Design and Development of a Dual-Frequency (Ku/Ka), Dual-Polarization, Wide-Angle Scanning Airborne Rain Radar Antenna System

Z. A. Hussein, S. L. Durden, and E. Im

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109

Abstract- **A compact, dual-frequency (Ku/Ka-band), dual-polarization, wide-angle scanning antenna system has been developed as part of an airborne instrument for measuring rainfall. This system is an upgrade version of a prior single frequency airborne rain radar instrument, and was designed to generate spatially coincident horizontally and vertically polarized beams at both frequencies with 3-dB beamwidths that match within 25 percent, and have low-sidelobe levels over a wide scan angle at each polarization-and-frequency combination. The calculated results, as well as the measured electrical performance over wide-angle scanning, are presented.**

I. INTRODUCTION

A dual-frequency (Ku/Ka-band), dual-polarization, wide angle scanning airborne rain radar instrument has been developed by the Jet Propulsion Laboratory (JPL) to measure rain fall. The dual-frequency is incorporated into the system to improve the measurement sensitivity and retrieval of the rain-fall rate. The dual-polarization provides the capability to separate rain particles and hydrometeors. This experimental system has been flown on NASA's DC-8 aircraft in the configuration shown in Figure 1. This paper focuses on the design and the development of the antenna system [1]. The RF and digital design portion are given in [2]. The antenna system includes an elliptical, flat scan plate with an offset parabolic reflector illuminated by a common-aperture, dual-frequency, and dual-polarization feed horn. The antenna configuration is shown in Figure 2a and b. The offset reflector has a focal-to-diameter ratio F/D of 0.3, and an illumination angle of ϕ-α = 51.696 degrees. The elliptical, flat reflecting plate has an aspect ratio of 1.47 with major and minor axes of 0.635 m and 0.4318 m respectively. The plate is positioned at a 45-degree angle, inclined as shown in Figure 2. One particularly challenging requirement is to generate two dual-polarized (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.

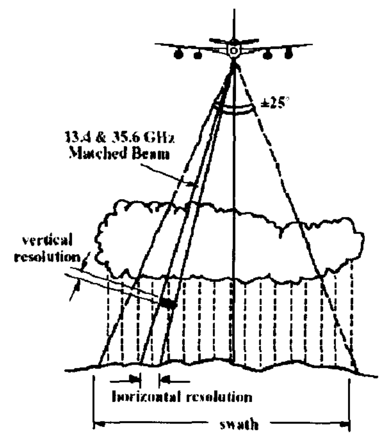

Figure 1. Configuration of the JPL's rain radar observation from the NASA DC-8 aircraft.

The calculated results, as well as the measured electrical performance over wide-angle scanning for the co- and cross-polarization radiation patterns and return loss are presented. The technique used to compute the antenna radiation patterns is based on physical optics (PO) and agrees well with the measurements and our design goals.

II. ANTENNA SYSTEM ANALYSIS AND DESIGN

A. System Analysis and Design

Referring to Figure 2a, spherical waves from the feed transform into plane waves propagating in a direction parallel to the z-axis of the reflector upon reflection from the offset paraboloidal surface. The elliptical, flat reflecting plate, tilted by 45° to the elevation plane, y-z, reflects the emerging rays that are parallel to the reflector axis in a direction orthogonal to it. The elliptical, flat plate is mechanically rotated in azimuth (electronically driven by a motor) to scan the antenna beam in the cross-track direction (+/- 25°) for wide-swath coverage, and in elevation to compensate for the motion of the

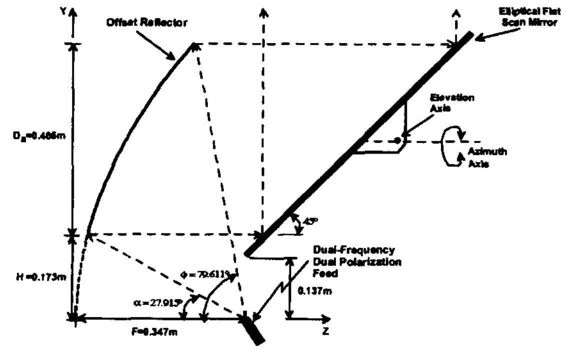

Figure 2a. The geometry of the offset reflector and elliptical, flat scan mirror for the airborne rain radar antenna system. F/D = 0.3; D = 2 (D_a + H); H is the height of the offset reflector. The aspect ratio of the plate (mirror) is 1.47 with major axis in z-y plane =0.635m, and minor axis in x-y plane =0.4318m.

Figure 2b. Airborne rain radar antenna system

aircraft. The PO analysis [1] shows that the scattered field from the plate in both elevation and azimuth principal plane cuts, for a 45° tilt, agrees very well over the antenna main beam. This is expected, since for a plate at a 45° incline angle, its projected aperture in the x-z plane is circular, and hence one would expect a matched 3-dB beamwidth for elevation and azimuth plane cuts. It is anticipated that the angular rotation of the plate in elevation plane, which compensates for the aircraft motion, to be within ±2 degrees from the 45° inclination angle. PO analysis shows that the rotation of the plate within this angular region compensates for the aircraft motion and results in elevation-to-azimuth beamwidth ratio much less than 1.05 [1].

B. Feed Design

The dual-frequency and dual-polarization feed horn (with four input ports) has been designed to make it possible for the antenna system to obtain spatially coincident horizontally and vertically polarized matched beams at both frequencies. 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. The feed is shown in Figure 3.

Figure 3. Front view of the dual-frequency (Ku- and Ka-band) and dual-polarization at each frequency corrugated feed horn.

When a signal source at 13.405 GHz is fed into one feed port with vertical or horizontal polarization, a TE_{11} mode is excited in the 1.5875cm (0.625 in) diameter circular waveguide section. The discontinuity at the junction of the 1.5875 cm waveguide is a generator of the TM_{11} mode. This mode excites the HE_{11} mode in the corrugated horn. Similarly, when a signal source at 35.605 GHz is fed into a vertical or horizontal polarization port, a TE_{11} mode is excited in the 0.56134 cm (or 0.221 in) diameter circular waveguide. The discontinuity at the junction of the 0.56134 cm waveguide is a generator of the TM_{11} mode. Hence, this mode excites the HE_{11} mode in the corrugated horn. Corrugation depths are chosen to maintain a balanced HE_{11} mode at both frequencies. This was achieved by setting the corrugations to be a quarter wavelength deep at 11.7 GHz and therefore three-quarter wavelengths deep at 35.1 GHz. Hence, a good, balanced hybrid mode is realized at 13.405 GHz and 35.605 GHz. Figures 4a and b show that the feed-return loss is better than –28 dB at 13.405 GHz and 35.605 GHz and over +/- 25 MHz band respectively.

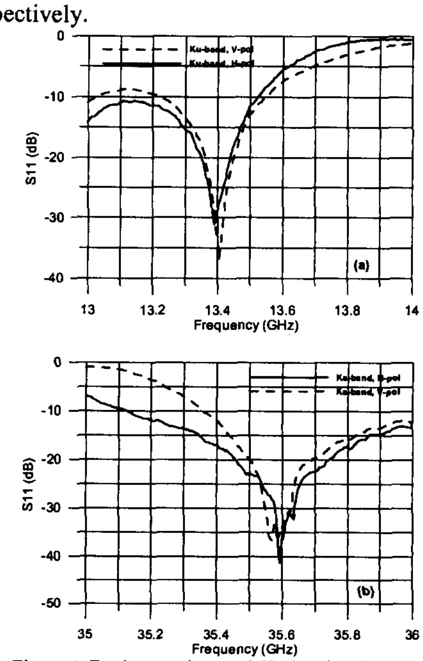

Figure 4. Feed return loss. (a) Ku-band and, (b) Ka-band.

III. Antenna Measured RF Performance and Theoretical Results

Table 1 below shows a summary of the measured antenna system RF performance. The measured antenna principal plane cuts for both polarizations and frequencies show match beam and low sidelobe levels (Table 1 and Figures 5 and 6). Details of antenna RF performance can be found in [1].

TABLE 1
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 (MHz)	> 50	> 50	> 50	> 50

A comparison between measured and theoretical results based on PO technique of the antenna's principal plane radiation patterns at Ku- and Ka-band is shown in Figures 5a and b respectively [1]. As can be seen, very good agreement between both results are obtained.

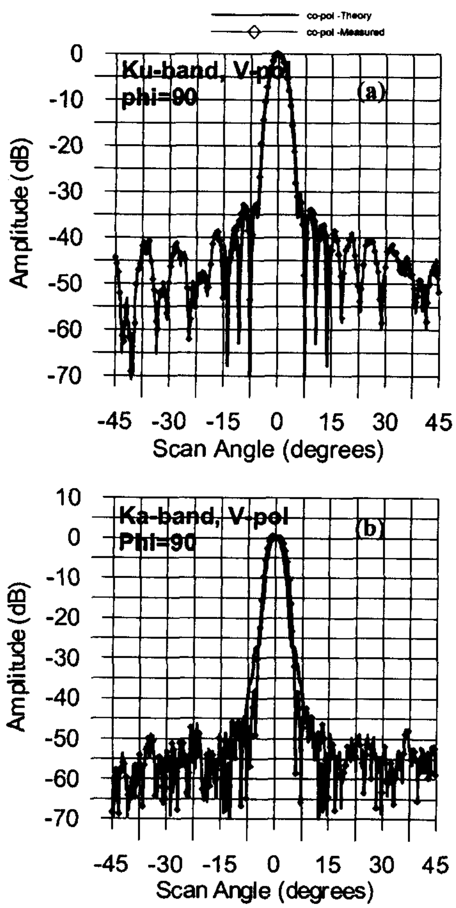

Figure 5. Comparison between measured and theory based on PO technique.

The elliptical, flat scan mirror is rotated in azimuth to scan the antenna beam. The antenna radiation patterns at Ku and Ka band were measured. Figures 6a and b show the antenna radiation patterns for 0°, 10°, and 19.3° scan beams at Ku-band, and 0°, 10.6° and 18° scan at Ka band. As expected, the antenna performance was retained for wide-angle scanning.

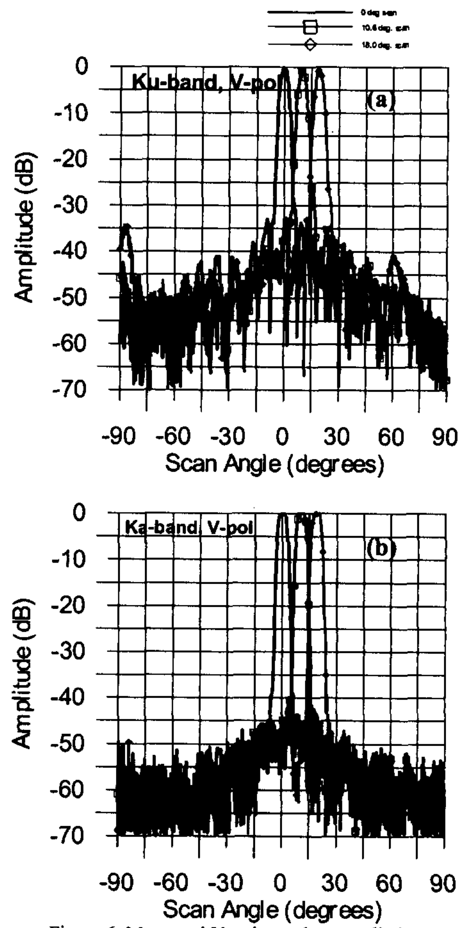

Figure 6. Measured V-pol scan beam radiation patterns.
(a) Ku-band and, (b) Ka-band

Acknowledgment

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References

[1] Z.A. Hussein, K. Green, E. Im, and S.L. Durden, "Design of an offset reflector with elliptical flat scan mirror and its applications to a dual-frequency, dual-polarization airborne rain radar observations," *IEEE Antennas and Propagation Int. Symposium, San Antonio, Texas*, pp. 642-645, June 2002.

[2] G.A. Sadowy, A.C. Berkun, W. Chun, E. Im, and S.L. Durden, "Development of an advanced airborne precipitation radar," *Microwave J.*, vol. 46, no. 1, pp. 84-98, January 2003.