CASA PHASED ARRAY RADAR SYSTEM DESCRIPTION, SIMULATION AND PRODUCTS

Anthony P. Hopf, Jorge L. Salazar, Rafael Medina, Vijay Venkatesh, Eric J. Knapp, Stephen J. Frasier, and David J. McLaughlin

Center for Collaborative Adaptive Sensing of the Atmosphere*
Electrical and Computer Engineering Department
University of Massachusetts, Amherst, USA

ABSTRACT

This paper discusses the systems architecture of the CASA Phased Array Radar System, the Phase-Tilt Escan Radar System, for deployment in a CASA DCAS network of low power, solid-state phased array radars. The paper highlights the high-level system's architecture accompanied by measured data from the subsystems.

Index Terms— phased array, radar networks, system description, phase-tilt, casa

1. INTRODUCTION

The Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), an engineering research center sponsored by the National Science Foundation, is advancing the technology to enable future deployment of dense networks of low-power, short-range radars that overcome coverage gaps due to earth curvature and complex terrain [1]. Currently, the center has deployed a network of four small radars in a research network in Oklahoma, USA. The radars in this test bed utilize X-Band, mechanically-scanned antennas, with magnetron transmitters, and coherent-on-receive receiver/data collection systems. The next step in the evolution of this technology in dense networks of low-power, short-range, low cost paradigm is to realize these radars using solid-state electronics and electronically-scanned phased arrays. A driving consideration in the design is the ability to realize these systems commercially at costs in the $100k range [1].

In an effort to create the first prototype of the electronically scanned phased array radar, CASA has developed a system architecture taking into consideration the important characteristics of the system, scalability and modularity. These are achieved by designing the system in such a way that the line replaceable sections of the radar can be increased or decreased depending on the application, and the sub-systems can be swapped out as new technology is produced. The system consists of the Phase-Tilt Antenna Structure, IF Digital Transceiver, Up/Down Conversion, and Host Computer subsystems.

The remainder of this document will consist of four sections used to describe the architecture of the Phase-Tilt Escan Radar system; one section used to describe measured parameters and illustrate the predicted performance of the Phase-Tilt Escan Radar with actual data, and a final section containing conclusions and future work.

*This work is supported primarily by the Engineering Research Centers Program of the National Science foundation under NSF award number 0313747. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation.

2. SYSTEM OVERVIEW

The Phase-Tilt Escan Radar system, shown in Figure 1, is a dual-polarized linear phased array of solid-state Transmit/Receive (T/R) modules composed of four line replaceable units (LRU). Each LRU consists of 16 center-fed, dual-polarized, patch-array antenna columns arranged to scan electronically in the azimuth direction and mechanically in the vertical direction [2]. Each of the 16 columns employs a separate T/R module for phase, amplitude, and polarization diversity. The 16 T/R modules are individually controlled via a field-programmable gate array (FPGA) controller, that creates control signals, interfaces with the host computer, mechanical actuator, and IF digital transceiver. The transmitted signal is produced by an arbitrary waveform generator within the IF transceiver. The received RF signal from the T/R modules is combined, then down-converted, filtered, digitized and tagged with beam location information by the receiver within the IF transceiver and processed by the host computer. The host computer controls the system and contains the signal processor, the beam steering computer and the interface to CASA's Meteorological Command and Control (MC&C) computers, which determine the scheduling of the beam locations.

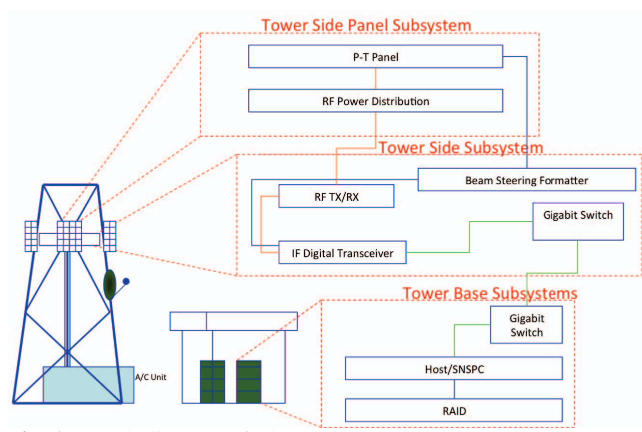

Fig. 1. Block diagram of Phase-Tilt Escan Radar system prototype shown deployed on a tower

2.1. Array Structure Subsystem

The Phase-Tilt Array Structure Subsystem is made up of four LRUs, a formatter board, tilt mechanism, radome and weather enclosure. Each of the four LRUs are made up of a 0.25m x 0.5m passive array, 16 T/R modules, RF and DC power distribution backplane, and AC-to-DC power converters.

Each column of the dual-polarized phased tilt antenna is a dual linear polarized (V and H) array composed of 32 aperture coupled microstrip patch antennas (ACMPA) interconnected by series-fed networks for each polarization operating at 9.6GHz. The phase-tilt antenna is designed to scan $\pm 45^\circ$ in azimuth with a maximum beam width, using a Taylor 24dB distribution, of 2.4° in azimuth and 3.5° in elevation. The phase and amplitude in the aziumth plane allows virtually any taper to be applied to that plane. The specifications for sidelobe, cross-polarization, co-polarization, and efficiency levels are shown in Table 1. Figure 2 shows plots of the excellent performance of the low cost antenna configuration in terms of sidelobes, cross-polarization, and co-polar patterns.

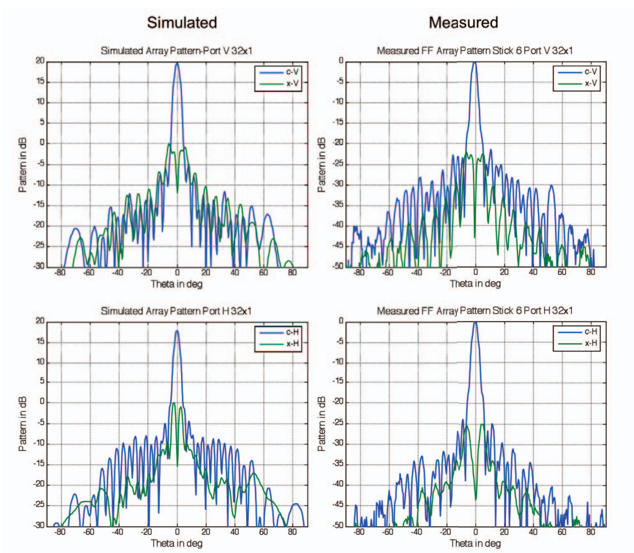

Fig. 2. Passive array antenna elevation patterns, simulated and measured, for co- and cross-polarization in horizontal and vertical planes

The architecture of the T/R module was chosen to have a "common leg" in both transmit and receive paths with distributed gain based on noise figure, third-order intercept, gain trade-offs and antenna calibration methods. The main functions of the T/R modules are for high power transmit amplification, low noise receiver amplification, creating a common gain/phase control circuitry, transfer switching, and circuit control.

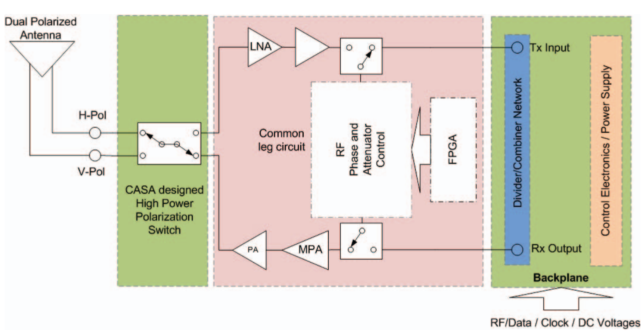

Fig. 3. Block diagram of the T/R module component

The gain/phase control circuit consist of a 6-bit digital phase shifter providing 360° phase coverage, a gain block, a 6-bit digital attenuator with 31.5dB of attenuation coverage, and two T/R SPDT switches, shown in Figure 3. The entire T/R module, besides the two switches, is composed of commercial off-the-shelf (COTS) components, which offer low RMS phase and insertion errors with little temperature dependence. In addition to the microwave circuits, the T/R modules make use of an integrated FPGA for the required extensive support interfaces and logic circuits.

Each LRU contains a backplane component, shown in a simplified system block diagram, Figure 4, which is designed to do RF signal distribution/combination, DC power distribution, and digital distribution. The backplane components is the interface between the T/R modules and other subsystems and components; formatter board, AC-to-DC converters and IF digital transceiver.

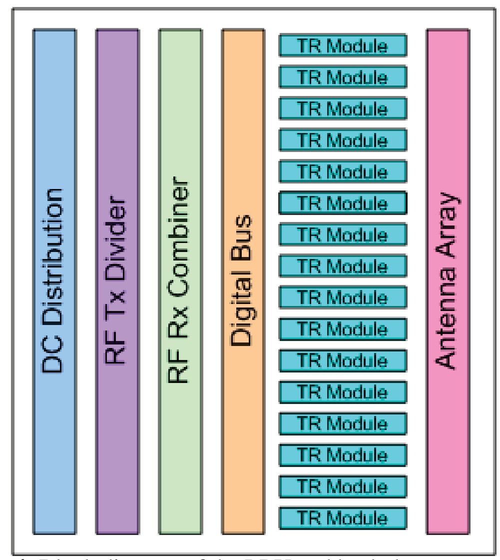

Fig. 4. Block diagram of the LRU and backplane component

The RF power distribution network subcomponent is two passive corporate feeds, one used as a power divider and the other as a power combiner/beam forming network. The power divider and power combiner use two stages of analog divider/combiner networks to connect the IF Digital Transceiver Subsystem to the T/R module subcomponents. The power distribution network is tasked with distributing multiple DC power and ground planes to all of the subsystems, components, and subcomponents. The digital backplane distributes the digital signals of the Array Formatter to the T/R modules. The digital backplane panels use standardized signals to communicate with the Array Formatter.

The role of the Array Formatter, is to translate the beam position, polarization and transmit/receive data from the Host Computer and IF Digital Transceiver to T/R modules through the backplane. A FPGA evaluation board will be the first prototype used as the array formatter with four serial interfaces acting as transceivers to the 64 T/R modules.

The Mechanical Structure is designed with a skeletal frame at the center of the design to allow for the scalable and modular architecture of the Phase-Tilt Escan System. Figure 5 shows a breakdown of the Mechanical Structure fully populated with four LRUs and the Radome Frame. Table 1 has the specifications of the Mechanical Structure. The Radome Frame uses a single layer of hydrophobic fabric to seal and protect the front of the system from the elements.

The elevation scanning of the Phased-Tilt Escan Radar will be performed using a mechanic tilt mechanism based on an AC servo-motor. The tilt mechanism must scan no less than 90 degrees with a scanning rate of no less than that of the previous CASA radars [3].

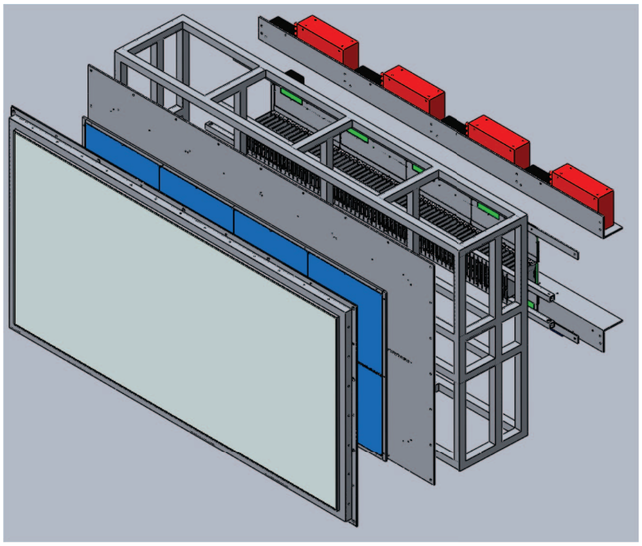

Fig. 5. Mechanical Structure of the Array Structure Subsystem with four populated LRUs

2.2. IF Digital Transceiver Subsystem

The IF Digital Transceiver Subsystem is a commercially available transceiver used to create the frequency-modulated transmit waveform, digitize the received signal, and demodulate the digitized signal. The transceiver takes as inputs an external clock for both synchronization and as a system clock and TTL or LVDS signals for triggering the transmitter and receiver. The transmitter is made up of digital to analog converters that include interpolation filters and an upconverter stage capable of using baseband data files to produce a single-sideband upconversion analog output. Similarly, the receiver uses analog to digital converters to provide input to an FPGA, to format, process or route the data to digital downconverters (DDC) whose output is baseband digital I&Q data files. Through the use of the FPGA and feedback paths between the DDC, the signal can be passed through pulse compression filters before being sent to the DDC input. Energy on target will be increased by using combinations of long period linear FM (LFM) or non-linear FM (NLFM) chirps, with conventional short single tone pulses.

2.3. Host Computer Subsystem

The Host Computer Subsystem (HCS), in the instance of this prototype, is the interface between the human operator and the rest of the subsystems. The HCS contains the graphical user interface (GUI) for human control and status, the beam steering computer (BSC) that catalogs the present and future beam locations, the signal processor that produces the weather products, and finally the interface to outside connectivity. The HCS will communicate to the rest of the subsystems through a gigabit network connection. The BSC formats the digitized I&Q data for real-time signal processing with appropriate tags for data type, beam direction, pulse type, and GPS time. The signal processor in the HCS, based on the signal processor used in previous CASA radars, provides user defined real-time processing of the digital I&Q for weather phenomenon of interest for display and archival [3]. The interface to outside connectivity provides remote control and display of the products and fault indication of the various subsystems. There will also be provisions for a RAID in order to do data archiving of processed and raw data for post processing.

Future versions of the HCS will also contain software that will allow the Phase-Tilt Escan Radar System to be seamlessly integrated into a Distributed Collaborative Adaptive Sensory (DCAS) network [4].

2.4. Up/Down Conversion Subsystem

The first prototype of the up/down conversion subsystem is made up of COTS components. Because the T/R modules contain the first stages of the receiver and last stages of the transmitter, the up/down conversion subsystem is more simple than traditional weather systems and is shown in Figure 6. A calibration loop was added to the end of the subsystem to be used during field calibration. The up/down conversion subsystem also contains a gain control section that can be used in conjunction with short and long pulse sequences to improve the dynamic range of the system. The up/down conversion subsystem contains the synchronization clocks for the RF oscillator, formator board, and the IF digital transceiver.

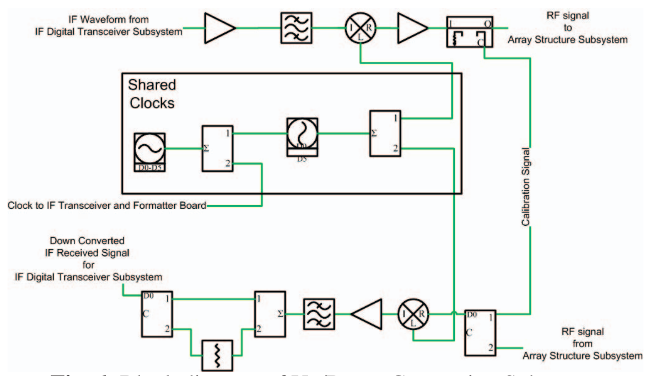

Fig. 6. Block diagram of Up/Down Conversion Subsystem

3. PRODUCTS AND SIMULATION

The requirements for the Phase Tilt Escan Radar System were developed using work from [1][2][5][6]. The passive array, T/R module and IF have been bench top tested and measured individually, and those values are also reflected in Table 1.

The primary objective of the phased array simulator is to evaluate sidelobe contamination and loss of angular-resolution for various synthesized apertures. Figure 7a is a high resolution mesocylcone-scale observation of a high precipitation supercell near Woodward, OK on May 13th 2008, as seen by the University of Massachusetts Amherst (UMass) X-POL radar. The far-field pattern of the Phase-Tilt Escan Radar antenna is calculated by in turn multiplying an analytical model of the element pattern of a microstrip patch antenna with the array factor. The convolution of the reflectivity field observed by X-POL (here considered “truth”), as shown in Figure 7a, and the two-way far field pattern of the antenna results in the image that would be expected from the Phase-Tilt Escan Radar antenna. Figure 7b illustrates the predicted performance of the phased array. The figure shows the expected resolution due to the widened beam width (relative to X-POL) and sidelobe contamination from the scanning of the array. While this may be an issue for a single radar, this degradation in sampling will be decreased in a network environment [6].

System Parameter	Unit	Value
Operating Frequency	GHz	9.6
Peak Power	W	>60
Range Resolution	m	>50
Bandwidth	MHz	<80
Antenna		
Gain	dB	>36
Efficiency	%	60-70
Elevation Peak SLL	dB	-22-24
Azimuth Sidelobe Taper		Programmable
Elevation Beamwidth	degrees	3.5
Azimuth Beamwidth	degrees	2 (broadside)
		3 (@ $\pm 45°$ scan)
Cross-polarization	dB	-35 (broadside)
Azimuth Scan Range	degrees	± 45
T/R Module		
Gain	dB	33
Peak power	W	1.25
Noise Figure	dB	<4.5
Polarization isolation	dB	>45
Module efficiency	%	>15
Mechanical Structure		
Elevation Scan Range	degrees	0-90
Elevation Scan Rate	deg/sec	>20
	deg/sec^2	>120

Table 1. Radar Parameters

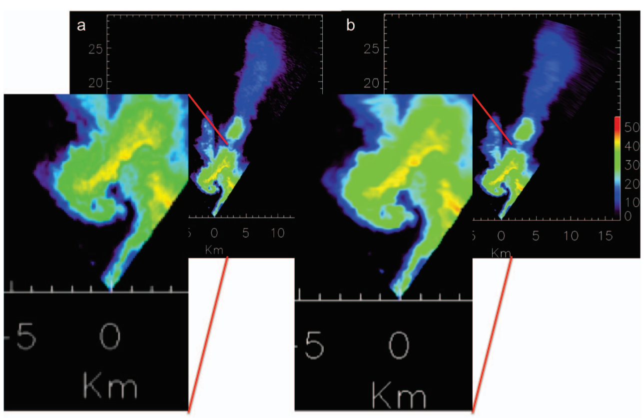

Fig. 7. **a**: Ground truth reflectivity as seen by X-POL of a supercell on May 13th, 2009 near Woodward, OK. **b**: Resultant reflectivity fields from the simulated phase-tilt antenna system.

4. CONCLUSION

This paper has described the architecture and projected performance of the next generation of CASA radars, built on scalability and modularity with the purpose of bringing down the cost associated with current state of the art weather radars. The first four sections of the paper went into detail on the breakdown of the system through the use of block diagrams and artist's renderings of the system deployment. The last section described the procedure used to simulate the predicted performance of the Phase-Tilt Escan Radar System using actual radar data collected by the UMass XPOL radar team.

Future work for this project is the integration of the subsystems and deployment of the radar on the CASA MA1 radar tower. Simulations will also be done to investigate the affects of scanning range on the Phase-Tilt Escan Radar System to polarization products.

5. REFERENCES

[1] D.J. McLaughlin and et. al., "Distributed weather radar using x-band active arrays," *Radar Conference, 2007 IEEE*, pp. 23–27, April 2007.

[2] Jorge L. Salazar, Rafael Medina, Eric J. Knapp, and David J. McLaughlin, "Phase-tilt array antenna design for dense distributed radar network for weather sensing," Boston, MA, 2008, IEEE International Symposium on Geoscience and Remote Sensing.

[3] F. Junyent and et. al., "Salient features of radar nodes of the first generation netrad system," *Geoscience and Remote Sensing Symposium, 2005. IGARSS '05. Proceedings. 2005 IEEE International*, vol. 1, July 2005.

[4] D.J. McLaughlin, V. Chandrasekar, K. Droegemeier, S. Frasier, J. Kurose, F. Junyent, B. Philips, S. Cruz-Pol, and J. Colom, "Distributed collaborative adaptive sensing (dcas) for improved detection, understanding, and prediction of atmospheric hazards," San Diego, CA, 2005, 9th Symp. Integrated Obs. Assim. Systems - Atmos. Oceans, Land Surface (IOAS-AOLS), Amer. Meteor. Soc.

[5] Francesc Junyent, *Department of Electrical and Computer Engineering*, Ph.D. thesis, University of Massachusetts Amherst, Amherst, MA, 2007.

[6] A.P. Hopf, E.J. Knapp, and D.J. McLaughlin, "Scalable multifunction dense radar network," July 2008, vol. 4, pp. 1018–1021.