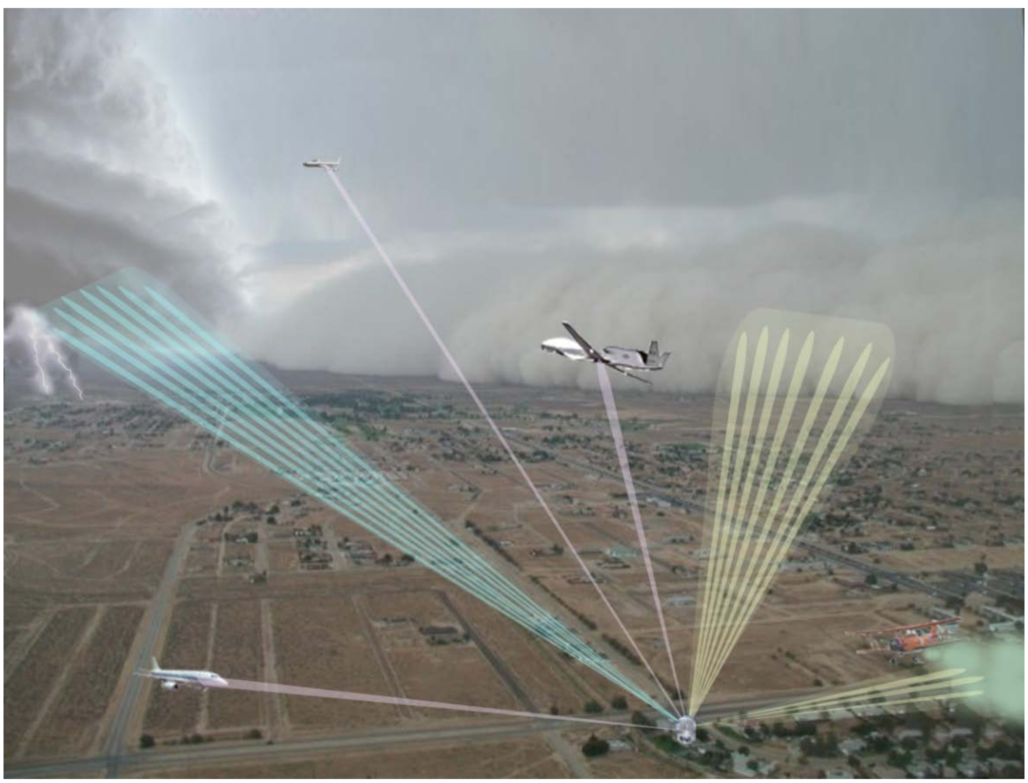
INTERDEPARTMENTAL COMMITTEE FOR
METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH

COMMITTEE FOR COOPERATIVE RESEARCH (CCR)

WORKING GROUP FOR MULTIFUNCTION PHASED ARRAY RADAR (WG/MPAR)

Multifunction Phased Array Radar Unified Research and Development Plan

FCM-P37-2011



June 2011

Office of the Federal Coordinator
for Meteorological Services and
Supporting Research (OFCM)
8455 Colesville Rd, Suite 1500
Silver Spring, MD 20910

MR. JUDSON STAILEY, Executive Secretary
Office of the Federal Coordinator for
Meteorological Services and Supporting Research

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FOREWORD

Surveillance and weather radar capability constitute a critical part of national infrastructure. Whether being used to forecast tornados or flash floods, safely guide aircraft to and from runways at busy airports, or monitor our skies for potential national defense or terrorist threats, radar helps ensure the safety of our citizens and supports the health of our economy. Unfortunately, all our radar systems are aging, and most will become obsolescent within the next 10 years. In addition, because of the large number of different radar systems in use and their age, they are logistically inefficient and incorporate technologies that do not provide an optimal level of service.

The need for a comprehensive radar replacement program has arisen at an opportune time. Technology that has been providing military surveillance solutions for decades is becoming more affordable for civilian applications. Economies of scale, logistical simplicity, and leveraged technology from the wireless industry have combined to make phased array radar an attractive solution for weather and aircraft surveillance, especially if that surveillance can be conducted using one scalable platform. The Office of the Federal Coordinator for Meteorological Services and Supporting Research has been coordinating a risk reduction effort among the departments that use weather and surveillance radar data in their missions: the Department of Commerce (National Oceanic and Atmospheric Administration—NOAA), Department of Transportation (Federal Aviation Administration—FAA), Department of Defense, and Department of Homeland Security. The effort focuses on a potential solution referred to as Multifunction Phased Array Radar (MPAR).

Risk reduction for MPAR is feasible in the context of a comprehensive research and development (R&D) program that seeks to leverage radar development work across the Federal agencies, industry, and academia; discourage investment in redundant work; and encourage collaboration among agencies. This document presents a unified plan for R&D to address the primary risks associated with using a phased array radar for the broadest possible spectrum of weather and aircraft surveillance needs. It organizes the various elements of research that together address the key risk reduction issues: cost, multifunctionality, and dual polarization for weather.

We believe that, with the help of the Working Group for MPAR, we have articulated a comprehensive R&D program in this plan. Nevertheless, we consider it to be a living document that will evolve as work moves forward, risks are retired, and new needs for R&D are revealed. We invite your comments and suggestions.

Samuel P. Williamson
Federal Coordinator for Meteorological Services
And Supporting Research

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1. Introduction and R&D Strategy

This plan presents the research and development (R&D) necessary to support a decision on whether the Nation's future needs for surveillance radar can be met with a network of multifunction phased array radars (MPARs). It supersedes the original MPAR R&D plan, which was published as Chapter 6 and Appendix D of *Federal Research and Development Needs and Priorities for Phased Array Radar* (OFCM, 2006), taking into account the work that has been accomplished since 2006 and incorporating initiatives that are underway or envisioned. It is organized around two major plan components: (1) technology development and testing, and (2) proof of operational concepts. An effort has been made to specify where the research elements may be addressed given our current understanding of the objectives and capabilities of the various research initiatives related to MPAR. However, it is understood that R&D on phased array radar is widespread. Not all relevant research efforts across the phased array radar enterprise have been included, and an ongoing effort must be made to recognize and leverage those solutions that are developed external to the MPAR initiative.

This update of the R&D plan covers the period through 2017, which can be thought of as the risk-reduction period. It assumes that a full-scale development decision will be made in the 2017-2018 timeframe based on the results of this effort, and additional R&D will be conducted leading up to a deployment decision.

After the overview of R&D strategy, including goals and objectives, in Section 1, Sections 2 and 3 present the two major components of the R&D work proposed for the risk-reduction period. Section 4 briefly addresses considerations related to broadening the network concept to include shorter-wavelength radar, and Section 5 presents a timeline for the major R&D activities. Further details of the R&D plan components are provided in Appendix A. Section 6 explains the methodologies employed in assigning risk factors and priorities to the R&D.

1.1 Goal and Objectives

The goal of the proposed R&D strategy is to demonstrate whether an affordable,[1] 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. The following major objectives are to be achieved by the proposed activities:

- 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.

[1] See Item 1 in Section 2 for an explanation of "affordable."

1.2 Leveraging Available Facilities and Ongoing Radar R&D Programs

To the maximum extent possible, the MPAR R&D activities should leverage existing capabilities at Federal and university research laboratories and in industry. Ongoing weather radar R&D, specifically using the National Weather Radar Testbed (NWRT), should be leveraged to substantial advantage. In the near term, the NWRT will play a major role in activities such as testing scanning strategies, time management of radar resources for tracking aircraft and weather, specialized signal processing, and advances afforded by the agile beam. However, the most important aspects of multiple use coupled with digital beamforming will require developmental work in active phased array radar.

Maximum use will be made of available and emerging military technologies, as well as components used by the cellular telephone industry, by interacting with government and industry representatives and tracking announcements of the latest developments and acquisitions in these fields.

1.3 Provisional Concept for an MPAR Network

As a provisional concept for a nationwide, domestic radar network of MPAR units, the OFCM-sponsored Working Group for MPAR (WG/MPAR)[2] envisions a scalable unit architecture usable for both larger, long-range MPAR units and smaller units that would provide low-level coverage, particularly near airports (Terminal MPARs). To meet desired future capability, the network of these two MPAR size variants could be augmented with smaller, shorter-wavelength radars. Development activity related to these smaller radars is proceeding under a separate initiative, but some work related to integrating shorter wavelength radars may be conducted as part of MPAR network enhancement (see Section 4).

The risk-reduction R&D program will solidify requirements for radar units in this network—such as the component radar power-aperture configurations, waveforms, numbers of independent channels, numbers of concurrent beams per channel, and multifunctional tasking—in sufficient detail to define subsequent tasks and subsystem-level specifications for a potential MPAR implementation. In addition, scanning strategy options will be tested and assessed, and resource allocation concepts will be tested with simulations in the laboratory and by using available full-scale arrays.

2. Technology Development and Testing

The proposed Technology Development and Testing component combines recent advances in solid-state technology with application know-how obtained from operating weather surveillance radars and air traffic control radars. Some aspects of the technology have been proven in other applications; other aspects require further development and testing. Whereas the core technology components of MPAR have been demonstrated in military applications, the scale and complexity necessary to support the multifunction capabilities will require concept verification and

[2] WG/MPAR comprises representatives from NOAA, FAA, DOD, the Department of Homeland Security (DHS), and other interested agencies, as well as subject matter experts from academia and laboratories. It serves as the focal point for MPAR risk reduction.

engineering test and evaluation. Another aspect that needs concept testing and refinement is the use of dual-polarization phased array antennas on a multiple-use radar unit.

Key engineering activities will include development and testing of low-cost, critical component technologies such as transmit/receive (T/R) elements, analog and digital beamforming architectures, and efficient processing algorithms. Early work on small dual-polarized panels, emphasizing different technology challenges, will be encouraged and assessed. To ensure progress in addressing critical issues, a concept development and analysis effort, collaboratively funded by FAA and the National Oceanic and Atmospheric Administration (NOAA) and managed by FAA, is being pursued. This effort comprises three major components: phased array antenna maturation, radar back-end definition, and technology assessment/engineering studies. The outcome of this initiative will support the FAA's NextGen Surveillance and Weather Radar Capability (NSWRC) program Initial Analysis Readiness Decision (IARD) and any NOAA investment decisions related to future weather radar initiatives.

Figure 1 summarizes key parameters of the envisioned MPAR approach and provides a rough, subjective indication of the level of technical development challenge each poses.

<table>
<tr><th>Level of Challenge</th><th>Key Technical Parameter</th></tr>
<tr><td rowspan="3">Substantial</td><td>Total Number of T/R Elements per Radar</td></tr>
<tr><td>Dual Polarization</td></tr>
<tr><td>Real-Time Controller Software Complexity</td></tr>
<tr><td rowspan="2">Moderate</td><td>Number of Frequency Channels</td></tr>
<tr><td>Number of Concurrent Receive Beams</td></tr>
<tr><td rowspan="4">Minimal</td><td>Bandwidth (per channel)</td></tr>
<tr><td>T/R Element Peak Power</td></tr>
<tr><td>Size, Weight Constraints</td></tr>
<tr><td>Prime Power Constraints</td></tr>
</table>

Figure 1. MPAR Key Technical Parameters and Subjective Measure of Challenge.

To meet these challenges, the Technology Development and Testing program includes the tasks listed below. The first eight tasks are associated with panels or sub-arrays, while tasks 9-13 pertain to a larger array like the NWRT or other system large enough to function as an operational antenna.

1. Reduce the cost of antenna panels containing T/R elements that provide the requisite power output and multichannel capability to well below $100 per element. To accomplish this reduction, leverage both DOD-sponsored development and commercial sector technology (e.g., the cell phone and wireless industry).

2. Assess the requirements for simultaneous (versus sequential) pulse dual-polarization measurement capability. If the simultaneous capability is required, the impact on T/R-element cost and complexity must be quantified since this would essentially double the number of components (e.g. phase shifters, amplifiers) required per element.

3. Verify and validate the requirements for pulse bandwidth (for example, to support non-cooperative target length measurements or weather radar "rapid scan" modes). Bandwidth requirements are an important factor in the cost of T/R elements, in downstream processing complexity, and in central processing unit requirements.

4. Demonstrate highly digital array technology. For example, "overlapped sub-array" beamforming technology is an effective approach for generating the multiple concurrent receive beam clusters required to meet the timelines of the multiple surveillance functions.

5. Develop and demonstrate transceivers that can perform channel separation, down-conversion, and digitization for the T/R-elements or sub-arrays in a modern phased array radar system.

6. Develop and demonstrate efficient processing architectures for the real-time beamformer. Multiple array outputs must be processed in parallel to form the large number of concurrent beams required to meet user needs. The associated processing load may be very large and will require careful design of both the processing algorithm and the processor configuration.

7. Evaluate alternative array geometries (e.g., planar, cylindrical, hemispherical), element grid geometries (e.g., rectangular, triangular), and "element-thinning" options.

8. Develop a current-technology single-face dual polarized (dual pol), "full aperture" radar that is large enough to support the investigation of challenges that cannot be addressed with a passive array, individual panels, or simulation by computer models. Substantial nonrecurring engineering costs are anticipated for the initial development of this single-face phased array radar, but the technologies should support low-cost production in the future. If possible, integrate a second aperture as a follow-on effort based on the same or other appropriate technology.

9. Use the full aperture radar (see item 8 above) to provide an end-to-end demonstration that component technologies are realizable and that required multifunction surveillance capabilities can be achieved at the projected level of performance. Field tests of this technology will solidify key technical requirements such as number of independent channels and number of concurrent beams per channel.

10. Use the full aperture radar (see item 8 above) with other suitable systems (e.g., NWRT, modified existing system) to demonstrate the operational capability enhancements that can be realized through collaborative surveillance strategies that exploit the unique capabilities of a highly interconnected phased array radar network. Develop and test associated communications, control, and conflict resolution architectures. (This task dovetails with tasks to define the MPAR network concept. See Section 4)

11. Develop and test new aircraft surveillance post-processing techniques that exploit the unique capabilities of phased array radar to meet the performance of legacy air traffic

control search radars. Consider at least the following capabilities: multi-target/multi-mission track modes, height resolution, non-cooperative target identification, and integration with future cooperative target surveillance technologies such as Automated Dependent Surveillance-Broadcast (ADS-B). (This task dovetails with late-stage tasks for proof of MPAR operational concepts. See Section 3.4.)

12. Develop and demonstrate the unique capabilities and associated algorithm/system requirements for MPAR meteorological surveillance using the NWRT and other full-scale antenna systems. (This task dovetails with late-stage tasks for proof of MPAR operational concepts. See Sections 3.1 and 3.3.)
    - Develop and demonstrate the use of MPAR in "warn on forecast" severe weather mitigation concepts and in improved aviation weather diagnosis and forecast services.
    - Develop common, scalable radar technologies that support long-range severe weather surveillance and hydrometeorological applications.

13. Develop, implement, test and optimize field calibration of the radar. The system will need frequent, possibly daily, diagnostic checks for failed elements on both transmit and receive because module failures affect sensitivity of the radar. The system will also need to be calibrated to compensate for temperature gradients across the antenna and also to characterize and maintain gain and phase balances throughout the various T/R modules, digital receivers, and digital beamformer channels. An active phased array polarimetric radar system must also be calibrated to characterize polarization purity, which is very dependent on the scan angle because the two polarizations become less orthogonal as the beam is scanned off broadside. The field calibration system should be configured so as to minimize impact on time resources that can be allocated for radar operations as well as processor utilization in the real-time controller.

2.1 MPAR Component Technologies

Tasks 1 through 5 in the preceding list, which address the cost reduction required in antenna panels having the requisite performance characteristics, are critical to the risk-reduction effort prior to a decision on the Nation's next-generation radar surveillance systems. Antenna technology used for military system applications may not be appropriate, as military applications often require very high performance under difficult conditions (e.g., high output power under environmental extremes). Such systems must operate on military platforms that impose constraints on size, cooling, or prime power. Technologies developed for the commercial wireless industry may be exploited to provide the performance necessary for MPAR units at much lower cost. This task will thus require close collaboration with industry to develop and test affordable antenna technology with multichannel and dual pol capability. Bench tests on the power, efficiency, and polarimetric characteristics of candidate T/R elements and associated sub-array components will provide an early test of many of the assertions made in this plan.

Demonstrations of low-cost module approaches and multi–channel transceivers are needed to validate their ability to support the performance goals of MPAR. This work is underway in laboratories and within industry and academia, and ongoing development will be encouraged and leveraged through the NSWRC and other initiatives. Development and testing on this small scale will enable exploration and resolution of key technical issues, while demonstrating whether the core technologies underlying the envisioned MPAR approach are viable and sufficiently robust.

2.2 Potential Full Aperture Radar

It is not expected that the NSWRC would include a full aperture system prior to IARD in 2014. However, the follow-on procurement effort within FAA could conceivably include a full aperture prototype. In addition, in parallel with NSWRC effort, the modification of an existing production radar (the Army EQ-36) to provide a full-scale dual pol array is being explored. This exploration includes consideration of a number of options with varying flexibility, cost, and risk. The system would be transportable, which would allow for deployment in different weather regimes and types of terrain and near wind farms and other targets of interest.

3. Proof of MPAR Operational Concepts

The second component of the MPAR risk-reduction R&D plan encompasses a set of proof-of-concept experiments. Early-stage, proof-of-concept experiments are being conducted on the NWRT. However, a passive array phased array radar will not support the full spectrum of investigations necessary for proving MPAR operational concepts. A large active array like a follow-on prototype or a modified operational radar system will be necessary, and such a system should be portable to support experimentation in a variety of mission-area regimes.

Early-stage experiments, conducted in parallel with tasks 1 though 8 in the Technology Demonstration and Testing component, will use the existing NWRT in Norman, Oklahoma, and existing shorter-wavelength radars outside the MPAR program. These assets will be used to collect appropriate data to test, validate, and refine key operational concepts for a nationwide MPAR network, including severe weather "warn on forecast" capabilities, simultaneous surveillance of weather and aircraft, and interoperability with shorter wavelength (C-band and X-band) technology. An early goal of the risk-reduction program will be to demonstrate that MPAR units can meet or exceed the capabilities of the systems they would replace. The specification for each system to be replaced will be the basis for comparisons that will be a crucial part of this R&D component.

3.1 Signal Design for Weather Monitoring

Two major complementary technological developments make rapid acquisition of weather radar data possible. These are the transmission and processing of wide bandwidth signals and the agility of a phased array radar beam. Experiments using the NWRT have validated the latter capability: with beam agility, the existing NWRT phased array radar has demonstrated a fourfold decrease in the time required for a full-volume scan, and adaptive scanning has further reduced the time necessary to detect, identify, and track weather echoes. Work in these areas will continue on the NWRT and, as available, a full aperture system will support more advanced testing.

Oversampling and decorrelation of signals in range is a technique known to be effective at large signal-to-noise ratios. This key signal processing technique has been demonstrated with the NWRT. A full aperture system could demonstrate further capabilities that support rapid data access, specifically the capability to process in parallel multiple radials of received data from scatterers that have been illuminated simultaneously by a broader transmit beam.

3.2 Beamforming and Processing

Concept definition studies and subsequent engineering model testing will define the number of concurrent beam modes needed for MPAR units in the envisioned network and the functionality of each beam mode. For example, a fan beam similar to that produced by the current aircraft surveillance radars could be transmitted. The digital beamformer on receive could be programmed to focus simultaneously in a pencil-beam fashion at all the elevations illuminated by the transmit beam. Other possibilities for wideband illumination and pencil-beam reception will be explored. A common feature of these options is that multiple array outputs must be processed in parallel to form the required number of concurrent beams. Substantial theoretical study will be followed by careful design of both processing algorithms and processor configuration.

3.3 Weather Processing Algorithms

A key feature of an electronically steerable phased array radar beam is that it can be used to obtain volumetric data with variable spatial and temporal resolutions. Because positioning of the beam has no associated mechanical inertia, the beam can be moved nearly instantaneously in arbitrary directions. Thus, the volume of interest can be covered by a constellation of data samples of differing data density, similar to the differences in density that occur in a three-dimensional wedge of fruitcake. Certain regions in the target volume can be represented by high-resolution data, while regions of lesser interest are represented by a relative paucity of reflection data.

These adaptive volume coverage patterns can be developed and tested initially on the NWRT. Adjustments of the standard weather processing algorithms can be made to adapt them to the phased array radar environment. The best way to make these adjustments to exploit the unique features of phased array radar will be determined. Moreover, the variable resolution of phased array meteorological radar data presents new and exciting challenges for display and visualization in both research and operational applications. Important early work in this area has been accomplished on the NWRT and will continue on that and subsequent platforms.

3.4 Aircraft Processing Algorithms

Early demonstrations of multifunction capability could use the single, electronically scanned agile beam of the NWRT. Although full-capability non-cooperative aircraft surveillance may require dedicated frequency channels and multiple, concurrent receive beams, the NWRT is being modified to support early proof-of-concept demonstrations. Significant effort is needed to develop and demonstrate efficient multipurpose use.

The Next Generation Air Transportation System (NextGen) emphasizes cooperative surveillance technologies such as ADS-B for air traffic control services. Nevertheless, the FAA has determined that it will retain primary surveillance radar capability within the airport terminal environment. In addition, the Department of Homeland Security (DHS), with assistance from DOD, has the responsibility for detecting, identifying, and tracking non-cooperative and non-compliant aircraft. MPAR could play an important role in providing this complementary capability. While a significant body of knowledge from prior and current military applications supports a high level of confidence in the ability of phased array radar to meet a large portion of DHS requirements, the details of designing, building, and operating MPAR to actually achieve that goal must be addressed.

A full aperture system could be used to refine and demonstrate non-cooperative aircraft surveillance capabilities. MPAR's capability for height resolution and dedicated track modes is expected to provide significant reductions in false-track occurrence and should provide more accurate estimates of target location and track velocity. This part of the risk-reduction plan is intended to validate MPAR as an ADS-B back-up and assess the impact of these enhanced capabilities on non-cooperative target threat assessment.

4. Refinement of the MPAR Network Concept

The previous MPAR R&D plan included a third major component—refinement of the MPAR network concept. This component included, in principle, transitional considerations such as the use of data from the Terminal Doppler Weather Radar, some of the air surveillance radars, and the existing NEXRAD weather radars (WSR-88Ds) until these radars are completely replaced. However, the primary thrust of this R&D component, especially as evidenced by the detailed information in Appendix D of the 2006 OFCM report cited earlier, was studies related to shorter-wavelength (i.e., 3- and 5-cm) radars. Much of the research in this area is being conducted within the Collaborative Adaptive Sensing of the Atmosphere (CASA) program, a National Science Foundation-funded project to investigate the possibility of deploying numerous short-range radars that work together to perform weather surveillance. The National Severe Storms Laboratory, host of the NWRT, is also conducting research on shorter-wavelength radar. It is thought that CASA-like radars could be deployed as gap-fillers in a future MPAR network and to provide data on the boundary layer. The potential for boundary layer observations (especially for wind and humidity) could be important to several key weather initiatives, including "warn on forecast" for severe weather and forecasting initiation of convection to support aviation operations in the NextGen era.

Research on shorter-wavelength radar is important to the overall surveillance enterprise, and the MPAR effort will monitor work in that area, collaborate as appropriate, and prepare as necessary to incorporate data from those sensors into the overall radar network. However, the evolution of radar R&D programs since the 2006 report allows the shorter-wavelength radar R&D to proceed effectively outside the MPAR initiative. Thus the MPAR R&D plan, while it does include a few elements related to 3- and 5-cm radar, does not subsume that research initiative.

5. Timeline and Elements of R&D

The timeline for this plan is based on a combination of ongoing and planned initiatives, as well as milestones on the FAA roadmap, which presents the most challenging development schedule. As MPAR would likely be deployed over an extended time, it should be assumed that R&D would continue during the deployment phase such that each radar would employ the latest technology. However, R&D during the deployment phase is not addressed in this plan. Figure 2 shows the R&D timeline for the NSWRC and major MPAR hardware initiatives and illustrates the interactions among those initiatives. It is not comprehensive in that it does not include some studies, modeling, smaller scale hardware efforts, or potential leveraging of work outside the MPAR initiative.

Figure 2 shows the NSWRC program and potential follow-on programs, along with existing panel development efforts and the potential production radar modification. Should the FAA follow-up effort produce a functioning prototype antenna, investigation of adjacent aperture issues might be made by deploying a modified production radar with the prototype.

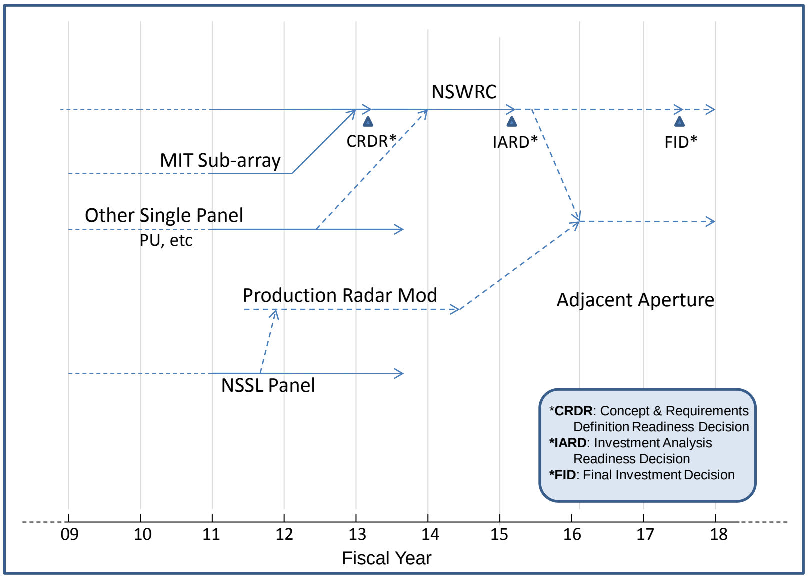

Figure 2. MPAR R&D Timeline. The NSWRC provides the baseline against which major hardware initiatives and planned (solid lines) and potential (dashed lines) interactions among the initiatives are shown.

Appendix A presents the detailed R&D elements within the two major components, relates those elements to the hardware platforms on which the research will be conducted (or the R&D organization at which that element will be conducted) and the respective timeframe of the work, and offers risk factors and priorities for each element. The table in Appendix A is the detailed expression of the MPAR risk-reduction R&D plan. As such, it should be a living document to be updated as new issues arise, work is completed, additional work is planned, outside research that can be leveraged is discovered, and so on.

Risk Assessment and Priorities

6.1 Quantifying Risk

Risk assessment for this plan acknowledges both technical and programmatic risks. The risk in these two areas is expressed on a scale of 1 to 5 as follows:

1 Minimal
2 Low
3 Moderate
4 High
5 Extreme

/For both the technical and programmatic risk assessments, a measure of overall risk was derived by combining the numeric scores for two risk components, which were given equal weight. Each of the component scores run from 0.5 to 2.5, based on answers to specific questions. Thus, the lowest possible overall risk, for either technical or programmatic risk, is 1 (based on a 0.5 score from each component) and the highest is 5 (based a 2.5 score from each component).

Technical Risk. For technical risk the two component scores assess fabrication risk and performance risk. Fabrication risk recognizes that there may be challenges in building the test or demonstration unit to the necessary specifications. Performance risk recognizes that the expected capabilities of a test or demonstration unit may not in fact be realized. Criteria and respective risk scores for technical risk are presented in Figure 3.

Type of Risk	Criterion	Score
Fabrication	The unit (or something very similar) has been built before or well-understood techniques and materials will be used [note: for research elements that do not involve fabrication of hardware (e.g., “studies”), a score of 0.5 is automatically assigned	0.5
	Fabricating the unit involves application of advanced technology, but there is reasonable confidence in the processes	1.5
	Fabrication of this type has never been done before and presents significant challenges	2.5
Performance	Past experience suggests high confidence in positive results; success is likely	0.5
	Objectives present some challenges, but there is reasonable confidence that challenges can be overcome; success is achievable, but not guaranteed	1.5
	Challenges will be difficult to overcome; success would require significant advances in current knowledge and/or technology	2.5

Figure 3. Technical Risk Categories, Criteria, and Respective Scores. Scores for Fabrication and Performance risk are added to determine the overall technical risk on a scale of 1 to 5, 5 being highest risk.

Programmatic Risk. For programmatic risk the two component scores assess the availability of funding and the availability of a contract vehicle. Funding risk recognizes that budgets are limited and that funds are not always in the accounts of those organizations that can spend them. Contract risk recognizes that a vehicle for spending funds is not always readily available, and establishing a contract vehicle is a time-consuming process with inherent risks. Criteria and respective risk scores for programmatic risk are presented in Figure 4.

Type of Risk	Criterion	Score
Funding	Funds are in the budget and secure	0.5
	Funds are in the budget, but at risk	1.5
	There is no funding identified for this work	2.5
Contract	A contract vehicle for this work is available, or work doesn't require a contract	0.5
	Effort is underway to put a contract vehicle in place for this work	1.5
	There is no contract vehicle available or planned for this work	2.5

Figure 4. Programmatic Risk Categories, Criteria, and Respective Scores. Scores for funding and contract risk are added to determine the overall programmatic risk on a scale of 1 to 5, 5 being highest risk.

6.2 Priorities

All elements of this MPAR Unified R&D Plan for the risk reduction period are important, or they would not be included in the list of issues to be addressed. However, some are more important than others, and this distinction allows for the establishment of relative priorities. Assignment of priorities at this point is somewhat subjective, but should be based on a consistent thought process. As a minimum, priorities should be based on general definitions, which help in assigning, giving meaning to, and providing a record of the rationale behind them. Definitions of priorities used in this plan must recognize that the R&D elements range from investigating very technical issues to validating basic operational capabilities. Thus, it is helpful to use more than one definition to accommodate the fundamental differences between considering technical versus operational issues. Figure 5 shows the subjective definitions of the priorities for these two types of issues.

Technical Impact	Operational Impact	Priority
Fundamental	Essential	High
Important	Significant	Medium
Helpful	Useful	Low

Figure 5. Definitions of Priorities Assigned to Elements in Appendix A. Priorities for elements are abbreviated in bold uppercase letters; priorities for subelements are lowercase.

It is important to note that not all R&D elements fall exclusively into the technical or operational category, and this complication introduces additional subjectivity into the process of assigning priorities. No effort has been made to document whether the technical or operational category, or a blend of the two, was used in particular cases to assign priorities. To aid in assigning priorities to the more complex elements (those with subelements), priorities were also assigned to the subelements. To help differentiate between priorities for elements and subelements, priorities for research elements are abbreviated in bold uppercase letters (**H**, **M**, **L**) and lowercase for subelements (h, m, l).

As the several research initiatives support a variety of research elements, the priorities in Appendix A suggest where the emphasis in each research initiative should be placed to satisfy the most important research goals.

APPENDIX A: RESEARCH ELEMENTS

	A	B	C	D	E	F	G
1	***Component***	***Research Element***	***Time Frame***	***Research Initiative***	***Risk Factor***		***Priority***
2					***Technical***	***Programmatic***	
3	Technology Development and Test	Dual Polarization					**H**
4		• Cross-polar isolation	2011-2013	OU Cylindrical Array	4	1	h
5			2011-2012	MIT-LL Sub-array	2	1	
6			2011-2013	Purdue University Panel	4	3	
7			2011-2013	NSSL Panel	3	2	
8			2011-2014	NSWRC Phased-Array Antenna Maturation (PAM)	3	3	
9		• Implementation (simultaneous/ sequential)	2011-2014	NSWRC PAM	3	3	h
10			2011-2012	NSWRC Technology Assessment-Engineering Studies (TE-AS)	3	3	
11		• Application in X- and C- band	2011-2017	NSSL	4	2	l
12			2011-2013	CASA	4	1	
13		Sensitivity					**H**
14		• Laboratory measurement against technical requirements	2011-2012	MIT-LL Sub-array	2	1	h
15			2011-2013	Purdue University Panel	3	3	
16			2011-2013	OU Cylindrical Array	4	1	
17			2011-2013	NSSL Panel	3	2	
18			2011-2014	NSWRC PAM	3	3	
19		• Range measurements for characterization	2012-2014	NSWRC PAM	3	3	h
20		Cost					**H**
21		• T/R Unit/Sub-array	2011-2012	MIT-LL Sub-array	2	1	h
22			2011-2012	NSWRC TE-AS	3	3	
23		• Antenna	2011-2014	NSWRC PAM	3	3	m
24			2011-2013	NSWRC TE-AS	3	3	
25		Frequency (single/multiple)					**M**
26			2011-2014	NSWRC PAM	3	3	
27			2011-2013	NSWRC TE-AS	3	3	
28		Beamforming					**H**

	A	B	C	D	E	F	G
1	***Component***	***Research Element***	***Time Frame***	***Research Initiative***	***Risk Factor***		***Priority***
2					***Technical***	***Programmatic***	
29			2011-2012	MIT-LL Sub-array	2	1	
30			2011-2013	Purdue University Panel	3	3	
31			2011-2013	OU Cylindrical Array	4	1	
32			2011-2013	NSSL Panel	3	2	
33			2011-2014	NSWRC PAM	3	3	
34		A-D/D-A Conversion, Data Processing/Management Considerations					**H**
35			2011-2012	Purdue University Panel	4	3	
36			2011-2014	NSWRC PAM	3	3	
37			2011-2013	NSWRC TE-AS	3	3	
38		Power					**M**
39			2011-2014	NSWRC PAM	3	3	
40			2011-2012	MIT-LL Sub-array	2	1	
41			2011-2013	NSWRC TE-AS	3	3	
42		Calibration (Lab/Test)					**M**
43			2011-2012	MIT-LL Sub-array	2	1	
44			2011-2013	Purdue University Panel	3	3	
45			2011-2013	OU Cylindrical Array	4	1	
46			2011-2013	NSSL Panel	4	2	
47			2011-2014	NSWRC PAM	3	3	
48			2011-2013	NSWRC TE-AS	2	3	
49		Overlap Sub-array Performance					**M**
50			2011-2012	MIT-LL Sub-array	2	1	
51			2011-2014	NSWRC PAM	3	3	
52			2011-2013	NSWRC TE-AS	3	3	
53		Heat Management					**M**
54			2011-2012	MIT-LL Sub-array	2	1	
55			2011-2013	NSWRC TE-AS	3	3	
56		Stability/Reliability					**M**
57			2011-2013	NSWRC TE-AS	3	3	
58		Adjacent Array RF Interference					**H**

	A	B	C	D	E	F	G
1	***Component***	***Research Element***	***Time Frame***	***Research Initiative***	***Risk Factor***		***Priority***
2					***Technical***	***Programmatic***	
59			2011-2013	NSWRC TE-AS	3	3	
60		Beam Multiplexing					**M**
61			2011-2017	NWRT	1	1	
62			2011-2017	Portable Radar	3	3	
63		Array Geometry					**M**
64			2011-2014	NSWRC PAM	3	3	
65			2011-2013	OU Cylindrical Array	4	3	
66		Mechanical Issues					**L**
67		• Physical Stability			0	0	l
68		• Weight			0	0	l
69		Individual Radar Architecture					**H**
70			2011-2014	NSWRC BED			
71		Algorithm Refinement					**M**
72			2011-2017	NSSL	2	1	
73		Refractivity Studies					**L**
74			2011-2017	NSSL	1	1	
75			2011-2017	OU	1	1	
76			2011-2017	NCAR	1	1	
77			2011-2017	NWRT	1	1	
78			2011-2017	Portable Radar	3	3	
79		Spectrum Width Studies					**M**
80			2011-2014	NSWRC PAM	2	3	
81		Range-Doppler Ambiguity					**M**
82			2011-2017	Portable Radar	3	3	
83		Fast Scan Data Studies (display, assimilation, storm detection & dynamics, clutter filtering, correlation tracking)					**H**
84			2011-2017	NSSL	2	1	
85			2011-2017	NWRT	2	1	
86		Adaptive Transmission (PRTs, sampling, revisit times)					**M**
87			2011-2017	NSSL	2	1	
88			2011-2017	NWRT	2	1	
89			2011-2013	NSWRC TE-AS	3	3	

	A	B	C	D	E	F	G
1	***Component***	***Research Element***	***Time Frame***	***Research Initiative***	***Risk Factor***		***Priority***
2					***Technical***	***Programmatic***	
90		Wind Retrieval, Velocity De-aliasing, Data Quality, Profiling					**M**
91			2011-2017	NSSL/OU	1	1	
92			2011-2017	NWRT	1	1	
93			2011-2017	Portable Radar	3	3	
94		Spatial Filtering—Design of Receivers, Multi-channel Clutter Rejection					**M**
95			2011-2017	NSSL	2	1	
96		Staggered PRT					
97			2011-2017	NSSL	2	1	
98			2011-2017	NWRT	2	1	
99		Phase Coding					**M**
100			2011-2017	NSSL	2	1	
101			2011-2017	NWRT	2	1	
102	Proof of Operational Concepts	Sensitivity					**H**
103		• Weather echo detection/ characterization	2011-2017	Portable Radar	3	3	h
104		• Target acquisition/tracking	2011-2017	Portable Radar	2	3	h
105		Field Calibration					**H**
106			2011-2017	Portable Radar	3	3	
107		Spectrum Issues					**H**
108			2011-2017	Portable Radar	3	3	
109		Deployment Issues					**M**
110		• Siting	2011	MIT-LL Study	1	1	m
111		• Transition					m
112		Operational Reliability					**M**
113			2011-2017	Portable Radar	3	3	
114		Maintainability					**M**
115			2011-2013	NSWRC TE-AS	3	3	
116		Multifunctionality					**H**
117		• Beam width/spoiling strategies	2011-2017	NWRT	2	1	m
118			2011-2017	Portable Radar	3	3	

	A	B	C	D	E	F	G
1	**Component**	**Research Element**	**Time Frame**	**Research Initiative**	**Risk Factor**		**Priority**
2					**Technical**	**Programmatic**	
119		• Scan pattern strategies	2011-2017	MIT-LL Study	1	1	h
120			2011-2017	NWRT	2	1	
121			2011-2017	Portable Radar	3	3	
122		• Data sharing vs. dedicated scans	2011-2017	NWRT	2	1	h
123			2011-2017	Portable Radar	3	3	
124		• Frequency/sensitivity relationship	2011-2013	NSWRC TE-AS	3	3	h
125		Detection Techniques and Issues					**H**
126		• Ground clutter suppression/management	2011-2017	NWRT	2	1	h
127			2011-2017	Portable Radar	3	3	
128		• Wind generator interference/mitigation	2011	DHS Study	3	1	h
129			2011-2017	Portable Radar	3	3	
130				Naval Sea Tests	2	5	
131		• Wind shear detection	2011-2017	NWRT	2	1	h
132			2011-2017	Portable Radar	3	3	
133		• Direct measurement of cross-beam winds	2011-2017	NWRT	2	1	m
134			2011-2017	Portable Radar	3	3	
135		• Detection/ characterization/tracking of birds	2011-2017	NWRT	3	1	l
136			2011-2017	Portable Radar	3	3	
137		• Detection/tracking of volcanic ash and smoke	2011-2017	NWRT (Smoke)	2	1	m
138			2011-2017	Portable Radar (Smoke, Ash)	3	3	
139			2014-2015	Model Studies with 88D data (Smoke, Ash)	3	3	
140		• Dual polarization applications					h
141		o Precipitation rate	2011-2017	Portable Radar	3	3	
142		o Precipitation type	2011-2017	Portable Radar	3	3	
143		o Aircraft characterization	2011-2017	Portable Radar	4	3	
144		o Solid object ID and characterization (birds, smoke, volcanic ash)	2011-2017	Portable Radar	4	3	

	A	B	C	D	E	F	G
1	***Component***	***Research Element***	***Time Frame***	***Research Initiative***	***Risk Factor***		***Priority***
2					***Technical***	***Programmatic***	
145		o Lightning detection	2011-2017	Portable Radar	4	3	
146		Air Surveillance					**H**
147		• Critical airspace surveillance (e.g., NCR)	2011-2017	Portable Radar	3	3	h
148			2011-2017	NWRT	2	1	
149		• Improved border security	2011-2017	Portable Radar	3	3	h
150		• UAS Ground-based sense-and-be-seen	2011-2017	Portable Radar	3	3	h
151		• ADS-B backup	2011-2017	Portable Radar	4	3	h
152			2011-2017	NWRT	2	1	
153		Weather Surveillance Demo					**H**
154		• Severe weather detection and warning	2011-2017	NWRT	2	1	h
155			2011-2017	Portable Radar	3	3	
156		• Initialization of storm-scale forecast models	2011-2017	NWRT	2	1	h
157			2011-2017	Portable Radar	4	3	
158		Man-Machine Interface					**M**
159			2011-2017	NWRT	2	1	
160		Adjacent Array Issues					**M**
161		• Target handoff					m
162		• Data seams, collaboration, reconciliation, assimilation					m
163		Operational Test					**M**
164		• Mission Prioritization	2011-2017	NWRT	2	1	h
165			2011-2017	Portable Radar	3	3	
166		• Data management	2011-2017	NWRT	2	1	m
167			2011-2017	Portable Radar	3	3	
168		• Communications					m
169		• Interface with operational systems					l

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1	***Component***	***Research Element***	***Time Frame***	***Research Initiative***	***Risk Factor***		***Priority***
2					***Technical***	***Programmatic***	
170		• Networking considerations					l
171		• Operational data archival					l
172		• Overall system V&V					m
173		Broad Network Integration of Diverse Radars					**L**
174			2011-2017	NSSL	3	1	
175			2011-2013	CASA	4	1	
176		Societal Impact					**M**
177			2011-2017	NSSL	2	1	

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