Radtec Engineering Inc.

RDR-200GX/DP Weather Radar Systems

SHMU Dual Polarity Radar Site
Kosice, Slovakia

RDR-200GX
Antenna/Transmitter/Receiver

Lockheed-Martin RDR-200GX

Radtec Offset Feed Antenna

Weather Radar Systems

Innovative Technology
Affordable
Proven

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RDR Radar Advantages

- **n Technology-** The RDR family of radar systems uses the most up to date technology available for magnetron radar systems, including;
  - Stable Design Concept
  - Coaxial magnetron
  - Fully solid state linear IGBT modulator
  - Integrated low noise receiver front end
  - Digital receiver and signal processor

- **e Company** with complete in-house radar design and manufacturing capabilities
  - Assures product integrity and reliability throughout the product's life
  - Assures complete system integration and performance verification
  - Easily facilitates performance upgrades and enhancements
  - Assures affordable technical support and protection against obsolescence throughout the product's life
  - ISO 9001-2000 certified

- **Performance-** The low noise integrated receiver front end, and stable linear IGBT solid state modulator, combined with a digital receiver, provide frequency and phase stability approaching that of a fully coherent Klystron. The benefit is more accurate velocity data, better ground clutter cancellation, and superior dual polarity operation.

  The RDR-200GX has a maximum PRF of 5000 pulses per second, more than double that of many other weather radars. The high PRF means accurate Doppler measurement of high wind velocities - double that of many radars.

- **Ground Clutter-** Velocity based clutter filters, in conjunction with a precision COHO phase locked to the magnetron provide 40 dB or better clutter rejection. An optional offset feed antenna provides 35 dB or better side lobe suppression for additional ground clutter rejection (most ground clutter is due to antenna side lobes).

  The offset feed antenna substantially reduces ground clutter, which assures reliable detection and warning of wind shear conditions even in the Terminal Control Area, with the clutter inherent in an airport location.

  The combination of DFT velocity processing with the offset feed antenna and linear IGBT modulator provides the most effective and reliable state-of-the-art clutter suppression available today- under virtually all operating conditions.

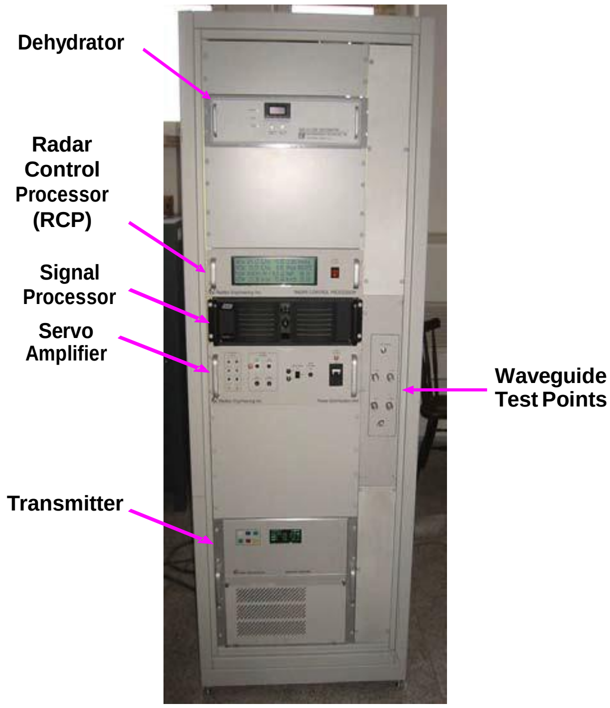
- **Reliable-** The RDR family of radars use a stable well proven design, with a minimum number of components, and are fully solid state (with the exception of the magnetron tube).

- **Operating Cost-** The stable, well proven design, with standard components wherever possible, adds up to a system with very low operating costs. In addition, wherever possible, all RDR models share components within the X, C-band and S-band product line. This commonality leads to initial cost savings, as well savings in the on-going cost of support, training, maintenance, etc.

- **Capabilities Protect Investment-** Modular design allows upgrading to meet future requirements, protecting today's investment:

  - Antenna
    8 ft. (2.4 m) offset feed antenna for superior ground clutter rejection, 0.9° beam width, 45 dB gain, ε35 dB first side lobe suppression (one way, single polarity)
  - Optional hydrological analysis software provides full analysis product generation capability including volume scan products and hydro - meteorological rainfall analysis.
  - Optional aviation support software provides product generation, detection, time of arrival forecast and warning capabilities for wind shear, microbursts, gust fronts, etc.
  - Multiple radar networking provides expansion of coverage area, status/control and processing for all radars at a central location, unattended operation of radars in remote locations
  - Overlay and underlay capability allows easy selection/inclusion of a wide range of maps, satellite imagery, etc. on radar images
  - Optional dual polarity operation provides improved accuracy of rainfall measurement and measurement of precipitation type (rain, hail, snow, graupel, etc.).

The RDR Family Of Radar Systems



"Conventional" RDR-200GX/DP Transmitter/Receiver

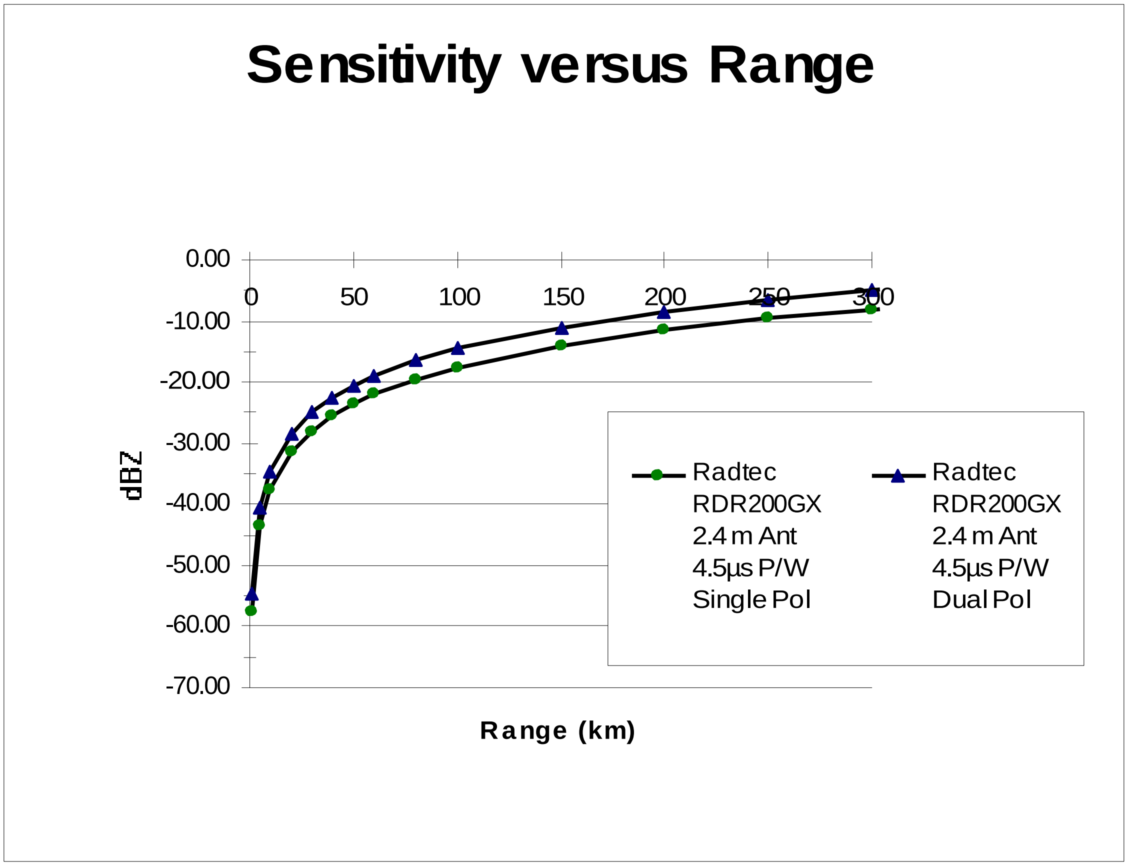
"Package" RDR-200GX System For Mounting Inside Radome

The RDR family of radar systems is made up of a number of models which can be configured to meet virtually any weather radar requirement.

RDR-200GXDP: The RDR-200GX/DP is an advanced, digital Doppler weather radar designed to provide reliable precipitation measurement in a high clutter environment. It features an offset feed antenna to minimize ground clutter, and optional dual polarity operation for maximum rainfall measurement accuracy and precipitation classification. It includes the REI-DSP digital receiver and signal processor which provides PPI and volume scan data and analysis products of scientific quality and accuracy.

Sensitivity versus Range

The following graph indicates the sensitivity of the RDR-200GX/DP magnetron radar out to 200 km range. These sensitivity calculations assume a 2.4 m antenna with 0.9° beam width, and a 4.5 µsecond pulse width.



Sensitivity (dBZ) vs. Range For RDR-200GX/DP 200 kW X-Band Radar

Proven Reliability, Low Risk of the RDR Family

Commercial-off-the-shelf availability - very low technical risk.

Coaxial magnetron technology - cost effective, proven reliability.

Solid state Linear IGBT modulator - reliable, no thyratrons to replace; accurate pulse stability.

Virtually maintenance free pedestal - Long life AC servo motors, low mass antenna

Integrated front end receiver- minimizes complex setup and calibration adjustments

Digital signal processor - more accurate velocity data for superior ground clutter rejection

Available options - assure ability to meet future needs, protecting today's investment

Transmitter

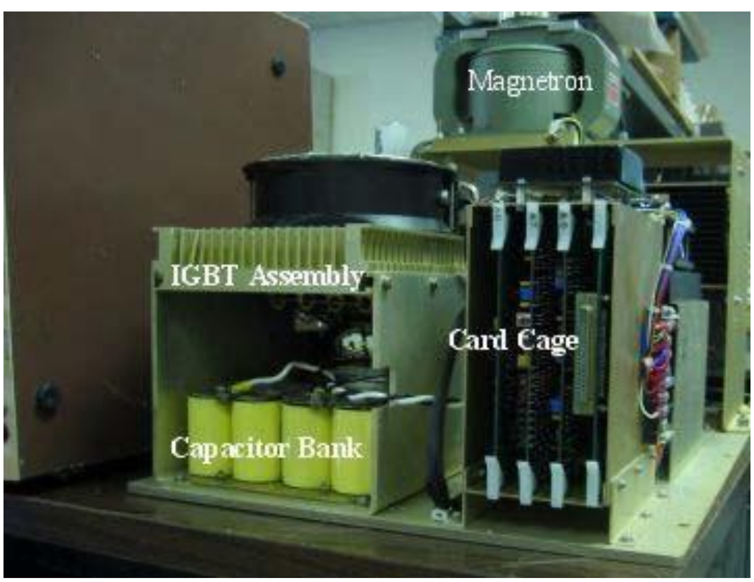
Accurate Doppler velocity data requires that the radar's operating frequency and phase be extremely stable. When pulses are received, any change in frequency/phase is assumed to be Doppler shift due to velocity of the target precipitation. If the change is the result of instability in the transmitter, the signal processor has no way to detect which part of the change is due to the target velocity, and which is due to transmitter instability, thus, velocity data is less accurate.

One of the major advantages of a Doppler radar is the ability to use velocity based clutter filters. This means that targets with zero velocity are assumed to be clutter, and filtered out. To do this effectively, the radar must have very accurate velocity data.

In the RDR radar's receiver and digital signal processor-receiver, the measurement of the magnetron burst is used for phase locking (Digital COHO) and for Automatic Frequency Control (AFC) of the Stable Local Oscillator (STALO). The stability of the transmitter and accuracy of the burst phase measurement permit 40 dB or better of ground clutter cancellation in the velocity based clutter filters.

In a Doppler radar, the maximum range and the maximum velocity that can be measured are related to the Pulse Repetition Frequency (PRF). Longer ranges require lower PRF's; higher velocities require higher PRF's. Thus, there is a trade-off between velocity and range. This is sometimes referred to as the Doppler Dilemma.

The RDR-200GX/DP solid state linear IGBT modulator permits selecting a PRF's from 500 to 5000 pulses per second. This permits adjusting the PRF to the optimum value for the existing conditions. In addition, pulse staggered velocity unfolding is available with 2/3, 3/4 and 4/5 ratio.



- **Linear IGBT modulator has fully programmable pulse widths and pulse rates. No fixed time constants (Pulse Forming Network, charged delay line, etc.) are used.**

  The only limitation on pulse width/rate combinations is the magnetron duty cycle. Pulse width/rate changes are automatically checked to prevent exceeding the maximum duty cycle.

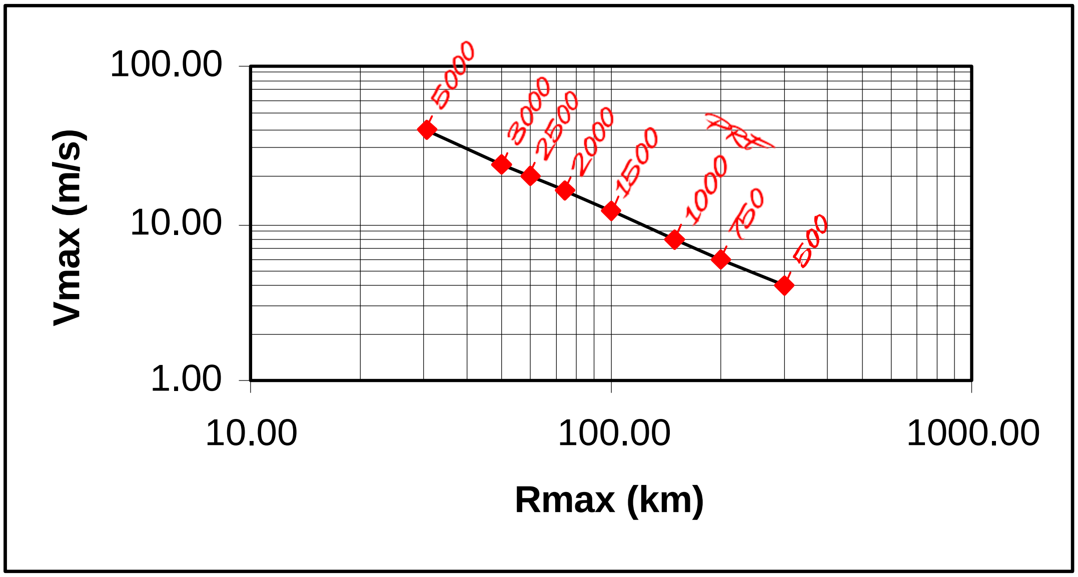


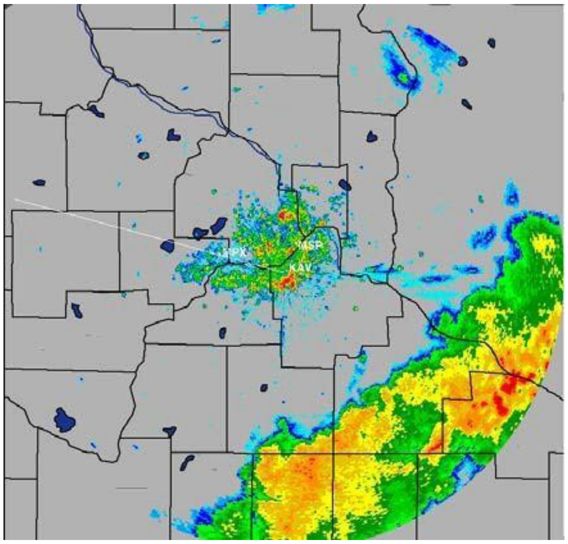
Chart of RDR-200GX/DP - PRF (pulse rate) versus R_{max} (maximum unambiguous range) and V_{max} (maximum unambiguous velocity).

Precision Offset Feed Antenna

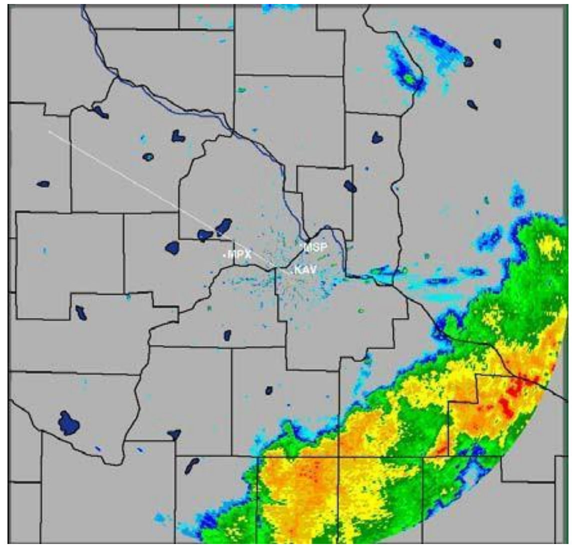
Offset Feed Antenna

Offset Feed Antenna

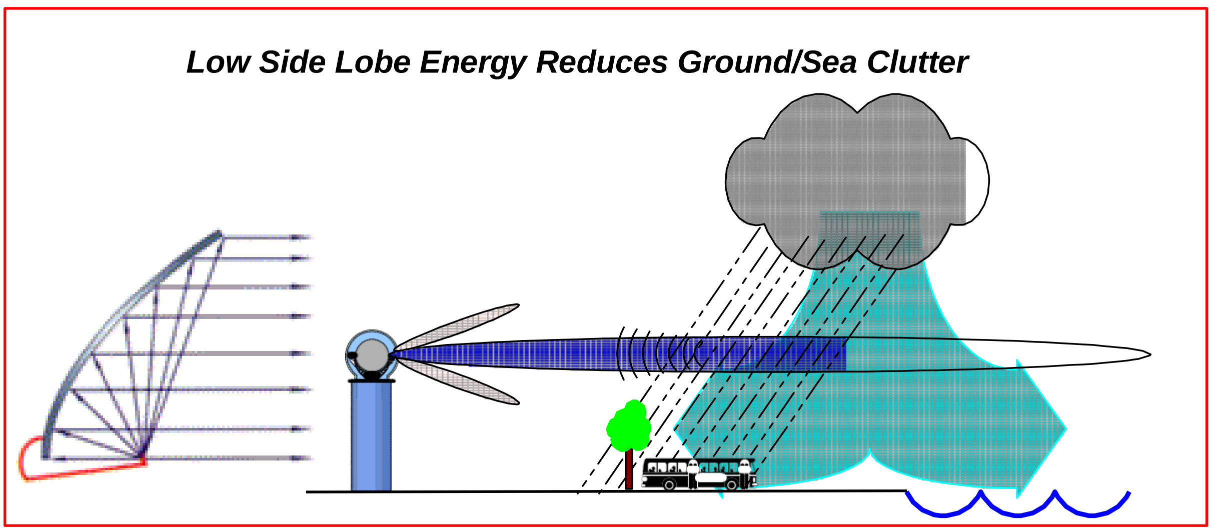
- Superior ground clutter rejection
- d on RDR-200GX/DP
- Parabolic reflector
- Precision offset feed
  2.4 m (8 ft) or 4.3 m (14 ft)
- 45 dB gain
- width
- First side lobes
  δ-35dBc (one way single polarity)
  δ-30dBc (one way dual polarity)
- Rigid composite materials
  Low mass
- Reduced driveline stress
- Longlife AC servomotors



Severe Ground Clutter Typical Of A Large City



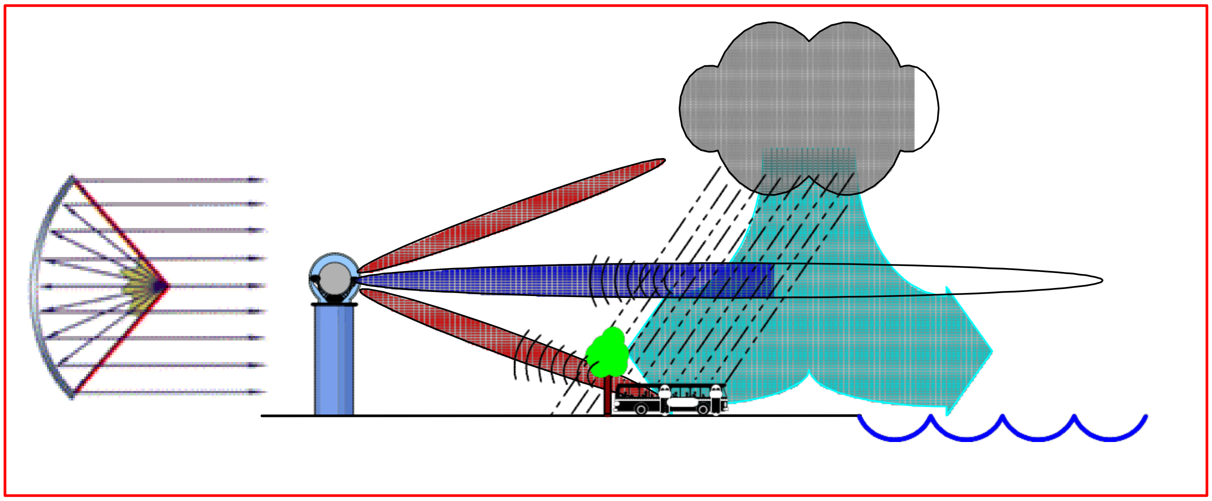
The Same Image With An Offset Feed Antenna And Velocity Based Clutter Filtering



Antennas with low side lobe energy avoid ground clutter. Moving ground clutter, such as produced by vehicles and waves cannot be filtered out, thus avoiding moving clutter is extremely important. The Radtec precision offset feed antenna simply avoids most ground clutter.

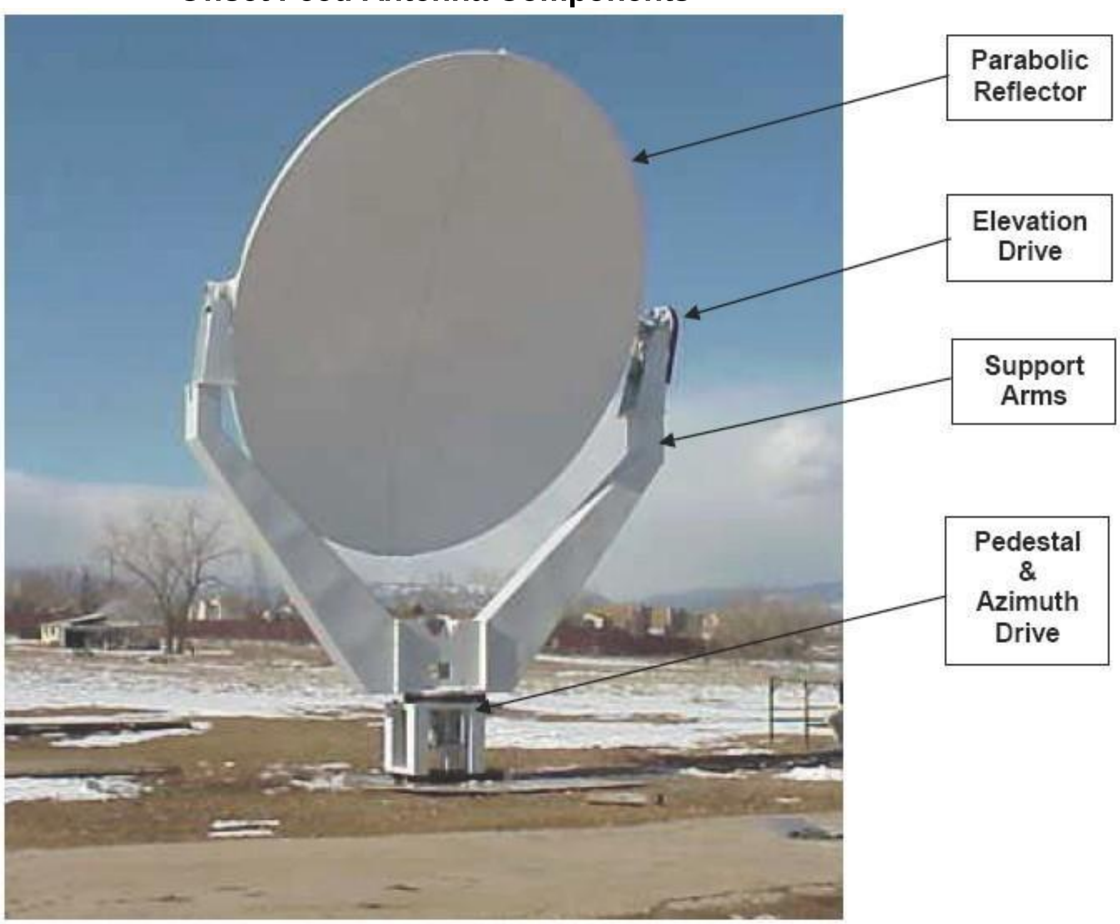
The feedhorn support struts and waveguide do not interfere with the beam of the exclusive Radtec precision offset feed antenna. Thus its first side lobes are typically -35dBc (one way).

The performance of a parabolic antenna is also determined by the accuracy of its shape. The accurate shape of a Radtec offset feed antenna reflector is inherent in the reflector; not dependent on supporting structure. The light weight, very rigid composite materials, and precision manufacturing, assure that the Radtec offset feed antenna will retain its accurate shape, and, therefore, design level performance, throughout its life.

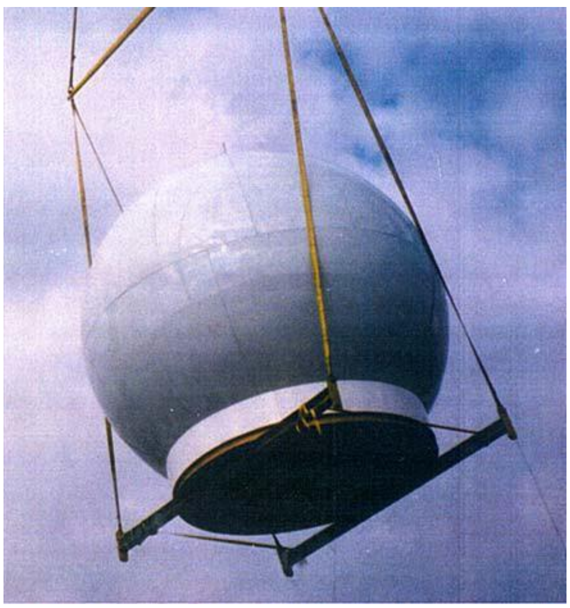


Conventional center feed antennas place the feedhorn and its support struts in the main beam. The interference with the main beam produces side lobes which cause reflections from clutter targets.

Offset Feed Antenna Components



Radome


Radtec laminated radome

- (12 ft.) for 2.4 m offset feed antenna (22 ft) for 4.3 m
- me
- 0.3 dB for A-sandwich radome
- 230 Km/hr (138 mph) wind survival for undamaged radome
  -50° C to +70°C
- Hydrophobic surface
- 90% transmission when wet

RDR radomes are moisture resistant and corrosion proof. Undamaged radomes have withstood winds in excess of 200 mph. Many similar radomes are in use in installations worldwide, many with over 20 years of successful service.

Radome Technology And Dual Polarity

Both the laminated and A-sandwich radomes are truly spherical ↓not composed of segmented, flat panels. The pedestal design is such that the center of rotation for both azimuth and elevation is placed at the center of the radome, resulting in a symmetrical electrical signal path length for all antenna motions.

When used in dual polarization mode, a major cause of discrepancies between the horizontal and vertical polarization planes is caused by a radome frame, especially a metal frame. MFG Galileo A-sandwich radomes have seams, but no frame. The seam has very good RF performance. The RF transmission of the seam is very close to that of the rest of the radome. Additional details on MFG Galileo A-sandwich radome construction and performance are available in a Radtec technical exhibit.

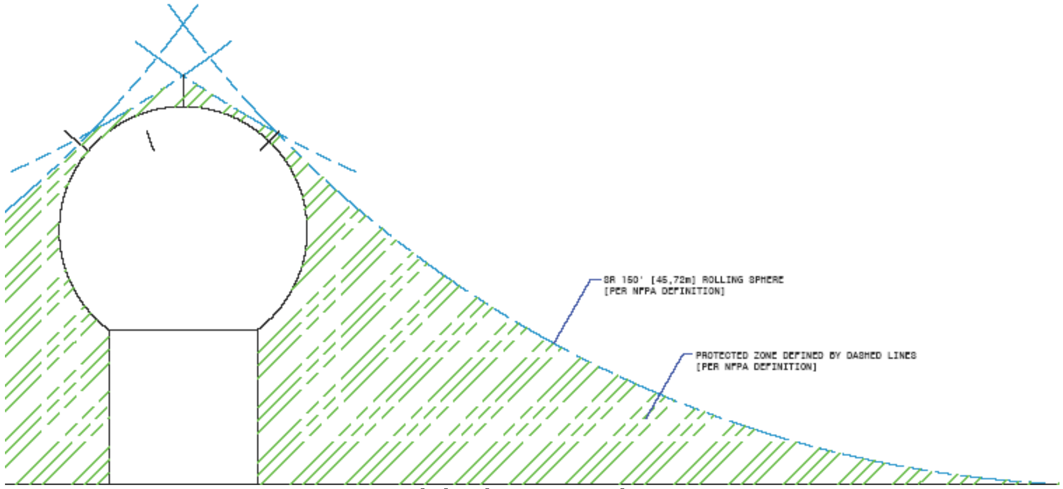
Advanced Lightning Protection Program

Lightning is the single most frequent cause of damage to weather radar systems. The risk of damage to the radar system can be significantly reduced through certain design and construction features of the radar and its installation:

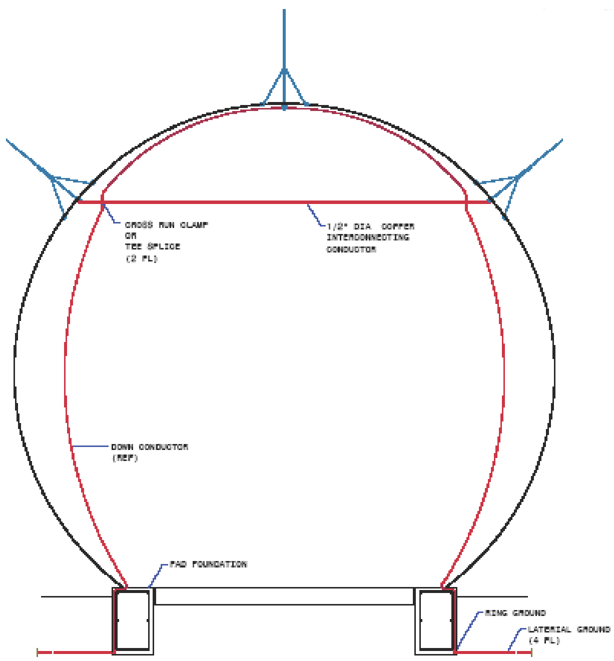
- Radome lightning protection system- The radome and antenna are particularly vulnerable to lightning strikes. Adequate protection is required to reduce the potential for damage to the radar from lightning strikes on the radome and antenna.

  Radtec offers MFG Galileo's lightning protection system, which is compliant with both the "rolling sphere" concept defined in the National Fire Protection Association (NFPA) standard 780, and the US Federal Aviation Administration (FAA) standard FAA-STD-019C which covers lightning protection for ground based aviation related equipment and facilities in the United States.
- Adequate earth grounding- Radtec recommends an earth ground for the radar system of not more that one ohm ground resistance.
- Adequate isolation of the radar system from incoming power and communication circuits

The following diagrams illustrate a lightning protection system described by NFPA standard 780.



Lightning Protection
"Rolling Sphere" Area defined by National Fire Protection Association Standard 780



Typical Radtec Lightning Protection Configuration Per NFPA Std. 780
Provides 3-dimensional lightning protection around the radome.

Dual Polarity RDR-200GX/DP

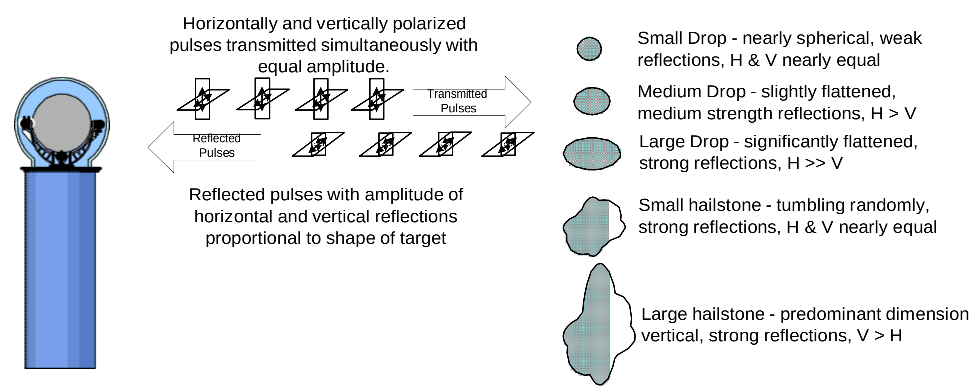
Dual polarity capability is available as an option on Radtec radars. The option includes all required features for the antenna, transmitter, receiver, signal processor and the required processing software. The radar is still capable of providing all normal reflectivity and velocity products in addition to the dual polarity products.

Radtec radars with the dual polarity hardware option currently support the following dual polarity data products:

- ZDR- Differential Reflectivity
- KDP- Specific Differential Phase Shift
- √DP- Differential Phase Shift
- 〉hv- Co-polar Correlation Coherency Coefficient
- LDR- Linear Depolarization Ratio
- Rainfall rate and accumulation
- Precipitation Classification (Rain, Drizzle, Snow, Small Hail, Large Hail, Graupel)

With traditional weather radar technology, the radar can only measure the total reflection. The total reflection is a function of the size, number and phase (rain, snow, hail, etc.) of precipitation particles (hydrometeors). Thus determining the actual amount of liquid in the precipitation, or detecting a specific type of precipitation, such as hail, from only a radar image becomes at best an estimate which may be subject to large errors. Doppler adds the ability to measure velocity, which greatly enhances the radar's ability to detect certain types of severe weather.

A significant amount of research has been done to determine how to get more precipitation information using a radar system. Much of that research has been focused on radar systems that have the ability to control the polarization angle of the transmitted signal and to analyze reflectivity data at specified polarization angles. This is called a polarimetric (dual polarity) radar. Polarimetric techniques provide accurate rainfall measurement at all locations within the radar's coverage area, and accurate measurement of specific types of precipitation within a storm cell. These advances are likely to make as big an improvement in radar based weather forecasting over Doppler radar as the addition of Doppler capability did over conventional weather radar.



ZDR (differential reflectivity) is one of the simplest polarimetric techniques. For ZDR, the radar transmits pulses with horizontal and vertical polarization, either simultaneously, or on alternating pulses. The differences in amplitude between the horizontally and vertically polarized reflections are analyzed to extract more information about the precipitation.

Small raindrops are nearly spherical and reflect horizontally and vertically polarized signals nearly equally. As raindrops become larger, they tend to flatten into oblate spheroids. This flattening is the result of air flow pressure on the bottom of the drop as it falls. Therefore, drops will tend to fall with the widest dimension of their shape aligned horizontally. The widest dimension (horizontal) will reflect horizontally polarized signals more strongly than the narrower dimension (vertical). Thus, the difference between the horizontally and vertically polarized reflections can provide an estimate of the size of the raindrops. This technique is referred to as differential reflectivity or ZDR.

ZDR has been demonstrated to provide ability to differentiate between hail and other types of precipitation. Small hail stones tend to be relatively symmetrical and tumble randomly as they fall. Therefore, there is little difference in amplitude between horizontally and vertically polarized reflections from hailstones. Large hail stones tend to be assymmetrical and fall with the longest dimension vertical (prolate), thus reflecting the vertically polarized signal more strongly. As a result, an area showing high dBZ reflectivity with a ZDR value of 3 or 4 dB is likely to be heavy rain. If the ZDR value is near zero, the reflection is very likely to be small hail. If the ZDR value is negative, it is likely to be large hail.

KDP is a parameter that research suggests may be useful in improving the accuracy of radar based rainfall estimates. Note that the “K” in KDP is different than the “K” in the Probert-Jones equation. In KDP, “K” is the specific differential phase shift per unit of distance, typically in degrees per km. In other words, KDP compares the phase shift of a horizontally polarized signal with the phase shift of a vertically polarized signal over the same distance. The research to date indicates that KDP has several significant advantages:

- Radar precipitation estimates that are independent of radar calibration.
- Measurement that is nearly linear with respect to rainfall intensity.
- Less dependence on drop size distribution than other parameters.

The following diagram of the cross-section of a storm cell was prepared by Dr. J. Straka of Oklahoma University using the NCAR CP-2 radar. It is indicative of the sophisticated type of storm analysis that becomes possible with advanced radar polarimetric techniques.

Conventional precipitation estimation algorithms: shortcomings for operational use

When using a classical Z/R relation, the primary sources of error are:

- Calibration error
- DSD (Drop Size Distribution) uncertainty (a single Z/R relation does not apply to all precipitation types).
- Attenuation (the measured Z is underestimated).

Dual polarization technique in weather radars is not new (the research effort started 20 years ago). Using the differential reflectivity (ZDR) or the specific differential phase shift (KDP), researchers have been able to demonstrate that they could improve the rain rate estimate:

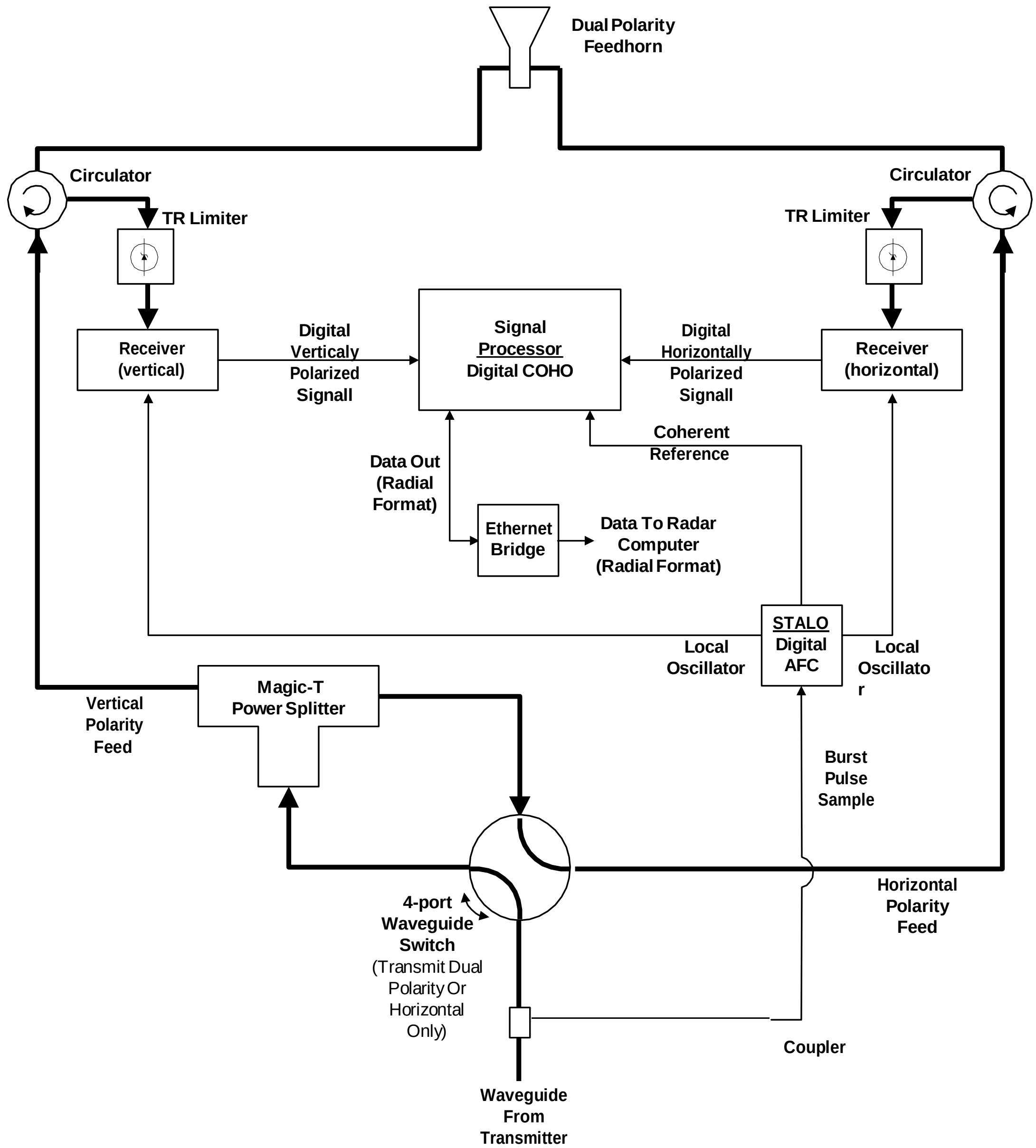
- R(ZDR) estimator is independent of error calibration;
- R(Z,ZDR) estimator is independent of DSD uncertainty;
- R(KDP) estimator is independent of calibration error and of attenuation.

Simultaneous Transmission, Parallel Reception

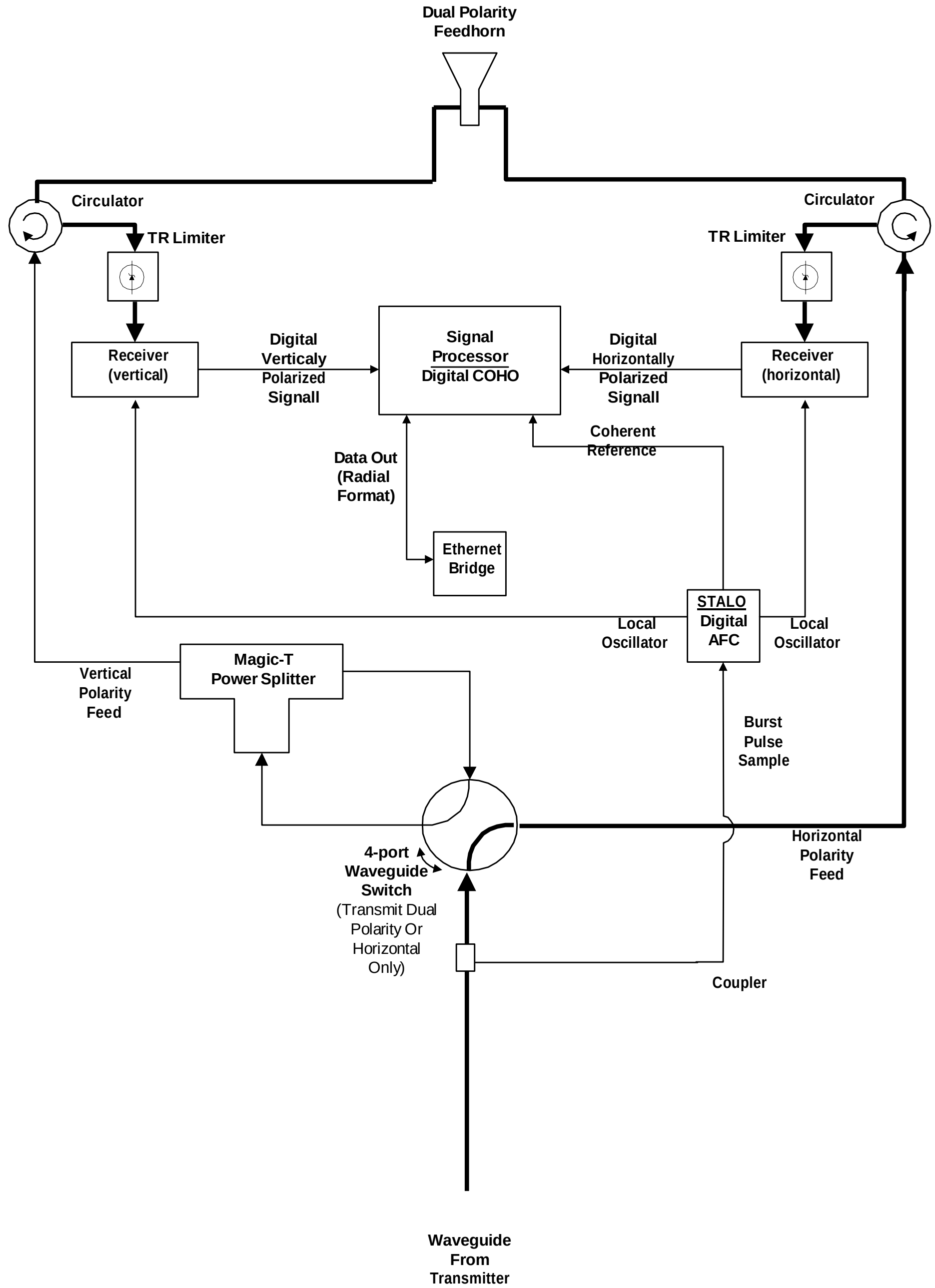
With the dual polarity option installed, Radtec systems transmit two orthogonally polarized signals simultaneously. This is done by using a power splitter to split the transmitter output into two separate signals. These signals are carried to the antenna in two separate waveguides, and transmitted from the antenna using a feedhorn that transmits two separate signals; one with linear horizontal polarization, and the other with linear vertical polarization. Horizontal and vertical reflections are received simultaneously, and carried back down the separate waveguides. This arrangement requires two separate circulators, two separate T/R limiters and two separate integrated low noise front ends.

Radtec's Implementation Of Dual Polarity Radar

Radtec's implementation of dual polarity transmits horizontally and vertically polarized pulses simultaneously. This is referred to as STAR mode (Simultaneous Transmission And Reception). STAR mode was developed and patented by Dr. Dusan Zrnic of the U.S. National Weather Service. The patent (#5,500,646) is held by the U.S. Dept. of Commerce, and is licensed to Radtec.



Dual Polarity Mode Block Diagram



Horizontal Only And LDR Mode Block Diagram

A power splitter is used to divide the transmitter's output equally between the horizontally and vertically polarized antenna feeds. A separate receiver is used for each polarity. The major advantage of this method is that it is entirely electronic, and therefore highly reliable.

A bypass arrangement is included to bypass the power splitter and provide full transmitter output for operation in conventional single polarity, horizontally polarized mode.

The received horizontal and vertical signals are converted to a common I/F frequency, and are digitized and multiplexed onto a fiber optic link for transmission to the Enigma III Signal Processor.

The signal processor processes the two data streams simultaneously in real time.

The output from the signal processor is a real-time data stream in radial format. Each radial of data includes an ID (radar ID, azimuth and elevation angles, time, etc.) followed by the data for each range bin in the radial. Each radial is a complete data set for that radial.

Note that when operating in dual polarity mode, the output data rate is significantly higher than in single polarity mode. In single polarity mode, the data includes reflectivity (Z), velocity (V) and spectrum width (W) data values for each range bin. In dual polarity mode, the data includes Z, V and W as well as data values for Z_{DR}, K_{DP}, L_{DR}, $\surd_{DP}$ and $\rangle_{HV}$. To preserve full real time operation, the data link between the radar and the central site must have sufficient bandwidth to handle the additional products. In most cases, this will require the full bandwidth of at least a T1/E1 (1.544/2.048 Mbits/sec) circuit.

As a reference, the AMS Bulletin, Vol. 80, No. 3, March 1999 includes a paper by Zrnic and Ryzhkov titled *Polarimetry for Weather Surveillance Radars* that provides a substantial amount of information about dual polarity applications.

RDR Radar Technical Characteristics

RDR Model	RDR-200GX/DP
Summary	Advanced technology, 200 kW X-Band Doppler weather radar with precipitation measurement capability
Transmitter	
Technology	Coaxial Magnetron Linear IGBT Solid State Modulator
Frequency	X-band, tunable 9.3 to 9.7 GHz
Peak Power	200,000 Watts
Pulse Width	Programmable 0.2 µsec to 4.5 µsec.
PRF	Programmable, 500 to 5000 pulses per second
Polarization	Programmable linear horizontal or simultaneous horizontal & vertical dual polarity
Receiver	
Technology	Integrated low noise front end, digital I/F
Minimum Detectable Signal	-114 dBm (2 µs pulse)
Dynamic Range	90 to >110 dB
Noise Figure	δ3 dB
dBz @ 50 km	-23.59 dBZ (4.5 µsec. P/W, single polarity mode)
Signal Processor	
Technology	ENIGMA IV
Antenna	
Size	8 ft (2.4 m) offset feed / 14 ft (4.3 m
Beam Width	0.9° for 8 ft (2.4 m) antenna / 0.5 for 4.3m
Gain	45 dB for 8 ft (2.4 m) antennas
Side Lobes	Typically -35 dBc

RDR Model	RDR-200GXDP
Pedestal	
Technology	Long life AC motors
Azimuth	360°, 0 - 4 rpm
Azimuth Accuracy	±0.1°
Elevation Range	360° continuous with offset feed antenna
Elevation Rate	0 - 15°/sec.
Elevation Accuracy	±0.1°

Radome	
Size	12 ft (3.7 m) diameter / 22 ft (6.7 m)
Construction	A-sandwich
Attenuation Loss	δ0.3 dB typical, A-sandwich radome
Wind Survival (for undamaged radome)	>138 mph (230 km/hr)

Specifications subject to change without notice as product improvements are made.

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