

DESIGN AND DEVELOPMENT OF A 2-D ELECTRONICALLY SCANNED DUAL-POLARIZATION LINE-REPLACEABLE UNIT (LRU) FOR AIRBORNE PHASED ARRAY RADAR FOR ATMOSPHERIC RESEARCH

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1. INTRODUCTION

A modular dual-polarized two-dimensional electronically scanned C-band phased array radar is currently under consideration by the National Center for Atmospheric Research (NCAR) for the next generation of airborne radar for meteorological research (Wen Chau L., et al. 2013) NCAR's Earth Observing Laboratory (EOL) is conducting a two-year project to develop a small prototype array that will be used as proof of concept for this future airborne radar. The design of the NCAR Airborne Phased Array Radar (APAR) envisions it being flown on the NSF/NCAR C-130. It would consist of four distinct dual-polarized and 2-D scanning active phased array antennas, strategically located about the fuselage, as illustrated in Figure 1. The C-130 aircraft is the airborne platform for atmospheric observations, facilitating real state and prime power for the installation of four active electronically scanned array antenna panels. The C-130 aircraft also includes atmospheric instruments such as dropsondes and other standard thermodynamic, microphysics, and radiation sensors for sampling and remote sensing of clouds, chemistry, and aerosols (Hildebrand et al. 1996).

The active electronically scanned array (AESA) antennas will be operated primarily in two modes: dual-Doppler and surveillance. Dual-Doppler mode will be the primary mode of operation. In this mode, each of the four AESAs will generate a single "pencil" beam that will scan in azimuth and elevation. Scanning in azimuth will be between two fixed angles, one fore and one aft, separated by approximately 40°. Given the proposed configuration on the C-130, the fore and aft azimuth angles will not be symmetrical around 0° (normal to the fuselage) as is the case for the present ELDORA system, which is likely to be +5°/-35°. (Loew et al. 2007)

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Scanning will be done to maximize the number of independent samples while covering the desired spatial domain ($\pm 50^\circ$ in elevation) in the least amount of time. The "composite" scanning of all four AESAs yields a 360° dual-Doppler coverage, as in the current ELDORA. It is worth mentioning that the dual-polarization data will only be collected on the fore beams and within $\pm 20^\circ$ elevation angles to ensure the best quality of the dual-polarization data.

This paper describes the LRU architecture and its components. It provides preliminary test results for the antenna radiating element. Emphasis is placed on the radiator aperture board and its performance.

2. AIRBORNE RADAR DESCRIPTION

The proposed APAR system consists of four C-band active electronically scanned array antennas strategically mounted on the fuselage of the NSF/NCAR C-130 aircraft (Loew et al, 2007). One AESA will be mounted on each side of the fuselage behind the rear doors; the third will be mounted on the top of the fuselage and the fourth on the upper portion of the tail ramp, as shown in Figure 1 a) and b)

Each AESA is designed to operate at 5.4 GHz and the size of the aperture fits the maximum aperture available in the C130 fuselage (1.6 m x 1.9 m). A planar array with a spacing square grid of $0.5 \lambda_0$, is composed of 3,584 active radiating elements arranged in a rectangular array of 56 line-replaceable units (LRUs). Each LRU is composed of 64 (8x8) radiating elements. Figure 1 c) shows a simplified block diagram of an APAR. It consists of six components: (1) the RF array antenna front end, (2) quad T/R modules, (3) array antenna backplane, (4) radar digital backend, (5) radar processor/display, and (6)

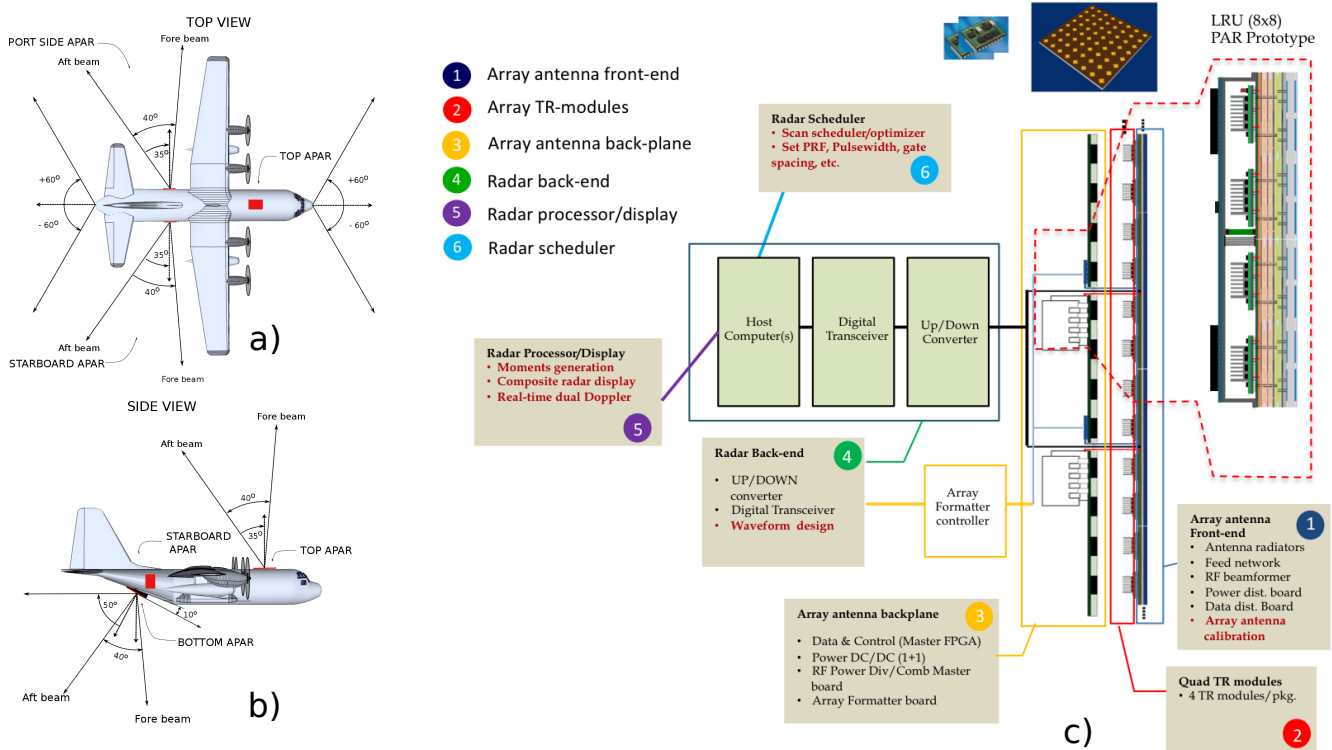


Fig. 1. APAR concept on NCAR C130 aircraft and simplified block diagram of APAR. Subsystems 1-3 reside outside the fuselage, enclosed by fairings, and the rest of the system resides inside the cabin.

radar scheduler. Components 1-3 reside outside the fuselage, enclosed by fairings, and present the greatest technical challenge. NCAR is currently working with MITLL to develop a quad T/R module. NCAR is developing the RF array front end and array antenna backplane (components 1 and 3) for an LRU. Table 2 presents a summary of the characteristics of the proposed APAR system.

3. LRU ARRAY DESIGN

A. LRU array architecture

The LRU is a modular design adopted from the Multifunction Phased Array Radar (MPAR) developed by MIT Lincoln Laboratory (Heard, et al. 2010). The concept permits a tileable planar arrangement to populate 56 (7x8) LRUs to obtain the aperture required for the NCAR airborne radar system. Figure 2 gives an exploded view of the concept with the four sub-parts. The first part is the aperture antenna board and it is composed of radome, antenna radiating elements, and RF distribution for H and V polarization and a power/data distribution board. The second part is composed of the T/R modules and heat sinks.

The third part consists of a metal frame that provides support and canalizes air flow for thermal dissipation. The fourth part is the backplane. This board provides the power conditioning and interfaces with the radar back end board to provide functionality and power to the LRU panel.

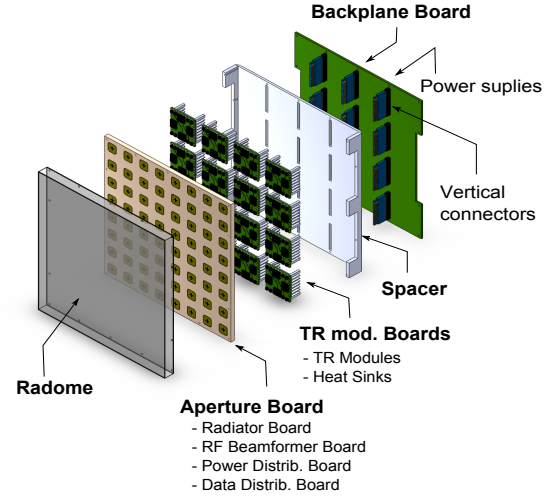
The proposed APAR contains 3584 TR modules per aperture and 64 for the LRUs. Alternate transmit and simultaneous receive (ATSR) polarization is the T/R module configuration currently implemented by MIT Lincoln Laboratory. In order to achieve a radar sensitivity below -18 dB at 10 km radar range, peak transmit power is limited to 4W at 10% duty cycle. A trade-off study that includes the physical constraints (space, weight restriction, thermal management, prime power conservation) and radar parameters (resolution, sensitivity, scanning strategy, lifetime and cost) is presented in Salazar et al. 2013 and Loew et al. 2013.

B. Radiating aperture board design.

Two important requirements for dual-polarized antenna radar must be satisfied to provide errors less than 0.2 dB in differential reflectivity (Z_{dr}) when an alternate transmit mode

TABLE 1. SYSTEM CHARACTERISTICS OF APAR SYSTEM

Parameter	Units	APAR(C-band)
Frequency	GHz	5.4
Wavelength	cm	5.5
# Elements (EI/Az)	-	64/56
# Total elements per panel	-	3,584
Beamwidth (EI/Az)	deg	1.6/1.8
Antenna gain	dB	41
Min. detect. signal at 10 Km	dBZ	-15
Sidelobe level	dB	-25
Pulse repetition frequency	Hz	2000
Peak transmit power	Kw	14.3
Spatial resolution at 10km	m	314
Along-track resolution	m	40 (*)
Pulse width	us	0.5-50
Polarization	-	Dual Linear
Beam overlapping	%	35
Unambiguous range	km	75
Unambiguous velocity	m/s	50
Transmitted waveform	-	Pulse compression (PC)



is needed. The first requirement is that the mismatch between antenna patterns (H and V) over the scan volume should not exceed 5% integrated power over the main beam.

The second requires that the cross-polarization isolation between the H and V patterns should be less than -20 dB across the scan volume (Wang et al. 2006 and Bringi et al. 2001). In Phased array antennas, the cross-polarization isolation level required (below -35 dB) is easy to achieve in the cardinal planes (E- and H-plane). However, the cross-coupling between the H and V channels increases significantly along boresight. Achieving a cross-polarization isolation below -25 dB outside the principal planes (for example, in D-plane) and low mismatch (<10%) between the co-polar beam patterns in H and V ports requires a special radiating element design that takes into account high port isolation, low spurious radiation, low surfaces waves, and low diffracted fields at the edges of the LRU array antennas.

A new dual-polarized radiating element was designed with new features to provide the mismatch and cross-polarization requirements for ATSR polarization radar mode. The antenna aperture board was implemented in five dielectric layers in order to arrange the patch radiators, polarization feeds (H and V), and ground.

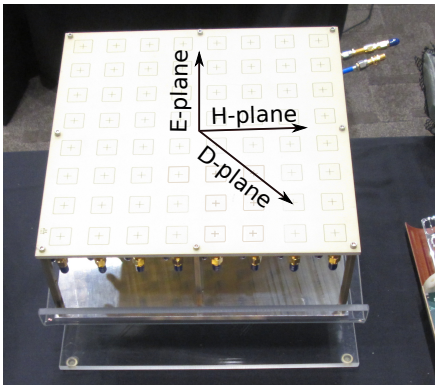
Fig. 2. Representation of LRU concept of NCAR APAR development.

As part of the radiator board, six layers were added to incorporate the RF beamformer, power, and signal distribution layers.

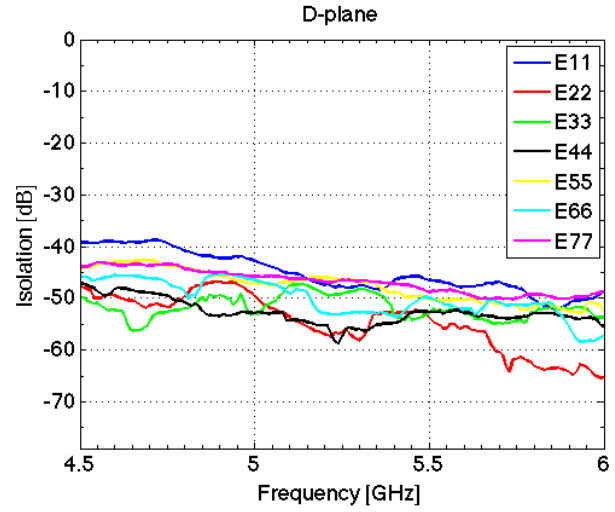
3. LRU PRELIMINARY RESULTS

The LRU antenna array (8x8 elements) was prototyped and tested. Scattering parameters (return loss and isolation) for each element in the array in the E-, H-, and D-planes were measured using an Agilent Network analyzer. Figure 3 presents a picture of the antenna LRU array, representation of the principal planes (E-, H-, and D-planes), and measurements of return loss and isolation for each antenna element (placed in D-plane only due to the limited space).

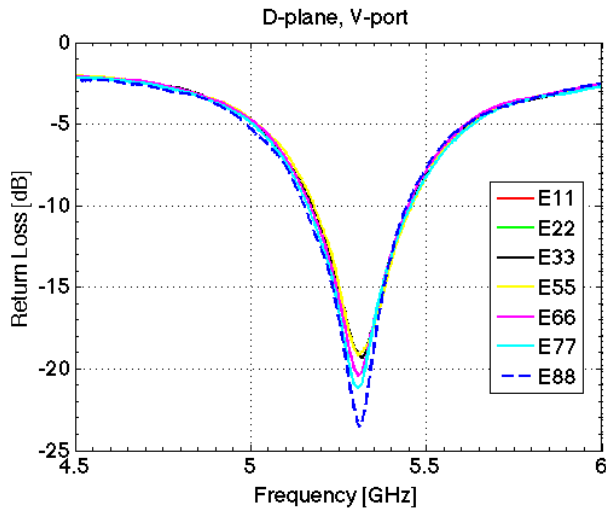
Figure 3 b) shows the measurement of port isolation (between H and V) for each element. The isolation reported for the required bandwidth of 340 MHz is better than -40 dB. Figure 3 c) and d) show the return loss measurements. Better than -18 dB at 5.4 GHz and better than -10 dB for the required bandwidth is reported.



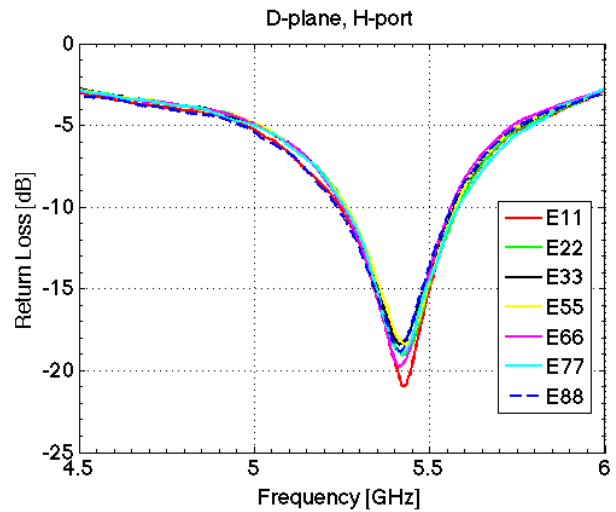
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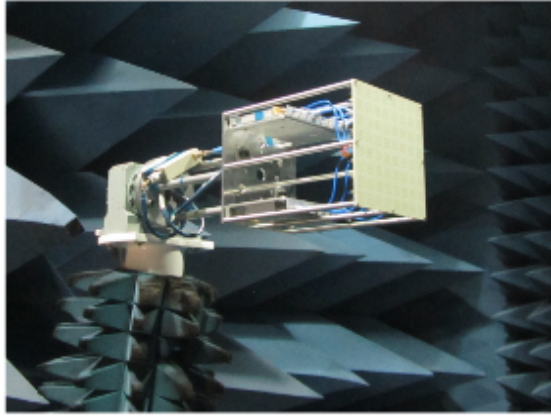


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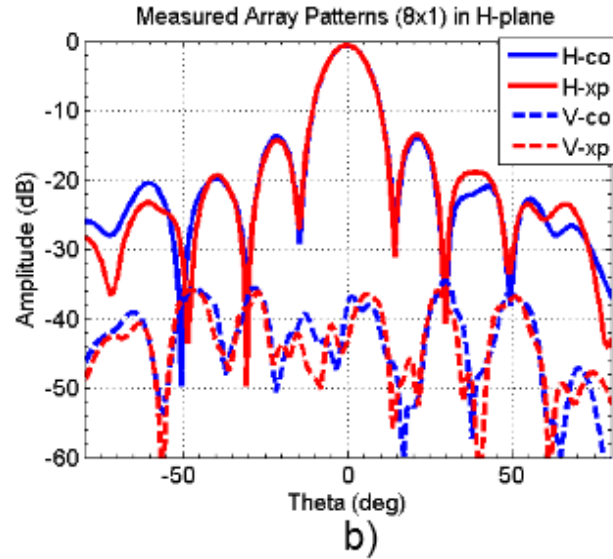


d)

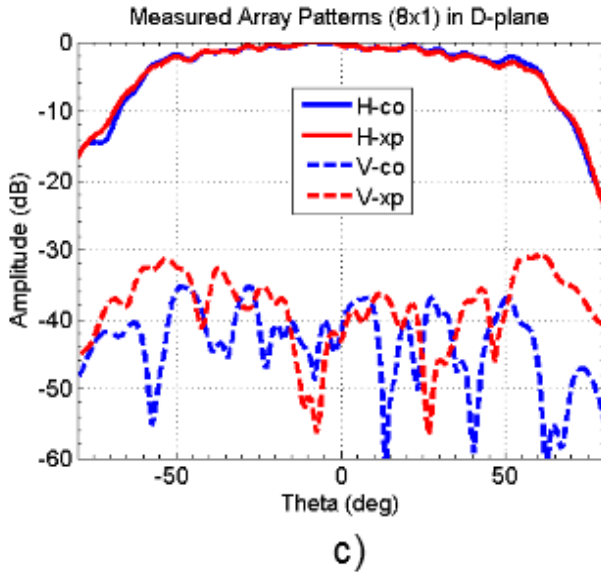
Fig. 3. LRU array antenna. a) Picture of LRU array antenna. b) Measured isolation between H and V port for elements in D-plane. c) Measured return loss versus frequency for each antenna element placed in D-plane.



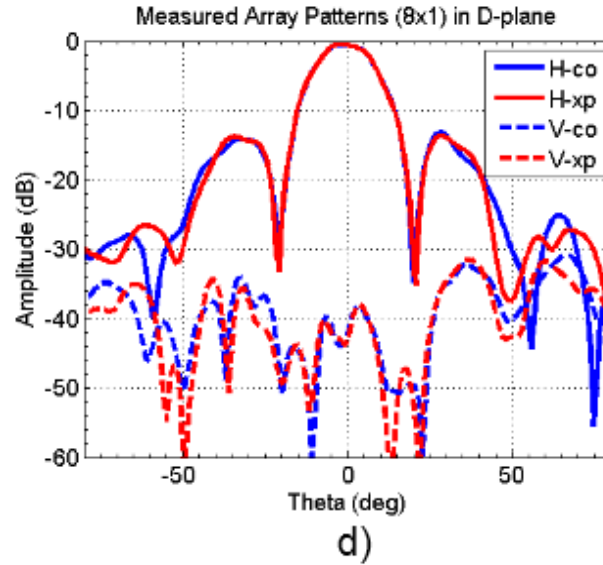
a)



b)



c)



d)

Fig. 4. LRU array antenna. a) LRU array antenna in first RF anechoic chamber. b) Antenna patterns for 8x1 array, co-, and cross-pol for H and V in H-plane. c) Antenna patterns for 8x1 array, co- and cross-pol for H and V in E-plane. d) Antenna patterns for 8x1 array, co- and cross-pol for H and V in D-plane.

The First RF planar NSI near-field system was used to obtain measured antenna patterns. The embedded element patterns in the LRU antenna and also the linear array pattern of 8x1 elements in the H-plane ($\phi=0^\circ$), E- ($\phi=90^\circ$), and D-plane ($\phi=45^\circ$) were measured. Figure 4 shows the antenna under test at First RF range facility and also the measured antenna patterns (co- and cross-polar) for H and V polarization at the center frequency (5.4 GHz) for E-, H-, and D-planes. Figure 4 b) presents the measured antenna patterns for 8x1 array in H-plane, co-, and cross-polarization for H and V. The main beam present a good match between H and

V patterns (less than 5%). Cross-polar patterns below -35 dB are obtained. Figure 4 c) shows antenna patterns in E-plane where the array of 8x1 elements were excited in H-plane. The co-polar antenna patterns correspond to the one element (E-plane). Ripples in the main beam are below 0.8 dB and matched for H and V polarizations. It is important to mention that ripples levels will be reduced when more LRU tiles are added. Cross-polarization below -32 dB was obtained for this plane. Figure 4 d) illustrates the performance of the co- and cross-polar antenna patterns for 8x1 array placed in H-plane measured in D-plane. Cross-polarization below -32 dB was obtained. Cross-polarization measurements are 5 dB higher with respect to simulated patterns in HFSS. This difference

can be attributed to two factors. The first can be attributed to the reflections in the room, principally in the floor and rooftop, where the range system is not fully covered with absorbers. And the second difference can be attributed to the fact that we are not using a calibrated cross-pol probe OEWP. This can lead in a ± 5 dB uncertainty in the cross-pol measurements (Newell, 2009).

4. SUMMARY

APAR with dual-polarization and dual-Doppler capability (greatly improved from ELDORA) allows microphysical (e.g., precipitation types and sizes, quantitative precipitation estimation) and 3-D wind estimation in a precipitation system. Multiple AESA radars on a C-130 fuselage enhance spatial and temporal resolutions of measurements. Multiple options (S-, C-, and X-band) have been evaluated, and a trade-off between wavelength, sampling, sensitivity, cost, and resolution has been considered in order to define the APAR architecture. C-band APAR is the architecture selected for the NCAR APAR system. A design of the APAR architecture based on ATSR polarization modes was initiated. To achieve accurate polarimetric measurements, high cross-polarization isolation antennas with excellent beam matching is required. NCAR's Earth Observing Laboratory (EOL) is conducting a two-year project to develop a small prototype array that will be used as proof of concept for this future airborne radar. Preliminary measured results of the antenna LRU aperture board demonstrate the possibility of performing dual-polarization radar for 2D scanning planar AESA.

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