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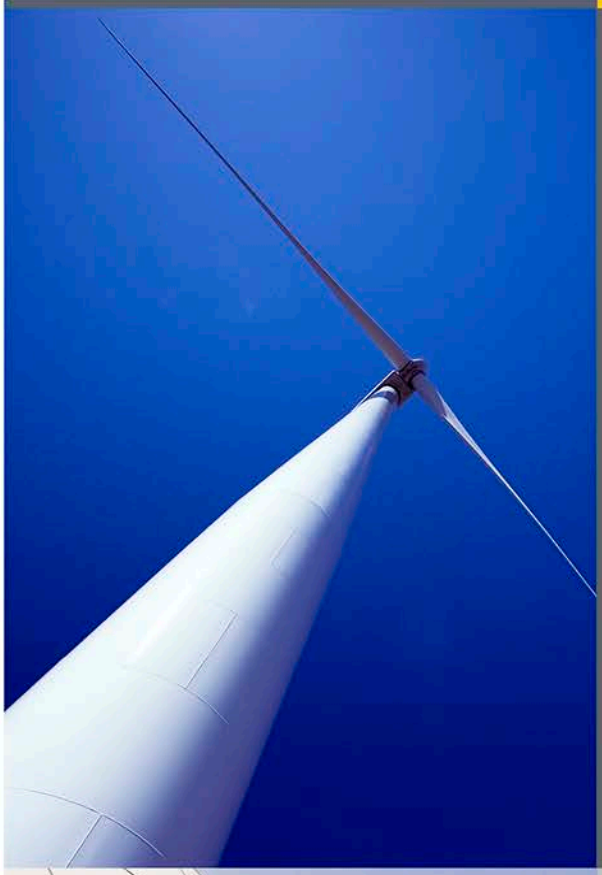
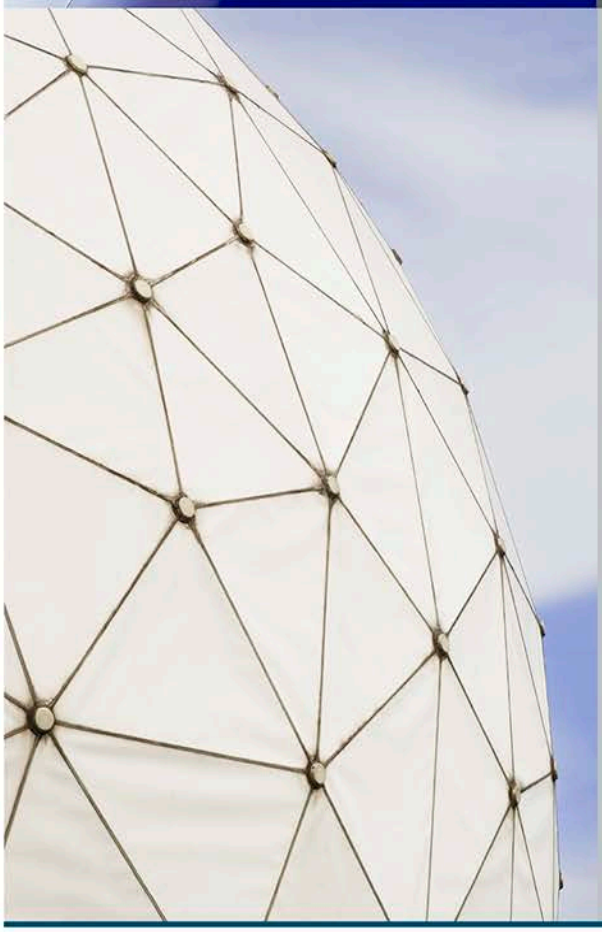


Federal Interagency Wind Turbine Radar Interference Mitigation Strategy

January 2016



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Authors

Patrick Gilman, *U.S. Department of Energy*
Lou Husser, *Scientific Research Corporation*
Bryan Miller, *BEM Int'l*
Lauren Peterson, *Allegheny Science &Technology*

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Foreword

This strategy document elaborates on and serves as the action plan for the *Memorandum for Understanding: Establishment of the Wind Turbine Radar Interference Working Group* (see Appendix A) between the U.S. Department of Energy (DOE), U.S. Department of Defense, Federal Aviation Administration, and the National Oceanic and Atmospheric Administration. As outlined in the memorandum, DOE is responsible for the construction of a strategy in coordination with its signatory partners. In response to this requirement, DOE developed this strategy and coordinated it with the other memorandum signatories. Key input was also received from the U.S. Department of Homeland Security and the U.S. Department of the Interior.

List of Acronyms

DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
FAA	Federal Aviation Administration
IFT&E	Interagency Field Test & Evaluation
MOU	memorandum of understanding
NOAA	National Oceanic and Atmospheric Administration
R&D	research and development
WTRIM WG	Wind Turbine Radar Interference Mitigation Working Group

Executive Summary

Wind energy is one of the fastest growing sources of new electricity supply in the United States. Wind energy development carries with it many economic, social, health, and environmental benefits; the nearly 66 gigawatts of cumulative utility-scale wind energy that had been deployed in the United States through 2014 (Wiser and Bolinger 2015) have resulted in increased personal income and reduced electric rates, fewer greenhouse gas emissions, improved air quality, and decreased water consumption (U.S. Department of Energy 2015).[1] Wind development located within the line of sight of radar systems, however, can cause clutter and interference, which at some radars has resulted in significant performance degradation (Karlson et al. 2014). As wind turbines continue to be installed, and as advances in wind energy technology enable wind farms to be deployed in new regions of the country, the probability for wind development to present conflicts with radar missions related to air traffic control, weather forecasting, homeland security, and national defense is also likely to increase, as is the potential severity of those conflicts.

Under a memorandum of understanding signed in 2014 and building off of the successful Interagency Field Test & Evaluation (IFT&E) program radar mitigation testing campaigns, a consortium of federal agencies composed of the U.S. Department of Defense, the U.S. Department of Energy, the Federal Aviation Administration, and the National Oceanic and Atmospheric Administration established the Wind Turbine Radar Interference Mitigation (WTRIM) Working Group (WG) to address these conflicts.

Through a set of collaborative activities and the coordination of each agency's investments in outreach on the wind turbine radar interference issue, research and development of appropriate mitigation measures, and facilitating the deployment of such measures, the WTRIM WG seeks, by 2025, to fully address wind turbine radar interference as an impact to critical radar missions, ensure the long-term resilience of radar operations in the presence of wind turbines, and remove radar interference as an impediment to future wind energy development.

To achieve these objectives, the WTRIM WG will coordinate activities within three broad strategic themes:

1. Improving the capacity of government and industry to evaluate the impacts of existing and planned wind energy installations on sensitive radar systems
2. Developing and facilitating the deployment of hardware and software mitigation measures to increase the resilience of existing radar systems to wind turbines
3. Encouraging the development of next-generation radar systems that are resistant to wind turbine radar interference.

[1] Wind power in the United States in 2013 was estimated to have reduced direct power-sector carbon dioxide (CO_2) emissions by 115 million metric tons (127 million short tons), equivalent to eliminating the emissions of 20 million cars during the year. An estimated 157,000 metric tons (173,000 short tons) of SO_2 emissions and 97,000 metric tons (107,000 short tons) of NO_X were avoided due to the wind power generated in 2013. Wind power generation in 2013 is estimated to have reduced power-sector water consumption by 36.5 billion gallons, or roughly 116 gallons per person in the United States.

Given scarce resources and the particular missions and authorities of each of the WTRIM WG agencies, the WTRIM WG envisions that its role in activities under the three above themes will vary. For example, WTRIM WG agencies are investing in research and development to improve modeling and simulation capabilities to evaluate the impacts of proposed wind facilities on radars. But with respect to improving the resilience of future radar systems, it is likely that the bulk of WTRIM WG efforts will focus more on outreach to the responsible programs to ensure that they incorporate WTRIM as a key design consideration.

Tracking the progress of agency investments under the three strategic themes identified above, ensuring regular coordination between the organizations comprising the WTRIM WG, and promoting coordination on WTRIM issues outside the working group itself and across the government will be critical to the success of this strategy. To that end, the WTRIM WG will conduct periodic teleconferences, quarterly face-to-face meetings, and periodic Technical Interchange Meetings to explore emerging WTRIM and related issues; participate in other relevant government forums, such as the National Airspace System Modernization program; and hold an annual, government-wide WTRIM meeting to share results and gather feedback on future activities.

Given the importance of the WTRIM WG's efforts to the future development of wind energy as well as to potential vendors of mitigation measures, the WTRIM WG will also conduct regular outreach to industry groups through the publication of a brief annual progress report, publication of publicly releasable results from all WTRIM WG-sponsored studies, and participation in relevant industry forums such as the American Wind Energy Association's annual Wind Project Siting Seminar and WINDPOWER conference. The WTRIM WG will also monitor international WTRIM activities, engage with the entities performing those activities, and when appropriate, participate in international WTRIM forums.

Realizing the substantial benefits of continued wind energy deployment while ensuring the integrity of critical radar missions is a substantial challenge. Overcoming this challenge will require continued coordination of investment in mitigation measures across the whole of government, as well as dialogue between the wind industry and government agencies charged with carrying out critical radar missions. Through this strategy, the WTRIM WG seeks to build off of the considerable progress made by the IFT&E program and other efforts in addressing the challenge of wind turbine radar interference and map out a credible path to eliminate the need for the WTRIM WG over the coming decade.

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Introduction

Wind turbines have significant electromagnetic reflectivity as large structures and blades cause large and numerous Doppler returns because of their motion relative to the affected radars. In May 2011, the White House Office of Science and Technology Policy completed an internal decision-making study at the request of the National Security Staff that found that wind turbines were interfering with government radars used for national defense, national security, aviation safety, and weather forecasting "by creating clutter, reducing detection sensitivity, obscuring potential targets, and scattering target returns. These effects on radar systems tend to inhibit target detection, generate false targets, interfere with target tracking, and impede critical weather forecasts" (Biddle et al. 2014).

As the number and size of wind turbines in the United States will continue to grow significantly over the next half century on land and offshore,[2] so could their potential effect on national flight safety, weather and ocean forecasting, homeland security, and national defense radars. In addition, because the next generation of more massive wind turbines will open up new areas to development and has the potential to obstruct radar signal coverage at greater distances, the area impacted by wind turbine radar interference will increase (Zayas et al. 2015).

To preserve critical radar missions as well as to accommodate future wind energy development, new technologies to mitigate wind turbine radar interference are required. Moreover, because existing radar systems serve multiple missions across a number of agencies, collaboration across the federal government will be needed to develop and gain acceptance for new wind radar interference mitigation technologies. With appropriate planning and funding of wind turbine radar interference-related mitigation research and development (R&D), coupled with funding for the deployment of appropriate mitigation solutions, the impact of wind turbines on radar systems may be minimized or eliminated for the near, mid, and long term.

1.1 Wind Turbine Radar Interference Mitigation Working Group

Established under a memorandum of understanding (MOU) in 2014, the Wind Turbine Radar Interference Mitigation (WTRIM) Working Group (WG) includes representatives of several federal agencies, national laboratories, and consultants who are committed to finding viable solutions to the wind turbine radar interference challenge. In terms set forth by the MOU, the U.S. Department of Energy (DOE) is responsible for the development of a strategy in coordination with its signatory partners: the U.S. Department of Defense (DOD), the Federal Aviation Administration (FAA), and National Oceanic and Atmospheric Administration (NOAA). This strategy document communicates the WTRIM WG's approach to the issue and presents a comprehensive overarching framework divided into three strategic themes through which WTRIM activities are coordinated.

[2] The primary analysis of the U.S. Department of Energy Wind Program's 2015 *Wind Vision* report centers on a future scenario in which wind energy serves 10% of the nation's end-use demand by 2020, 20% by 2030, and 35% by 2050.

1.1.1 History of the Wind Turbine Radar Interference Issue

The wind turbine radar interference issue was first brought before the U.S. Congress in 2006 in a report to the defense committees, which stated that the significant physical size of the rotating wind turbine blades result in a substantial radar cross section target and their rotation results in a Doppler velocity return.

In 2010, the issue gained national attention when DOD initially opposed construction of the Shepherds Flat Wind Farm in Oregon, because radar clutter (i.e., false targets) from the wind turbine blades would seriously impair the agency's ability to detect, monitor, and safely conduct air operations. That same year, the White House asked DOD, DOE, FAA, and the U.S. Department of Homeland Security (DHS) to participate in a sub-Interagency Policy Committee called the Obstruction Evaluation Working Group, which was tasked with further investigating the effects of wind turbines on surveillance systems in an effort to reduce barriers to wind project installation/deployment through the application of mitigation methods.

As a result of this effort, the Interagency Field Test & Evaluation (IFT&E) program was established to conduct a series of flight tests with three goals: 1) characterize the impact of wind turbines on existing air surveillance radars; 2) assess near-term mitigation capabilities proposed by industry; and 3) collect data and increase technical understanding of interference issues to advance development of long-term mitigation strategies. Results from the tests are summarized in the *IFT&E Industry Report*.

That same year, the DOD Siting Clearinghouse was shaped by Congress in the Ike Skelton National Defense Authorization Act for Fiscal Year 2011. The Clearinghouse acts as a single DOD voice to provide a timely, transparent, and repeatable process to assess potential mission compatibility impacts of energy-related projects filed in the Federal Aviation Administration Obstruction Evaluation process, explores mitigation options, while preserving military mission readiness and operations. If a major potential impact is identified, DOD establishes a Mitigation Response Team to evaluate mitigation options and negotiate implementation of mutually acceptable solutions to the mission compatibility challenge.

1.2 Existing Mitigation Approaches

Several approaches currently exist to minimize wind turbine radar interference. The most important and straightforward of these is the proper siting of wind facilities on the landscape as well as "micro siting" of wind turbines within planned facilities. Early coordination with the FAA, NOAA, and DOD's Siting Clearinghouse in the siting process can help prevent the emergence of an interference issue long before a facility is actually built. Certain sites extremely close to radar systems, where a wind facility might dominate the radar picture, or in a few areas around the country where pristine electromagnetic environments are required for unique military testing or training activities, wind development may simply not be viable. In the vast majority of areas, however, any impacts are likely to be manageable. In these areas, possible siting and configuration optimization methods that minimize wind farm interaction with a radar signal include "terrain masking" by placing turbines on the opposite side of elevated terrain from the radar so that the turbines are blocked from view of the radar; relocating planned turbines that might pose interference issues outside of the radar line of sight; lining turbines up along radials

from the radar to minimize the azimuthal area impacted by the turbines; or spacing the specific locations of wind turbines farther apart to enable detection of targets between them.

In more extreme cases, a mitigation agreement may be negotiated that requires either changes to the operation of the wind facility or that industry funds some mitigation upgrade to the existing radar system. Under operational curtailment agreements, for example, the wind farm operator is required to "feather" all turbine blades, causing the turbines to come to a near stop. When the turbines come to a stop, turbine interference on Doppler-based radars disappears. Because curtailment results in lost revenue, this approach poses financial risk to project developers, so the amount of curtailment must be limited for such agreements to succeed. Additionally, as some of the hardware and software mitigation approaches discussed below become available—such as an upgrade to the long-range Common Air-Route Surveillance Radar recently announced by the DOD/DHS Long Range Radar Joint Program Office (Air Combat Command 2015)—some mitigation agreements are beginning to require wind developers to provide funding to the government to implement these approaches.

1.3 Memorandum of Understanding: Establishment of the Wind Turbine Radar Interference Mitigation Working Group

Formally chartered in 2014 under an MOU between DOD, DOE, FAA, and NOAA, the WTRIM interagency effort is working to identify and develop newer, more effective mitigation solution recommendations. Although these recommendations are primarily technology-driven, the WTRIM organization can also provide a forum for reviewing and discussing common policy and legislative proposals as necessary. The MOU establishes a general framework of cooperation and coordination between the agency signatories with the purpose of mitigating the technical and operational impact of wind turbine projects on critical radar missions.

The MOU directs DOE to coordinate the development of a strategy with its signatory partners working toward the common goal of evolving an environment in which aircraft and weather surveillance radar systems fully meet their mission requirements in the presence of robust exploitation of national wind resources. The strategic objectives of the WTRIM WG are to, by 2025, fully address wind turbine radar interference as an impact to critical radar missions, ensure the long-term resilience of radar operations in the presence of wind turbines, and remove radar interference as an impediment to future wind energy development.

To accomplish this objective, the WTRIM WG has identified the following three strategic themes around which it will coordinate federal investments in WTRIM issues:

1. Improve the capacity of government and industry to evaluate the impacts of existing and planned wind energy installations on sensitive radar systems
2. Develop and facilitate the deployment of mitigation measures to increase the resilience of existing radar systems to wind turbines
3. Encourage the development of next-generation radar systems that are resistant to wind turbine radar interference.

The ongoing activities of the WTRIM WG fall under these three strategic themes. The activities are differentiated both by mitigation approach as well as relative payoff time, as some solutions

are mature enough to be put into effect immediately where applicable, whereas others require further exploration, development, and evaluation.

2 Strategic Themes

2.1 Theme 1: Improve Government and Industry Capacity to Evaluate the Impacts of Wind Turbines on Sensitive Radar Systems

Mitigation of wind turbine radar interference starts with ensuring that wind developers and responsible agencies have an understanding of the potential impacts to radars early in the project development process, preferably before substantial funds are invested in a particular site (such as in the deployment of meteorological towers). Early engagement by wind developers with entities like the DOD Siting Clearinghouse and NOAA's Radar Operations Center are critical to this understanding, as are accurate modeling and simulation tools. Many such tools exist and are currently being used, but further work is needed to verify the performance of such tools against real WTRIM data; to fill gaps in modeling and simulation capabilities so that all significant potential wind radar conflicts can be evaluated; and to improve the capabilities of tools currently available to the public.

Second, although a great deal is now understood about the potential effects of wind turbines on many types of radar as well as their impacts on the missions those radars support, new issues are likely to arise. The WTRIM WG needs to ensure that it can rapidly evaluate these new issues, identify potential mitigation measures, and prioritize investment in those mitigations against other WTRIM WG priorities.

2.1.1 Activity 1.1: Develop Improved Modeling and Simulation Tools to Aid in the Siting and Evaluation of Planned Wind Facilities and Assessment of Potential Mitigation Measures

The WTRIM WG has identified seven modeling and simulation tools used by four agencies in support of their missions. These tools have been developed to facilitate proper siting of proposed wind turbine projects by screening potential impacts on government surveillance operations in the preliminary planning stages of a project. Examples of these tools include DOD's Preliminary Screening Tool (Federal Aviation Administration 2015), a simple geographic information system tool that allows project developers to understand the overlap between their project boundaries with radar and military mission coverage; and the Tools for Siting, Planning and Encroachment Analysis of Renewables (Sandia National Laboratories 2015), developed in a partnership between the private sector and Sandia National Laboratories, which models the impacts of multiturbine projects on specific radar systems and produces a scorecard predicting potential impacts. Agencies also maintain a number of more sophisticated analysis tools to predict the operational impacts of wind projects on particular radars and agency missions.

Even though each tool serves its own purpose corresponding to the mission of its sponsoring organization, the WG is currently analyzing the suite of tools for gaps and evaluating how to fill these gaps where appropriate. In some cases, the WTRIM WG will advocate for improving tools in which performance is lacking. WTRIM will also consider integrating new simulation parameters that coincide with novel wind turbine radar interference scenarios, such as offshore wind farms potentially interfering with coastal radars, given the advancements in wind energy technology that have opened up new areas for project development.

To ensure that potential wind turbine radar interference conditions are being accurately modeled for the end users of modeling and simulation tools—whether it be federal agency representatives of the WTRIM WG or wind developers—MIT Lincoln Laboratory is currently validating the performance of certain modeling and simulation tools using data gathered during the IFT&E program and criteria compiled by the WTRIM WG.

2.1.2 Activity 1.2: Quickly Evaluate Emerging WTRIM Issues and Identify Effective Pathways to Mitigation as Appropriate

A wide variety of radars and other electromagnetic systems have the potential to be impacted by wind turbine radar interference—some of which, given limited resources or foresight, have yet to be explored. For example, a DOE-funded offshore electromagnetic systems study found that high-frequency radar used to monitor ocean and weather systems are likely to be impacted by offshore wind energy systems (Ling et al. 2013), which raises new concerns for coastal radar operators over the development of offshore wind farms. When the WTRIM WG learns about a new issue such as this, it examines the problem and either determines if the available technological solutions within the WTRIM strategy are viable pathways to addressing it, or if new technological efforts are warranted.

2.2 Theme 2: Develop and Facilitate the Deployment of Mitigation Solutions to Increase the Resilience of Existing Radar Systems to Wind Turbines

The IFT&E campaigns identified a number of possible mitigation solutions, particularly infill radars, as potential off-the-shelf radar interference mitigation solutions. As part of the near-term path forward, the WTRIM WG is working to develop approaches to employ these promising off-the-shelf solutions over the next few years. The WTRIM WG is also investing in mitigation measures with longer-term payoffs, such as software and hardware upgrades to existing radars, along with command and control/automation system improvements to filter out turbine clutter or "fuse" radar pictures together where multiple radars cover airspace over a wind facility. Finally, the WTRIM WG is exploring potential mitigations that might be applied to the turbine or wind facility rather than the radar, such as the application of radar-absorbing materials to wind turbine blades.

2.2.1 Activity 2.1: Facilitate the Rapid Deployment of Current Off-the-Shelf Mitigation Measures Such As Those Evaluated in the IFT&E Program

From 2010 to 2013, three IFT&E program testing studies at radar sites in Tyler, Minnesota, Abilene, Texas, and King Mountain, Texas, assessed a number of near-term mitigation capabilities proposed by industry (Karlson et al. 2014). A number of solutions evaluated under the IFT&E program performed well enough to merit near-term consideration for deployment (see Figure 1 for examples of IFT&E-tested mitigation solutions).

Source: Bryan Miller and Jason Biddle

Figure 1. Several wind turbine radar interference approaches tested in the IFT&E campaigns (clockwise from top left: Raytheon X-band Radar; Booz Allen Hamilton canceling post; Lockheed TPS-77 Radar; C-Speed Lightwave Radar; SRC LSTAR Radar; Terma Scanter 4002 Radar; and Aveillant Holographic Radar)

One class of mitigation solutions that performed well in the IFT&E campaign was augmentation or "infill" radars. Where a potential siting conflict manifests itself, an impacted legacy radar's performance loss may be restored by placing one of these infill radars, with advanced clutter suppression techniques, closer to wind farms to restore the lost surveillance coverage.

A variety of candidate infill radars were rigorously tested under the IFT&E campaign. Although none completely met all requirements, several showed promise and have subsequently been improved. To deploy these systems and ensure that they meet the needed performance expectations, the WTRIM WG is pursuing the Pilot Mitigation Project initiative. The initiative provides a mechanism in which government can partner with industry to facilitate both wind energy development as well as the operational deployment and long-term onsite testing of mitigation solutions.

A currently envisioned Pilot Mitigation Project would apply to wind energy projects that have been assessed as having a potential impact on DOD or DHS radar missions, and thus require an approved mitigation agreement allowing the project to move forward given a specific requirement mitigation solution. Mitigation terms are negotiated through the appropriate DOD or DHS office. Where technical mitigations appear feasible for DOD purposes (and for joint efforts, with DHS), Section 358 of the Fiscal Year 2011 of the National Defense Authorization Act authorizes the department to "accept a voluntary contribution of funds from an applicant for a project filed with the Secretary of Transportation pursuant to section 44718 of title 49, United States Code." Once such an agreement is signed, the appropriate agency would acquire the mitigation solution using the funds contributed. The accepted mitigation solution would then be monitored by the WTRIM WG to gather performance data to compare against baseline radar performance data and evaluate the applicability of the solution for other potential sites.

The desired effect of the Pilot Mitigation Project approach is to: 1) protect the quality of DOD and DHS mission capabilities that existed prior to the proposed wind turbine project, 2)

minimize the wind turbine project impact and mitigation cost to government, and 3) support renewable energy goals while managing the risk to stakeholders.

2.2.2 Activity 2.2: Develop and Facilitate the Deployment of Hardware and Software Upgrades to Make Existing Radars More Resilient to the Impacts of Wind Turbines

Another approach is to improve the wind turbine interference mitigation capabilities of existing radars through signal processing software upgrades and minor hardware modifications, which is likely to result in lower-cost solutions compared to wide-scale deployment of short-range infill radar systems. An upgrade that significantly improves the radar's resolution in range, Doppler, or altitude could potentially yield performance similar to a new radar installation.

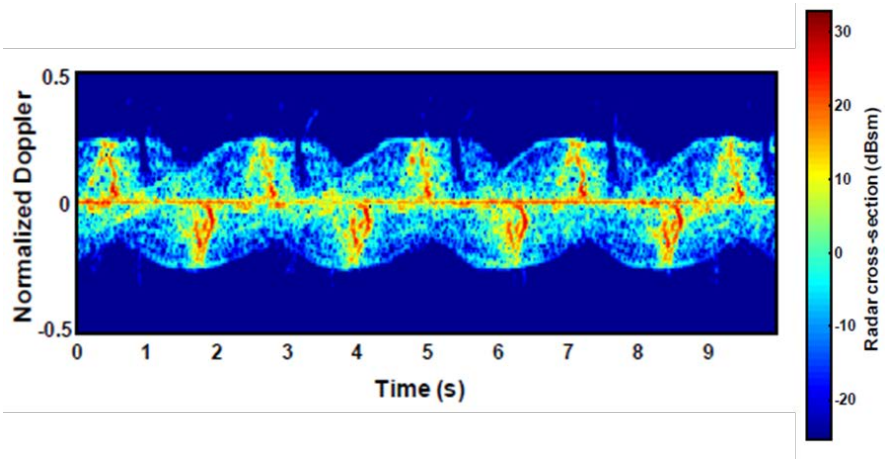

Figure 2. Dynamic radar cross section and Doppler measurements of a utility-scale wind turbine

A key objective of the IFT&E program and test campaign was to gather raw, signature-level radar data from existing National Airspace System air surveillance and air traffic control radars (see Figure 2). These data provide the basis for ongoing R&D efforts to develop new algorithms and signal processing techniques. For example, MIT Lincoln Laboratory, with funding from multiple WTRIM WG agencies, developed and is currently field testing increased range resolution and multibeam elevation nulling (see Figure 3), which reduce the spatial region (from the radar's perspective) impacted by wind turbine interference.

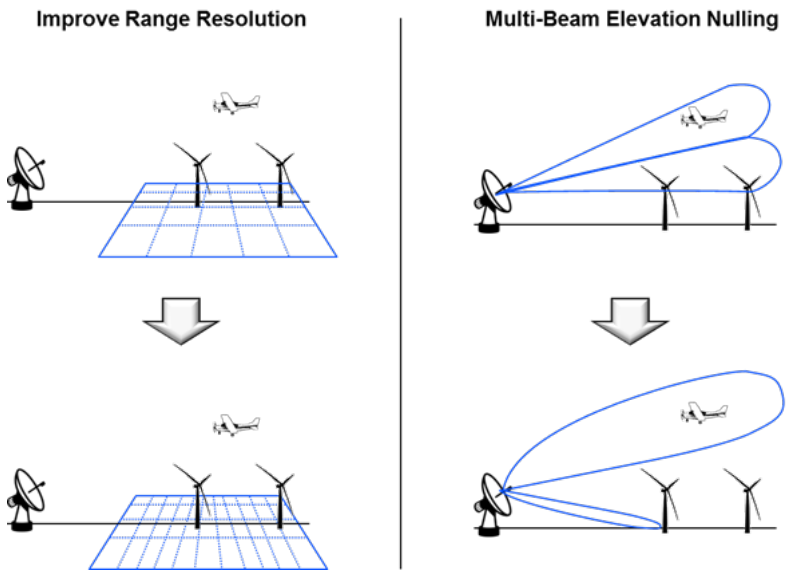

Figure 3. Examples of potential approaches to improve the performance of existing radars against wind turbines

These concepts are being developed to restore degraded performance for the airport surveillance radar (ASR)-11 airport terminal radar and could be applied to other systems as well. More advanced signal processing techniques are also being explored, including space-time adaptive processing (Melvin 2004) and signature-based wind turbine classifiers (Metcalf et al. 2014).

2.2.3 Activity 2.3: Improve the Capacity of Existing Automation and Command and Control Systems to Mitigate Wind Turbine Interference Impacts to Radars

Each radar site sends data to different automation or command and control systems based on the missions being performed by that radar. These systems run trackers, which take each incoming detection and either filter it out, update an existing track with it, or use it to initiate a new track. They also drop tracks that have not been detected after a few minutes. To varying degrees, they will also fuse information coming from multiple radars. The output of the automation system is what human users typically monitor and base decisions on. Therefore, the performance of the automation system, how it behaves around wind farms, and how it deals with mitigation systems, is crucial to the overall surveillance mission.

The WTRIM WG is actively studying the impact of wind turbines on these automation systems, as well as command and control mitigation approaches. Of particular interest is “radar fusion,” which could be promising in areas where there is overlapping coverage from multiple radars above wind farms. If the wind turbines are not visible to at least one radar because of the Earth’s curvature and/or terrain masking, then the automation system tracker can, in theory, maintain nominal performance above a certain altitude (depending on the geometry) by ignoring detections from the impacted radars and only displaying detections from the unimpacted radar(s) over wind facilities.

2.2.4 Activity 2.4: Explore At-the-Turbine Mitigation Methods That Reduce the Radar Impact of Wind Turbines

New design and operational methods for future wind turbines deployed in close proximity to vital radar assets could reduce radar impacts either independently or in conjunction with mitigation measures applied at the impacted radar systems. With a particular emphasis on blade fabrication, Sandia National Laboratories demonstrated the technical feasibility of integrating radar-absorbing materials into the standard construction methods currently used for manufacturing wind turbines (McDonald et al. 2012). The study identified multiple pathways to apply radar-absorbing material to a blade in a targeted way that could minimize the added cost leading to an economically viable mitigation option for the wind industry. Vestas, one of the largest global wind turbine manufacturers, developed a "stealth blade" based on a similar concept (Vestas 2014), but there is currently no independent technical evaluation of their technology or its effectiveness.

Beyond radar-absorbing materials, there are additional at-the-turbine solutions that the WTRIM WG could explore. Reduced radar impact lightning protection systems, materials, and structures are especially important for over-the-horizon radar systems. New operational methods in which data from individual turbines are combined with radar data in real time could also be explored as a potential mitigation method for current or newly deployed wind farms. Lastly, having publicly validated design tools for wind turbine designers to evaluate the potential radar interference impacts of their proposed turbine designs would enable new technology solutions to be more rapidly and cost-effectively developed and deployed.

2.3 Theme 3: Encourage the Development of Next-Generation Radar Systems That Are Resistant to Wind Turbine Radar Interference

Many of the radar systems currently impacted by wind turbine interference are likely to be upgraded significantly or replaced by next-generation radars over the next few decades. Resilience to wind turbine interference should be a key design requirement for these next-generation systems. Accordingly, the WTRIM WG will engage in outreach and R&D to ensure that relevant radar development and acquisition programs are aware of the wind turbine radar interference issue and fully address it in the design process.

2.3.1 Activity 3.1: Collaborate With the Developers of Next-Generation Radar Systems to Ensure That They Are Designed to Be Highly Robust Against Wind Turbine Interference

The replacement of the existing National Airspace System and weather radar fleet with radars that are more robust to wind turbines is a long-term solution to wind turbine radar interference. These next-generation systems are currently in development and it is critical that they incorporate resilience to wind turbine interference as a system requirement. The Multi-Function Phased Array Radar is an example of such a radar that is currently being considered for multiple weather, surveillance, and air traffic control missions, and could have significant advantages over current systems (Cho et al. 2012). The Three-Dimensional Expeditionary Long-Range Radar is another example of a new radar that has been engineered to detect and track hostile aircraft and missiles, as well as replace the legacy U.S. Air Force AN/TPS-75 radar system (U.S. Air Force 2013).

A key role of the WTRIM WG is to ensure these systems include requirements for wind turbine interference mitigation at early stages of the development and acquisition cycle. The WTRIM WG is reviewing the designs of these new radar systems to determine if they will likely be robust to wind turbines, and where appropriate may work well with the programs developing these radars on testing to evaluate their resilience.

3 Operational Plan to Execute the WTRIM Strategy

An outgrowth of the IFT&E program was the recognition of a need for a more comprehensive interagency approach to the WTRIM issue; thus the creation of the WTRIM WG as formally chartered through the MOU. The WTRIM MOU establishes the general framework under which the signatory agencies—DOD, DOE, FAA, and NOAA—can work together to identify common outcomes and leverage intellectual and fiscal capital to invest in mutually beneficial activities, thereby reducing redundancies in future R&D. This strategy outlines seven specific activities, under three broad strategic themes, which the WTRIM WG will pursue to meet the overall goals of the WTRIM signatories. These activities will also be facilitated and strengthened by two vital, associated actions—intergovernmental coordination and public and industry outreach.

3.1 Intergovernmental Coordination

Executing the activities outlined in Section 2 will require disciplined coordination of investments by the WTRIM WG agencies. To work together effectively, the WTRIM WG agencies will support the following activities:

- **Periodic Teleconferences.** DOE will convene teleconferences of the WTRIM WG on a monthly or more frequent basis to update members on the status of constituent activities that are relevant to the group's progress. This includes highlighting upcoming calendar events, reviewing assigned outstanding action items, updating current laboratory tasks, and introducing new developments in the wind-radar community.
- **Quarterly Meetings.** A senior steering group composed of members from each of the agencies will meet quarterly during the fiscal year to conduct progress reviews to ensure that the spirit and purpose of the MOU is being satisfactorily pursued and to provide strategic course corrections as well as hear status updates on key activities. The fourth quarter meeting will include a 2-day, government-wide conference to discuss a wide variety of topics related to wind turbine radar interference, including WTRIM WG progress updates and results, and to provide senior leadership with the opportunity to provide input on and approve the group's proposed activities for the following year.
- **Technical Interchange Meetings.** DOD will schedule and coordinate technical meetings to compile and exchange information related to emerging R&D initiatives. These meetings will be supported by appropriate agency science and technology advisors, including select national laboratories. This is a way to anticipate or explore various technology areas that may offer some advantage to assessing, mitigating, or facilitating the group's understanding of the impact of renewable energy projects on missions and infrastructures.

3.2 Public and Industry Outreach

There are other organizations outside the WTRIM WG that share an interest in or involvement with the wind turbine radar interference issue. Connecting with these national and international organizations in a single setting at conferences or directly through digital communications, such as via email or a webinar, creates and supports a knowledge network in which WTRIM WG items can be publicly promoted, stakeholder feedback can be received, and the WTRIM WG can gain exposure to new developments in technical and political areas that exist outside of the WG.

3.2.1 Event Participation

The WTRIM WG will assess and make itself available, as appropriate, to various government, industry, and public meetings as a means to educate as well as encourage an open dialogue with the audience concerning the purpose of the WTRIM WG and progress on its mission, and to obtain feedback on their issues where relevant for WTRIM WG attention. The following are examples of various forums in which the WG will routinely consider participating in, as appropriate, to the immediate goals of the group and as resources allow:

- **The DOD/FAA National Airspace System Interagency Working Group** (previously referred to as the National Airspace System Modernization Working Group). A DOD and FAA-led interagency team that meets quarterly to coordinate activities related to modernizing the National Airspace System.
- **American Wind Energy Association Symposiums**. Offer an opportunity to keep the wind industry abreast of federal progress in developing affordable WTRIM solutions while being able to network with leaders in the wind energy industry.
- **International Energy Agency Topical Experts Meetings and Canadian Wind Energy Association Annual Conference and Exhibition**. Provides the WTRIM WG exposure to international developments in technical and policy areas outside the United States.

3.2.2 International Information Exchanges

Wind turbine radar interference manifests itself around the world, and has driven a particularly strong investigative reaction within our allied community. As appropriate, the WTRIM WG will utilize existing international technical exchange agreements, as well as more informal fact-finding activities, to gather information regarding potentially useful foreign-developed mitigation solutions.

4 Conclusion

The Federal Interagency WTRIM Strategy specifies mutual goals and objectives established under an MOU between DOD, DOE, FAA, and NOAA for ongoing collaboration to mitigate technical and operational impacts of wind turbine projects on critical radar missions that operate in close proximity. The collection of WTRIM WG activities outlined in the strategic themes of this document encompass the WTRIM WG's approach to implementing the strategy.

Realizing the benefits of continued wind energy development while ensuring national safety and security can only be accomplished through continued dialogue and proactive mitigation actions between renewable energy developers and those charged with executing critical radar missions, and coordinated investment across the federal government in mitigation measures. The WTRIM WG, along with its predecessor, the IFT&E program, has made considerable advancements to address the wind turbine radar interference challenge, and views this strategy as a means to achieving its ultimate resolution.

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Appendix A. Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

Between the Following U.S. Federal Government Agencies

DEPARTMENT OF DEFENSE (DOD)
DEPARTMENT OF ENERGY (DOE)
DEPARTMENT OF HOMELAND SECURITY (DHS)
FEDERAL AVIATION ADMINISTRATION (FAA)
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

I. PURPOSE.

A. This Memorandum of Understanding (MOU) establishes a general framework of cooperation and coordination between the forenamed agencies. Its purpose is to mitigate the technical and operational impact of wind turbine projects on critical radar missions. The goals of the Interagency effort include:

   a. Develop near (5 years), Mid (10 Years), Long term (20 years) mitigation solution recommendations. These will be primarily technology driven but will also extend to policy and legislative proposals as necessary
   b. Determine funding requirements to implement workable solutions and include a process for each MOU participant to fund execution of specific near, mid and far term mitigation as outlined in Section II

II. REQUIREMENTS

A. Whereas the DoD, DOE and the DHS have been tasked by internal management and in some cases, additionally by Congress, to identify wind turbine/radar interference mitigation solutions; their representatives will:

   a. Take the lead in the organization of an Interagency team modeled after the former Interagency Field Test & Evaluation program
   b. Coordinate the development of agency budgets and the commitment of funding required for studies, field tests or other agreed to expenditures based on the principle of cost-sharing commensurate with meeting agency equity needs

B. Whereas DOE has proposed that Federal Agencies having a stake in resolving the wind turbine radar interference issue should develop a common vision and framework to coordinate activities; DOE will:
    a. Commit senior Departmental oversight and leadership
    b. Align this effort with the other interagency team member requirements.
    c. In collaboration with the Interagency team, manage the construction of an Interagency Renewable Energy Compatibility & Integration Strategy
        i. The Strategy is to be composed of near, mid, long term mitigation and integration components
C. DOE Co-lead the effort to educate the wind industry on radar interference issues, support the development of appropriate radar mitigation technology, and promote wind industry funding to validate and deploy measures that adequately mitigate radar interference caused by wind energy facilities.
D. Whereas FAA and NOAA have critical radar systems that are also threatened by wind turbine interference and need to identify workable and affordable mitigation measures, they will;
    a. Commit senior Departmental oversight and leadership
    b. Participate in the budget process by helping to identify required studies, field tests or other agreed to expenditures based on the principle of cost-sharing commensurate with meeting their equity needs
E. The Interagency team will collaborate as appropriate with;
    a. The Air Domain Awareness Board (ADAB) in the identification and development of solutions that would help them resolve any threatened mission requirements
    b. The DoD/FAA National Air Surveillance (NAS) Modernization Working Group, the joint working group responsible for addressing common NAS information assurance needs

Now, therefore, the MOU signatories agree that the undertaking shall be implemented with the following stipulations.

III. STIPULATIONS (Subject to applicable Federal laws, regulations, and policy)

A. Management of the Interagency effort will be conducted as follows:
    a. An executives level Senior Steering Group (SSG) composed of members from each of the agencies to oversee and ensure:
        i. Conduct progress reviews at least quarterly to ensure that the spirit and purpose of the MOU is being satisfactorily pursued
        ii. Development of a 5 year plan for studies, field tests or other agreed to activities on which agency funding requirements can be determined based on the principle of cost-sharing commensurate with meeting the respective agency equity needs
        iii. Development of a yearly progress report to be submitted to their agency heads at the end of each calendar year. The report should include objectives for the following years

iv. Appointing and tasking of a subordinate working group composed of a representative from each agency, as appointed by the SSG, that will carry out taskings as assigned by the SSG. The working group_ may, as they determine necessary, be augmented by non-voting participants whose services may include:

a. Technical – Scientists, engineers and other recognized technical subject matter experts
b. Policy – Agency policy analysts
c. Budget - Agency budget development analysts
d. Operational – Analysts knowledgeable in radar employment
e. Other analysts and administrative support

IV. MUTUAL UNDERSTANDINGS.

A. This MOU defines the general terms upon which the signatories will cooperate. Performance by each Party under the terms of this MOU is subject to the availability of appropriated funds and personnel resources through their respective funding procedures. This MOU is neither a fiscal nor a funds obligation document. Any endeavor involving reimbursement or contribution of funds or transfer of anything of value, between Parties to this MOU will be handled in accordance with applicable laws, regulations, and procedures. Such endeavors mandated by the SSG will be outlined in separate agreements, such as work plans or statements of work, which shall be made in writing by representatives of the Parties and shall be independently authorized by appropriate statutory authority.

B. This MOU may be modified or amended by mutual agreement of all parties in writing.

C. This MOU may be terminated at any time by mutual written agreement of the Parties, or by any Party upon 90 days written notice to the other Parties.

D. This MOU will remain in force for a period of five years from the date of its execution.

V. **POINTS OF CONTACT.** The following individuals will be the working level points of contact for this MOU:

DEPARTMENT OF DEFENSE
William Van Houten
Deputy, DoD Siting Clearinghouse

DEPARTMENT OF ENERGY
Patrick Gilman
Office of Wind and Water Power Technologies

DEPARTMENT OF HOMELAND SECURITY
Unappointed

FEDERAL AVIATION ADMINISTRATION
James Baird
Surveillance Lead, NAS EA Division

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Judson Stailey
Lead Meteorologist, Office of the Federal Coordinator for Meteorology Alternate

EFFECTIVE DATE. The parties have by their signatures on the following pages, executed this MOU as of this date:

MEMORANDUM OF UNDERSTANDING
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

As the designated representative for the Department of Defense, I, by my signature, implement the foregoing Memorandum Of Understanding as of this date:

OCT 0 8 2014

John Conger
Acting Deputy Under Secretary of Defense
Installations & Environment

MEMORANDUM OF UNDERSTANDING
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

As the designated representative for the Department of Homeland Security, I, by my signature, implement the foregoing Memorandum Of Understanding as of this date:

As of the date of execution DHS has chosen not to sign the MOU

MEMORANDUM OF UNDERSTANDING
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

As the designated representative for the Department of Energy, I, by my signature, implement the foregoing Memorandum Of Understanding as of this date:

Steven Chalk
Deputy Assistant Secretary for Renewable Energy
Office of Energy Efficiency and Renewable Energy

MEMORANDUM OF UNDERSTANDING
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

As the designated representative for the Federal Aviation Administration, I, by my signature, implement the foregoing Memorandum Of Understanding as of this date:

October 15, 2014

Michele Merkle

Michele Merkle
Director, NAS Systems Engineering Services (ANG-B) FAA NextGen Office

MEMORANDUM OF UNDERSTANDING
Establishment of the Wind Turbine Radar Interference Mitigation Working Group

As the designated representative for the National Oceanic and Atmospheric Administration, I, by my signature,
implement the foregoing Memorandum Of Understanding as of this date:

December 22, 2014

John D. Murphy, Director
Office of Science and Technology, National Weather Service

Figure A-1. Copy of the official memorandum of understanding for this work

Wind Energy Websites

U.S. Department of Energy Wind Program
wind.energy.gov

Lawrence Berkeley National Laboratory
emp.lbl.gov/research-areas/renewable-energy

National Renewable Energy Laboratory
nrel.gov/wind

Sandia National Laboratories
sandia.gov/wind

Pacific Northwest National Laboratory
energyenvironment.pnnl.gov/eere/

Lawrence Livermore National Laboratory
missions.llnl.gov/energy/technologies/wind-forecasting

Oak Ridge National Laboratory
ornl.gov/science-discovery/clean-energy/research-areas/sustainable-electricity/wind

Argonne National Laboratory
anl.gov/energy/renewable-energy

Idaho National Laboratory
inl.gov

Savannah River National Laboratory
srnl.doe.gov/energy-secure.htm

American Wind Energy Association
awea.org

Database of State Incentives for Renewables & Efficiency
dsireusa.org

International Energy Agency – Wind Agreement
ieawind.org

National Wind Coordinating Collaborative
nationalwind.org

Utility Variable-Generation Integration Group
variablegen.org/newsroom/

For more information on this report, contact:

Patrick Gilman, U.S. Department of Energy
Patrick.Gilman@ee.doe.gov

Lauren Peterson, Allegheny Science &Technology
Lauren.Peterson@ee.doe.gov

On the cover:

Big Horn Wind Farm (top), *Photo from Iberdrola Renewables, Inc., NREL 15222*

Radar Guiding System (bottom), *Photo from iStock Images, 14420208*

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

For more information, visit:
eere.energy.gov / wind.energy.gov

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