”Multifunction Phased Array Radar (MPAR) Automatic Dependent Surveillance – Broadcast (ADS-B) Backup Requirements” Study Synopsis

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This report provides a synopsis of a study that was carried out for the Federal Aviation Administration by MIT Lincoln Laboratory to examine the ability of the Multifunction Phased Array Radar (MPAR) to serve as a backup to Automatic Dependent Surveillance – Broadcast (ADS-B).

Introduction

In 2005, the Federal Aviation Administration asked Lincoln Laboratory to evaluate technology issues, operational considerations and cost-trades associated with the concept of replacing current national air traffic and weather surveillance radars with a single network of multifunction phased array radar. Based on this request, Lincoln Laboratory described a conceptual MPAR high-level system design, and carried out initial development and testing of critical subsystems. This work has suggested that MPARs can be cost-effective replacements for existing, mechanically scanned operational air traffic and weather surveillance radars [1, 2, 3].

The FAA’s air traffic control surveillance architecture for the future is based on the application of Automatic Dependent Surveillance via Broadcast (ADS-B) technology. However, in order to have a robust ATC system, provisions must be made to deal with failure modes of ADS-B (e.g., malfunction of the ADS-B avionics in a given aircraft, loss of GPS capability, etc.). The FAA’s ADS-B backup strategy study concluded that current primary surveillance radar networks should be maintained to guard against single aircraft avionics loss, and that roughly half of today’s secondary radars should be retained to allow for continued full-capability ATC services in the event of a loss of GPS signal.

The study addressed the use of MPARs for ADS-B backup. The approach employed was to first identify the required aircraft and weather surveillance goals, and then examine various alternative networks for achieving this surveillance performance. Design tradeoffs were examined to determine the required power and number of phased-array elements for the en route and terminal MPARs, and scan strategies were developed meet the performance goals. It was found that designs could be devised with provide comparable accuracy to ADS-B for aircraft surveillance, and much better update rate and volume coverage for weather surveillance.

Surveillance Goals

The required surveillance performance for ADS-B is shown in Table 1 [4]. The position accuracy is shown as a function of Navigation Accuracy Category – Position (NAC_P), and the update interval is shown as a function of airspace.

Table 1. ADS-B Required Surveillance Performance

Parameter	Airspace	Value
Position Accuracy	**All**	**35-100' (95%) NACp = 9*** **100-300' (95%) NACp = 8** **300-600' (95%) NACp = 7**
Update Interval	**Terminal** **High Rate En Route**	**3 sec (95%)**
	En Route	**6 sec (95%)**

$^*NAC_P$ = Navigation Accuracy Category (position).

Figure 1 shows the required MPAR azimuthal resolution vs range as a function of NAC_P, assuming a 20:1 cross-range resolution improvement with monopulse processing. It can be seen that for NAC_P = 7, a 1° beam can satisfy the aircraft surveillance requirement out to nearly 120 nm range, and a 2° beam can satisfy the requirement out to nearly 60 nm range.

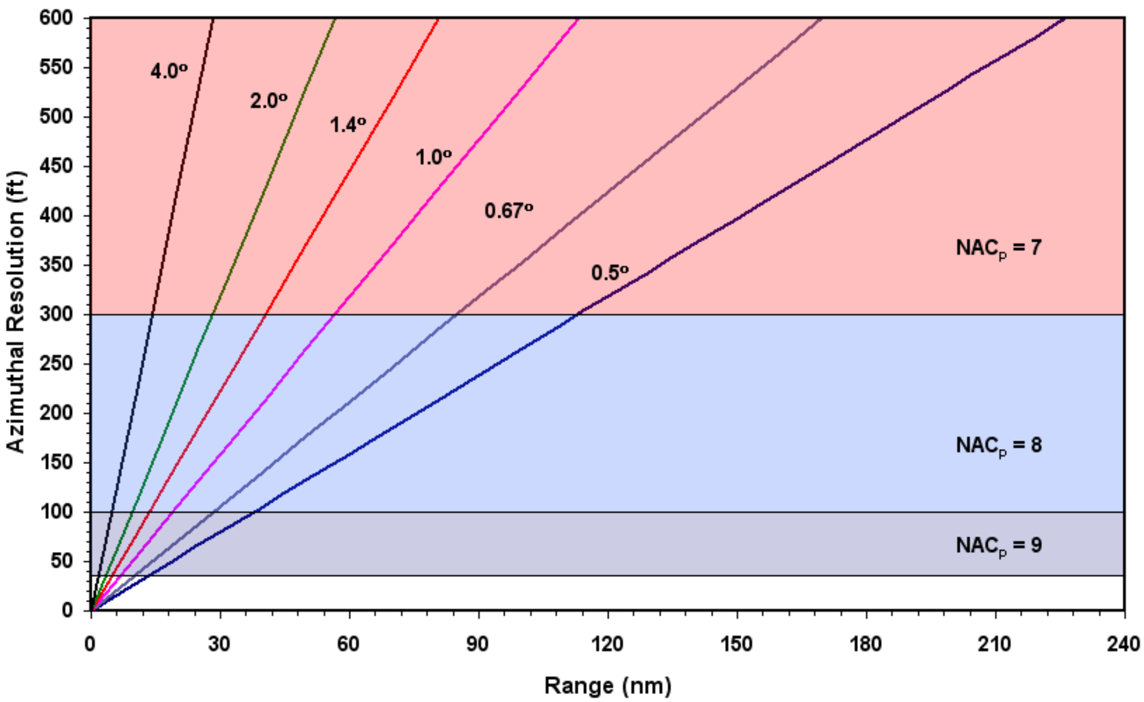


Figure 1. MPAR Azimuthal Resolution vs Range (20:1 monopulse)

Given the above considerations, the aircraft and weather surveillance goals that were established for en route and terminal MPAR are shown in Table 2. These goals improve aircraft surveillance to be comparable with ADS-B, and maintain or improve weather surveillance.

Table 2. MPAR Aircraft and Weather Surveillance Goals.

	Sensitivity	Coverage		Angular Resolution		Update Rate
		Range	Altitude	Az	El	
Terminal Surveillance	**1 m^2**	**60 nm**	**20,000'**	**2.0°**	**5.0°**	**3 s**
En Route Surveillance	**2.2 m^2**	**200 nm**	**60,000'**	**1.0°**	**2.0°**	**6 s**
Terminal Weather	**0 dBZ**	**60 nm**	**15,000'**	**1.4°**	**2.0°**	**60 s**
En Route Weather	**0 dBZ**	**120 nm**	**60,000'**	**1.0°**	**1.0°**	**300 s**

Network Configuration

Having determined the MPAR performance goals, the next step was to determine the network configuration. The proposed approach is shown in Figure 2, in which there are a set of long-range (i.e., 250 nm) MPARs to guard the CONUS border and a larger number of medium-range MPARs to provide coverage of the interior en route airspace.

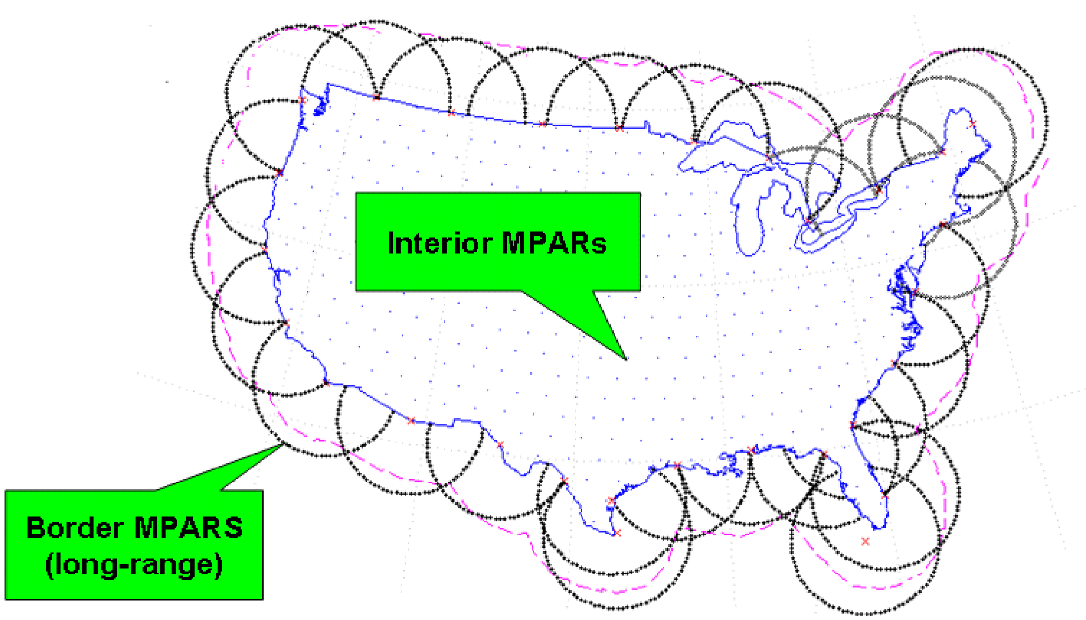


Figure 2. Proposed MPAR network configuration.

Figure 3 shows the terrain coverage at 18,000’ for the en route MPARs for various ranges. It can be seen from the figure that 120 nm spacing is adequate for en route surveillance, and requires a modest number of 155 sensors.

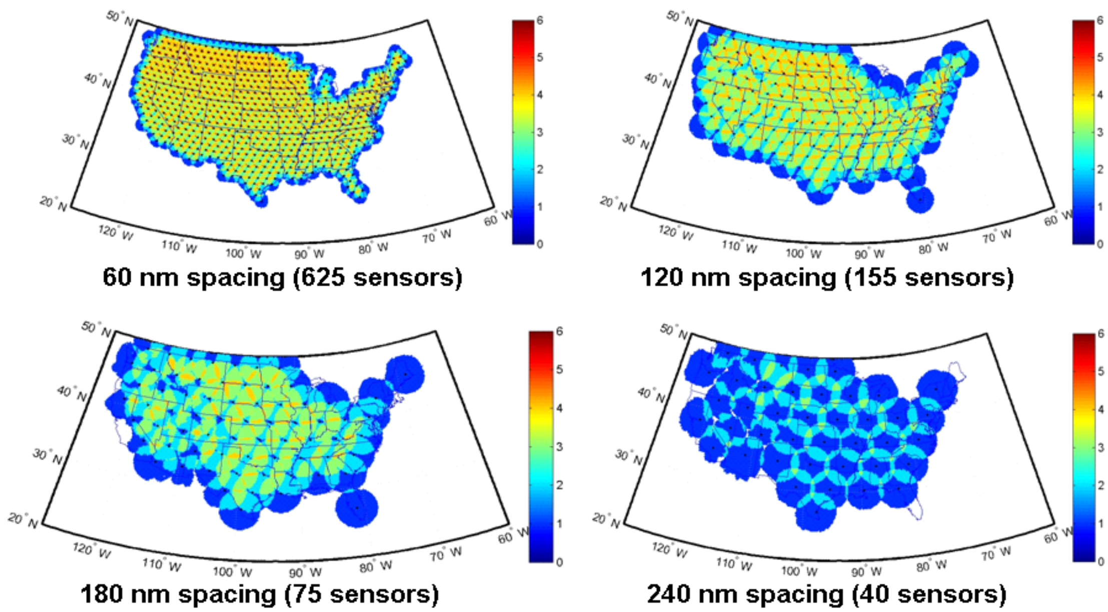


Figure 3. En Route MPAR terrain coverage at 18,000’ for different ranges.

Phased-Array Elements

The next consideration in the study was the power per phased-array element and the total number of elements required. Figure 4 shows the aircraft surveillance range vs power per element for en route and terminal MPARs for various beam widths. It can be seen from the figure that 2 W per element for En Route MPAR surveillance (1° beam, 120 nm range) and 5 W per element for Terminal MPAR surveillance (2° beam, 60 nm range) meet the design requirements.

Figure 5 shows an example of one possible tradeoff between element power and weather sensitivity. In this example, the minimum detectable weather signal in dBZ is shown vs range for NEXRAD, en route MPAR, TDWR and terminal MPAR. In the case of the MPAR designs, it is necessary to employ short uncompressed pulses at short range to get the necessary range resolution and longer compressed pulses at longer ranges to get the necessary sensitivity. The transition between uncompressed and compressed pulses occurs at the discontinuity in minimum detectable signal in each case. For this example, the en route MPAR requires 2.5 W per element for a 1° beam and the terminal MPAR requires 10 W per element for a 2° beam. These beam widths correspond to 20,000 elements per face for en route MPAR and 5,000 elements per face for terminal MPAR.

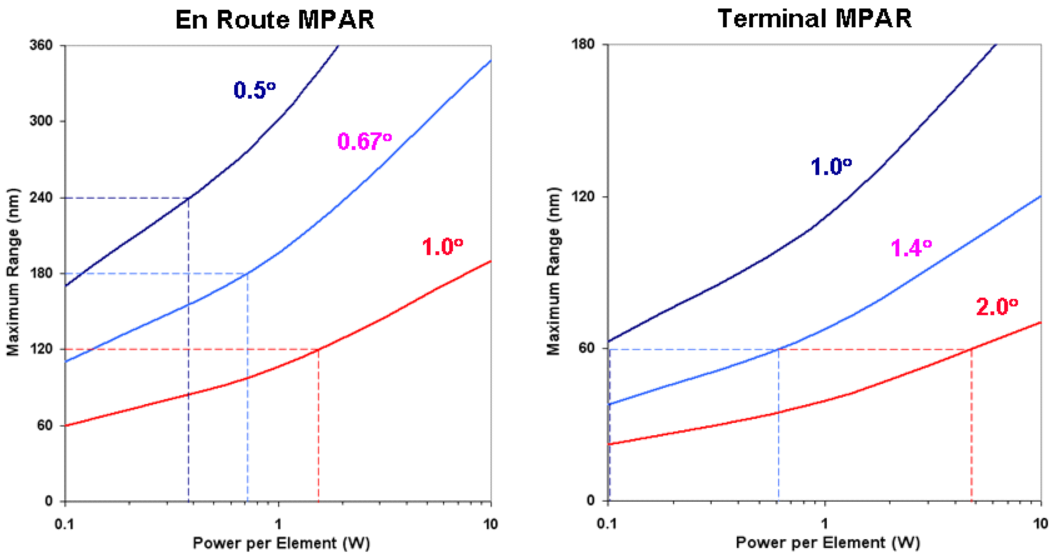


Figure 4. Aircraft surveillance range vs power per element.

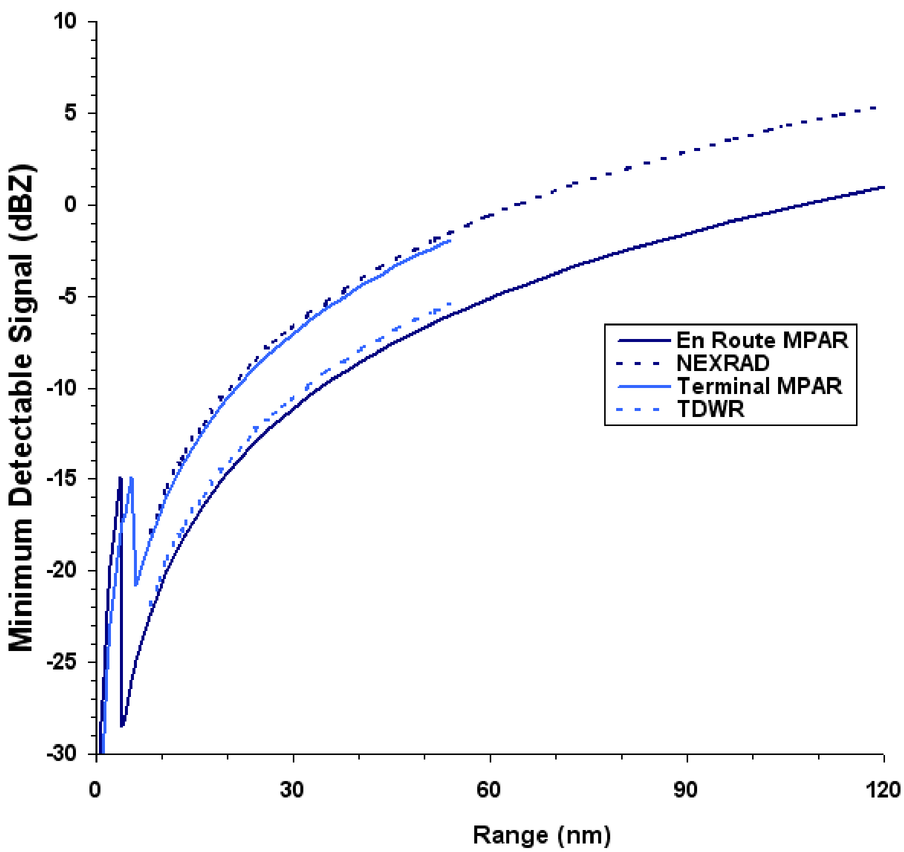


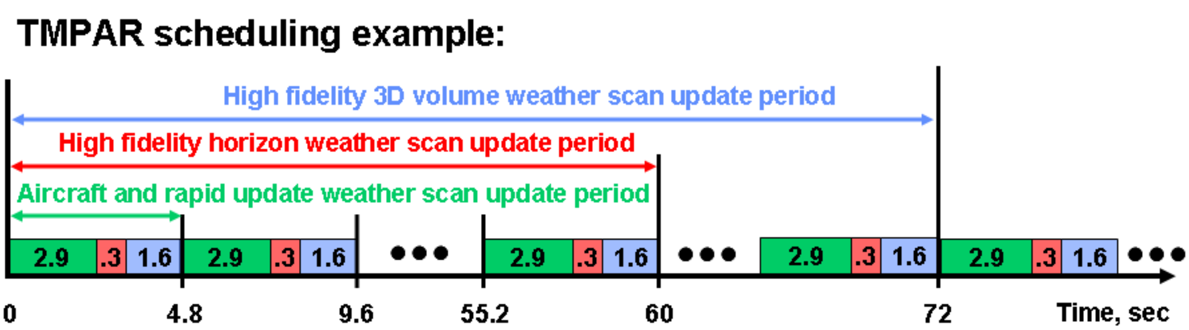
Figure 5. Example of weather sensitivity tradeoff.

MPAR Scan Designs

The final study task was to design scan strategies for en route and terminal MPARs. Of the two cases, the terminal MPAR scan strategy is the more challenging because of the need to check for wind shear hazards such as microbursts every 60 seconds. The approach that was adopted is illustrated in Figure 6. In the case of terminal MPAR, it is necessary to carry out aircraft surveillance every 4.8 seconds in order to be comparable to existing airport surveillance radars.

However, it is possible to carry out the necessary aircraft surveillance in roughly 2.9 seconds by employing a multiple-beam design developed at Lincoln Laboratory. This leaves the remainder of the 4.8 seconds available to carry out portions of the weather scans, including a horizon scan for wind shear hazards every 60 seconds and a 3-D weather volume scan for storms every 72 seconds. Although this scan strategy does not meet the 3 second terminal aircraft surveillance update rate, it is likely that reducing the PRI (Pulse Repetition Interval) and number of pulses for higher elevation scans would likely meet this goal.

A similar analysis was applied to the en route MPAR scan design. In this case, the 6 second aircraft surveillance goal is met, and the horizon and 3-D weather update rates are 120 seconds. This represents a significant improvement over existing en route weather scans. Another advantage for both the en route and terminal MPAR weather scans is that the beams are contiguous in the vertical dimension, whereas the NEXRAD and TDWR vertical beams are not contiguous and relatively widely spaced.



Function	Terminal	En Route
Aircraft "Track While Scan"	4.8 s	6.0 s
High Fidelity Horizon Weather Scan	60 s	120 s
High Fidelity 3D Volume Weather Scan	72 s	120 s

Figure 6. MPAR scan designs.

Conclusions

This study examined the feasibility of using multifunction phased-array radars as a backup for ADS-B. It was found that a network consisting of approximately 30 long-range (240 nm) MPARS or existing ASRR-4s for border protection, 155 medium-range (1° beam, 120 nm) en route MPARs and 200 short-range (2° beam, 60 nm) terminal MPARs would provide the necessary coverage for CONUS.

The accuracy of the MPARs would be comparable to ADS-B (for $NAC_P = 7$) for aircraft surveillance, and that the weather surveillance would be much superior to existing weather radars by offering both higher update rate and contiguous beams.

Scan strategies were also devised for both the en route and terminal MPARs. The terminal strategy meets the existing aircraft update rate of 4.8 seconds but could likely meet the 3 second terminal ADS-B update rate with reduced PRI and pulses aloft. The en route strategy meets the 6 second ADS-B aircraft update rate with 120 second 3-D weather updates.

The recommended MPAR radar characteristics for the en route MPAR is 20,000 elements per face yielding a 1° beam, and 2.5 W per element for 120 nm aircraft and weather surveillance range. This design yields good performance for both aircraft and weather surveillance. The recommended terminal MPAR configuration is 5,000 elements for a 2° beam, and 10 W per element for 60 nm aircraft and weather surveillance range. This design yields good aircraft surveillance accuracy and acceptable weather resolution.

References

[1] Weber, M.E. *et al*, "Multi-purpose Phased Array Radar For U.S. Civil-Sector Surveillance Needs", *32nd Conf. on Radar Meteorology*, Albuquerque, NM, Amer. Meteor. Soc., 2005.

[2] Weber, M.E *et al*, "Multifunction Phased Array Radar: Technical Synopsis, Cost Implications and Operational Capabilities", *23rd Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, San Antonio, TX, Amer. Meteor. Soc., 2007.

[3] Herd, J.S. *et al*, "Preliminary Multifunction Phased Array Radar (MPAR) Preprototype Development", *23rd Conf. on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology*, San Antonio, TX, Amer. Meteor. Soc., 2007.

[4] "Automatic Dependent Surveillance – Broadcast (ADS-B) Out Performance Requirements to Support Air Traffic Control (ATC) Service", Docket No. FAA-2007-29305, Notice No. 07-15, October 2, 2007.