Advanced Radar Research Center, University of Oklahoma

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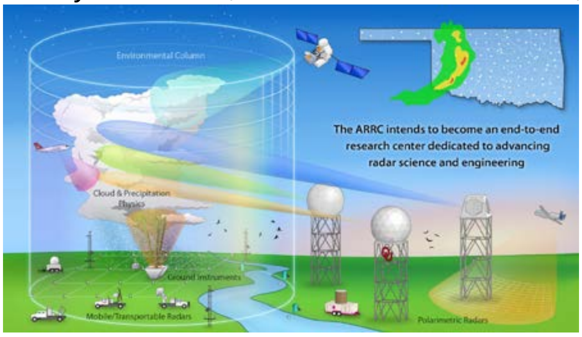
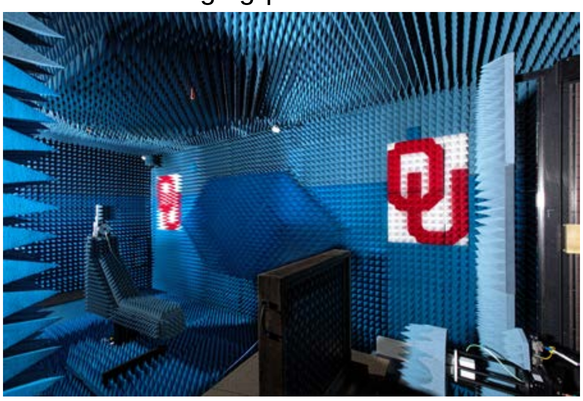
Norman has a long history of radar research, development, and application among the University of Oklahoma (OU), National Oceanic and Atmospheric Administration (NOAA), and local industrial partners. Under the leadership of President Boren, the Strategic Radar Initiative ("Radar Initiative") was started in 2003. Soon thereafter, scientists and engineers from Norman worked together to develop an ambitious plan with the goal of developing a core of resident intellectual leaders and student talent unsurpassed in the world. Under the strategic *Radar Initiative*, existing and new hired faculty members were united in 2004 to form the interdisciplinary Advanced Radar Research Center (ARRC, http://arrc.ou.edu) with the mission of solving challenging radar research problems, preparing students to become the next generation of scientists and engineers, and serving to empower economic growth and development in the field of weather radar. Currently, ARRC has 14 faculty members, four research scientists, eight engineers in radar software, hardware, and mechanical design and development, five administrative staff and more than 100 undergraduate and graduate students, postdocs, and visiting scholars from meteorology, hydrology, and engineering. ARRC is arguably one of the country's largest academic research centers focused on advancements in weather radar.



ARRC's areas of emphasis exist in rapid hardware prototyping, advanced signal processing, antennas, hydrometeorology, clear-air sensing, UAS sensors, severe weather, applied electromagnetics, and microwave engineering, as highlighted in the left figure. ARRC operates a unique and extensive set of instruments to investigate existing areas of study, and to explore new and important research fields. Included in the ARRC facilities is a diverse set of radars of complementary wavelengths, scanning options, and polarimetric capabilities including (1) S-band: Polarimetric Phased Array Radar (PPAR) demonstrator (portable), (2) C-band: OU-PRIME (ground-base, dual-pol, 1MW magnetron transmitter, and 0.5^{o} beam width), SMART Radars (one single-pol and one dual-pol mobile radars), (3) X-band: PX-1000 (compact, portable, dual-pol, solid state, polarimetric radar), RaXPol (mobile, dual-pol, and rapid scan of 180^{o}/sec), AIR (mobile imaging radar with ultra-high temporal resolution) and (4) UHF Wind Profiler: 915 MHz Boundary Layer Radar (clear-air turbulence sensing).

Through the collaborative nature instilled in its members, the ARRC has proven effective at developing synergy between science and engineering in the field of radar. In the National Weather Center and in its extensive laboratory and radar facilities, meteorology and engineering faculty and students work side-by-side to learn from each other and to tackle challenging problems in remote sensing, microwave engineering, and applied electromagnetics. One of the two anechoic chambers in the recently completed Radar Innovations Lab (RIL) is shown on the right figure, which is dedicated to precise antenna characterization and is available for both researchers and students. This interdisciplinary *esprit de corps* has already had a profound effect on both the undergraduate and graduate educational experiences in radar provided to OU students. ARRC also strives to establish and strengthen partnerships with academic, research, and operation institutions and private sectors both nationally and internationally. For example, ARRC



and DPRI and RISH from Kyoto University have had formal partnership to “enhance mutual cooperation and exchange of experience and knowledge toward sustainable capacity-building and the prevention and mitigation of weather-related disasters.”

Research Achievements and Challenges

The ARRC consists of a vibrant group of faculty and students from both engineering and meteorology, focused on solving challenging radar problems and preparing the next generation of students. The technology and science emerging from the ARRC is absolutely on the bleeding edge of the field, much of which is targeted at solving challenging phased array weather radar problems – the key component of future severe weather sensing systems. Additionally, ARRC developed and fielded several sophisticated mobile radar systems along with accompanying signal processing algorithms. These innovative sensing systems with enhanced capability can not only help us better understanding fundamentals of severe storms, but also provide early warning of these hazardous weather events. These can therefore reduce the risk of these weather related disasters. Some examples are provided in the following.

Atmospheric Imaging Radar (AIR)

Fast updates of radar observations on the order of few seconds have been desirable. For example, sequences of radar images, visual observations, and videos in tornadoes and sub-tornado-scale vortices confirm the need for observations with volumetric updates on the time scale of 1 – 10 s, in order to capture their formation and evolution, and their relationship to their parent storm. Additionally, the rapid advection and small scales of the rolls in hurricane boundary layer require

temporal sampling on time-scales of tens of seconds or less to be able to understand their formation and evolution, particularly as they merge and interact with low-level features that occur at different scales and across surface roughness interfaces. In order to improve the temporal resolution on spotlight operation, the single-polarized X-band Atmospheric Imaging Radar (AIR) was developed in the ARRC, as shown on the left figure. AIR operates in a ``floodlight'' mode, utilizing a 25^{o} vertical fan beam on transmit and 36 receiving arrays capable of a 1^{o} beam width using digital beamforming (DBF). In other words, a Range Height Indicator (RHI) of radar measurements can be formed *simultaneously*, similar to taking a picture with an electromagnetic camera. This configuration, combined with mechanical scanning in azimuth, allows the current AIR to collect 180^{o} by 20^{o} volumes in approximately 9 s. The AIR has operated during each of the past three spring convective seasons in the Southern plains (2012-2014), and is scheduled to operate in the Spring of 2015. As of 2014, a total of 8 tornadoes and over 20 supercells have been scanned at ranges as close as 3 km. The 3D view of storms with ultra-high update times offered by AIR demonstrates its ability to accurately determine vertical vortex structure without the concern of advection.

Polarimetric Phased Array Radar Technology

Based on a sound theoretical foundation built over many years of research, the ARRC in collaboration with the National Severe Storms Lab (NSSL) of National Oceanic and Atmospheric Administration (NOAA) built a portable polarimetric phased array radar (PPAR) testbed, which can support both conventional planar arrays (enhanced with dual polarization capability) and cylindrical arrays. The ARRC has designed and built complete polarimetric transmit/receive (TR) modules exploiting the latest advances in gallium nitride semiconductor technology. The project has also developed a diversified waveform generation, transmission and acquisition solution scalable to large arrays. This small-scale demonstrator is a significant achievement; however, a full-scale, higher performance system is the ultimate goal. Consequently, a design study for the full system, funded by OU with Lockheed Martin as a sub-contractor, was completed in early 2014. The full system is expected to exploit latest technologies to perform multiple tasks such as observations of weather and aircraft, including unmanned aerial systems for collision avoidance and target identification.

PX-1000

The PX-1000 is a transportable polarimetric X-band radar that utilizes two solid-state transmitters, and a parabolic reflector with 1.8° beam width. The control, data processing and visualization of PX-1000 are handled by a sleek software termed “iRadar”, developed in the ARRC. Designed, fabricated, and operated by the ARRC, the PX-1000 dual-channel independent transmit chain opens up possibilities of novel waveform diversity for improving polarimetric radar quality. For example, a time frequency multiplexing (MTF) waveform, which was designed to alleviate the limitation of blind range inherited in pulse compression, was tested and demonstrated using PX-1000. In addition to advanced signal processing, development such as spectral analysis and adaptive clutter filtering, real-time acquisition of time-series data also facilitates pulse compression development. The PX-1000 is well suited for long-term field campaigns. For example, PX-1000 was deployed in Oklahoma, New Mexico, Colorado, etc in the US for the study of wind shears, tornadoes, cloud electrification in lightning, and quantitative precipitation estimate in mountainous areas. In addition, PX-1000 was successfully deployed in South Korea near Gwangju for a field campaign of snow precipitation. The added value of a compact X-band radar in mountainous areas is best demonstrated by PX-1000 on the right panel. The area of interest is in the Mineral County, Colorado depicted by yellow circle on the top panel. It is evident from the top panels that the adjacent S-band WSR-88Ds (KGJX) cannot provide the information of surface precipitation due to severe beam blockage, while the strategically located PX-1000 can offer accurate and timely information of the precipitation, as shown on the bottom panel, which was used by the local forecast office and emergence managers for the decision of issuing warning.

Research Challenges and Opportunities

It is recognized in the ARRC that the greatest technological challenges in future weather radar is the seamless integration of polarimetry and phased array in a practical system. Based on the technological foundation built in the past few years, the ARRC is moving forward on the design, fabrication, test, and deployment of the most advanced weather radar in the world. The planned polarimetric phased array radar will have over 7,000 antenna elements per face, each with its own digital transmission and reception circuitry. This “all-digital” design will be the first of its kind in the world, and will allow for optimal use of both polarimetric and phased array technology, solving the primary roadblock for the development of advanced weather radar. In addition, this radar will allow for the first time virtually complete control over the way electromagnetic energy is transmitted into the atmosphere. Within one year of the beginning of the project, it is planned to have a functioning Line Replaceable Unit (LRU), which will be replicated to build the entire radar. Initially started as an internally funded project, congressional authorization will be required in order to support the completion of this ambitious project. Early estimates for the cost of the entire system are near $30M.