X- and W-band Mobile Doppler Radar Observations from VORTEX2 and Current Developments

(Invited Paper)

S. J. Frasier, V. Venkatesh, K. Orzel, T. Hartley,
J. Salazar, R. Medina, E. Knapp and O. Ibe
Microwave Remote Sensing Laboratory
University of Massachusetts
Amherst, MA 01003
Email: frasier@ecs.umass.edu

H. B. Bluestein, J. Snyder, R. Tanamachi
School of Meteorology
University of Oklahoma
Norman, OK

Abstract— **Over the past several years, UMass has developed and deployed two mobile Doppler radars for severe storm research. One is a W-band (95 GHz) Doppler radar that is used for fine-scale observations of tornadic features. It features a very narrow (0.18°) beamwidth. The other is a dual-polarized X-band Doppler radar used for coarser scale observations and polarimetric measurements for scatterer identification, and precipitation estimation. We show sample observations by these systems obtained during the 2009 and 2010 VORTEX2 experiments. UMass is presently developing a dual-polarized, solid-state, phased-array radar.**

I. Introduction

Since the early 1990s the University of Massachusetts' Microwave Remote Sensing Laboratory has collaborated with the University of Oklahoma's School of Meteorology in the study of tornado and severe storms with mobile Doppler radar systems. This paper describes two of the radar systems developed and shows sample observations from the recent VORTEX2 field experiment from 2009 and 2010. MIRSL is also presently building several dual-polarization solid-state phased-array radars as a result of initial development in the CASA Engineering Research Center. One of these is intended for mobile application. The current status of that system is also described.

II. Mobile Radar Systems

A. W-band mobile Doppler radar

The W-band mobile Doppler radar [1] is a fully polarimetric radar operating at 95 GHz with a peak transmit power of 1 kW. A 1.2 m diameter Cassegrain antenna provides a 0.18° beamwidth, and range resolution is typically 30 m. The radar is integrated on an azimuth-over-elevation pedestal on a modified Ford F350 truck chassis. Data acquisition and control electronics are housed in a rack inside the truck's crew-cab which provides seating for three. AC power is provided by a 3 kW inverter system attached to a pair of high capacity marine batteries which are recharged by the trucks alternator when enroute. Battery power is sufficient for approximately 3 hours of operation with the truck engine off. Bore-sighted video is used to monitor beam pointing and is recorded for post-experiment interpretation.

Fig. 1. The UMass W-band mobile Doppler radar on May 25, 2010 near Tribune, KS. Tornado is visible in distance. photo (c) R. Tanamachi.

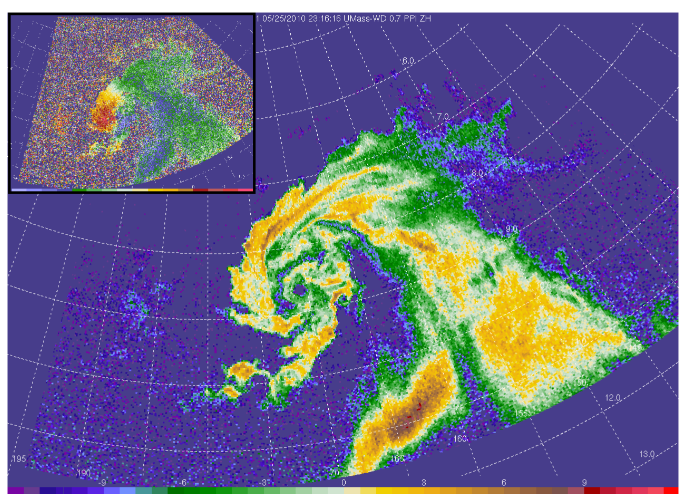

Fig. 2. Equivalent reflectivity and de-aliased Doppler velocity (inset) of the developing Tribune, KS tornado.

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Originally designed as a bistatic (two-antenna) radar, this W-band radar was adapted in the early 1990s for severe storm research performed in collaboration with the University of Oklahoma School of Meteorology. It was rebuilt in 2004 when the extended interaction klystron and modulator were replaced. It currently employs a single antenna with a network of latching circulators serving as a transmit/receive and polarization switch. The transceiver employs two multiplied frequency sources and a double down-conversion receiver with intermediate frequencies at 1.2 GHz and 120 MHz. A digital receiver samples the final IF signal, producing baseband inphase and quadrature samples.

Due to the 3 mm wavelength of the radar, the unambiguous velocity interval for W-band radars is very narrow. For example, a pulse rate of 5 kHz provides a Nyquist velocity range of only ± 3.95 m/s. A dual-PRT scheme is therefore employed with a ratio of 11:10 providing unambiguous velocity measurements up to 40 m/s. Fig. 2 shows detailed structure of a tornado observed near Tribune, KS on May 25, 2010. The inset shows the dual-PRT derived velocity field. While the W-band radar can provide very fine detail owing to the very narrow beam, the scan rate is necessarily slower than that obtained with other coarser-resolution radars.

In addition, raindrops (with a typical diameter of 2 to 7 mm) scatter in the Mie regime at W-band wavelengths. This results in rapid attenuation of the W-band signal in precipitation, limiting the practical range to 10 – 12 km, or even less in heavy precipitation. Because the exact locations of tornadoes are very difficult to anticipate and because they often occur in conjunction with heavy precipitation, successfully collecting W-band data in tornadoes is difficult. Despite these challenges, the UMass W-band successfully collected data in tornadoes during VORTEX2, including the entire life cycle (formation to decay) of the 25 May 2010 Tribune, Kansas tornado (Figs. 1-2).

Fig. 3. The UMass X-Pol mobile Doppler radar and the decaying Goshen County WY tornado observed on 5 June 2009. photo (c) J. Snyder.

B. X-band mobile Doppler radar

The UMass X-Pol radar [2], [3] is a dual-polarized X-band radar operating at 9.4 GHz with a peak transmit power of 6.25 kW (per polarization) channel provided by a modified marine navigation radar transmitter. Often used in tandem with the W-band radar, it is deployed on a nearly identical truck platform. X-Pol employs the simultaneous transmission and reception (STAR) of both H- and V-polarizations and typically employs a dual-PRT waveform to obtain unambiguous velocities up to 40 m/s. A refurbished Army Signal Corps SCR-584 type of scanning pedestal common to many mobile weather radars is used. Similar to the W-band radar, the power system employs an inverter supplied from marine batteries that are recharged by the truck's alternator. Typically, a one-microsecond pulse is transmitted providing range resolution of 150 m.

Fig. 4 shows several sample data products collected from the Goshen County tornado. Reflectivity shows a pronounced hook and bounded weak echo region while Doppler velocity shows a tornado vortex signature. A small hole in the correlation coefficient signature may indicate debris scattering and centrifuging of hydrometeors consistent with observations in [4]. However, it may also be attributable to the reduced SNR in this region. An increasing trend (with range) in differential-phase to the right of the tornado is associated with heavy precipitation in this region.

A solid-state pulse-compression transceiver has been developed compatible with X-Pol in anticipation of integration with the phased-array antenna described in the following section. Pulse compression is necessary for the radar to acheive sufficient average power for sensitivity to weather targets while maintaining a low peak power and conserving range resolution (maintaining a desired bandwidth).

III. Phased Array Development

Through the NSF Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere (CASA), we have developed a linear phased-array antenna that enables phase scanning in the azimuth plane (only) with mechanical actuation in the elevation plane [5]. The so-called "phase-tilt" array (Fig. 5) consists of 64 dual-polarized "stick" antenna elements.

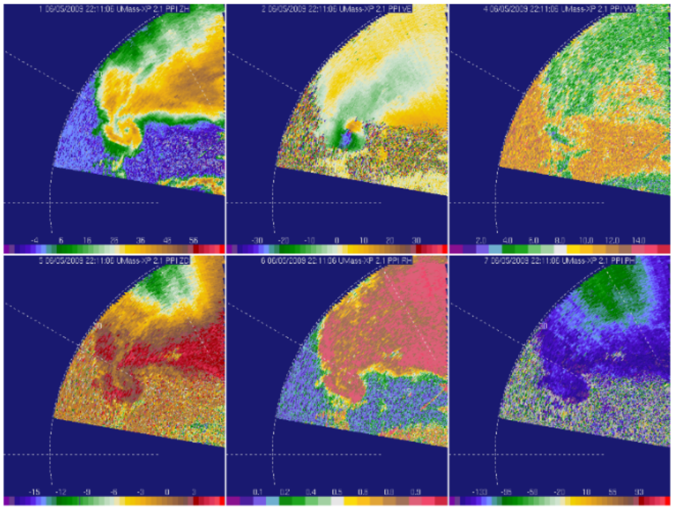

Fig. 4. Left to right from upper left: Reflectivity, Doppler velocity, Doppler spectrum width, Differential Reflectivity, Polarization correlation coefficient,and Differential Phase observations of the Goshen County tornado.

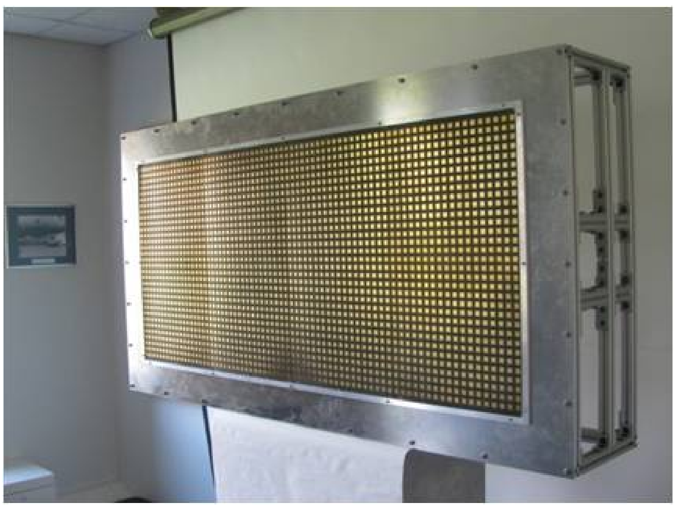

Fig. 5. The radiating face of the CASA "Phase-tilt" dual-polarized phased-array. The array consists of four modules of 16 elements comprised of series-fed aperture-coupled microstrip patches.

Each element is a center-fed microstrip patch array antenna that may be excited in either vertical or horizontal polarization. Each element has a fan-beam pattern with 3.5° beamwidth in the elevation plane and approximately 120 degrees in the azimuth plane. The 64-element array has a 2° azimuth beamwidth at boresight, which degrades with scan angle due to the reduced projected aperture in the beam direction. To mitigate edge effects, passive elements are appended at both ends of the array.

Behind each array element a transmit-receive module (Fig. 6) provides independent amplitude and phase control on both transmit and receive. The GaAs power-amplifier on each T/R module is capable of producing 2W of peak power, approximately half of which is lost between the subsequent polarization switches and the antenna's feed network. Thus,

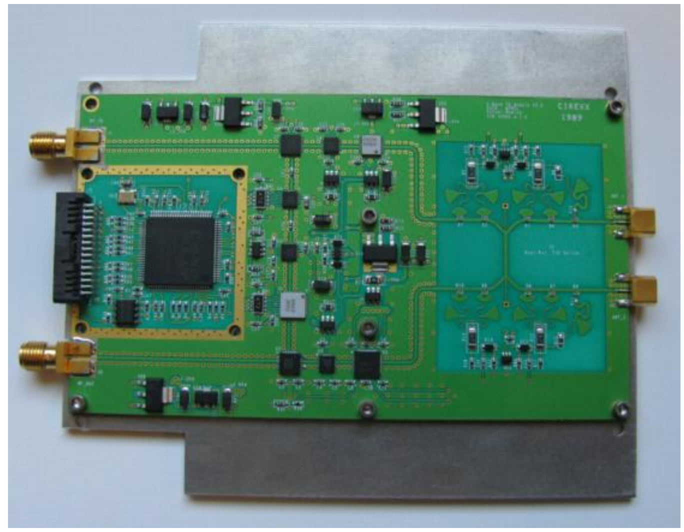

Fig. 6. A T/R module developed for the CASA solid-state X-band dual-polarized phased-array. Transceiver ports are on the left, antenna ports are on the right.

each element radiates approximately 1W.

Each T/R module includes a small field programmable gate array (FPGA) containing a state machine and memory to hold several amplitude and phase values for the attenuator and phase shifter. These are attached to a "backplane" bus which communicates with the host PC via a high-speed serial link. A beam-scheduling application on the control computer is able to preload and define several beam configurations and beam sequences that are executed by the state machines implemented in the FPGAs.

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