Low Cost X-Band Dual Polarization Phased Array Antenna: Scanning Performance

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***Abstract*— In this paper the scanning performance of the X-band phased-array antenna to be used for a solid state weather radar system is discussed. A simple and low-cost antenna array architecture based on series-fed array of dual-polarized aperture coupled microstrip patch antennas was designed, implemented and tested in order to prove the concept of low-cost phased array radar system for metereological applications. The measured results presented indicates a good scanning performnace.**

***Index Terms*— Phased-array antenna, aperture-coupled patch antenna, dual-polarized, CASA radar**

I. INTRODUCTION

Weather radars implemented with Phased-array technologies are receiving increased interest by the weather radar community due to the fast beam steering and high flexibility to implement a diversity of scanning modes and multifunction capabilities. In 2001 The National Research Council (NRC) have identified the Phased-Array technology as the best candidate to upgrade the current US radar system. Potential replacement of 500 radars (Weather/ Air traffic surveillance) with 300 Multifunction Phased Array Radar (MPAR) network can be a cost effective solution that can reduce in $3B the life cycle cost [1]. A fundamental limitation of any long-range radar network systems (spacing with more that 200 km) is the inability of observing at lower altitudes because the curvature and terrain blockage problems. An alternative approach that provide more compressive coverage radar of a lower part of the atmosphere (below 3 km altitude) using the concept of low-cost, low-power dense radar network is proposed by the Engineering Research Center (ERC) for Collaborative Adaptive Sensing of the Atmosphere (CASA) [2]. CASA envisions a dense radar network with radars arranged in a triangular grid of 30 km spacing and having full overlapping coverage. This topology allows multiple and simultaneous views of a specific region and also to reduce the design complexity requirements (cost, antenna size, peak transmitted power and infrastructure required). Dual-polarized radar measurements are required principally for improving the quantitative precipitation and hydrometer classification, and also to compensating for attenuation at X-band frequencies. A dense radar deployment with several thousand of shorth-range and small phased-array radars nodes are attractive for providing large production volume (million of components) that will helps to break down the cost of the phased-array radars. Short-range radars (<40 km), low-power (<100W), short wavelength (~3 cm), small antenna sizes (<1m^2) and weight (<200lb) are suitable to reduce the infrastructure cost since is possible the reuse of existing infrastructure (rooftops, sides of buildings and cell-phone towers). Phased array radars are more reliable than a single and centralized transmitter, the life cycle are much larger and the operational cost can be significantly reduced that a conventional dish radar system. Two approaches have been researched in order to obtain a dual-polarized e-scan array for CASA, one approach has been developed by Raytheon which is based on low-cost microwave semiconductors combined with low-cost packaging, fabrication and assembly techniques [3]. The second approach which has been developed by the CASA solid state group is based on a low-cost antenna architecture that uses only 64 T/R modules to perform e-scanning in azimuth while in elevation is realized using a fast mechanical part [4],[5].

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II. ANTENNA ARCHITECTURE AND PERFORMANCE

The antenna is a planar structure of 64x32 antenna elements designed to operate at 9.36 GHz (±60MHz). Each column is made up of 32 dual-polarized aperture coupled patch antenna elements interconnected by series-fed networks for vertical and horizontal polarization. Each column is fed by a 1.25 W Transmit and Receive (T/R) module that features 360° of phase control with 5.6° of resolution, and 31.5 dB of amplitude control with 0.5 dB of resolution [6]. In this section the design considerations and measured results of the antenna array such as S-parameters, embedded element pattern, linear (1x32) and planar array patterns (64x32) are presented.

A. Radiating antenna element

The radiating antenna element in the array consists of a dual-polarized square aperture coupled microstrip patch antenna. Rogers RT/Duroid 5880 was selected as RF substrate for the top (patch antenna) and bottom layer (feed). To reduce the backlobe beam, a square patches based reflector plane at 250 mil (~$\lambda_o/4$) apart from the feed is placed. To support the antenna and feed, a foam (Rohacell 31HF) with low dielectric

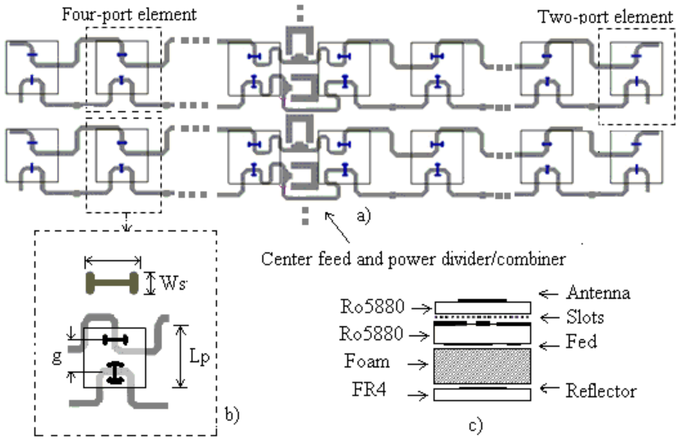

Fig. 1. a) Representation of the array of dual-polarized aperture coupled microstrip patch antenna elements using series-fed configuration) Four-port element and dog-bone-shaped aperture. c) Antenna stack-up.

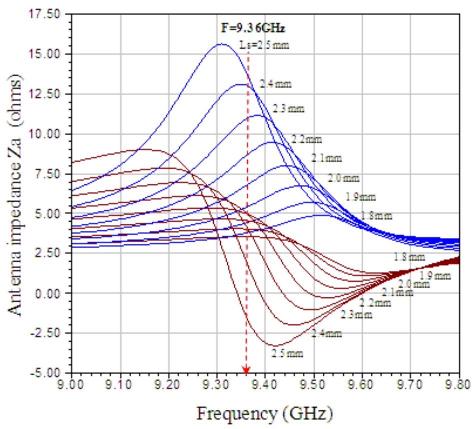

Fig. 2. Antenna impedance for 4-port aperture coupled microstrip patch antenna for horizontal polarization.

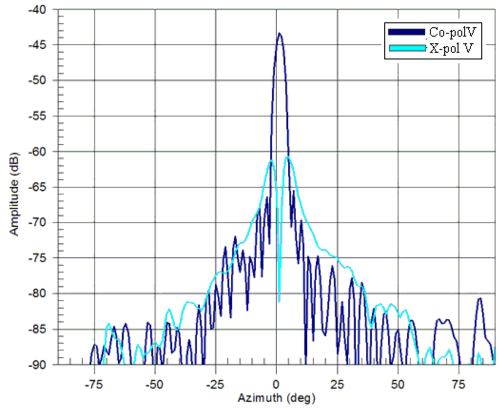

Fig. 3. Measured vertical polarized elevation paterns of a linear array of 1x32 embedded in a planar array of 18x32

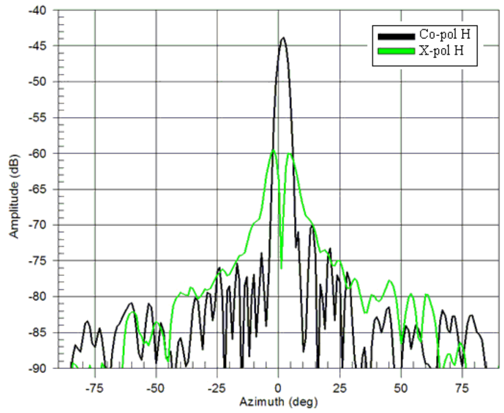

Fig. 4. Measured horizontal polarized elevation patterns of 1x32 linear array embedded in a planar array of 18x32 elements.

constant (ε_r: 1.04) and tangent loss ($\tan\delta$: 0.0017) is used. The stack up configuration of the array antenna is described in Figure 1 c. The microstrip patch antenna is excited by two orthogonal aperture slots to obtain linear dual-polarized fields. In this design, the dog-bone-shaped coupling aperture was adopted because it requires less area than rectangular slots. It also provides equivalent and more uniform coupling energy than rectangular slots, and emits low spurious radiation that helps to improves the cross-polarization isolation of the antenna [7]. Typically, rectangular slots apertures are located at the center of the patch to obtain maximum energy coupling for the fed. In this design, an orthogonal arrangement of the slots, also known as, “T”slots configuration (see Figure1b), is considered to improve the cross-polarization and port isolation [8].

B. *Linear Array antenna*

To interconnect the 32 elements in the elevation plane, two serpentine lines of 100 ohms are used to fed serially each element in both polarizations. Series-fed configuration offers the advantages of being less complex, uses less substrate area and presents less loss than a corporate fed. A limitation of using series-fed, is due the fact, the multiple bends can increase reflections which can affect the hability of sinthesize the amplitude distribution and progressive phase required to achieve the elevation patterns for a given required sidelobe level and beam position. For this design the amplitude distribution in the elevation plane is based on Taylor -25 dB ($\overline{n}$=2). A symmetric center feed composed of a T-junction power divider, with quarter-wavelength sections to match the 100 Ohm serpentine microstrip lines are considered. Because the left and right halves of the array are mirror images, one branch of the vertical polarization requires an additional 180° phase shift.

The spacing between elements of 17 mm (equivalent (0.53λ_o) was determined in order to facilitate the accommodation of the serpentine lines and power dividers in the feed layer. Figure 1a illustrates the drawing of the linear array antenna of 1x32 elements. The procedure to design this linear array antenna was realized using a synthesis technique developed and discussed previously in [4]. Changes in the characterization of the antenna impedance versus slot length of the 4-port antenna element including the mutual coupling effects were considered in order to obtain better results in the antenna impedance, amplitude and phase distribution along the linear array. Figure

2 shows the characterization of the real and imaginary parts of the impedance for the 4-port antenna element as function of the slot length for V polarization. Figure 3 and Figure 4 shows the measured patterns of the linear array antenna embedded in the array of 18x32 elements for both polarizations (H and V). The cross-polarization, which is shown in previous figures, presents values of -34 dB and -39 dB at broadside for V and H respectively. The impedance bandwidth measured at -10 dB return loss of the array antenna is about 120 MHz for V and 200 MHz for H port. The beam position shifted in 3° from broadside is because of the lack of alignment during the measured process.

C. Planar array antenna

The planar array antenna composed of 72x32 elements is designed in 4 sub-panels called Line Replacement Unit (LRU), in order to facilitate the assembly, and also to reduce the fabrication cost and maintenance. Each sub-panel consists of 18 columns of 32 elements each. In the complete array 8 columns (4 in each side only in the azimuth direction) are used as dummy elements, in order to minimize the diffraction of the fields because of the antenna. The lattice spacing in azimuth-plane of 17 mm ($0.53\lambda_o$) which is also the same for the elevation-plane was determined due to limited space available to accommodate the serpentine fed lines and SMP connectors for each polarization. Besides the effort to reduce the spacing in the azimuth plane to avoid grating lobes in the visible region, the coupling between feed lines compromises the cross-polarization performance of the antenna.

1) Dembedded element pattern and active reflection coefficient: Figures 5 and Figure 6 show the measured H-plane embedded element pattern of the unit cell in an array composed by 18x32 elements (corresponding to one LRU) at both polarizations. The plots show only the lower, center and upper frequencies of the required bandwidth (100 MHz). In azimuth plane, each element corresponds to one column (32x1 linear array), and for this measurement each polarization was excited independent while the other ports of the 17 columns were terminated in 50 Ohms. The ripples presented in H-polarization, with amplitude variation less than ±0.8 dB, are because the coupling in E-plane are larger than in V, where the fields are positioned collinearly in the azimuth direction. At 9.36 GHz the dembedded element pattern for H-polarization, presents a rapid roll off that ends in a null at around ±62.5°. This null corresponds to the position of the grating lobe. For both ports the cross-polarization level at broadside is better than -31 dB. An integrated cross-polarization value of -30 dB is obtained across the ±90°scanning range. Figure 7 and Figure 8 show the active reflection coefficient of a dembedded element for all frequencies (between 9.3 GHz and 9.4 GHz) based on the measured active element pattern and using the expression (37) of [10] .

2) Full scanned array antenna patterns: The full array antenna array of 72x32 elements populated with 64 TR modules were characterized, calibrated for both transmission and reception modes at different temperatures. The approach used is described in [9]. Antenna calibration results indicate a good agreement between calibrated and measured settings. Figure 9

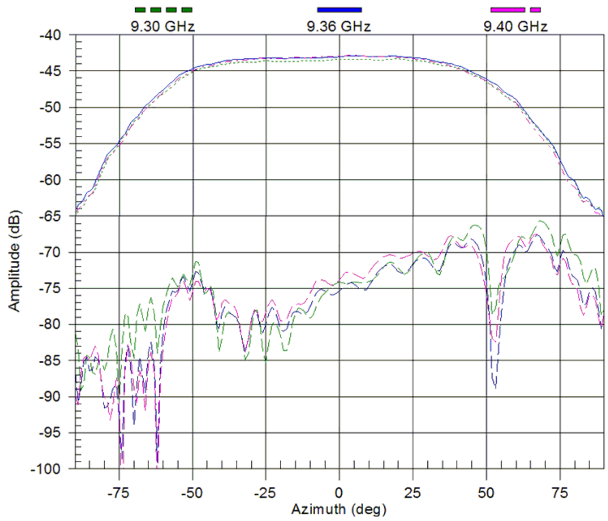

Fig. 5. Measured vertical polarized embedded element pattern in a planar array of 32x18 elements.

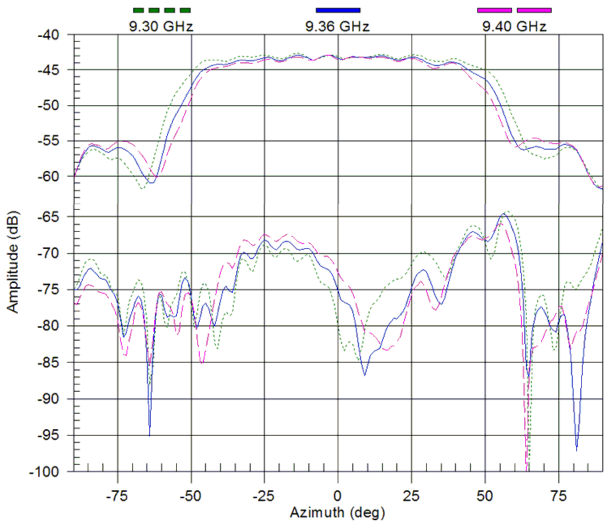

Fig. 6. Measured horizontal polarized embedded element pattern in a planar array of 32x18 elements.

and 10 show two measured scanned patterns in a NSI Near-field range system for V and H polarizations respectively. The TR modules were calibrated to follow a tapered amplitude corresponding to -25 dB Taylor distribution (ñ=4) and in phase with beams steered at 0°,15°,30° and 45°. The sidelobe level at broadside is -24 dB with a 1 dB degradation at 50° scanning. The cross-polarization in the overall scanning range is lower that -25 dB for both polarizations.

III. Summary

This paper has presented an updated design and results of a low-cost phase-array array antenna for the solid state radar for CASA ERC. Also this paper discuss the scanning performance of the array based on recent measurements of the antenna patterns and S-parameters. Measured results of the second prototype presents a significant improvements in the elevation patterns and S-parameters when the mutual coupling is included

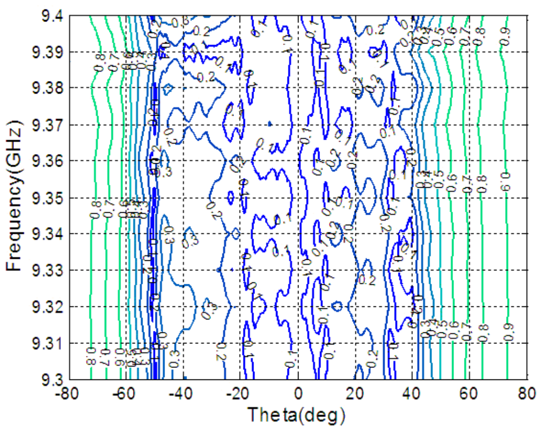

Fig. 7. Vertical active reflection coefficient for frequency and incident angle (azimuth plane), based on measured vertical polarized embedded element pattern in a planar array of 32x18 elements.

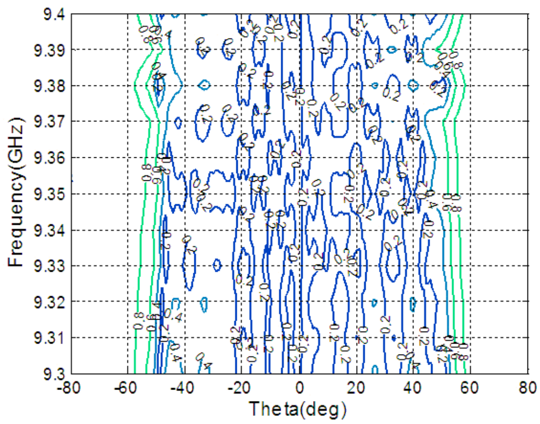

Fig. 8. Horizontal active reflection coefficient for frequency and incident angle (azimuth plane), based on measured horizontal polarized embedded element pattern in a planar array of 32x18 elements.

in the synthesis approach to design the linear array using series fed configuration. The development of the phased-array antenna prototype has been designed, integrated, characterized and tested. Measured results shows a excellent performance for a low cost antenna architecture ($74k for single prototype).

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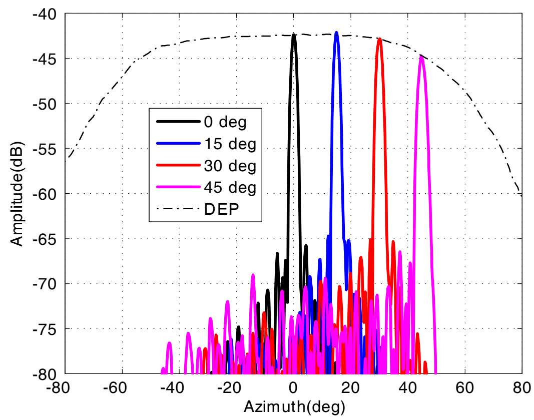

Fig. 9. Measured antenna patterns of CASA phased-array antenna (64x32 elements) in the azimuth plane for for 0°, 15°, 30° and 45° for vertical polarization, at 9.36GHz

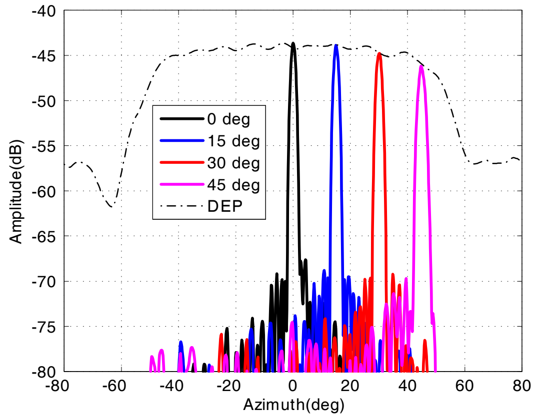

Fig. 10. Measured antenna patterns of CASA phased-array antenna (64x32 elements) in the azimuth plane for for 0°, 15°, 30° and 45° for horizontal polarization, at 9.36GHz

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