The UMass Mobile W-Band Radar: System Overview and Sample Observations

Pei-Sang Tsai*, **Stephen Frasier**
Microwave Remote Sensing Laboratory, Department of Electrical and Computer Engineering
Amherst, Massachusetts 01003

Robin L. Tanamachi, Howard B. Bluestein
School of Meteorology, University of Oklahoma, Norman, Oklahoma

Abstract

The Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts has maintained and operated a mobile W-band Polarimetric Doppler Radar since the early 1990s. This radar has been a focal point of ongoing collaboration between UMass and the University of Oklahoma School of Meteorology in studies of severe thunderstorms and tornadoes using mobile radars. Over the past two years, the W-band radar has undergone a major rebuild and upgrade. Modifications include a new modulator for the klystron transmitter and associated redesign to accommodate the same, a new control and data acquisition system based on FPGA and digital receiver technology, real-time display, and new mechanical packaging, and conversion of the entire system to battery power recharged by the truck's engine, eliminating the need for a generator.

Due to the 3 mm wavelength of the radar, the unambiguous velocity interval for W-band radars is very narrow. A limitation of the prior data acquisition system was a single pulse-pair interval requiring use of polarization-diverse pulse-pair methods to obtain unwrapped velocities in high-wind events. The new system relieves this constraint allowing dual- or multiple-PRT methods to obtain unwrapped velocities. Real-time full spectrum (FFT) processing is in development. This paper documents the upgraded system and shows selected results from recent deployments.

*peisang@mirsl.ecs.umass.edu

Figure 1: UMass W-band mobile radar.

1. Introduction

The first generation of the University of Massachusetts mobile W-Band radar was implemented in 1993 (Mead J.B. and R.E. 1994) mounting a compact W-band radar and pedestal into a passenger van (Bluestein and Pazmany 2000) with an outboard portable generator. At the time, the radar system was built with state-of-the-art mm-wave components and a VXI-based data acquisition system. It was equipped with a 1-ft diameter lens antenna with a half-power beamwidth of 0.7 degrees. Two years later, a 1.2 m Cassagrain antenna was added to

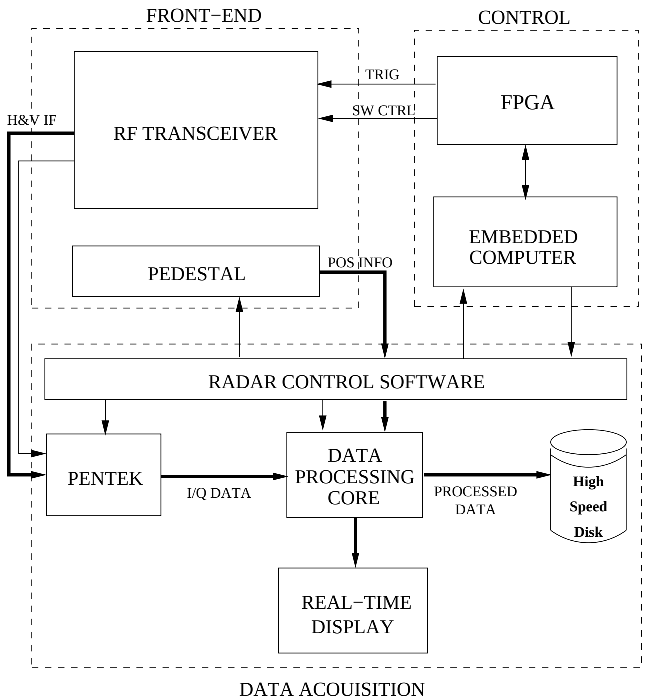

Figure 2: UMass W-band radar subsystems and signal flow.

Table 1: UMass W-Band Radar System Characteristics

Transmitter	Klystron
Center Freq.	95.04 GHz (3.3 mm)
Peak Power	1.2 kW
Pulse Width	200 ns - 1 us
PRF	13 kHz
Pulsing Scheme	HHHH,VVVV, HHVV, staggered
Max. unambiguous Range	12 km
Max. unambiguous velocity	40 m/s
Antenna	Cassegrain dish
Size	1.22 m/4ft
3dB Beamwidth	0.18°
Gain	59 dB
Scan Rate	2 rpm
Receiver	Pentek 7631
Dynamic Range	84 dB
Bandwidth	6.25 MHz
Intermediate Freq.	120 MHz
Sensitivity(single pulse)	-26.3 dBZ at 1km

the radar to improve the sensitivity and angular resolution to 0.18 degrees. In 1997, the system was migrated to a pickup truck platform enabling more agility in pointing the radar. The radar was deployed in this configuration routinely until 2004. Following 2004, a complete rebuild of the radar was necessary to replace an aging W-band transmitter and a now obsolete data acquisition system. At the same time, the radar installation on the mobile platform was updated. This paper describes the current realization of the University of Massachusetts mobile W-band radar used for severe storm applications.

2. Radar System Description

The UMass W-Band radar consists of several subsystems as shown in Figure (2). The RF Subsystem consists of the transceiver and the antenna which are both mounted above a two-axis (elevation-over-azimuth) pedestal. The Timing Control Subsystem consists of an embedded computer that includes a field-programmable gate array (FPGA) which is used to generate radar and data-acquisition triggers as well as several switching control signals. The Data Acquisition Subsystem employs a high-speed digital receiver for sampling the intermediate-frequency output of the radar receiver and producing baseband in-phase and quadrature samples. These are processed in real-time by the host computer to produce profiles of reflectivity, Doppler, and other products. The host computer also runs software for user interface and a real-time display. Both the Timing and RF subsystems are contained within a common weatherproof enclosure which is located immediately behind the antenna. The data acquisition subsystem is located inside the truck cab. The detailed specifications of the UMass W-band radar are listed in Table 1.

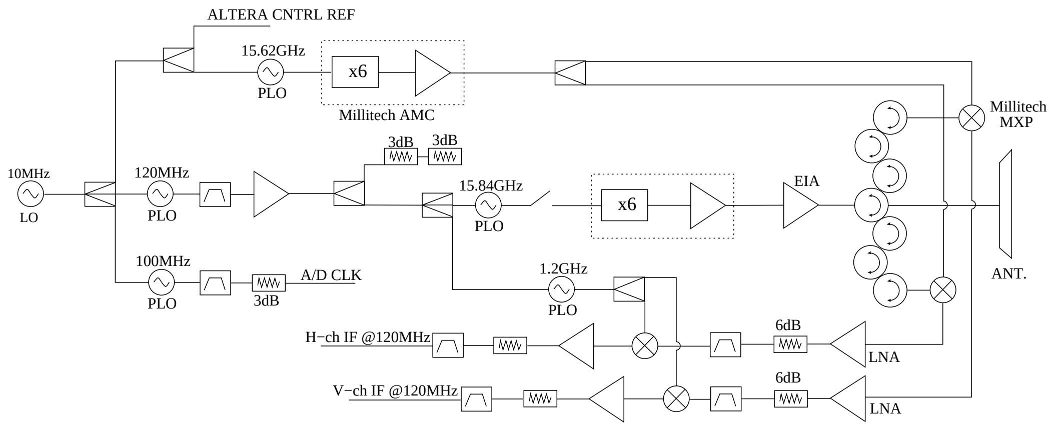

Figure 3: UMass W-band radar system diagram.

RF Subsystem

Figure (3) shows a block diagram of the W-band radar transceiver. In the transmitter, pulses at the 120 MHz intermediate frequency are up-converted and multiplied to 95.04 GHz and fed to the the extended interactive klystron amplifier (EIA) which produces a peak power of 1.2 kW. The high-power transmit signal then passes through a network of latching circulators connected to an orthomode transducer(OMT) on the feed of the antenna. The switch network selects transmit polarization and serves as the transmit-receive switch. Depending on the pulsing scheme, it directs the transmit signal into the vertical (V) or the horizontal (H) port of the OMT. The H- and V-polarized signals are then transmitted from the antenna. On transmission this switch network provides approximately 90dB of isolation between the transmitter and the receiver.

The antenna is a 4-ft diameter Cassegrain dish with a 3-dB beamwidth of 0.18° and a gain of 59dBi. The very narrow beamwidth provides 15 m cross-beam resolution at range 5 km (Bluestein et al. 1995). It is mounted on a pedestal which is capable of highest scan rate 2rpm in both elevation and azimuth. The scan motion is limited to 70° in elevation and a sector scan of 300° in azimuth.

Received echo signals pass through the switch network and are immediately downconverted to a first intermediate frequency (IF) of 1.32 GHz before entering a low-noise amplifier. A second downconversion is made to 120 MHz which is presented to the digital receiver. The resulting noise figure of this receiver is 13 dB. Improved sensitivity could be obtained by installing W-band LNAs which are now readily obtainable. For the present application, however, such sensitivity is not a requirement.

Timing Control Subsystem

The Timing Control subsystem provides triggers and switch control signals. An embedded Linux-based computer located inside the radar housing communicates with host computer via ethernet. The embedded computer interfaces directly with an Altera FPGA based timing generating circuit. This allows the radar operator to alter parameters such as pulsing schemes, pulse width, pulse repetition frequency and sampling parameters. These changes are communicated to the FPGA via the embedded computer. The FPGA then generates the appropriate timing control signals such as triggers, switch controls and transmit waveforms for the RF transceiver.

The available pulsing schemes include single or alternating polarizations, and conventional or staggered pulse-repetition frequency. The default mode of operation is H-polarization on transmit (receiving both H and V), and staggered PRF. The staggered PRF employs a ratio of PRFs of approximately 1.1:1, as the Nyquist velocity interval for W-band is extremely narrow. This provies a tenfold increase in the velocity interval which is needed for severe storm observations.

While the radar transceiver supports fully polarimetric operation, truly polarimetric W-band observations are not emphasized with the present system owing to the limited cross-polarization isolation (≈ 10 dB) afforded by the very high-gain antenna. An improved high-gain antenna will rectify this limitation.

Data Acquisition Subsystem

The data acquisition subsystem is composed of a high-speed digital receiver, a data processing core, and a real-time reflectivity and Doppler display. A commercial digital receiver (Pentek 7631) is integrated into the host computer and serves the data acquisition function. Onboard 14-bit A/D converters sample the two 120 MHz IF receiver channels (H and V) at 100 MHz. The resulting sampled IF signals alias to an apparent intermediate frequency of 20 MHz. The digital receiver subsequently filters and decimates these signal producing 16-bit inphase and quadrature samples at a 6.25 MHz rate.

At this point the data are either streamed directly to disk or to a data processing core that accumulates various covariance-based products over a specified number of pulses. These products are then merged with positioner and time information and streamed to disk and also displayed. At present, only covariance-based algorithms are implemented; however FFT-based processing accomodating more complex Doppler spectra are planned.

Mobile Platform

The UMass mobile W-Band radar is mounted on a Ford F350 crew-cab pick-up truck chassis (Figure 1). This size vehicle provides good maneuverability and agility, while being just large enough to accomodate all needed instrumentation and three personnel (driver, navigator, and radar operator). Hydraulic leveling jacks level the radar system when parked. The radar and pedestal reside on a shock-mounted platform attached to the truck bed. A video camera is attached to the antenna and records simultaneous video observations of the field-of-view. Both radar and video are synchronized to GPS time.

All radar electronics are presently powered via an in-

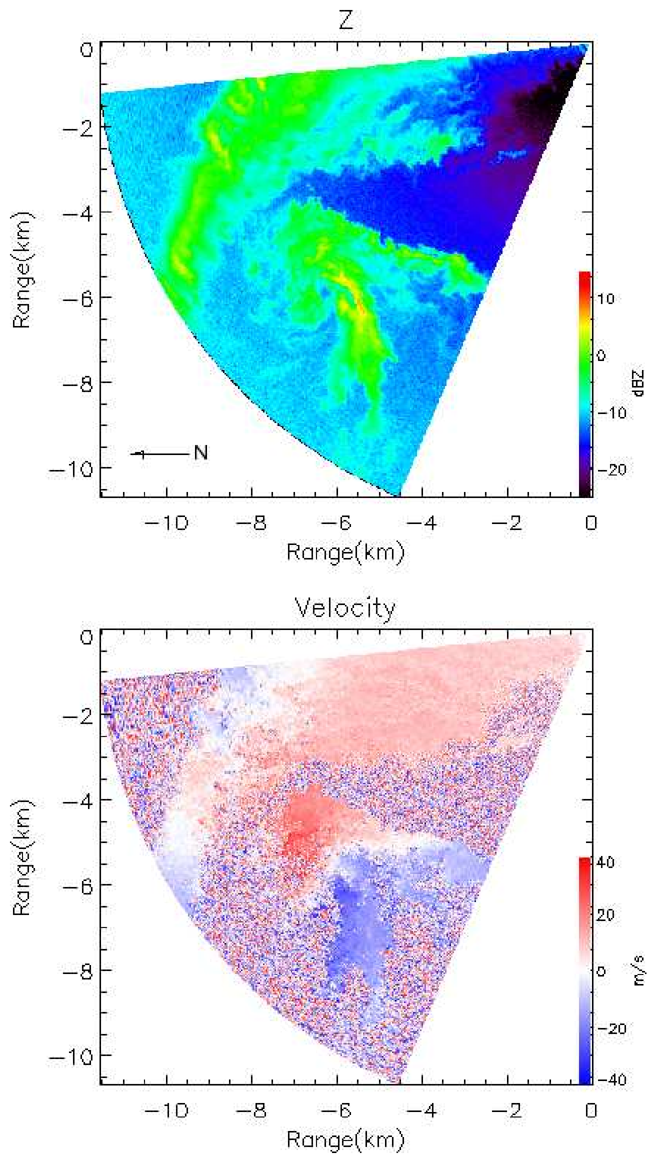

Figure 4: A PPI scan from UMass W-band radar at 2157 UTC, May 23, 2008. The elevation angle is 0.446°. Upper: reflectivity, lower: velocity

verter system that draws DC power from a pair of large 12V deep-cycle marine batteries. These batteries can hold sufficient charge to run the radar for nearly three hours on their own. They are recharged by means of the truck's alternator. An isolator installed in the engine compartment ensures they do not impact the truck's starting battery. When the engine is running, much of the power is drawn from the alternator. In addition to being much quieter than the onboard generator used in years past, this mobile power configuration decreases the deployment time significantly allowing researchers to collect data from more rapid-evolving severe storms and tornadoes.

3. Sample Observations

The UMass W-band radar was deployed during Spring 2008 for field experiments on the Great Plains in collaboration with the OU School of Meteorology. During this time, several severe storms were documented. Figure 4 shows a PPI display of W-band effective reflectivity (Ze) and Doppler velocity from a convective storm observed west of Dighton, KS on May 23, 2008. A weak-echo eye feature is well resolved at a range of 9 km where the azimuthal resolution of the radar is approximately 28 m. Range resolution is fixed at 30 m for these data. A well-defined rain curtain wrapped around the circulation is also shown with higher reflectivity. At W-band, attenuation is significant even in very light rain, so these reflectivities are all, in fact, attenuated reflectivities.

This feature is associated with strong inbound velocities and also very likely to be associated with the rear-flank downdraft (RFD). Furthermore, the velocity data clearly shows strong circulation. Wind velocities reach about $\pm 35 m/s$. Simultaneous video documentation is also shown in Figure 5 along with the radar data to identify the surface features.

Figure 5: Simultaneous video documentation of the rain curtain shown in Figure 3 reflectivity plot. View is to the northwest.

4. Conclusions

This paper highlights the recently updated UMass W-Band radar and explains the several subsystems. This system was recently deployed for tornado research. It is shown that this radar system can resolve detailed storm features. One particular case a weak-echo eye near ground surface was observed with strong vortex circulation of up to $\pm 40 m/s$. A real-time processing core and system agility enables researchers to adjust the observation techniques such as observation range and angle, pulsing and polarization schemes based on the ongoing weather phenomena. Furthermore, the new hardware configuration has not only improved the setup time but also made the system more sustainable for longer deployments.

Acknowledgement Operation of the UMass W-band mobile radar is been supported by NSF Grant 0641201 to the University of Massachusetts and Grant ATM-0637148 to the University of Oklahoma. Mr. Chad Baldi is acknowledged for conceiving of and implementing the battery-inverter power systems for the UMass mobile radars.

References

Bluestein and Pazmany, 2000: Observations of tornadoes and other convective phenomena with a mobile, 3-mm wavelength doppler radar: The spring field experiments. *Bull. Amer. Meteor. Soc.*, **81**, 2939–2951.

Bluestein et al., G. J., Pazmany A.L., 1995: Studies of the substructure of severe convective storms using a mobile 3 mm wavelength radar. *Bull. Amer. Meteor. Soc.*, **76**, 2155–2169.

Mead J.B., S. S., Pazmany A.L. and M. R.E., 1994: Millimeter-wave radars for remotely sensing clouds and precipitation. *Proc. IEEE (82)12*, 1891–1906.