DOE/SC-ARM/TR-121

ARM

CLIMATE RESEARCH FACILITY

C-Band Scanning ARM Precipitation Radar (C-SAPR) HANDBOOK

November 2012

U.S. DEPARTMENT OF ENERGY | Office of Science

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Acronyms and Abbreviations

ϕ_{DP}	differential phase
ρ_{HV}	correlation coefficient between H and V polarizations
ARM	Atmospheric Radiation Measurement (Program)
C band	frequencies between 4 GHz and 8 GHz
dB	decibel
dBi	antenna gain referenced to isotropic radiator
dBm	decibel referenced to 1 mW
dBZ	reflectivity
DQ	Data Quality
GHz	gigahertz (10^9 Hz)
Hz	hertz
Ka band	frequencies between 26.5 GHz and 40 GHz
K_{DP}	specific differential phase
kW	kilowatt
L band	frequencies between 1 GHz and 2 GHz
m	meter
MHz	megahertz (10^6 Hz)
MMW	millimeter wave (30GHz - 300GHz)
mW	milliwatt
NCAR	National Center for Atmospheric Research
PPI	Plan Position Indicator
PRF	pulse repetition frequency
RHI	Range Height Indicator
S band	frequencies between 2 GHz and 4 GHz
SGP	Southern Great Plains
TWP	Tropical Western Pacific
W band	frequencies between 75 GHz and 110 GHz
X band	frequencies between 8 GHz and 12 GHz
X-SAPR	X-band scanning ARM precipitation radar
Z_{DR}	differential reflectivity
Z_H	horizontal reflectivity
Z_V	vertical reflectivity

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1.0 General Overview

1.1 Introduction

The C-band scanning ARM precipitation radar (C-SAPR) (Figure 1) is a scanning polarimetric Doppler radar transmitting simultaneously in both H and V polarizations. With a 350-kW magnetron transmitter, this puts 125 kW of transmitted power for each polarization. The receiver for the C-SAPR is a National Center for Atmospheric Research (NCAR) -developed Hi-Q system operating in a coherent-on-receive mode.

The ARM Climate Research Facility operates two C-SAPRs; one of them is deployed near the Southern Great Plains (SGP) Central Facility (Figure 2) near the triangular array of X-SAPRs, and the second C-SAPR is deployed at ARM's Tropical Western Pacific (TWP) site on Manus Island in Papua New Guinea.

Figure 1. C-SAPR at SGP near Nardin, Oklahoma.

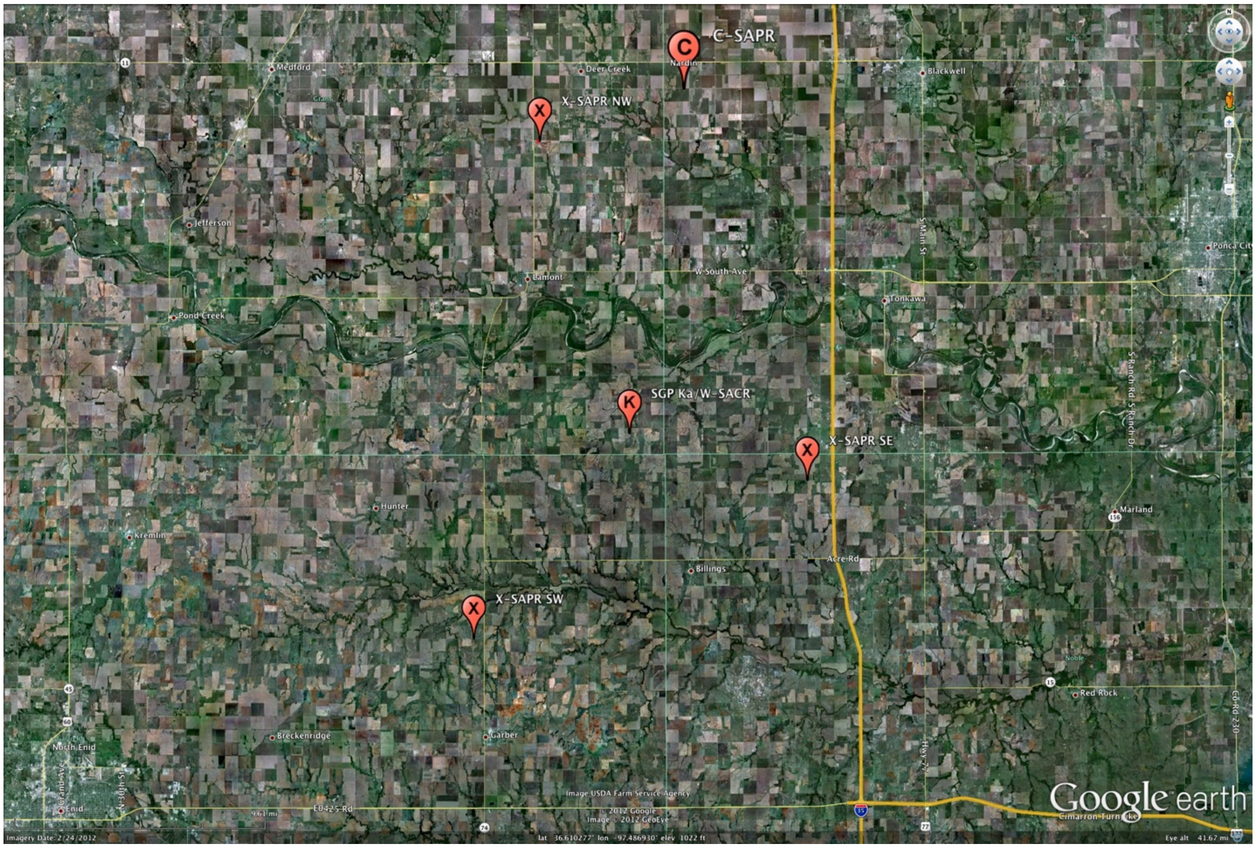

Figure 2. C-SAPR location at SGP.

Figure 3. C-SAPR in Papua New Guinea.

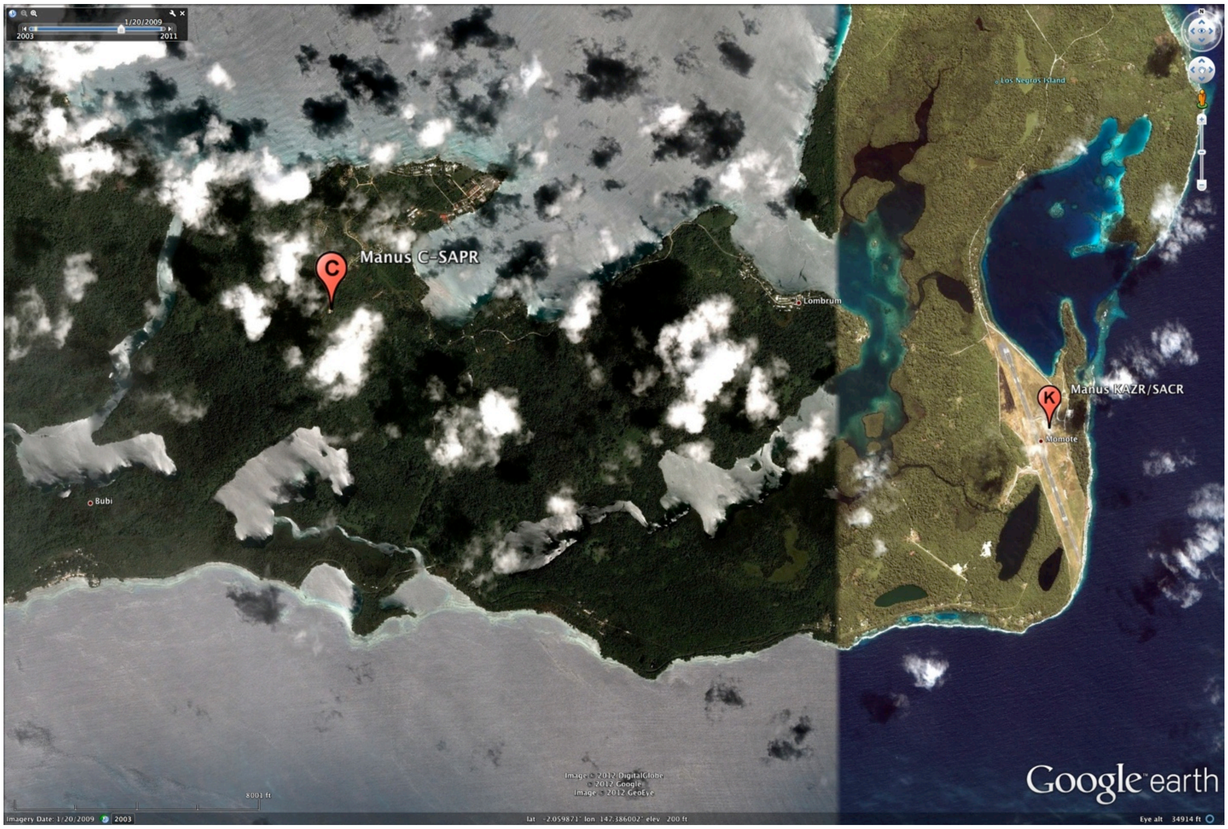

Figure 4. C-SAPR location in Papua New Guinea.

1.2 Specifications

1.2.1 Transmitter

Type:	Magnetron
Center frequency:	6.25 GHz
Peak power output:	350 kW
Pulse width:	200 ns–2 µs
Polarization:	dual polarization, simultaneous H and V
Maximum duty cycle:	0.1%
PRF:	200 Hz–2.7 kHz
Manufacturer:	Pulse Systems Technology

1.2.2 Receiver

Type:	coherent-on-receive, dual channel digital Hi-Q
Dynamic range:	> 80 dB
Noise figure:	2.8 dB
Sampling rate:	40 MHz
Decimation factor:	Adjustable
Video bandwidth:	Adjustable
Processing software:	TITAN
Manufacturer:	NCAR

1.2.3 Antenna/pedestal

Antenna Type:	direct feed parabolic reflector
Diameter:	2.4 m
3 dB beam width:	0.9°
Gain:	45.1 dBi
Cross polarization isolation:	- 32 dB
2-way radome loss:	<1.0 dB
Pedestal Type:	azimuth over elevation
Azimuth scan rate:	up to 36°/s
Elevation scan rate:	up to 30°/s
Pedestal manufacturer:	ARC

2.0 Contacts

2.1 Mentor

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2.2 Vendor/Instrument Developer

Advanced Radar Corporation (ARC)
2150 W. 6th Ave.
Broomfield, CO 80020
Website: http://www.radar-sales.com/

3.0 Deployment Locations and History

Location	Direction from CF	Site Designation	Date Installed	Date Removed	Status
Nardin, OK	NE	SGP/I7	02/18/2011		
Lombrum, PNG	WNW	TWP/I1	08/16/2011		

4.0 Near-Real-Time Data Plots

See http://radar.arm.gov.

5.0 Data Description and Examples

There are many different types of scans that the C-SAPR can perform. Scan strategies are defined for each site that alternate between the following types of scans:

- **RHI** (Range Height Indicator) scans are scans in which the azimuth axis is held constant while the elevation axis is changed. An RHI scan can go horizon-to-horizon over 180 degrees of elevation or a subset of that. The C-SAPR is limited to scanning 92 degrees in elevation.
- **PPI** (Plan Position Indicator) scans are what are typically thought of when thinking about weather radars. These are scans in which the elevation is scanned for 360 degrees and then the elevation is incremented. Figure 5 shows a scan with four different elevations.

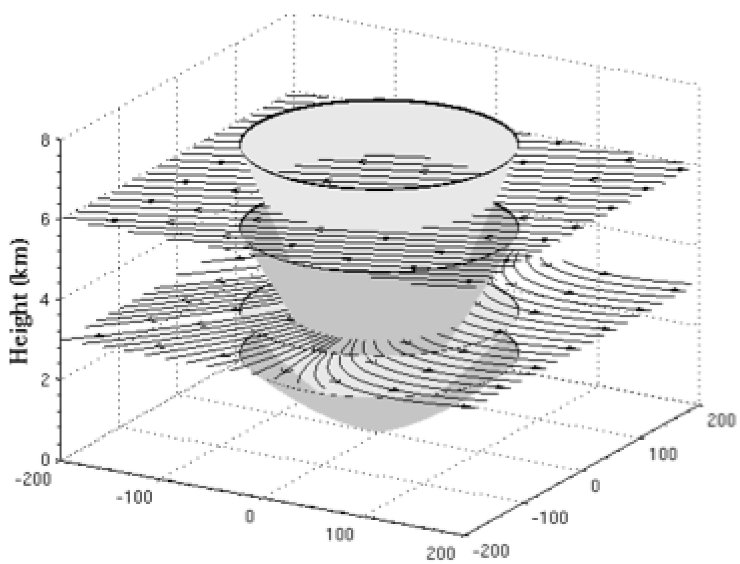

Figure 5. PPI Scan.

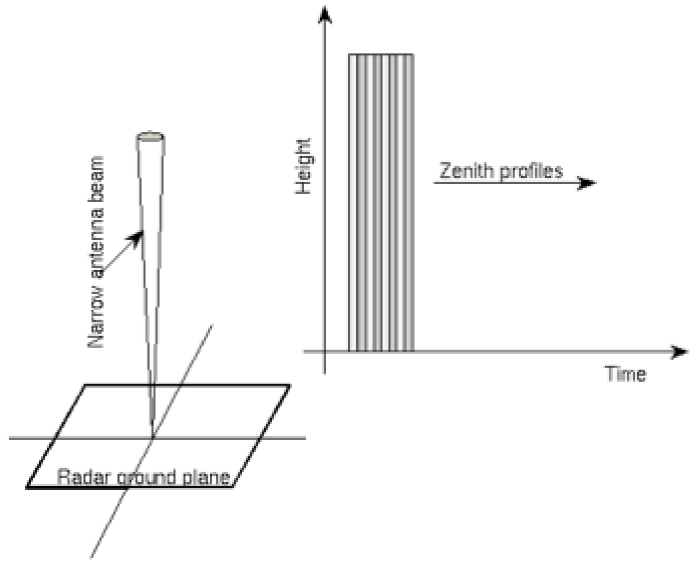

Figure 6. Vertical pointing.

- **Vertical pointing** – during part of the measurement period, ARM plans on operating the C-SAPR in a vertical pointing mode to obtain zenith cloud profiles profiles similar to those obtained by the Ka-band ARM zenith radar and W-band ARM cloud radar. Figure 6 shows an example of this type of scan.

5.1 Data File Contents

For the time being, ARM has decided to not ingest the C-SAPR data into netCDF. C-SAPR data are stored in the MDV format developed by NCAR. Data file descriptions are given in NCAR'S TITAN documentation. TITAN information is available at:

http://www.ral.ucar.edu/projects/titan/docs/

To obtain a text dump of an MDV file, retrieve a sample file from the ARM Data Archive and run the TITAN "PrintMdv" program.

5.1.1 Primary Variables and Expected Uncertainty

V	Linear channel Doppler mean velocity
W	Linear channel Doppler spectrum width
Z	Log channel reflectivity corrected for clutter
$\mathbf{Z_{DR}}$	Differential reflectivity
$\boldsymbol{\phi_{DP}}$	Differential phase
K_{DP}	Specific Differential phase
$\boldsymbol{\rho_{HV}}$	Dual-polarization correlation magnitude
NCP	Normalized coherent power

5.2 Annotated Examples

To be determined.

5.3 User Notes and Known Problems

To be determined.

5.4 Frequently Asked Questions

What is the meteorological radar range equation?

This is the equation to determine the reflectivity and is usually given in decibels of Z or dBZ.

$$Z = 10\log\left(\frac{1024\ln(2)\lambda^2 R^2 P_r L_a L_{sys}}{10^{-18} c\tau\pi^3 G_0^2 |K_w|^2 \theta_{3dB}^2 P_t}\right) \qquad dBZ \tag{1}$$

where:

Z = reflectivity (dBZ)
λ = wavelength (m)
R = range (m)
P_r = received power (watts)
L_a = two-way atmospheric loss
L_{sys} = radar system losses
c = speed of light (m/s)
τ = pulse width (s)
G_o = antenna gain
$|K_w|^2$ = index of refraction factor for liquid water at 0°C
θ_{3dB} = antenna beamwidth
P_t = transmit power (watts)

What dielectric factor for water is used to computer reflectivity in the radar range equation $/K_w/^2$?

The dielectric factor of water is a function of frequency and temperature of water drops as shown in Figure 7.

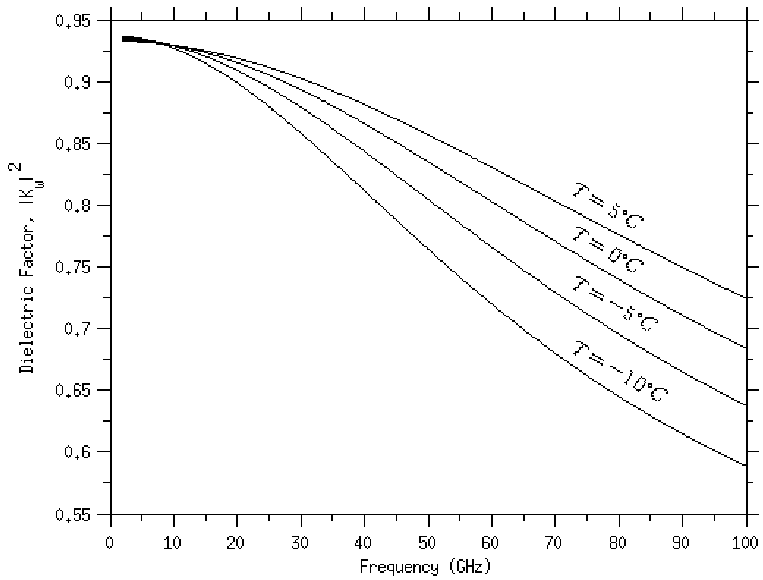

Figure 7. Dielectric function of water as a function of frequency and temperature.

The dielectric factor of water at 0°C is used for the computation of equivalent reflectivity factor. The value of dielectric factor used is 0.93 for the C-SAPR.

What are measurements are made with a dual-polarization radar versus that of a single polarization radar?

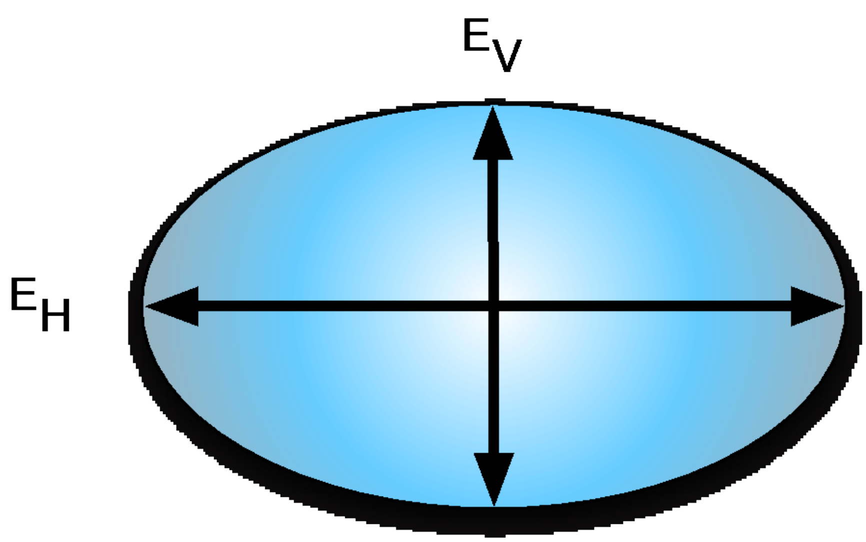

Figure 8. Large raindrop (idealized).

All Doppler weather radars provide a measurement of equivalent radar reflectivity factor (colloquially just reflectivity). Single-polarization radars cannot distinguish much in the way of the type of hydrometeor being observed. They also have varying degrees of success in estimating rainfall rates, and they depend on empirically derived parametric models to do this. These models are different for differing climatic regimes. The promise of dual-polarization techniques is to alleviate some of these shortcomings.

To understand the role of dual-polarization radars in meteorology, it is useful to consider the shape of water droplets. First you must realize they are not spherical, nor are they shaped like the customary teardrop. Water drops are roughly oblate spheroids. The larger the drop, the larger the horizontal axis is with respect to the vertical axis (Figure 8). Smaller drops are much closer to being spherical (Figure 9).

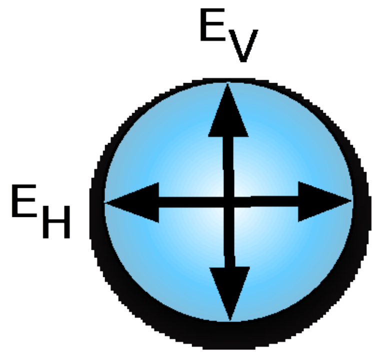

Figure 9. Small raindrop (idealized)

Keeping in mind the oblateness of raindrops, dual polarization adds the ability to measure the following variables:

- Horizontal reflectivity (Z_H) is a measurement of the reflectivity in the horizontal polarization plane. One can see that for large raindrops, the reflectivity in the horizontal axis is going to be much larger than that in the vertical axis, i.e., more oblate the larger the drop is.
- Vertical reflectivity (Z_V) is a measurement of the reflectivity in the vertical polarization plane. As the raindrop gets smaller, it becomes more like a sphere, i.e., less oblate the smaller the drop is.
- Differential reflectivity (Z_{DR}) is the ratio of the horizontal reflectivity (Z_H) to the vertical reflectivity (Z_v). For large water drops, $Z_H > Z_v$ and $Z_{DR} > 0$ dB. For small drops, $Z_H \approx Z_v$ and $Z_{DR} \approx 0$ dB. What about ice in the form of hail? Although hail is irregularly shaped, as it tumbles during its rise and fall in the atmosphere, it looks close to spherical and its $Z_{DR} \approx 0$ dB. Z_{DR} is unitless and reported in dB.
- Differential phase (ϕ_{DP}) is the measured cumulative differential phase shift between the horizontal signal (ϕ_{HH}) and the vertical signal (ϕ_{VV}). As the radar signal goes through water, its speed is reduced for that period of time it is in a raindrop inducing a phase delay in the signal. In large oblate drops, this phase delay, also called phase shift, is larger than smaller, less oblate drops. ϕ_{DP} is measured in degrees.
- Specific differential phase (K_{DP}) is defined as:

$$K_{DP} = \frac{\phi_{DP}(r_2)-\phi_{DP}(r_1)}{2(r_2-r_1)} \quad \left(\frac{deg}{km}\right) \tag{2}$$

K_{DP} is useful for estimating rainfall rates because it is not affected by spherical particles (i.e., tumbling hail). This allows the amount of liquid water in a rain-ice mixture to be estimated. Another important feature of K_{DP} is that it is a propagation variable, which means it is not dependent on the amount of received power.

- Dual-polarization correlation magnitude (ρ_{HV}) is also referred to as the correlation coefficient and is a measurement of the correlation between the horizontal and vertical radar signals. ρ_{HV} can be useful in hydrometeor discrimination, e.g., telling the difference between rain, hail, graupel, snow, etc.

6.0 Data Quality

6.1 Data Quality Health and Status

The Data Quality Office website has links to several tools for inspecting and assessing X-SAPR data quality:

- DQ Explorer
- DQ Plot Browser
- NCVweb: Interactive web-based tool for viewing ARM data.

Plots of reflectivity, Doppler radial velocity, and dual-polarization variables provide a good indicator of whether the system is operational or not.

6.2 Data Reviews by Instrument Mentor

Instrument mentors review C-SAPR data in the following ways:

- Routine review for nominal operation, usually daily Monday–Friday
- When requested by Site Operations
- When requested by the site scientist team
- When requested by an ARM data translator
- When requested by a data user
- When notified automatically by the X-SAPR's built-in test email messages.

6.3 Data Assessments by Site Scientist/Data Quality Office

To be determined.

6.4 Value-Added Products

There are no value-added products for C-SAPR at this time. There are plans to produce a "corrected moments" product, which will include velocity and range dealiasing and water vapor attenuation correction. After that, a gridded moments product with cloud boundaries will be produced Instrument Details.

7.0 Instrument Details

7.1 Detailed Description

Figure 10 shows the basic block diagram for the C-SAPR.

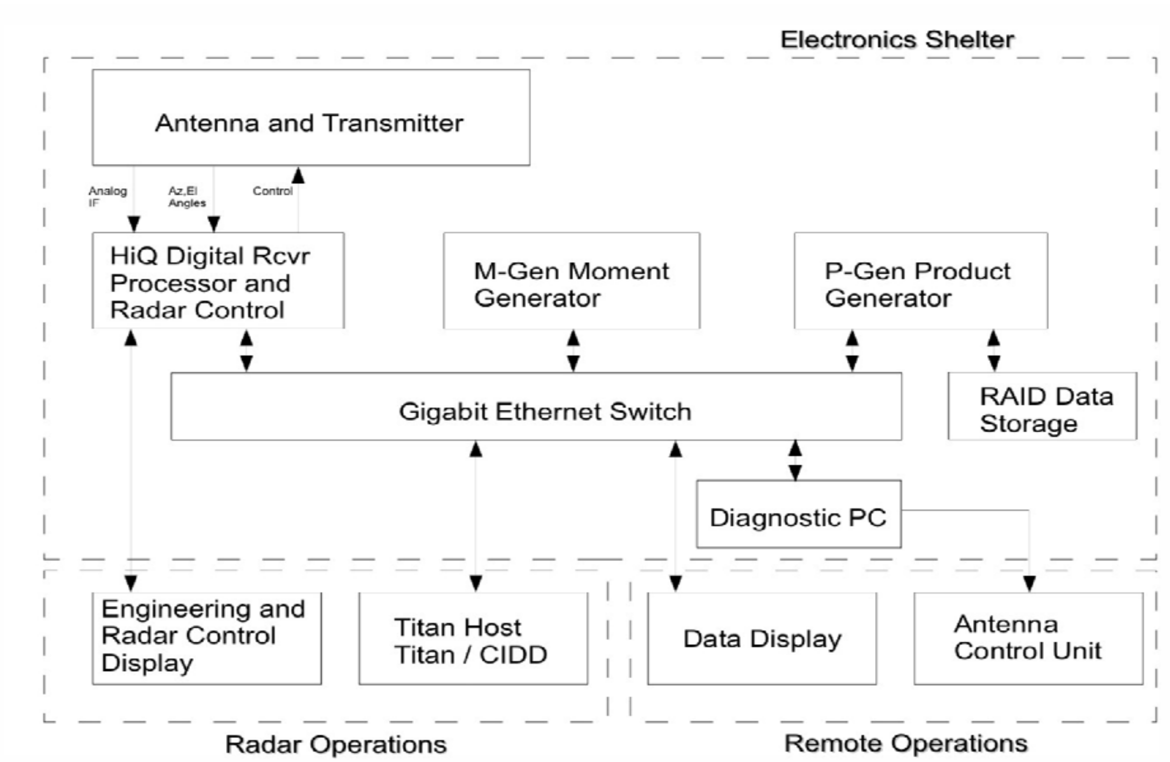

Figure 10. C-SAPR block diagram.

7.2 Theory of Operation

The theory of operation is available in the manufacturer's documentation. Contact the instrument mentor for information.

7.3 Calibration

To be included in manufacturer's documentation and the ARM Common Calibration database. Contact the instrument mentor for information.

7.4 Operation and Maintenance

See the NCAR TITAN documentation at http://www.rap.ucar.edu/projects/titan/home/index.php.

7.5 Citable References

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