4 TECHNICAL ASPECTS OF MEETING SURVEILLANCE RADAR NEEDS

Despite the inherent multifunction capability of agile-beam MPAR, meeting the varied user needs described in Chapter 2 with a single radar poses technical challenges. For example, weather radars use high-power, narrow "pencil beams," which scan relatively slowly in azimuth and elevation to provide accurate measurements of precipitation and winds. By contrast, aircraft surveillance radars typically use much broader, fan-shaped radar beams that scan rapidly to provide the frequent target echoes necessary for reliable tracking. Figure 4-1 illustrates these contrasting surveillance strategies. Supporting these two surveillance applications concurrently with one MRCR unit would be extremely challenging technically. This chapter will show how MPAR technology already in use for military radar systems can provide the capability to conduct both strategies (and others) concurrently.

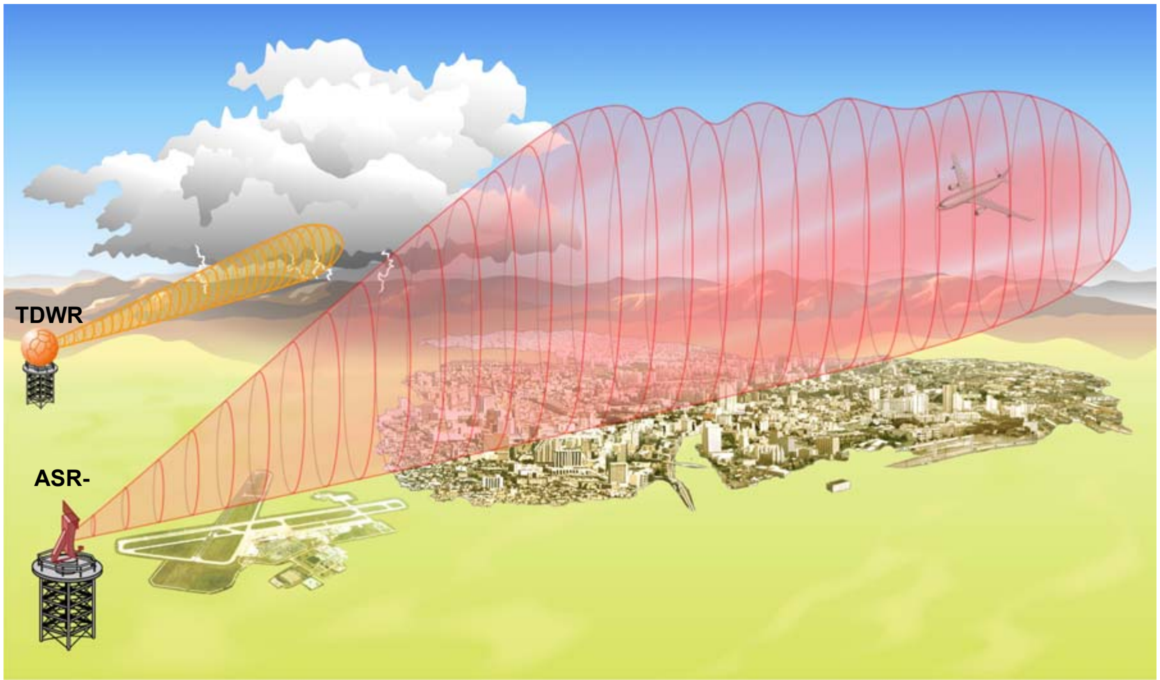

Figure 4-1. Contrasting surveillance strategies.

Different beam patterns are required for aircraft and weather surveillance. To define the three-dimensional structure of storms, weather radars employ narrow pencil beams that are scanned in azimuth and elevation. Aircraft surveillance radars use broad beams that are fan shaped in elevation. The beam is scanned in azimuth only at a high rate to provide the rapid sequence of target echoes needed to track fast-moving aircraft. This artist concept shows a Terminal Doppler Weather Radar (TDWR) and an airport surveillance radar (ASR), both located in the immediate vicinity of an airport outside an urban area.

A second technical consideration is the significant interest within the user community for more continuous surveillance of boundary layer weather phenomena (for both severe and non-severe weather events) and for better tracking of aircraft at low altitudes. The significant enhancements in weather diagnosis and forecast capability that would accrue from improved boundary layer measurements have motivated the NSF-funded Collaborative Adaptive Sensing of the Atmosphere (CASA) project. CASA is developing short-wavelength, electronically scanned radar technology as an enabler for a proposed dense network of atmospheric boundary layer sensors. While CASA continues to move toward its objectives as a separate research activity, the risk reduction R&D proposed here for MPAR as a national surveillance radar option would complement the CASA project. Development of a scalable active array architecture will provide a common technology base for both an MPAR network for long-range surveillance and a dense network of boundary layer–observing phased array radars.

This section outlines the high-level technical implications for MPAR to serve multiple surveillance applications. It lists engineering and implementation issues associated with these implications, which the R&D program described in chapter 6 is intended to address. Appendix B (Weber et. al. [2005]) provides a more detailed discussion of these issues.

4.1 Radar Configuration

The major parameters of an MPAR capability to meet the Federal agency needs presented in chapter 2 can be readily articulated. The angular resolution (1^o) required to measure weather phenomena of interest dictates the size of the antenna aperture. As shown in appendix B, a radar unit consisting of four planar antenna faces, each composed of approximately 20,000 T/R elements, can provide this resolution. To provide adequate power for detecting aircraft targets at long range and for certain weather phenomena, each T/R element must be capable of radiating on the order of 10 watts peak power.

The conflict between a short volume-scan time for aircraft surveillance and an extended dwell time for weather surveillance can be resolved by assigning independent frequency channels to the radar’s various missions (e.g., weather surveillance, terminal area aircraft surveillance, en route aircraft surveillance). These channels would differ sufficiently in frequency to allow the receivers to separate the signal specific to each function prior to processing. Independent beam clusters for transmitting and receiving can be formed separately for each function. Digital control and processing of the T/R elements is needed to generate these independent beams.

High angular resolution can be maintained for all surveillance functions by using the full aperture for receive-beam formation. Where needed, rapid volume scanning can be achieved by dynamically widening the transmit beam pattern so that the beam illuminates multiple resolution volumes concurrently. Figure 4-2 depicts notional transmit-beam and receive-beam patterns appropriate for three surveillance modes. Appendix B includes a detailed discussion of how a single active, electronically scanned radar can meet all of the required surveillance functions.

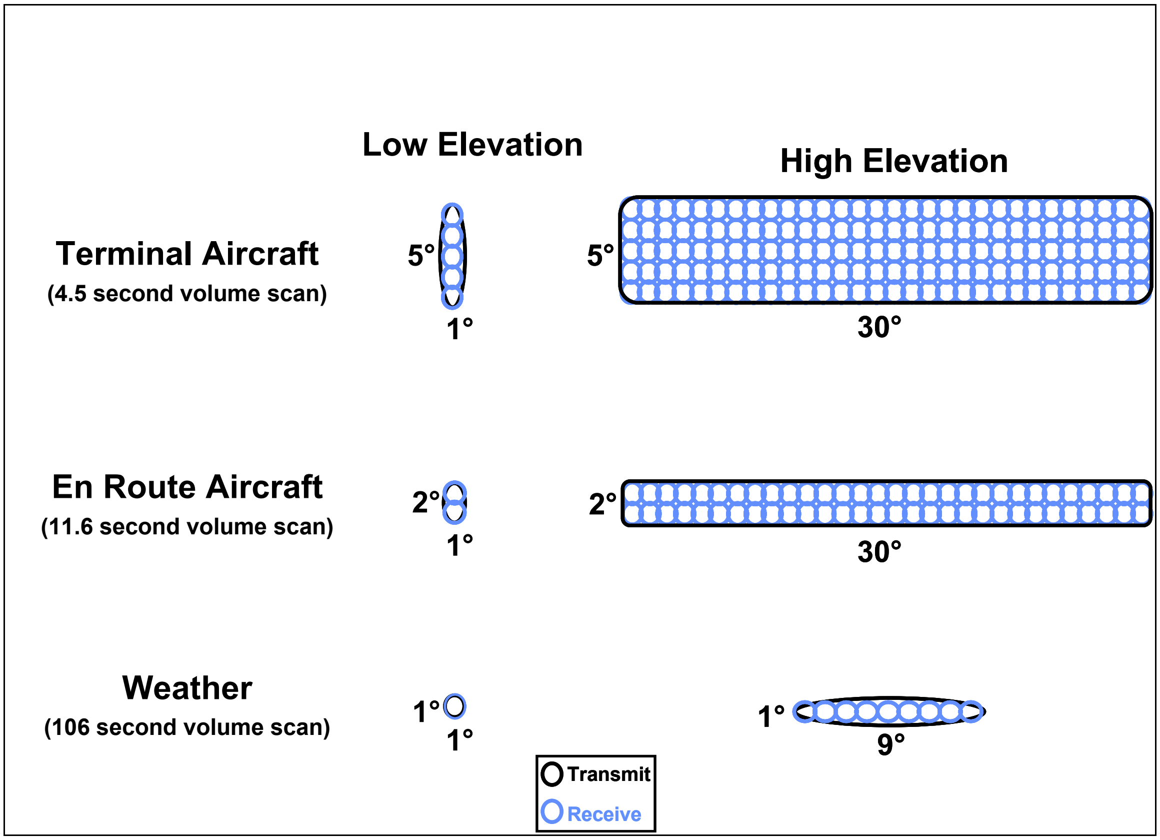

Figure 4-2. Transmit and receive patterns.

Notional beam patterns for multifunction radar surveillance modes. Less energy on target is required for aircraft surveillance (particularly at short ranges in terminal airspace) than for weather measurement. Thus, the transmitted energy can be spread in angle, allowing for multiple, simultaneous receive beams. At high elevation angles, maximum range to target falls off, allowing further widening of the transmit beam pattern. Optimal adaptation of the radar beam pattern to requirements of a particular surveillance mission is a core capability essential to multifunction radar.

Given these application-driven parameters for MPAR, targeted R&D can be conducted to minimize costs for T/R elements that will provide the requisite power output and multichannel capability. If simultaneous dual-polarization capability is required, this capability must be factored into the T/R element design, as it essentially doubles the number of components (e.g., phase shifters, amplifiers) required per T/R element. A second research focus is needed on array digitization issues, including cost minimization for "overlapped sub-array" beamforming technology, which is likely to be the most effective approach to implementing the necessary beamforming capability. A third focus should be to develop efficient, cost-effective processing architectures to form the large number of concurrent beams required to meet user needs.

4.2 Operating Frequency Band Options

In principle, Federal agency needs can be met by radars operating at wavelengths varying from 3 cm (X-band) to 10 cm (S-band). (L-band radars, which operate in the 30 cm region, as do today's air route surveillance radars, do not provide adequate sensitivity to meteorological targets to serve in the multifunction role required by MPAR.) Other factors being equal, a shorter wavelength requires a smaller antenna and increases sensitivity to meteorological targets. Thus, the CASA project is focusing on phased array radars with a 3 cm wavelength as a cost-effective means for short-range, boundary layer measurements of winds and precipitation. Longer-range weather and aircraft surveillance, however, is more easily accomplished at 10 cm wavelength. The conflicts resulting from range-Doppler ambiguity are less stressing, and the path length attenuation caused by rain is minimal.

Research is needed to project radar cost trade-offs associated with operating in these different frequency bands. Advanced processing algorithms and polarimetric measurement techniques should be pursued that address performance issues of sensitivity, ground clutter suppression, range-Doppler ambiguities, and attenuation for each band of potential interest.

4.3 Array Configuration Options

In addition to activities directed at optimizing the performance and cost of T/R-elements, alternative array geometries and “element-thinning” options should be evaluated. Since the major radar applications in chapter 2 require 360^o azimuthal coverage and significant above-horizon coverage in elevation, cylindrical, conical, or hemispherical array configurations may provide more efficient coverage than a multifaced planar array would.

Element-thinning is a technique for reducing the required number of T/R-elements in an array by spacing the elements in a non-uniform pattern such that inter-element spacing sometimes exceeds the optimal half-wavelength distance. This results in “grating lobes”: undesirable secondary beams pointing in directions away from the main beam. However, through careful design of the overall array, these grating lobes can be managed so that the radar’s measurement capabilities are not degraded. Element thinning is more easily accomplished using planar arrays. Options for element thinning also depend on the power output achievable from the individual T/R elements and the potential impact on beam patterns from failure of a small number of elements. Finally, options for the geometry of the T/R element grid (e.g., a triangular versus rectangular grid) should be assessed, as grid geometry can also affect the number of T/R elements necessary to achieve a required performance capability.

4.4 User Connectivity

Both the meteorological and aircraft surveillance communities are investing significant resources in combining the output from surveillance radars to facilitate incorporation of radar data products into decision support tools. For instance, real-time weather radar "base data"—full-resolution spectral moments data—are accessible from every NEXRAD on the internet. Data products from multiple radars are combined into regional and national *mosaic* maps of radar data. Agencies responsible for aircraft traffic flow management, homeland air defense, and even airport noise monitoring acquire and utilize real-time aircraft surveillance data in a variety of decision support tools.

An MPAR network should support flexible and efficient data access for both primary and ancillary applications. In contrast to today's "single-sensor" surveillance paradigm, in which each operational entity (e.g., a Weather Forecast Office, an en route sector controller) has a primary radar feed, the MPAR network will provide high quality, mosaicked products as a primary output. Users will have a choice of output levels ranging from raw data (e.g., time series data, weather radar base data, or aircraft primitives) to processed surveillance reports or meteorological products.

MPAR's agile-beam capability supports adaptive scheduling based on externally derived guidance. For example, the radar's weather surveillance control subsystem might be instructed to dwell in a certain sector of its scan volume to provide higher quality measurements for locations where an NWP model has indicated that more accurate data are needed to reduce predictive uncertainty or follow phenomena of special interest. At the same time that this "closer look" is implemented for the weather surveillance beam, an external decision support tool could instruct the aircraft surveillance control subsystem to execute high duty-cycle tracks on non-cooperative targets of interest.

The research activity for MPAR can explore these and other performance enhancements that can be realized through collaborative surveillance strategies that exploit MPAR's unique capabilities for flexible scanning agility. Associated communications, control, and conflict resolution architectures should be developed and tested.

4.5 Aircraft Surveillance Post-Processing

Relative to current aircraft surveillance radars, an MPAR network would support more-selective antenna patterns and flexible scan strategies, thereby improving the quality of non-cooperative aircraft surveillance. However, as depicted in figure 4-3, the radar front end will be significantly transformed with respect to the flow and content of the data provided to the post-processing algorithms. New post-processing techniques must be developed to meet or exceed the performance of existing air traffic control search radars. The following examples represent some of the supporting developmental work needed.

- The use of multiple beam clusters significantly expands the amount of data to be processed. How can commercial off-the-shelf solutions, within an efficient and affordable open architecture, be used to reduce acquisition costs? This architecture must also enable technology refresh and the future insertion of new technology and algorithms.
- Target detections will occur in multiple beams within each beam cluster. These detections will require a new algorithm for correlation and interpolation to the single centroided target report that is input to air traffic control display systems.

- Because selective elevation patterns will allow the altitude of detected targets to be estimated, new and highly simplified clutter elimination algorithms will be of value.
- ADS-B will replace beacon radars in some regions. Efficient scan strategies should be developed to allow MPAR units to confirm and augment ADS-B reports.

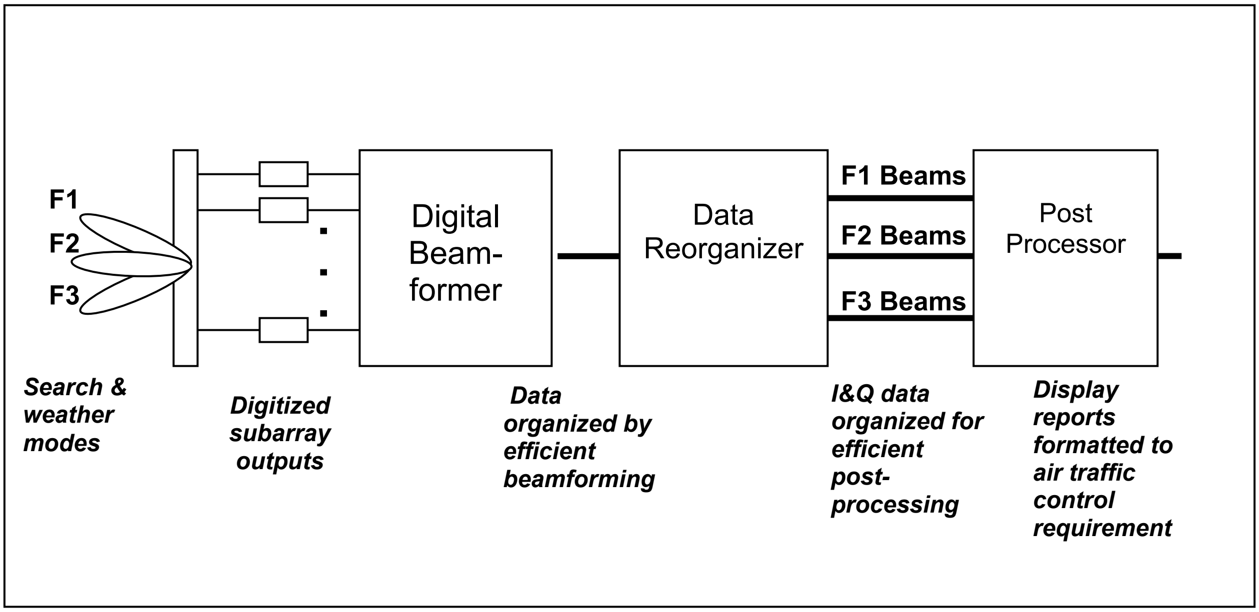

Figure 4-3. Post-processing block diagram for MPAR.

4.6 Weather Surveillance Post-Processing

To realize the performance advantages discussed in chapter 3, weather scan strategies and data processing algorithms should be developed that exploit the unique capabilities of MPAR. Data-adaptive beam steering, pulse scheduling, and processing techniques will revolutionize the quality of the meteorological data provided by MPAR, but these advances will also increase the complexity of the weather post-processing software. Multiyear algorithm development and validation efforts will be required to fully realize MPAR capabilities in this area. These efforts will require development and utilization of a full-up MPAR prototype as discussed in chapter 5.

Developing such techniques can significantly decrease the volume scan-time and/or improve data quality by allowing for longer dwell time along “high-value radials” such as low-elevation tilts for boundary layer wind mapping, tracking non-cooperative airborne targets, or investigating regions of suspected tornadic formation.

Spaced aperture techniques can be applied by separately processing received signals from halves or quadrants of the full aperture. Such techniques can potentially be used to estimate the cross-range wind component and three-dimensional turbulence fields and to provide information on hydrometeor size and shape (independent of the use of dual-polarization). These techniques should be investigated with respect to both capability enhancements and increased complexity of beamforming and post-processing.

Meteorological surveillance requirements for high-power aperture, angular resolution, and long dwell times are likely to have a significant influence on MPAR unit architecture and cost. Therefore, significant effort should go into evaluating and demonstrating efficient MPAR design options and processing approaches for meteorological surveillance applications.