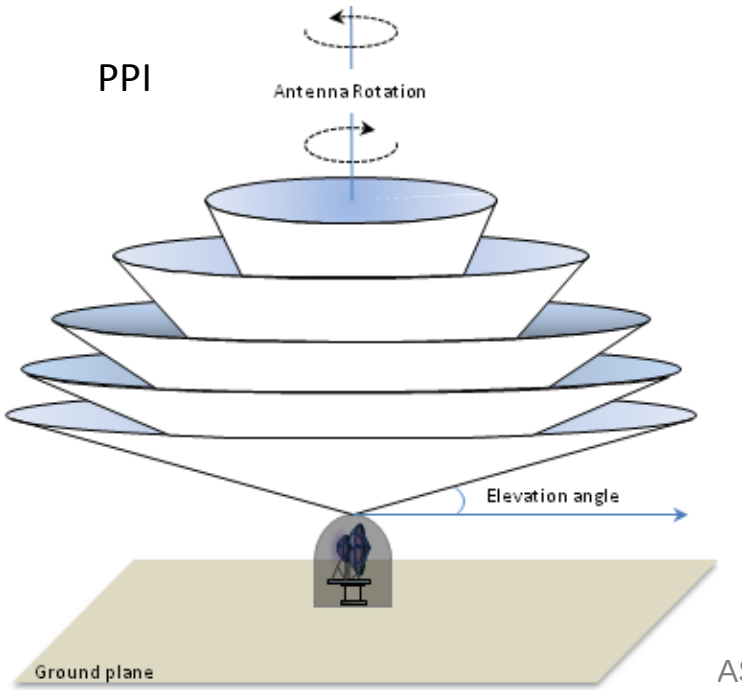
- Attenuation correction product will be provided
- X-SAPR
  - Vaisala's KDP estimation algorithm
  - Vaisala's version of attenuation correction algorithm
  - Mostly for rain and not mixed phase precipitation
- C-SAPR
  - ARC's KDP estimation algorithm
  - ARC's version of attenuation correction algorithm
  - 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

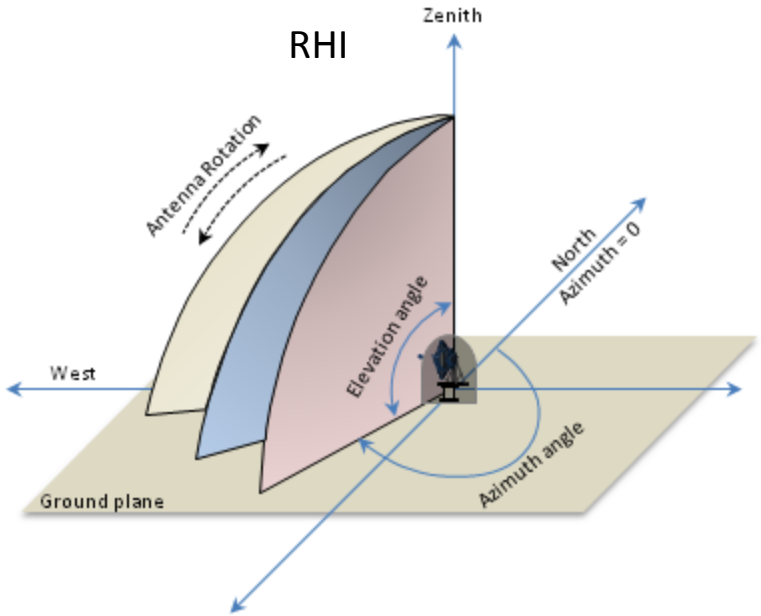
Table 2.1: Radar operating modes

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

PPI

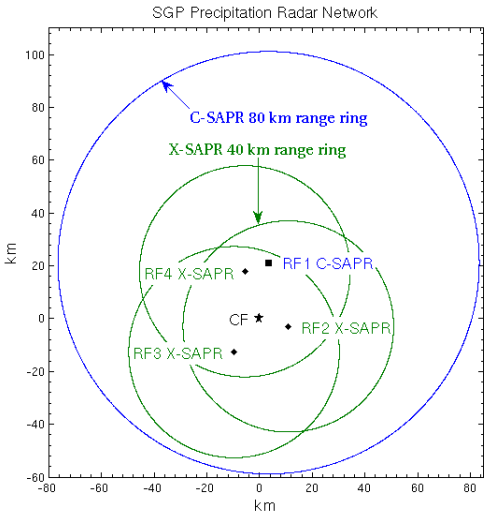


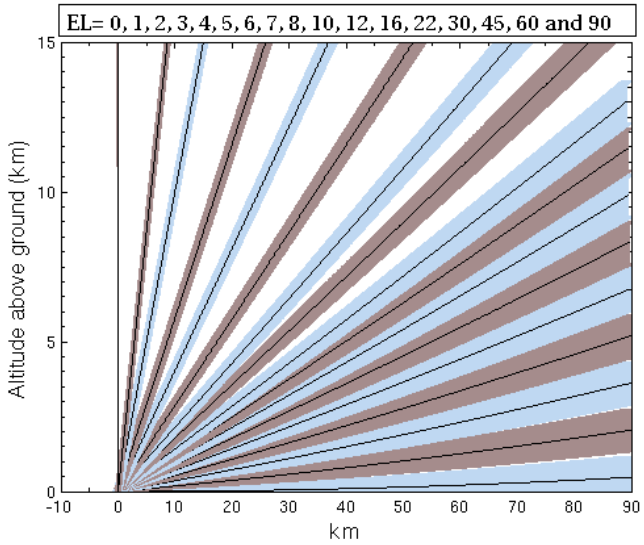
RHI

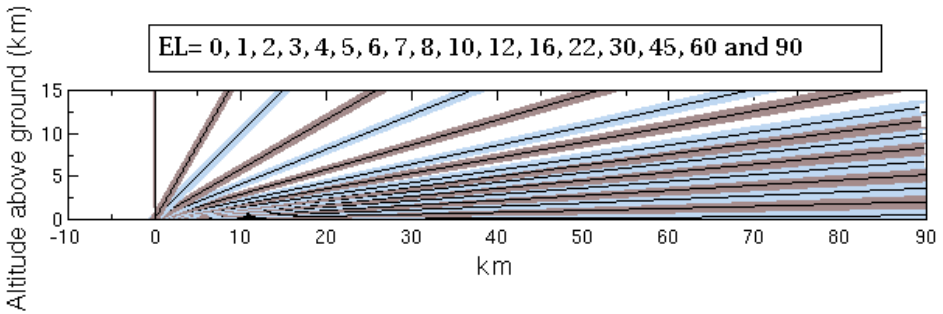


Example : Volume scan for X-SAPR

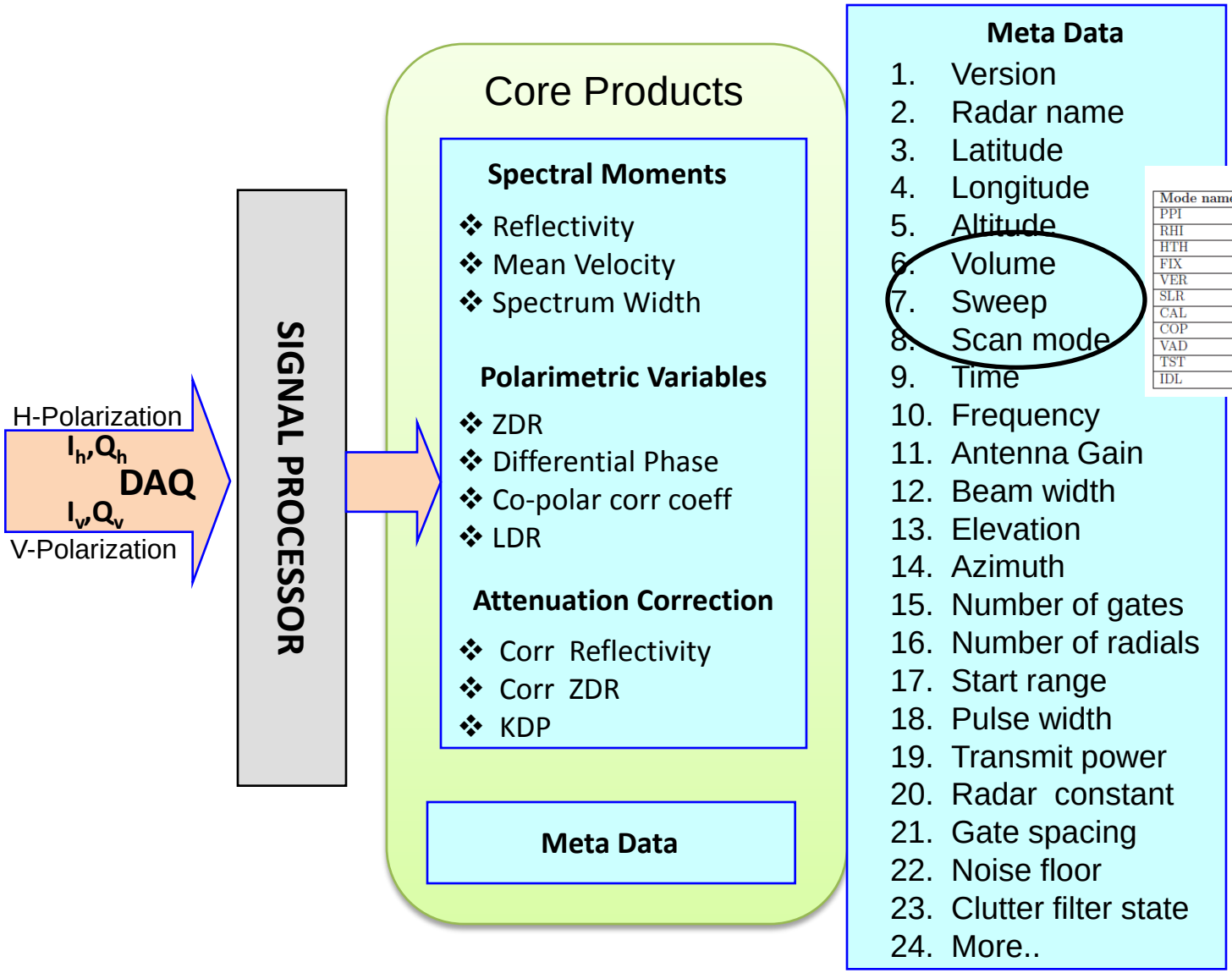
- 17 tilts with PPI sweeps of 360 degree (including zenith)
- 24 cuts with RHI sweeps of 90 degree (15 deg interval in azimuth)
- One of the 24 RHI is over Central Facility
- ``Bird bath'' (Zenith sweep) for ZDR calibration
- Scan speed 22.5 deg/s
- ~7 min (PPI+RHI) volume update
- Dual-PRF waveform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







Data Format



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SLR	TBD	Solar calibration
CAL	TBD	Calibration with blue sky or hard target
COP	TBD	Co-plane mode for dual-Doppler
VAD	TBD	Velocity azimuth display scan pattern
TST	TBD	Radar testing mode
IDL	TBD	Radar idle

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 …