6B.1 UNIFIED RESEARCH AND DEVELOPMENT PLAN FOR MULTIFUNCTION PHASED ARRAY RADAR RISK REDUCTION

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ABSTRACT

Multifunction Phased Array Radar (MPAR) is a multiagency initiative to reduce risk associated with designing one type of phased array radar to replace the seven models of mechanically rotating conventional radars currently operated by four Federal agencies. The effort investigates the potential for sharing data from approximately 330 multifunction radars, which would replace about 510 single-purpose installations. The Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) sponsors the Working Group for MPAR and the MPAR Executive Council. The *Unified Research and Development Plan* (R&D Plan) comprises two *major components* which together address the three key risk reduction issues. *Technology Development and Test* addresses the dual polarization and cost reduction, and *Proof of Operational Concepts* addresses multifunctionality. The individual research elements within the major components are prioritized, and a measure of risk is assigned to each element. Some effort was made to align the research elements with the various risk reduction initiatives underway or planned in the R&D community.

1. INTRODUCTION

Multifunction Phased Array Radar (MPAR) is a mulit-agency initiative to investigate the potential for replacing several weather and air surveillance radar systems with one system that could effectively perform the functions of those legacy systems. This paper provides background on the initiative, presents an overview of the *MPAR Unified Research and Development Plan* (OFCM 2011), and shows how collaborative risk reduction efforts facilitated by the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) relate to the R&D Plan and it's major components and research elements.

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2. BACKGROUND

Investigation into employing phased array radar (PAR) technology for weather applications has been underway since at least the mid-1990's (see, e.g., Owen, et al. 1997 and Owen, et al. 1998). Experiments comparing weather information derived from U.S. Navy SPY-1 PAR using the Tactical Environmental Processor to data from nearby WSR-88D radar (Maese, et al. 2000) showed excellent potential for PAR to eventually replace mechanically rotating conventional radar for remote sensing of weather information. The National Research Council, in a study of follow-on technology to the WSR-88D (NRC 2002), recommended exploring adaptive waveform selection and agile beam scanning strategies as well as establishing technical characteristics and costs of PAR systems.

In 2002, the Federal Committee for Meteorological Services and Supporting Research directed the Federal Coordinator for Meteorology to determine specific needs of the agencies, show the benefits of the phased array radar capability, and explore opportunities for expanded participation among other agencies interested in exploring the possibility of using phased array technology to meet both weather and aircraft surveillance requirements. Initial work on these tasks led to the formation of the Joint Action Group for Phased Array Radar Project (JAG/PARP) within the OFCM infrastructure. This group issued the report, *Federal Research and Development Needs and Priorities for Phased Array Radar* (OFCM 2006). Key findings of the report were that 1) a single MPAR network could perform all existing civil radar functions and meet emerging needs not met by existing radar systems, and 2) 334 MPAR units could potentially replace approximately 510 radar units in seven networks at lower life-cycle cost. Appendix D of the report served as the MPAR R&D Plan and provided a detailed timeline with costs, which was organized around three major components: MPAR technology development and test, proof of MPAR operational concepts, and refinement of MPAR network concept.

Meanwhile, a single U.S. Navy SPY-1 PAR antenna, originally built to support fire control systems on Aegis guided missile cruisers, was installed at the National Oceanic and Atmospheric Administration's (NOAA's) National Severe Storms Laboratory (NSSL) in Norman, Oklahoma, and became the National Weather Radar Testbed (NWRT). It has been operating since 2004, collecting data to study the capability of an operational PAR to support weather surveillance.

Agency acceptance of the JAG report led to the formation of a more permanent interagency body, the Working Group for Multifunction Phased Array Radar (WG/MPAR), in 2007. WG/MPAR, which is co-chaired by representatives of the four primary MPAR stakeholder agencies—Department of Transportation/Federal Aviation Administration (DOT/FAA), Department of Commerce/NOAA (DOC/NOAA), Department of Defense (DOD) and Department of Homeland Security (DHS)—has been the focal point for MPAR risk reduction and other associated interagency activities.

In 2008 the National Research Council released the report *Evaluation of the Multifunction Phased Array Radar Planning Process* (NRC 2008), which reviewed the JAG/PARP report and other related planning activities associated with MPAR. The NRC report recommended that the MPAR R&D program be continued and included seven specific recommendations related to the R&D plan appended to the JAG/PARP report.

To better coordinate interagency efforts and resources and to provide oversight and guidance to the WG/MPAR, the MPAR Executive Council (EC/MPAR) was established in 2008. The EC/MPAR is chaired by the Federal Coordinator for Meteorology and includes senior executives from the four stakeholder agencies.

The Second MPAR Symposium (November, 2009), generated an action item calling for the development of a unified research and development plan. Shortly after this symposium, the EC/MPAR, in reviewing and responding to the action items from that event, endorsed the action to develop a unified R&D plan and further stipulated that it include an assessment of risk associated with each element in the plan.

3. MPAR RISK REDUCTION

Phased array radar has been in operational use by military services for air surveillance for decades, and the capabilities of the technology are well understood and appreciated. However, the concept of applying a single phased array system to multiple missions for several Federal agencies is relatively new and introduces risks that must be addressed before procurement of an operational system can begin. WG/MPAR has identified three primary risk reduction issues: dual polarization, cost, and mulitfuctionality.

3.1. Dual Polarization

Dual polarization is a new application for phased array technology and presents new challenges, especially isolating the two polarized signals from each other within the radar electronics and separating the polarizations in the returned signal. In addition, because transmitting and receiving dual pol signals and managing the data introduces additional cost, dual pol implementations must be as simple and cost-effective as possible. Development of dual pol phased array technology is in the early stages. MPAR risk reduction focuses on this specific area in an effort to advance dual pol technology to the point where there is reasonable confidence that it can be implemented to meet requirements cost-effectively.

3.2. Cost

Conventional wisdom had asserted that only national defense requirements could justify the cost of phased array technology and, indeed, all current operational applications are defense related. Significant reductions in cost are needed if phased array technology is to be employed for weather and air traffic management missions. Component technologies from the wireless industry, new packaging techniques, and automated fabrication techniques that eliminate the touch work previously associated with building phased array antennas show potential for reducing cost. In addition, high volume acquisition and a single, consolidated logistics system could help lower the life cycle cost to where a multi-agency acquisition could be justified. MPAR risk reduction investigates the application of technological advances that reduce the cost of a system that meets the needs of the particular weather and surveillance missions in a peacetime, non-tactical environment.

3.3. Multifunctionality

While sharing data across missions (typically extracting weather data from surveillance systems) is not new, using one system as the primary platform for both weather and aircraft surveillance is an unproven concept that introduces significant challenges in system design and operations.

System design always involves compromises, balancing, for example, cost versus performance or perhaps ease of production versus ease of maintenance. However, balancing two different missions, characterized by the need to detect, track, and characterize fundamentally different radar targets, introduces particularly challenging issues. The objective is to hit the design "sweet spot" where the minimum (threshold) requirements for all users are met. This will require users to accept in system that does not meet ideal (objective) requirements in exchange for sharing the cost of the system with three other agencies. Risk reduction for system multifunctionality focuses on determining whether a system that meets the minimum requirements of all participating agencies can be built at acceptable cost.

System design may allow for effective weather and aircraft surveillance as separate functions, but performing both at the same time with a particular system may not be feasible. Operating a shared system to meet multiple missions simultaneously is the ultimate objective of multifunctionality. Success involves a combination of sharing data when it meets the purposes of more than one mission, and "sharing the beam" (i.e., parceling out the time the radar is used exclusively for one mission) when necessary. Risk reduction for operational multifunctionality explores operational concepts to develop methodologies to gather information as efficiently as possible.

4. THE MPAR UNIFIED R&D PLAN

The goal of the proposed R&D strategy is to demonstrate whether an affordable, dual polarized, multipurpose phased array radar system can be developed to replace existing National Weather Service and Federal Aviation Administration (FAA) weather radar and FAA and some Department of Defense (DOD) aircraft surveillance and tracking radar. Three objectives support this goal:

- Technical risk reduction for three key issues: cost, multifunctionality, and satisfactory implementation of dual polarization for weather;
- Establishment of a documented basis for cost comparisons between the MPAR and mechanically rotating conventional radar alternatives for meeting national domestic radar surveillance needs; and
- Formulation of the way forward for continued research, development, test, and implementation, should the MPAR option be selected for future surveillance radar.

The plan is broadly structured around the original R&D plan, Annex D of OFCM 2006. However, that plan was written in an environment where little work on an MPAR-like system was underway, and the NWRT was just beginning to show results. Thus it was based simply on what was needed. The new plan, in an effort to leverage on-going work, takes into account current and planned efforts related to MPAR. As a result, it relates the R&D elements to on-going or planned activities and recognizes the likely timeframes during which that work will be done. Another departure from the earlier plan was to structure the new plan around the first two major components (MPAR Technology Development and Test, and Proof of MPAR Operational Concepts) and delete the third major component (Refinement of MPAR Network Concept). This third component focused on developing and ultimately choosing between X- and C-band radar as a gap filler for the primary S-band MPAR. The decision to eliminate the component related to X– and C-band radar followed the recommendations from the NRC study cited earlier to develop linkages to appropriate organizations within the radar community rather than developing X– and C-band radars.

4.1. Technology Development and Testing

The first major component of the R&D Plan focuses on developing the technology needed for a lower-cost, dual pol PAR and assembling that technology into an operational radar. The Plan lists thirteen tasks that support this component. The first nine tasks relate to "Component Technologies," and include such efforts as developing the transceivers (T/R elements), demonstrating overlapping array beamforming technology, reducing costs, etc. The remaining tasks address the complexities of integrating the components into a "Potential Full Aperture Radar," calibrating

•Dual Polarization - Cross-polar Isolation - Simultaneous/Sequential Implementation - Application in X- and C-Band •Sensitivity - Lab Measurement vs. Technical Requirements - Range Measurements for Characterization •Cost - T/R Unit/Sub-array - Antenna •Frequency •Beam Forming •A-D/D-A Conversion, Data Processing/ Management •Power •Calibration (Lab) •Heat Management •Overlap Sub-array Performance •Stability/Reliability •Adjacent Array RF Interference	•Beam Multiplexing •Array Geometry •Mechanical Issues - Physical Stability - Weight •Individual Radar Architecture •Algorithm Refinement •Refractivity Studies •Spectrum Width Studies •Range-Doppler Ambiguity •Fast Scan Data Studies •Adaptive Transmission •Wind Retrieval, Velocity De-aliasing, Data Quality, Profiling •Spatial Filtering, Multi-channel Clutter Rejection •Staggered PRT •Phase Coding

Table 1. MPAR research elements associated with the Technology Development and Test major component.

and maintaining that radar, managing the data it produces, and integrating it in a network of radars. The R&D plan currently lists 31 research elements in the Technology Development and Test component, shown in Table 1.

4.2 Proof of Operational Concepts

Experiments on the application of PAR technology to weather detection and surveillance has been underway for some time at NSSL using the NWRT. However, a passive array system cannot support the full spectrum of investigation necessary to prove MPAR concepts of operations. Further, while PAR has been used for aircraft surveillance for decades, the effectiveness of a radar that is not optimized specifically for that mission must be investigated. In addition, dual use of data, time-sharing, prioritization, man-machine interface, data management at the network level, command and control, and other operational issues present challenges that must be addressed. The *Proof of Operational Concepts* major component requires continued experimentation with the NWRT augmented by investigations using a radar with a large aperture, dual pol antenna. The Proof of Operational Concepts component includes 41 research elements grouped into 15 research areas (see Table 2).

4.3 Risk Assessment

In reviewing the action items from the November 2009 MPAR Symposium II (see OFCM 2009), the MPAR Executive Council directed the MPAR Working Group to include an assessment of risk for each research element in the new Unified R&D Plan. Similarly, the NRC study recommended that "estimates of the likelihood of success/ failure" be developed. The Working Group developed a methodology that could be applied to an ambitious but modestly-funded interagency risk reduction effort. The methodology recognizes that each element faces both technological and programmatic risk, and seeks to establish an objective, traceable expression for each type of risk. The research element matrix lists for each element the specific research initiatives (projects, studies, etc.) planned or underway that would address that element. Because each initiative is

•Sensitivity - Weather Echo Detection/ Characterization - Target Acquisition/Tracking •Field Calibration •Spectrum Issues •Deployment Issues - Siting - Transition •Multifunctionality - Beam Width/Spoiling Strategies - Scan Pattern Strategies - Data Sharing vs. Dedicated Scans - Frequency/Sensitivity Relationship •Detection Techniques and Issues - Ground Clutter Suppression/Management - WTC Mitigation - Wind Shear Detection - Direct Measurement of Cross-Beam Winds - Bird Detection/ Characterization/Tracking - Smoke and Volcanic Ash Detection/Tracking - Dual Pol Applications	•Air Surveillance - Critical Airspace Surveillance (e.g,. NCR) - Improved Boarder Security - UAS Ground-Based See-and-be-Seen - ADS-B Back-up •Weather Surveillance - Severe Weather Detection and Warning - Initialization of Storm-Scale Models •Man-Machine Interface •Adjacent Array Issues - Target Handoff - Data Seams, Collaboration, Reconciliation, Assimilation •Operational Test - Mission Prioritization - Data Management - Communications - Interface with Operational Systems - Networking Considerations - Operational Data Archival - Overall System V&V •Broad Network Integration of Diverse Radars •Operational Reliability •Maintainability •Societal Impact

Table 2. MPAR research elements associated with the Proof of Operational Concepts major component.

different and encounters its own level of risk, a risk assessment was conducted for each initiative. This approach resulted in a variety of risk levels being assigned to many of the research elements.

4.3.1 Technical Risk

Two aspects of technical risk were considered and contributed to the final technical risk factor—fabrication risk and performance risk. Fabrication risk was a measure of confidence in whether a particular unit could be built, and performance risk was a measure of whether the unit would function as required. Analysts choose from three levels of confidence (essentially high, medium, and low) for both fabrication and performance risk based on written criteria related to current technology, knowledge, and experience. The resulting fabrication and performance risk factors were then summed to generate an overall technical risk factor. In cases where the research element did not involve hardware (e.g., "studies"), the fabrication risk factor was automatically set to the lowest level, and the entire technical risk was based on performance criteria.

4.3.2 Programmatic Risk

Determination of programmatic risk involved essentially the same approach applied for technical risk. It was based on two aspects of risk (funding and contract risk) each of which was assigned a low, middle, or high risk factor based on objective criteria. Funding risk was a measure of the availability of funds for the work and the potential for protecting and sustaining that funding. Contract risk was a measure of the availability of a contract vehicle for the execution of the work. The factors for funding and contract risk were summed to determine the overall programmatic risk.

4.4 Priorities

The NRC study recommended that priorities be assigned to the research elements. The Working Group developed a subjective methodology to express relative priorities of the elements based on very simple definitions. The definitions provided some basis for giving meaning to the priorities and documenting a rationale for their determination. The methodology also recognized the difference between investigating very technical issues and validating basic operational capabilities, and used different definitions of priorities for research elements in the technical and operational components of the plan. Priorities for technical elements were based on whether the "technical impact" was fundamental (high), important (medium), or helpful (low). Priorities for operational elements were based on whether the "operational impact" was essential (high), significant (medium), or useful (low). Priorities were assigned to each research element.

4.5 Costs

The original R&D Plan in OFCM 2006 included estimated costs for each year's work in each major component but did not break out the cost by task. The NRC study recommended providing estimated costs for each task. The most useful cost information available to the Working Group was the actual or estimated cost of the on-going or planned research initiatives. However, many of the research elements would be addressed by more than one research initiative, and all research initiatives were expected to support more than one research element. Dividing up the cost of each initiative among the various research elements it supported would be very complex, and the results were not expect to be of much value. Instead, the cost of each initiative could be provided to yield an overall expected cost. This approach, however, introduced budget sensitivity issues within the Federal agencies supporting the initiatives. Ultimately, the Group decided not to include costs in this version of the plan.

5. CURRENT R&D INITIATIVES

MPAR-related research and development has been underway for some time. In addition to relevant work in industry and academia, the NSSL has been investing several million dollars each year in work with the NWRT and other research efforts while the FAA through the William J. Hughes Technical Center pursued related work with MIT Lincoln Labs (MIT LL). More recently, NOAA and FAA MPAR funding has increased, and R&D is poised to accelerate. This section describes current and planned R&D initiatives, all of which are cited in the Unified R&D Plan as part of the work needed to reduce MPAR risk to an acceptable level.

5.1 NextGen Surveillance and Weather Radar Capability (NSWRC)

FAA and NOAA are collaborating on this FAA program to investigation options for replacing

FAA's terminal air traffic control radars (ASRs) and Doppler weather radars (TDWRs). The focus at this time is on replacing both fleets of radars with an MPAR-like system. With NOAA collaboration, the effort is including consideration of a dual pol solution and eventual replacement of the tri-service fleet of WSR-88D (weather) radars as well as the nation's long range air surveillance radars. Early work has included an updated siting study, a new cost study, and a study of spectrum issues. The program supports MIT LL's on-going work on developing a reduced-cost dual pol panel that can be tiled into a sub-array, and targets antenna maturation, back-end studies, and industry involvement in technology development. Program milestones include an Initial Investment Decision in 2014 and a Final Investment Decision in 2017 leading to deployment of a new system starting in 2023. In it's early stages, NSWRC aligns mostly with the *Technology Development and Test* major component of the MPAR Unified R&D Plan.

5.2 Transportable Dual Pol Radar

Developing a transportable dual pol radar supports many of the research elements in the *Proof of Operational Concepts* major component of the R&D Plan. However, there is a very limited number of efforts underway to develop dual pol panels, and no near-term plans to build multiple panels, tile them into an array, and assemble the array with a suitable back end to become a prototype radar that that can demonstrate operational concepts. There is, however, an opportunity to modify an existing operational radar for dual polarization, which, with minimal additional modification, would provide a relatively large dual pol array with operational capability within about 2 years from the start of work. The project, which is not yet funded, involves modifying a pre-production version on an Army counter-fire radar (EQ-36) to change out the single pol T/R elements for dual pol and make other necessary modifications. It also includes a year of experiments, with deployments from a base at the NSSL to areas of key weather and other operational scenarios.

5.3 Other Initiatives

In addition to the NSWRC program and the EQ-36 project, other work continues on addressing MPAR risk reduction issues. The NWRT, while having certain technological limitations, continues to serve as an effective platform for important weather investigations, and is being upgraded to track aircraft in modes that will support multifunctionality experiments. Aside from investigations involving the NWRT, the NSSL continues to conduct a variety of relevant studies and experiments. NSSL is also supporting development of a dual pol panel employing slot-dipole technology, and the University of Oklahoma is developing a cylindrical dual pol array to investigate the implications of that technology on cross-polar isolation and other challenges. Meanwhile, Purdue University's digital array has provided insights into the potential for digital-at-the-element technology and the challenges of data management in that context.

6. SUMMARY

The NSWRC, actively funded by a collaboration between two of MPAR's participating agencies, is providing the first robust interagency effort to move the MPAR initiative forward. The transportable radar (EQ-36) project, if funded, will provide an excellent *Proof of Operational Concepts* complement to NSWRC's *Technology Development and Test* work. Together, supported by smaller efforts addressing a more limited scope of challenges, these programs will address much of the work presented in the R&D Plan.

The *MPAR Unified Research and Development Plan* is a living document that will be adjusted as research proceeds, new initiatives arise, budgets change, and program timelines flex. The current version is available at http://www.ofcm.noaa.gov/p37-mpar-rd/fcm-p37.htm.

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