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Phase-Tilt Radar Antenna Array

Eric J. Knapp, Jorge Salazar, Rafael H. Medina, Akilesh Krishnamurthy and Russell Tessier
Dept. of Electrical and Computer Engineering, University of Massachusetts, Amherst, Massachusetts, 01003
knapp@ecs.umass.edu, jlsalazar@engin.umass.edu, rmedinas@engin.umass.edu,
akrishnamurth@ecs.umass.edu, tessier@ecs.umass.edu

***Abstract*—This paper describes the X-band Phase-Tilt Radar antenna array being developed at the Engineering Research Center for the Collaborative Adaptive Sensing of the Atmosphere (CASA) for use in distributed, collaborative and adaptive sensing (DCAS) networks. The architecture of the radar and its component parts including the T/R module, passive antenna elements, and array controller are described in detail. Test data for the full array will be presented in the final paper.**

Keywords-Phased Array; Dual Polarization; T/R Module; Radar; CASA

I. INTRODUCTION

The Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), an Engineering Research Center established by the National Science Foundation, is developing small, low-power X-band radars that are used in dense networks to improve the scanning of the atmosphere [1]. Dense networks of short-range radars can defeat the blockage due to the curvature of the earth, which limits today's long-range radar networks from viewing weather hazards and aircraft at the earth's surface. They also enable high spatial and temporal resolution views of the lower-troposphere with the potential to scan up to the tops of storms. Currently, the center has installed a network of four small radars in Oklahoma to proof the concept of adaptive scanning and high resolution view of the atmosphere. The radars used in this test bed utilize highly agile mechanically-scanned antennas, but the next step in the evolution of this technology is to realize these radars using solid-state microwave technology in phased array antennas.

Dual polarized phased-array antennas present a new challenge for weather radars. Unlike conventional reflector antennas, co-polar main beam patterns, sidelobes and cross-polarization isolation change with scanning beam position in electronically scanned arrays. A quantitative evaluation of the measurement accuracy in differential reflectivity due to cross-polarization isolation limitations is described in [2]. According to this evaluation, cross-polarization isolation levels better than -20 dB are needed to avoid contamination of less than 0.1 dB in Z_{DR} when using alternating polarization mode.

Current state of the art implementations of 2 dimensional phased array antennas are very expensive due in part to the high cost of the T/R modules populating the antenna. While technology is advancing to reduce cost in the phased array antennas for radar and communication applications, CASA is using the today's technology to develop a one dimensional dual-polarization active array antenna called the Phase-Tilt antenna [3]. The Phase-Tilt antenna is composed of an active linear array and a mechanical actuator which allow the antenna to perform electronic scanning in azimuth and mechanical scanning in elevation. The linear array is a planar structure 68 columns or sub-arrays; each column is made up of 32 dual-polarized aperture coupled microstrip patch antennas interconnected by series-fed networks in each polarization. The 64 inner columns are fed by dedicated T/R modules, which provide phase, amplitude and polarization diversity and the 8 remaining outer columns are used as dummy elements to reduce the effects of diffraction and non-uniform mutual coupling. Control of the phase and amplitude for beam steering and aperture power distribution in the azimuth plane is accomplished through an FPGA based micro-controller that communicates with the T/R modules and serves as the master timing control.

II. ANTENNA ARCHITECTURE

The Phase Tilt Radar [4] is composed of several major subsystems as shown in Fig 1. The Phase Tilt antenna is

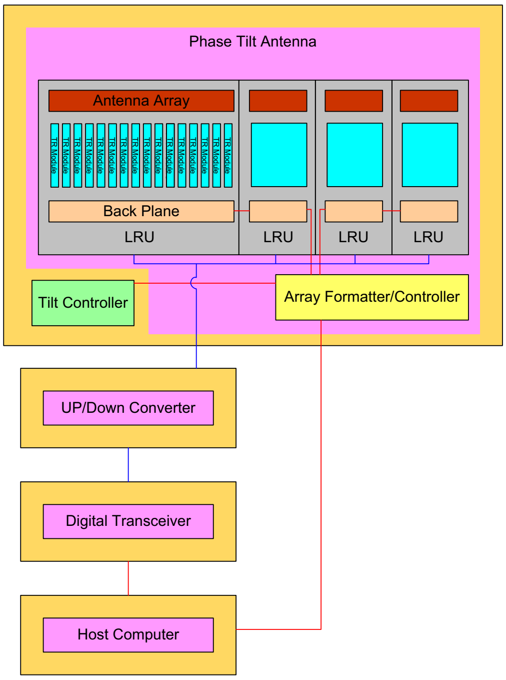

Fig 1. Phase Tilt Radar Block Diagram

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one of those subsystems and it can be broken down into four major sets of components; passive antenna array, T/R module, signal distribution backplane and array controller. The 64 T/R modules are grouped into 4 sets of sixteen elements, each with a passive array and backplane. The array controller is the interface between host computer and the antenna. The controller communicates with the T/R modules to set the azimuth beam position and the tilt controller to set the elevation position. In addition, it serves as the master timing control and generates all triggers and switching signals

III. ANTENNA ARRAY

A. *Radiating antenna element*

The radiated antenna element is a dual polarized aperture coupled microstrip patch antenna (DP-ACPA). This antenna element type provides less spurious radiation and also facilitates the design to achieve low cross-polarization coupling for a series-fed linear array. Two orthogonal dog-bone shape slots are used for H and V polarization because of the small size and better coupling with respect to the rectangular slots [5]. The size and their positions relative to the patch permits the control of the level of coupling for each polarization and their respective impedances. Since the element will be part of a dual-polarized linear array, four-port DP-ACPA and two-port DP-ACPA used as terminated radiating matched load were designed using numerical simulation based on a full-wave method of moments (MoM). The antenna element was designed at 9.36 GHz and impedance bandwidth of 100 MHz.

The antenna substrate structure, shown in Fig. 2, consists of four dielectric layers. The first two are low loss microwave substrates for the series-fed lines and patches. The third dielectric material is rigid foam that essentially serves as a spacer between the DP-ACPA and reflector patch layer, used to reduce the back lobe radiation to -25dB with respect to the main beam.

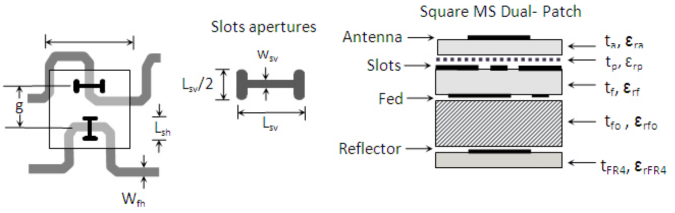

Fig 2. Dual Polarized Patch and stack up

The microstrip patch antennas are excited by two serpentine lines, one for each polarization. Each serpentine line excites an aperture slot (orthogonal to each other) behind each patch to obtain linear dual-polarized fields. In this design, the dog-bone-shaped aperture slot emits less spurious radiation that helps to improve the cross-polarization isolation of the antenna [5]. Typically, rectangular slots apertures are located at the center of the patch to obtain maximum energy coupling for the feed. In this design an orthogonal arrangement of the slots, known as "T" slots, is implemented to improve the cross-polarization and port isolation. The dimensions of the dog-bone-shaped aperture (L_s and w_s) and their position under the patch were defined according with the patch antenna dimension (L_{ph} and L_{pv}) in order to have the antenna element resonate at 9.36 GHz.

B. *Array Antenna*

To interconnect the 32 elements in the column, two serpentine lines are used to serially feed each element in both polarizations. The series-fed configuration offers the advantages of being less complex use less substrate area and also presents less loss, compared with a corporate feed [6]. The drawback of the series-feed is that the amplitude and phase are frequency dependent, limiting bandwidth, and the multiple bends can affect the amplitude distribution and progressive phase required to achieve low sidelobe levels. The serpentine lines are fed from the center using a T-junction divider with the lower half of the column being a mirror of the upper half. The horizontal polarization is unaffected by the mirroring, but the vertical polarization requires an additional 180° phase shift. The spacing between elements of 17 mm ($0.53\lambda_0$) was used in order to accommodate the serpentine lines, power dividers and connectors in the feed layer. Fig 3 illustrates the center of a linear array antenna of 1x32 elements.

The procedure to design this linear array antenna was realized using a synthesis technique developed and discussed in detail in [3]. An update to the technique that includes the effect of the mutual coupling was implemented in order to obtain better results in the antenna impedance, amplitude and phase distribution along the linear array. In the column, each element and its slot appears as series impedance along the feedline.

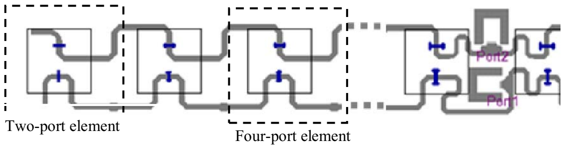

Fig 3. Linear array antenna for elevation plane

IV. T/R MODULE AND BACKPLANE

A block diagram of the T/R module is given in Fig 4. The T/R module architecture uses a "Common Leg" in both transmit (Tx) and receive (Rx) channels. The transmitter and receiver channels have independent input and output ports and share a common attenuator, gain block and phase shifter. Two T/R switches connect the common patch control circuitry to the transmitter and receiver blocks. The transmitter block consists of a high and medium power amplifier and the receiver block is comprised of a low noise amplifier and gain block. A custom designed high power Junction/Diversity Switch is a necessary component used to connect the two allowing transmit/receive and polarization diversity. The single transmit and receive channels limit the operation to

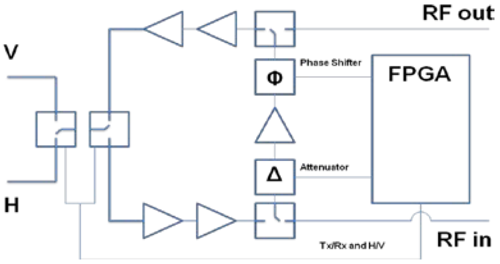

Fig 4. T/R module block diagram

alternating polarization mode. **T**he T/R modules has an integrated Field-Programmable Gate Array (FPGA) used for component interfacing, controlling the attenuator, phase shifter, T/R switches, and load switches for the amplifiers. Additionally, the FPGA reads the register of a temperature sensor located on the module. The on-board FPGA is locally programmable with an external PROM (Programmable Read-Only Memory) and has a dedicated 25 MHz crystal clock. The FPGA's internal memory is configured to be used as look-up table, which stores the attenuator and phase shifter states for 256 beam positions for four operation modes (TxV, TxH, RxH, RxV). A separate memory table, referred to as the sequence table, holds the look up table addresses for the polarimetric pulsing sequence to be performed. Since the sequence table holds only addresses, its values are common to all T/R modules.

The distribution backplane consists of two 16:1 power combiner/dividers, a power distribution bus and a 25 MHz LVDS bus for communication to the T/R modules. Individual T/R modules can be addressed by means of point to point commands that load the lookup table or directly control the phase shifter and attenuator output registers. When broadcasting the sequence table data, a point to multi point mode is used so that all T/R modules receive the data at the same time.

V. ARRAY CONTROLLER

The array controller, Fig 5, is a FPGA based microcontroller that controls communication between the host computer and the T/R modules and also serves as the master timing generator. Currently, the array controller interfaces with the host PC over a RS232 connection, but an Ethernet based connection is planned. T/R modules are connected to the array controller through a serial transmitter and receiver operating at 25 MHz.

In operation, the array controller receives the T/R module look up table data from the host computer and stores it in the off chip DDR SRAM. The controller then reads the data out of memory and sends it to the transmit FIFO which connects with the serial transmitter. The transmitter broadcasts the data over the LVDS bus using a point to point data format. The T/R module that is addressed echoes back the message to the array controller receiver where it is compared to the original message to verify that it was sent properly.

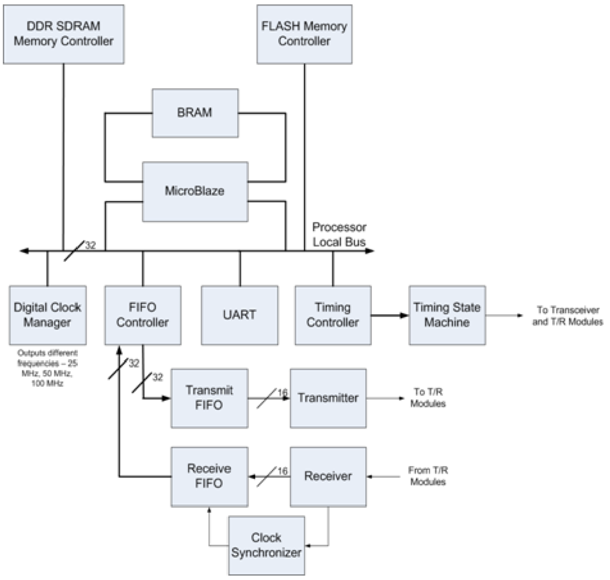

Fig 5. Array controller block diagram

After the look-up tables have been loaded, scan and timing data are sent from the host to the array controller. The host computer loads a scan, a series of azimuth beam positions at a fixed elevation, into the array controller memory. Each beam position has an associated 8 state polarization sequence (composed of TxV, TxH, RxV and RxH), the number of times the sequence is repeated (hereinafter referred to as the loop count), and the Tx pulse length and pulse repetition time (PRT). When the scan is loaded, the array controller first sets the elevation through the tilt controller. It then routes the first beam position's sequence to the transmit FIFO that broadcasts the data to all of the T/R modules in a point to multipoint operation. While the sequence is being broadcast, the pulse length, PRT and loop count are loaded into the timing state machine. When the serial transmitter has finished loading the sequence into the T/R modules, the timing state machine is started which generates the switching signals for the T/R modules and the triggers for the digital transceiver. One pass through the state machine steps the T/R modules through the sequence table one time generating four pulses. The state machine repeats the sequence until the loop count is reached. The second beam position is then read from memory and the process is repeated. When the final beam position in the scan is reached, the host computer loads the next scan.

VI. PRELIMANARY RESULTS

Four antennas LRU of 18x32 elements were implemented and tested. S-parameter and dual-polarized patterns in the elevation plane were measured and reported in [3] and [7]. For the entire frequency range (9.3 Ghz to 9.4 GHz) the first sidelobe is below -24 dB and the pattern roll-off decays rapidly from broadside. The cross-polarization, presents values of -35 dB and -32 dB at broadside for V and H respectively. Also

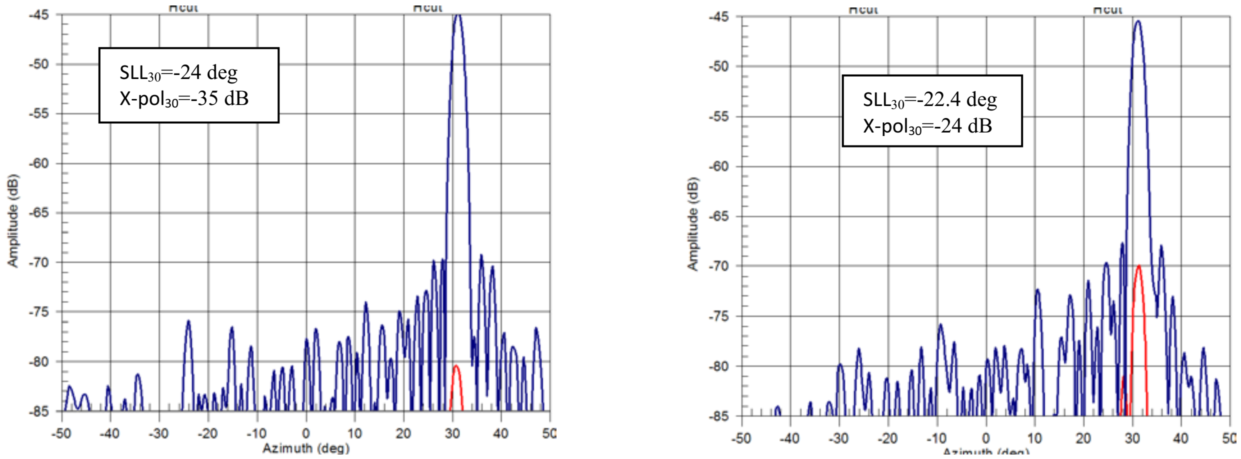

Fig 6. Measured antenna patterns of array 64x32 elements in azimuth plane at 30 deg. a) H-pol (left) and b) V-pol (right)

when those are integrated across 90 deg; values of -21.3 dB and -21 dB are obtained 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.

Sixty-four T/R modules were fabricated and tested. The modules presented a good electrical performance over the required bandwidth. The transmit peak power is about 1.25 watts and the noise figure is lower than the specified 5 dB. In addition, an isolation of 45 dB between antenna polarization ports and an isolation of 65 dB between transmitted and received channel ports are obtained, these amounts are enough to avoid any degradation of the polarization purity and any coupling between channels during the calibration. A calibration algorithm is used to find the attenuator setting and phase-shifter setting of each T/R module at each temperature that minimize the error between the desirable excitation and the characterized element data resulting in RMS phase errors of 1.6° and amplitude errors of 0.25 dB. Initial antenna calibration results indicate a good agreement between the calculated and measured patterns.

Figure 6 shows two-measured antenna patterns in the azimuth plane for 30 deg for H and V polarizations in reception mode only because the lack of space. For this measurement, the 64 T\R modules were calibrated at room temperature in amplitude to obtain a antenna pattern tapered corresponding to -25dB Taylor distribution (ñ=4) and in phase to have a beams steered at 0, 15, 30 and 45 deg. A Near-field range system was used to obtain the antenna patterns. The measured patterns presents a good agreement with calculated patterns, the 3dB beamwidth and respective broadening effect corresponds with predicted values. The sidelobe level at broadside is -24 dB having 1dB degradation at 30 deg scanning. The cross-polarization in the overall scanning range is lower than -25dB for both polarizations.

VII. CONCLUSIONS

A prototype antenna has been designed, fabricated and tested. It meets the polarization requirements needed by and defines a new state-of-the-art for remote sensing of weather using small radars. The prototype antenna will be mated with a Vaisala RVP900 signal processor to serve as a proof of concept radar for use in the CASA Massachusetts test bed. Additional units can be built for exploring networks comprised of many antennas arranged in a dense network as described in [8].

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