Design, Fabrication and Test of a TWT Transportable Polarimetric X-band Radar

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Abstract

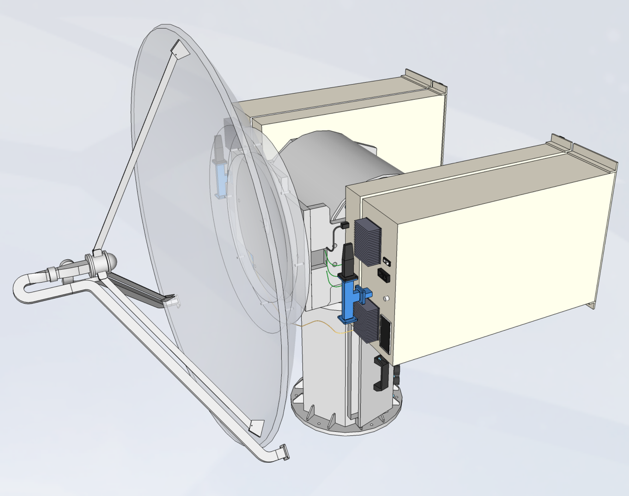
In this work, a Travelling Wave Tube (TWT) based, transportable, dual-polarization X-band radar is being developed at the Atmospheric Radar Research Center (ARRC) at the University of Oklahoma (OU). Internally, this radar has been referred to as the PX-1000. It will primarily be used as a platform to test various signal processing techniques, such as pulse compression, waveform studies, polarimetric signal processing, refractivity retrieval and meteorolgical validation. As of January 2011, the system-design block diagram has been finalized and major system components have also been acquired. The system features a pair of 1.5-kW TWT transmitters, a 1.2-m parabolic reflector dish with dual-polarization feed, and an azimuth-over-elevation pedestal. The radar is designed in a software-defined radio approach for system versatility. Long transmit pulse length of up to 15-us can be applied to compensate for the low peak power while pulse compression techniques will be used to enhance range resolution and radar sensitivity. The PX-1000 is designed to have the major components, i.e., the TWT transmitter, transceiver and data acquisition housed above the elevation axis and raw I/Q time series can be collected and streamed out of the radar system in real time. In this paper, a detailed description of the radar will be presented.

1. Waveform Design

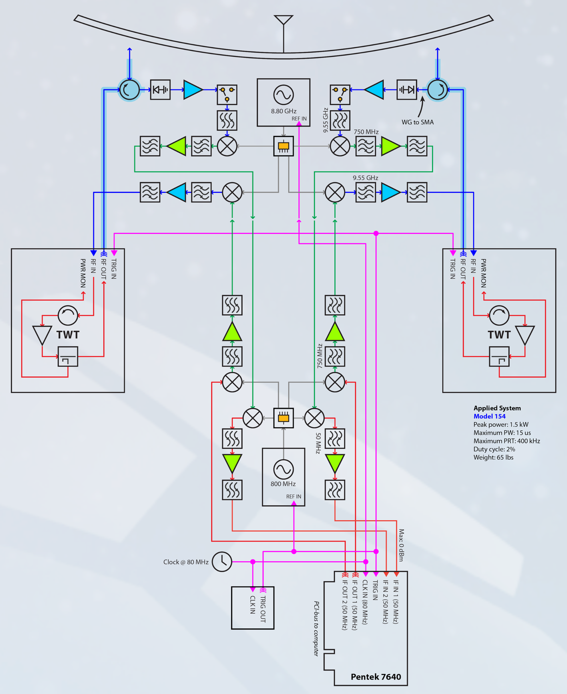
The motivation for a software-defined radar with a digital transceiver and TWT amplifiers is to gain the flexibility of utilizing various waveforms. While using other amplifiers such as Klystron and solid-state amplifiers could also provide this flexibility, they are generally more expensive. The TWT amplifiers offers the same phase coherency feature with the peak powers that is lower than of Klystron's. The average power, however, can be compensated by transmitting longer pulses. The range resolution is mitigated by using pulse compression techniques. With two identical TWT amplifiers, the waveforms for each channel can be different and the hope is to investigate various waveform designs that can *simultaneously compress the pulse and enhance the channel isolation.* For example, two frequency-chirping pulses that are sweeping a range of frequency in the opposite directions, i.e., one that chirps up while the other chirps down, can be used for simultaneous pulse compression and isolation improvement. By utilizing a digital transceiver, we envision to implement a wavetable synthesizer in order to let the transceiver produce arbitrary samples at intermediate frequency (IF), such as sub-pulse phase coded waveforms, inter-pulse phase coded waveforms, and frequency coded waveforms.

3. The PX-1000

We plan to temporally place the PX-1000 radar on the research campus of the University of Oklahoma, which is the southern area of Norman. A radome will be installed to cover the radar as most components are not water proof and to prevent heavy wind load to the pedestal. Installing the radar at the research campus allows for direct comparison test with the OU-PRIME radar, which is a 1-MW polarimetric C-band radar that was acquired recently by OU. In addition, the coverage of the radar overlaps with the Kessler Farm Field Laboratory (KFFL), which has a suite of weather instruments that can be leveraged for instrumental validations.



An artist depiction of the radar with transmitters and the dish installed on the pedestal. The total system weight is estimated to be approximately 550 lbs.



System block diagram

General	
Operating Frequency	9550 MHz
Sensitivity	7 dBZ @ 50 km
Estimated system loss	2 dB
Observation range	> 60 km
Antenna	
Antenna gain	38.5 dBi
Diameter	1.2 m
3-dB beamwidth	1.8°
Polarization	Dual linear
Polarimetric isolation	26 dB
Pedestal	
Contiguous rotation	Yes
Maximum payload	260 lbs
Maximum angular velocity	30°s^{-1}
Pointing precision	0.25°
Angular feedback precision	16 bit

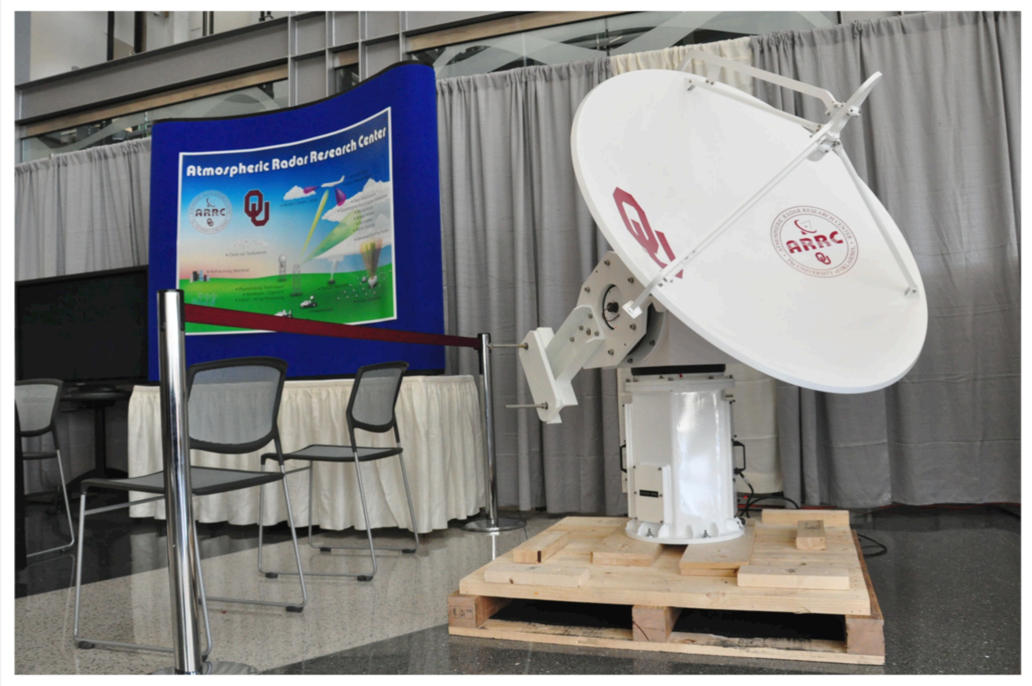
General system characteristics of the PX-1000

3.1 Antenna

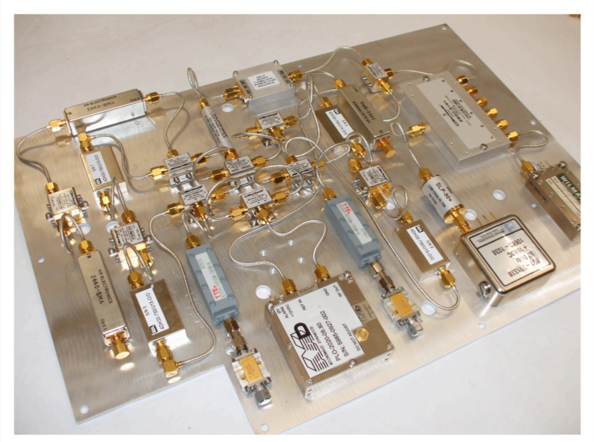
A commercial parabolic reflector dish made by Seavey Antenna was selected for the PX-1000. The antenna dish has a 1.2-m diameter. A dual-linear feed horn with 26-dB isolation between the two channels and the feed is supported by three spars. The 3-dB angular resolution is specified at 1.8° with an isotropic gain of 38.5 dBi. Laboratory measurements have confirmed that these specifications are as expected.

3.2 Pedestal

A light-duty pedestal capable of supporting 260-lb payload is used with the PX-1000 radar. It has an elevation-over- azimuth design and can perform continuous azimuth rotation. It uses a set slip rings for power delivery and Gigabit (1000-Mbps) Ethernet connection from the bottom panel of the pedestal to the equipment above the turntable. During operation, the pedestal can be configured to achieve a maximum angular velocity of 30°s^{-1} and the elevation coverage from -5° to the zenith. The pedestal has a pointing precision of 0.25° and a feedback angular readout of 16-bit resolution for both azimuth and elevation. Communication between the pedestal and the main host is accomplished through a microcontroller.

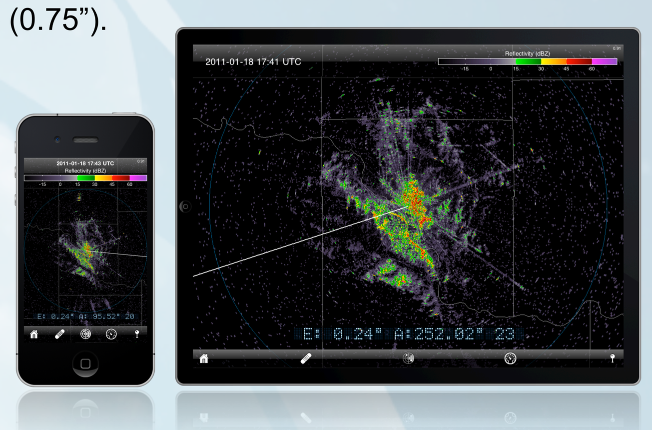


The antenna on the pedestal appeared in National Weather Festival 2010.



Two-stage up-down conversion that will be housed in a 1U enclosure (0.75").

Dual-polarization feed horn.



User interface for mobile devices have been developed. Before the completion of the PX-1000, OU-PRIME data stream is current used for demonstration. Ask presenter for a real demo!

3.3 Transmitter System

Using a digital transceiver system, arbitrary waveform can be generated at the IF providing us flexible waveform design. A two-stage up-conversion system is used to avoid extremely narrow-band bandpass filters at X-band, which is difficult to design and challenging to fabricate. The IF signal from the transceiver is has a carrier frequency of 50 MHz. The IF signal is sent into the first-stage up-converter, which has a mixer to modulate the IF signal with the 800 MHz sinusoid and a bandpass filter to reject other frequency components but retain the IF signal at 750 MHz. Then, the signal is fed into the second-stage up-converter that modulates the signal with the 8800 MHz sinusoid to produce the final radio frequency (RF) at 9550 MHz. A bandpass filter is used to reject another image signal. The RF signal is then amplified by the TWT amplifier to produce a transmit peak power of 1.5 kW for the antenna. The TWT amplifier is capable of producing signal at a maximum duty cycle of up to 2% and pulse width of 15 us. With these parameters, it can accomplish an average power of 30 W. Conservatively, we estimated a total system loss of 2 dB, which results in a system sensitivity of 7-dBZ at 50-km range, which is sufficient for the observations of typical storm events.

3.4 Receiver System

Similar to the transmit subsystem, a two-stage down-conversion is utilized in the receive chain in order to avoid extremely narrow-band bandpass filters at the RF. Of course, the order of mixing the signals is reversed here. A low-noise amplifier with a gain of 26 dB and noise figure of 0.9-1.0 dB is directly attached to the receiving end of the circulator to minimize receiver noise. The RF signal is demodulated with the 8800 MHz in the first-stage down-conversion process. A bandpass filter is used to retain the IF signal at 750-MHz. In the subsequent second-stage down-conversion, the IF signal is demodulated with 800-MHz signal and a bandpass filter to retain the (second-stage) IF signal at 50-MHz. The signal is ingested into the transceiver system in order to discretize the the signal and digitally down-convert the signal to the baseband. The digital samples are in 14-bit resolution providing a theoretical dynamic range of 84-dB. The transceiver host can transport the digital I/Q samples through the Gigabit connection to another host for signal processing and storage. The signal processing component of the PX-1000 will be tasked for a workstation utilizing the computation power of modern computers. The following table provides a summary of the characteristics of transmitter and receiver systems.

Transmitter	
Peak power	1.5 kW
Maximum pulse width	15 us
Maximum duty cycle	2%
Receiver	
Analog-to-digital quantization	Yes
Receive bandwidth	5 MHz
Minimum gate spacing	30 m
Maximum data throughput	320 Mbps

Transmitter and receiver systems

Upcoming Work

Much work are still needed for the PX-1000. We are expecting the system to be functional in 2011. The following are planned for the near future.

- Support structures for mounting equipment on the arms
- Support structure for a radome
- Implementation of signal processing algorithms
  - Dual-pol moment estimation
  - Ground clutter filtering
  - Radar refractivity
- System calibration and validation
- Software development
- Possibility of CASA integration on a campaign basis
  - Adaptive scanning
  - Multi-Doppler analyses
- Waveform design for various pulse compression schemes
- Waveform design for enhancing channel isolation
  - Maintain integrity of dual-pol measurement

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