

Design of Offset Reflector With Elliptical Flat Scan Mirror And Its Applications To A Dual-Frequency, Dual-Polarization Airborne Rain Radar Observations

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Abstract: This paper presents the analysis, design, and development of a dual-frequency (Ku and Ka-band), and dual-polarization at each frequency Airborne Rain Radar Antenna (ARRA) system. JPL is currently developing an airborne rain radar instrument to make such observations from NASA's DC-8 aircraft. The antenna system shown in Figure 1 uses a highly reflective elliptical scan mirror in conjunction with an offset parabolic reflector illuminated by a common-aperture feed system, consisting of a corrugated horn with four input ports. The reflecting mirror is rotated in azimuth to scan the antenna beam in the cross-track direction ($\pm 20^\circ$) for wide swath coverage, and in elevation to compensate for the motion of the aircraft. The calculated results, as well as the measured electrical performance over wide-angle scanning, are presented. The theoretical results (calculated) guiding the antenna optimization are based on physical optics (PO) analysis and agree well with the measurements and our design goals.

Antenna Analysis and Design: The antenna system was designed to meet stringent specifications. One particularly challenging requirement is to generate two dual-polarization (H and V) beams, at 13.405 GHz (Ku-band) and 35.605 GHz (Ka-band), in such a way that the beams radiated from the antenna will point in the same direction and have matched 3-dB beamwidths (within 25%) and low sidelobe levels at each polarization/frequency of operation. This is achieved by a common-aperture corrugated feed horn design that simultaneously under illuminates the offset reflector at Ka band and illuminates it with a 15-dB edge taper at Ku band [1]. Upon reflection from the offset paraboloidal surface, spherical waves from the feed are transformed into plane waves propagating in a direction parallel to the axes of the reflector. An elliptical flat reflecting mirror tilted by 45° in elevation plane, y-z, reflects the emerging rays that are parallel to the reflector axes in a direction orthogonal to it as illustrated in Figures 1a. The scattered field off the mirror in both elevation and azimuth principal plane cuts for a 45° mirror tilt agree very well over the antenna main beam as shown in Figure 2 [1]. This is expected since for a mirror at a 45° incline angle its projected aperture in x-z plane is circular, and hence one would expect a match 3-dB beamwidth for elevation and azimuth plane cuts. It is anticipated that the elevation angular rotation of the mirror to compensate for the DC-8 aircraft motion to be within ± 2 degrees from the 45° inclination angle. Figure 2b shows that the rotation of the mirror within this angular region to compensate for the aircraft motion results in elevation to azimuth beamwidth ratio much less than 1.05.

The cross polarization of the feed and cross-polarization isolation between the ports, as well as the offset geometry, contribute to the overall antenna system cross-polarization level, which tends to be high. As corrective measures to compensate for some of these effects, the orthogonal input ports of the feed were carefully spaced, and the corrugation depths of the feed horn were carefully chosen to maintain a balanced HE_{11} hybrid mode

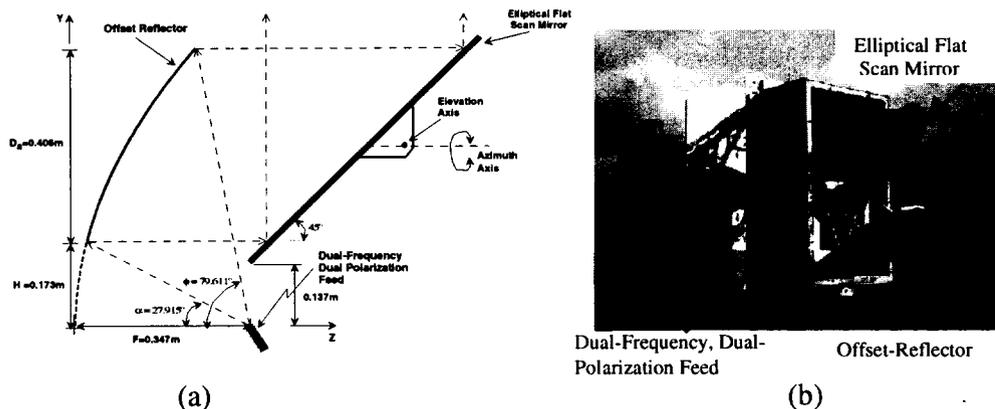


Figure 1. (a) The geometry of the offset reflector and elliptical flat scan mirror for the Airborne Rain Radar Antenna system. $F/D = 0.3$; F is the focal length and $D = 2(D_a + H)$; H is the height of the offset reflector; $\phi - \alpha$ is the illumination angle. The aspect ratio of the mirror is 1.47 with a major axis in z - y plane = 0.635 m, and minor axis in x - y plane = 0.4318 m. (b) Airborne Rain Radar Antenna system.

at both frequencies [2], resulting in a lower overall cross-polarization level of the antenna system (see Table 1). Figure 3 shows the feed horizontal and vertical radiation patterns at Ku and at Ka-band. For optimum performance, the feed phase center is normally kept at the focal point of the offset reflector for single-frequency operation. But in the present case, with widely separated frequencies, there cannot be a single phase center for the feed. An optimum location of a common phase center was determined to obtain optimum performance. Figure 4 shows the antenna performance and a comparison between the measured and theoretical results based on physical optics technique of the antenna principal plane cuts at Ku- and Ka-band. As can be seen a very good agreement between both results are obtained. It is demonstrated that as the mirror is rotated in azimuth, the antenna system retains its RF performance in terms of absolute gain and low sidelobe levels for wide-angle beam scanning as depicted in Figure 5. The impact of the reflective mirror curvature boundary shape, and orientation on the antenna performance are determined. It is demonstrated theoretically and experimentally that among the super-quadric curvature design boundaries of the mirror, an elliptical boundary results in a better side lobe levels [1].

Table 1. Airborne Rain Radar Antenna Measured RF Performance.

Parameters	Ku-band H-Pol	Ku-band V-pol	Ka-band H-pol	Ka-band V-pol
Gain	34.61 dB	34.60 dB	33.27 dB	33.21 dB
Beamwidth	3.8°	3.8°	4.8°	4.8°
Sidelobe level*	< -25 dB	< -25 dB	< -35 dB	< -35 dB
Cross-polarization*	< -21 dB	< -21 dB	< -20dB	< -20 dB
Bandwidth	> 50 MHz	> 50 MHz	> 50 MHz	> 50 MHz

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References: [1] Z. A. Hussein, "Design of a dual-frequency, dual-polarization, wide-angle scanning airborne rain radar antenna system", *JPL Internal Doc.*, ARRA Report: 3340-01-114, December 20, 2001.

[2] P.J.B. Clarricoats and A.D. Olver, "Corrugated horns for microwave antennas", Publ. by Peter Peregrinus Ltd., London, UK. 1984.

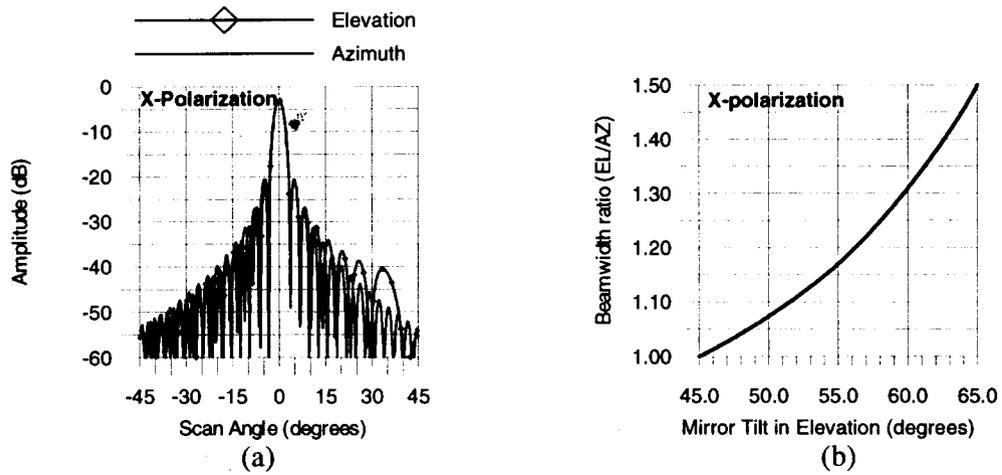


Figure 2. a) Scattered field due to x-polarized incident field and a 45° mirror tilt. (b) Scattered field 3-dB beamwidth ratio of elevation (EL) to azimuth (AZ) principal plane cuts versus mirror tilt in elevation.

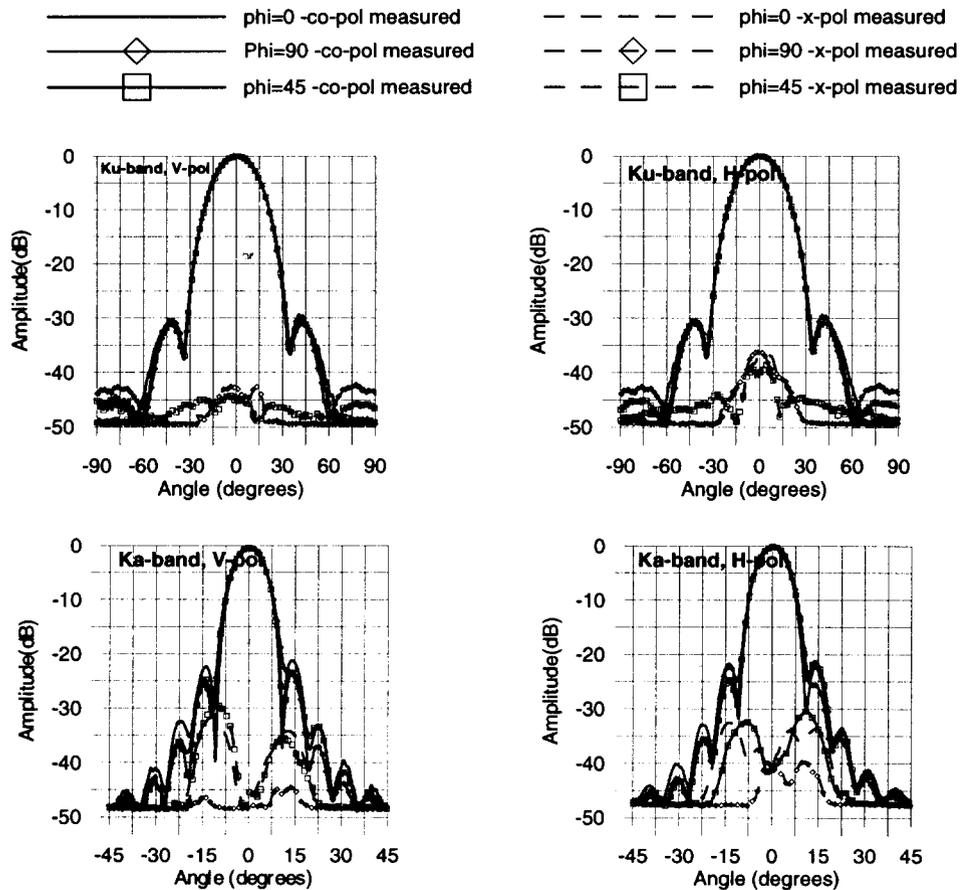


Figure 3. Corrugated feed horn horizontal polarization (H-Pol), and vertical polarization (V-Pol) radiation patterns at Ku-and Ka-band.

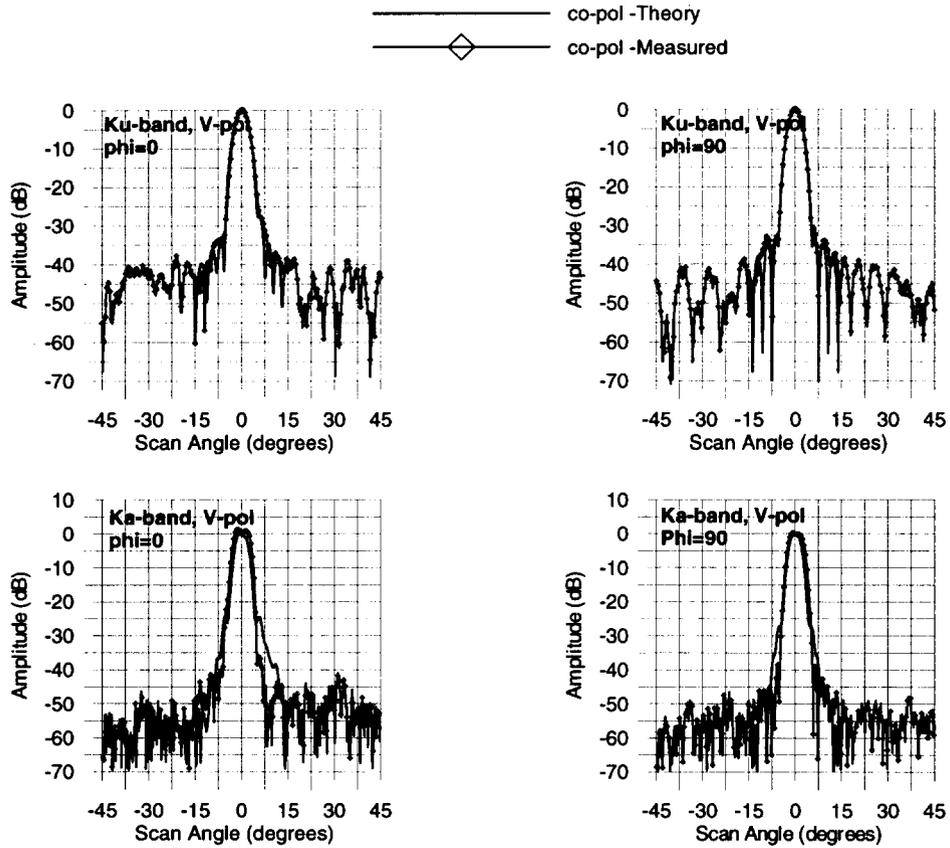


Figure 4. Comparison between measured and theory based on physical optics technique of the antenna V-Pol radiation patterns at Ku-band and Ka-band for $\phi=0^\circ$ and 90° plane.

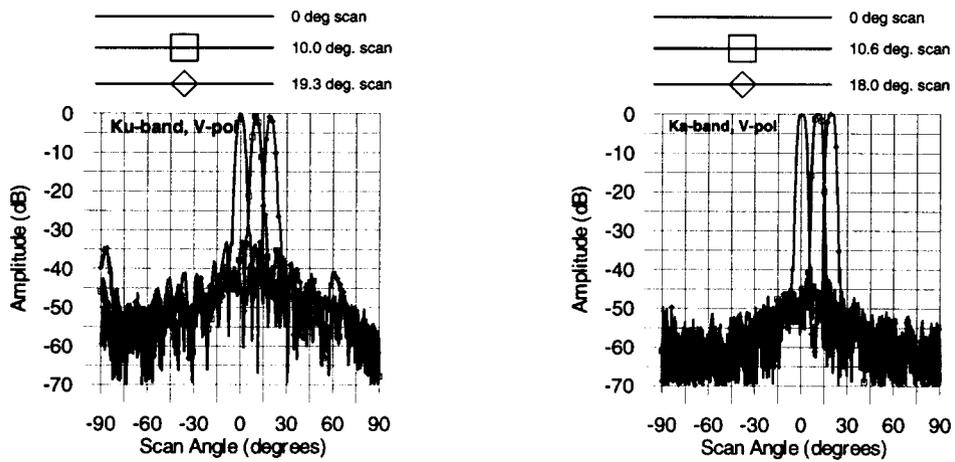


Figure 5. Measured V-pol far-field radiation pattern due to 0° , 10° , and 19.3° beam scan at Ku-band, and due to 0° , 10.6° , and 18° beam scan at Ka-band.