DOCUMENT 260-13

Range Commanders Council
Electronic Trajectory Measurements Group

THE RADAR ROADMAP

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DUGWAY PROVING GROUND
REAGAN TEST SITE
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THE RADAR ROADMAP

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Prepared by

ELECTRONIC TRAJECTORY MEASUREMENTS GROUP
RANGE COMMANDERS COUNCIL

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PREFACE

The Radar Roadmap is a unique type of document for the Electronic Trajectory Measurements Group (ETMG). This document is a statement from the technical community of the instrumentation radar requirements for 10, 20, and even 30 years into the future. Like an automobile roadmap, it is intended to show where we can go, and the best routes to get there. It is not a document that shows where we must go.

The Radar Roadmap was first published nearly fourteen years ago. The original document has held up surprisingly well. One major difference is to deemphasize the call for investments in active phased array radars at the test and training ranges. Existing phased-array radars are expensive and they require costly conversions to meet the needs of the test and training communities. Producing a new tailored design is also too expensive, especially when considering the limited number of systems that will be needed. Affordable instrumentation radars will require adapting new technologies to the requirements of the test community.

To keep pace with changing technologies, this update increases emphasis in several technical areas. These areas include Digital Beam Forming, High-Range and Doppler Resolution, Multiple-Object Tracking, and Remote Control. A few new sections have been added, including Requirements Validation, Open-Architecture Design, Spectrum Management, Stretch Processing, Range-Doppler Detection, and Remote Operations Capability (ROC). These new sections describe the requirements development process, address requirements for software and hardware extensibility, discuss interoperability considerations, describe desirable signal processing procedures, and outline approaches for integrating radars into a comprehensive system of systems (SoS).

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ACRONYMS

AFB	Air Force Base
API	application programming interface
C2	command and control
COTS	Commercial-Off-the-Shelf
CW	continuous wave
DoD	Department of Defense
ETMG	Electronic Trajectory Measurement Group
FMCW	frequency modulated continuous wave
GPS	Global Positioning System
km	kilometer
LFM	linear frequency modulated
MHz	megahertz
MOTR	Multiple Object Tracking Radar
MW	megawatt
RCL	radar control language
RF	radio frequency
ROC	Remote Operations Capability
SoS	system of systems
TSPI	Time, Space, and Position Information
UIR	Ultimate Instrumentation Radar
VoIP	Voice over Internet Protocol
WSMR	White Sands Missile Range

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CHAPTER 1

Introduction

The Radar Roadmap is a plan for taking the radar capabilities of the Department of Defense (DoD) test and training ranges into the mid-21st century. It is designed to help make the DoD radar community more capable, more flexible, more versatile, more efficient, and more cost-effective. Just as important, it will provide for new or enhanced capabilities needed for future testing.

Why radar? Isn't radar passé? Won't Global Positioning System (GPS) do everything radar now does? Hardly! There are still plenty of tasks where radar is needed. Radar is needed for Time, Space, and Position Information (TSPI) and other measurements on non-cooperative targets. These include:

- objects that are too small to be augmented for GPS coverage;
- objects that cannot be augmented cost-effectively;
- objects that cannot be augmented because it would alter the test conditions;
- objects that are under production and cannot be augmented;
- objects for which the radar cross section (i.e., stealthiness) is being measured;
- objects created by the impact of other objects; and
- objects for which the extent of damage must be estimated after impact.

Radar will also be needed for objects that are tested for (or in the presence of) GPS jamming and objects that must be independently monitored for flight safety purposes, whether these objects are cooperative (i.e., have a radar transponder) or not.

Why improve, upgrade, or augment radars at DoD test and training ranges? Don't we have enough radars already? The answer is that we don't have the necessary mix or all the needed capabilities. We don't have high-resolution radars for measuring miss distance and attitude to the accuracy required. We don't have the capability for measuring items such as submunitions or decoys deployed by a tracked object or for providing such measurement to range users in real time. We lack the capability of programming the radars to operate semi-autonomously under conditions that are stressing to the operator. We lack the capability to remotely control radars from long distances. We are short on inexpensive continuous wave (CW) radars that provide detail on events from unambiguous Doppler data. We are short on coherent radars with high-range resolution to observe high-altitude intercepts and low-level dispensing submunitions. We also lack the capability of merging several instrumentation radars into an integrated SoS needed to support more-complex open-air tests.

The 21st century radar fleet will be better, smarter, and more effective. In addition, it will be more efficient to build, to operate, and to maintain. The range instrumentation will incorporate many advanced capabilities used in modern military and commercial radars. Single-object tracking radars will be improved or replaced. High-resolution radars will augment ordinary instrumentation radars. Multiple-object tracking capabilities will be added or upgraded where needed and small, inexpensive CW radars will be purchased.

CHAPTER 2

The Ultimate Instrumentation Radars

The ETMG has conceptually designed a family of Ultimate Instrumentation Radars (UIR). Each UIR will incorporate various elements of advanced technologies so that it is suited to the unique mission of the particular test/training range using it.

To illustrate this family of technologies, let's discuss how a UIR might be designed to capitalize on advanced radar technologies. The UIR will have an open design with standardized interfaces between major components and it will have its software methods fully exposed. The UIR will be a self-contained, transportable, fully coherent, multiple- or single-object tracking instrumentation radar system. It will have range resolution of 15 centimeters or better for resolving and tracking closely spaced objects. It will have a solid-state transmitter with sufficient energy for long-range tracking. It will be fully programmable through the use of a radar control language (RCL), and thus be able to collect data on complex and rapidly changing scenarios. It will be extremely stable through the use of digitally generated linear frequency modulated (LFM) waveforms. It will be extremely versatile, using digital beam forming techniques to process several receive beams simultaneously. It will be remotely controllable to allow it to be operated from a centralized facility or used in hazardous or difficult-to-access areas. It will utilize extremely accurate and precise timing for combining data from multiple sources. It will record all raw data so the test can be processed in different ways for different information. It will make maximum use of Commercial-Off-the-Shelf (COTS) hardware, solid-state components, digital control, built-in test equipment, and automated calibration for maximum reliability, maximum maintainability, and minimum life-cycle costs. Finally, it will be imbedded in a real-time control and display system that will provide the user with finished data products either during the test or shortly thereafter, depending on the desired data product.

We now consider the major characteristics of these radars in more detail.

2.1 Requirements Validation

All UIRs must meet specific needs for the test or training community where they will be used. Users and stakeholders must identify and validate performance requirements using both formal and informal processes. One approach is to document a series of use cases that describe how the system must perform for tests commonly encountered at the range. Various radar architectures and design elements are then compared to the use cases to assess the overall effectiveness of various approaches. As a minimum, this analysis should identify and examine all design alternatives and it should select the best radar type (e.g., phased array, CW, pulsed, hybrid) to meet critical use cases. It should also recommend an operating frequency band, identify the number and mix of units needed, identify general characteristics (e.g., C-band, pulsed, transponder capable, narrow beam width, full coherency, high-resolution waveforms), address spectrum management issues, and provide a top-level SoS architecture for operating many radars if needed. The process should also provide a rough estimate of the total cost. The results of validation process should then be used to inform and guide the development of a detailed System Requirements Document.

2.2 Open Architecture

It will not be possible to design a single UIR to meet all of the needs of the test and training communities. The UIRs will consist of a number of different family members and it will be important that they work together. Another requirement is that it be easy to modify, replace, or extend functional blocks of the radars to meet new requirements. An open-architecture design addresses both needs. Open-architecture hardware usually identifies functional modules at a Line Replaceable Unit level. The signals and connections between each module are then standardized and fully documented in a manner that allows the module to be replaced without requiring specific knowledge about its internal design. Open software designs follow a similar pattern. Each software module (or ideally, each software method) uses a standard interface and its function and parameters are fully documented so that the module can be replaced without requiring specific knowledge about its internal workings. Interfaces to software methods should be fully exposed and should use a services interface and extensions so that software engineers can easily create new or modified capabilities from existing modules. Open application programming interfaces (APIs) should be utilized in all software applications. An open API provides a standard interface that allows third-party developers to use plug-in software to extend the capabilities of an application.

2.3 Supportability

The UIR family of radars must be easy to deploy and support in the field, even at remote or unprepared sites. All UIRs must be easily transported, self-contained, and remotely operable. Most UIR family members should be able to be dismantled, readied for transport, and reassembled in a new location with a small crew within a few hours. Ideally, all the field equipment needed for operations should be carried on a single trailer or transport vehicle. The UIR should not require extensive support facilities. Ideally, power and communications lines would be all the external support needed to set up the radar for operation. The radar needs to be able to operate remotely through a standard communications link so that it can be operated locally or at great distances (depending on the length of the link) or tied into a larger SoS network.

2.4 Full Coherence

Many of today's instrumentation radars are coherent, meaning the phase relationship between the transmitted and received signals is maintained or measured. Coherence allows measurement of phase change due to motion relative to the radar, whether the motion is translational or rotational. Coherence also implies Doppler measurement capability since Doppler is the negative time derivative of phase. Assuming adequate motion compensation, Doppler can be highly resolved, and highly resolved Doppler is an essential component for resolving, detecting, and tracking multiple objects in combined range-Doppler space. Coherent radars can be fully coherent or coherent-on-receive. Fully coherent radars are, as the label suggests, coherent under all conditions. By contrast, the typical coherent-on-receive radar is coherent only in the first range ambiguity (i.e., when the target is close enough for the first pulse to return before the next pulse is transmitted.) Many of today's instrumentation radars are fully coherent (e.g., AN/MPS-36 and AN/MPS-39, also known as Multiple Object Tracking Radars [MOTR]). The less costly coherent-on-receive approach uses mature technologies and can be implemented using standard engineering practices. Further, a radar can be made coherent in all zones by using the stable local oscillator to measure the phase of both the transmitted and received pulses and then matching them to the correct range ambiguity.

2.5 High-Range Resolution

High-range resolution is achieved through wide bandwidth. Typically, the frequency of each transmit signal is linearly swept over the entire bandwidth (the greater the swept bandwidth, the better the resolution of the range measurement). A bandwidth of 1000 megahertz (MHz) yields a range resolution of about fifteen centimeters. High-range resolution, along with Doppler resolution, is essential for resolving, detecting, and tracking multiple objects in combined range-Doppler space. Most of today's instrumentation radars do not have high-range resolution, but the techniques are well-known, the technology is mature, and relatively little development will be needed to incorporate it in a UIR. The requirements are that the signal be digitally generated and highly stable and have low noise.

2.6 Digital Waveform Generation

High-resolution radars must transmit, receive, and process highly stable, distortion-free, wide-bandwidth waveforms. Generating a waveform digitally means that a high-fidelity waveform can be reliably reproduced with little distortion. Digital waveform generation technologies already exist. They are widely used and commercially available, so little development is needed in this area.

2.7 Stretch Processing

Stretch processing is a technique often used to process extremely wide-bandwidth LFM signals used with high-range resolution applications. Stretch processing allows wide-bandwidth signals to be sampled at a much lower rate than would otherwise be necessary. Stretch processing mixes a delayed replica of the transmitted waveform with the received signal. This yields a frequency for each detected target that is proportional to the range of the target. Stretch processing uses the same digital waveform technology used for generating LFM transmitter signals, so little development is needed in this area.

2.8 Range-Doppler Detection

Most radars resolve and detect targets in one of two domains: range or Doppler. Some UIRs will use both domains simultaneously to better resolve and detect many closely spaced objects. Displaying both domains on a Range-Doppler Intensity plot allows an operator to better discriminate targets and to more easily select the desired ones for tracking. Advanced algorithms can begin tracking all of the resolved and detected objects within the range-Doppler space and then drop tracks on irrelevant or false targets as information on each object is accumulated. Because the UIR will be able to tolerate higher false alarm rates, the receiver can be adjusted to be much more sensitive.

2.9 Phased Array

Phased-array radars may still be required at some test ranges, especially where multiple objects must be tracked over large angular extents. The typical single-object tracker dish antenna has a field of view of 1^o or less, whereas multiple-object instrumentation radars can have a 60^o field of view. A MOTR system is a phased-array radar so no phased array development is needed for it. Ranges may adapt tactical phased-array radars for range use if they become available or if they are needed to support specific tests. Active array technology, where a small solid-state transmitter is included on each phased-array antenna element, should be utilized whenever possible and affordable.

2.10 Digital Beam Forming

A radar with a simple-array antenna can use digital beam forming to dynamically adapt the shape of its illumination and receive patterns. On the transmit side, the beam can be shaped by adjusting the individual phase and amplitude settings of each antenna element such that the resulting pattern illuminates a large angular extent. On the receive side, a sophisticated signal processing algorithm creates simultaneous, multi-directional receive beams. These beams can be adjusted to place nulls in strategic locations (to avoid clutter, jammers, or other unwanted signals) or to create several pencil beams for precision tracking of all of the illuminated objects. Such techniques can be used for tracking multiple targets over large angular extents; thus, they have potential as a low-cost alternative to a phased-array design. Digital beam forming may also be used to extend the capabilities of existing phased-array radars.

2.11 Interferometric Angle Measurements

Some UIRs will use interferometry to measure angles to tracked objects. An interferometer is about four times more precise in measuring angle than a monopulse antenna of the same size. Pairs of antennas measure angles based on phase difference of an arriving signal but the measurement may be ambiguous (i.e., have grating lobes). A third antenna with a different spacing is needed to resolve these grating lobe ambiguities. Interferometry is viable if the radar has adequate range resolution, the signals are sufficiently stable, the antenna elements are not too widely spaced, and the received signals are combined after analog-to-digital conversion.

2.12 Automated Setup and Calibration

The UIR will be automated for setup and calibration. Setup includes tuning the radar, verifying the loop gain, testing the performance of transmitter and receiver, phasing receiver channels, scaling error gradients, and, increasingly, setting parameters and verifying the correct operation of software-based subsystems. Calibration includes measuring and validating the systematic errors that affect a radar track, such as an incorrect zero setting, angle encoder orientation, or transponder relay value. Calibration is what sets instrumentation radars apart from surveillance radars and other tracking radars. Instrumentation radars must be set up and calibrated frequently to ensure the necessary accuracy and precision. Automating these processes will greatly reduce the effort needed and hence the number of highly skilled personnel. Many instrumentation radars have some degree of automated calibration already. Some additional development will be needed to more fully automate calibrations, but this should be straightforward engineering.

2.13 Spectrum Management

The UIR family may utilize different frequency bands and waveforms, but each variant will have to operate in an increasingly crowded electromagnetic spectrum. The UIR will use a variety of techniques to insure that it does not interfere with other systems. For large test ranges where many radars will be operating simultaneously it will be important to guard against interference with other UIR or legacy instrumentation radars. The UIR will use digitally produced waveforms to reduce frequency spurs. It will be digitally tunable in small frequency steps across its entire operating frequency band. It will also use digitally controlled waveforms to set its operating bandwidth for specific test demands but no wider. Pulsed radar systems will use a central automatic phasing system to manage transmit/reception time slots for each radar in the network. All LFM waveforms will use both up-chirp and down-chirp to reduce correlation between waveforms. Frequency hopping and waveform coding should be used only when necessary as these techniques complicate radar measurements.

2.14 Real-Time Data Recording, Processing, and Display

All data collected and all actions taken by the UIR must be recorded for subsequent processing and analysis. Many of the measurements will be obtained and displayed in real time (e.g., Range-Time-Intensity plots). Other measurements, such as miss distance, attitude, and damage assessment, will rely on high-resolution waveforms that may require additional post-test processing. For miss distance measurements a combination of data from multiple radars will be needed. Most of the radar signal processing development has or will have been done by the time the UIR is developed. Some other development will be needed on the real-time recording and display, but this should be straightforward engineering.

2.15 Real-Time Control

The UIR will be controlled in real time in a variety of ways. First, it will be controlled in general by a human operator. Second, it will be controlled by the RCL that will be programmed and activated by the human operator. Third, it may be guided by an expert system. Finally, it will often be integrated into a ROC that will combine the operation of many UIRs into a single integrated SoS.

2.16 Remote Operations Capability

The ROC will allow for the rapid connection of multiple individual UIRs and legacy instrumentation radars into a self-organized, interconnected, and inter-operable network of radar sensors. Likewise, a number of operator stations, support equipment, and planning and data reduction software will attach to the network, seek various services that might be available on it, and then subscribe to those services as needed to control the attached radars as a single integrated system. The ROC provides a central hub for planning, setting up, calibrating, and operating the radar and for post-test processing of data from many individual radars. The ROC will concentrate radar operations so that fewer operators will be needed to support complex tests. The ROC will also coordinate the operation of many radars on the same test by centrally managing their spectra. In addition to these requirements, the ROC must also be flexible. Some ranges may require only one ROC controlling all of its radar assets. Others may require many smaller and less capable ROCs operating together. Others may elect to operate multiple independent ROCs so that many smaller tests can occur simultaneously.

2.17 Radar Control Language

The UIR will need to be able to track multiple objects in a complex, rapidly changing environment - a situation that will often overtax the human operator. To remedy this situation, an RCL will be developed, which will be a high-level language that is programmed prior to the mission to control the radar in real time. It will be possible to program for deployments, dispenses, intercepts, and other events, changing the radar's behavior as the test scenario unfolds. Development of the RCL should be straightforward, especially if all of the command and control (C2) software methods are exposed, but it must be done carefully, since RCL will have to make operator-type decisions in real time. An expert system may have to be developed to help program the RCL.

2.18 Reliability

The UIRs will be designed and built to be reliable, both the equipment and the calibration of the radar. Present instrumentation radars are maintained and operated by highly skilled on-site technicians who are constantly repairing and calibrating to keep the radar in top condition. Future radars will have to be more reliable because they will have to be operated remotely and the number of highly-skilled technicians will be reduced to lower labor costs. Improved reliability will mean added initial costs, but the engineering to achieve the reliability is straightforward. A reliable design should also use modular units, as this eases maintenance and improves the availability of the system. The design should also avoid as much as possible components or subsystems that the marketplace does not support. The use of reliable, modular, and COTS components should be a goal of new radar subsystem designs.

2.19 Polarization Diversity

The UIR probably will not have polarization diversity. It may be used in some single-object trackers, however, where measurement of polarization is important to the test (e.g., verifying missile seeker characteristics).

CHAPTER 3

The Radar Roadmap

This plan addresses what we see as the relevant radar solutions to the perceived requirements of 10, 20, and 30 years into the future. It includes many excellent cost-effective solutions that are already in existence, and it includes various developments that are needed to meet the more stringent requirements anticipated for the future.

Future range radars will utilize a mix of different technologies to provide the specific measurement capabilities needed at each range; however, all range radars will utilize common hardware and software elements and they will use standard remote-control interfaces to allow any radar to operate at any range. Radars operated at the test and training ranges will not be identical. Nevertheless, we have identified four broad classes of radars that are likely to be used; Single-object Trackers, Multiple-Object Trackers, High-Resolution radars, and CW radars.

3.1 Single-Object Trackers

For many test and training applications, low-cost single-object trackers are a viable option. Single-object trackers generally use narrow beam widths and high-power pulsed waveforms. They can track skin (echo) pulses or they can track objects that have been augmented with standard range transponders.

Many test ranges operate AN/FPS-16 or other single-object trackers. These workhorse radars have a basic antenna and pedestal configuration that is very stable, providing angular accuracies of about 0.1 milliradians. Most of the pedestals have been kept in top-notch condition so updating the electronics around this pedestal makes better economic sense than procuring entirely new radars. Using this approach, an updated design can be procured via the Instrumentation Radar Support Program for about $5 million.

Of course this approach provides only range, azimuth, and elevation data, since the updated radars are neither coherent nor wideband. Some test ranges may prefer this low-cost approach as an initial investment and then use it as a stepping stone for subsequent improvements. Alternately, advanced radar technologies can be folded into the effort at the outset, albeit with some increase in cost.

The radar could be converted to use a 1-megawatt (MW) klystron or a cross-field amplifier to provide stable output for use with moving-target-indicator or pulse-Doppler tracking. A larger 5-MW transmitter could be used with an existing 30-foot dish for improved sensitivity or for tracking objects at orbital ranges. New transmitters should be designed to operate with full coherency. As much as possible, high-power solid-state transmitters should be used, as has been done at the Air Force Eastern and Western Ranges.

Digital waveform generation technology can be utilized to create high-resolution waveforms, and these can be interleaved with, or used in lieu of, skin and transponder waveforms to provide greater tracking flexibility. Clutter suppression, remote control, and Doppler tracking could be modular additions.

In some cases Single Object Tracking Radars will need only slight improvements to meet future testing needs. Manufacturers have built different parts of the radars at different times to sell to various domestic and foreign customers, so some parts are of current design and others are nearly obsolete. Upgrade efforts should focus on producing a standardized modular design with improved reliability, remote control, and automated calibrations. Upgrades should be designed with an open architecture so that future improvements can be easily added.

In other cases, new single-object tracker designs should be procured. As long as modular open-architecture designs are used and all interface standards are followed, they should be easy to integrate and operate on all of the test and training ranges. Most existing single-object trackers operate in a subset of C-band (5.4 to 5.9 MHz). To maintain transponder compatibility across the test ranges, new radars should be designed to also operate within this band.

3.2 <u>Multiple-Object Trackers</u>

The MOTRs are used to track many objects over wide angular extents. One approach is to use an electronically steered phased-array antenna to timeshare the beam among many tracked objects. Phased-array radars can track with full sensitivity over angles that extend to 60^{o} or even 90^{o}. Another approach is to simultaneously illuminate the entire angular extent and then track all of the detected objects within it. Both approaches can benefit from high-resolution waveforms so that they will be able to resolve, detect, and track closely spaced objects.

White Sands Missile Range (WSMR) and Patrick Air Force Base (AFB) operate the phased-array AN/MPS-39 MOTRs. The MOTRs are valuable assets, so these ranges should arrange for an ongoing product improvement program for them. This program would first update or replace obsolete operator consoles, the signal processor, the transmitter power supplies, and the computer subsystems. It would also be wise to separate the basic radar functions from the control functions and put them on separate computers. Improved reliability, both equipment and calibration, should be a high priority for all upgrades. These updates would insure that MOTRs will maintain their existing capabilities well into the 21^{st} century.

The MOTR product improvement program should also provide some additional capabilities. In fact, all of the advanced technologies except the active array and digital beam forming could be incorporated through relatively straightforward engineering in the next few years. The MOTR is already fully coherent, so no development is needed here. Automated setup and calibration have been incorporated to a large extent but will be increased. High-range resolution, including digital waveform generation and RCL, has been studied for implementation. Real-time data recording, processing and display, and control will naturally grow as the high-range resolution and RCL are implemented.

Large-aperture phased-array antennas such as the MOTR require thousands to tens of thousands of antenna elements. This complexity makes a new phased-array radar design tailored for test range needs unaffordable. It is unlikely that any of the ranges will be able to fund the development of a new phased-array radar or procure them in quantities large enough to offset the initial cost through large-scale production. Procuring existing phased-array radars and then modifying them for test applications is also cost-prohibitive. Another approach is needed.

Radars designed for tracking multiple objects do not have to utilize phased-array technologies. One approach is to use a wide-transmit antenna beam to illuminate all of the targets within a volume of interest. A wide-beam-width antenna will have less gain relative to the narrow beam widths used with phased-array antennas. This means the radar will be less sensitive than a comparable radar that uses a narrower beam; however, the approach does have several advantages. The transmit antenna is simple and much less costly. Detecting objects is quicker because all objects within its beam width are viewed simultaneously in range-Doppler space. (Phased arrays must incrementally search each beam position.) Wide-beam-width designs allow for greater waveform flexibility, with some high duty-cycle waveforms making up for lost sensitivity. It is also relatively easy to dynamically adjust the beam width so it can adapt its angular extent to testing requirements.

A conventional wide-beam-width receiver antenna may not produce sufficiently precise angle measurements. Instead, digital beam forming technologies applied to several antennas are used to create multiple simultaneous narrow beams.

Using this approach, test ranges that require multiple-object tracking could procure capabilities similar to the MOTR but at a fraction of its replacement cost.

3.3 High-Resolution Radars

High-resolution radars should be used to meet the needs of customers who require the utmost from radar data. For this reason these radars are identified as a separate class, although in practice their capabilities might be folded into many of the other radar types.

One challenging test area is high-altitude engagements. Here high-resolution radar data is needed to measure vehicle attitude and coning motions, detect deployed objects, establish radar cross section on individual scatterers, determine miss distance, assess damage, and estimate particle size of impact debris. Another area is in low-altitude munitions dispense. Here high-resolution radar data is needed to track many closely-spaced objects, detect fratricide, identify objects, detect events, measure ballistic coefficients, and track dispensed submunitions from deployment to impact.

One low-cost approach to adding high-resolution capability to a test range is to augment the existing radars with small, special-purpose, slaved (i.e., non-tracking), data-collecting radars. Eglin AFB and WSMR have developed and field-tested prototype high-resolution radars of this type, so little development effort is needed. The basic design can be tailored for high-altitude or low-altitude tests. A slightly more complex design will allow it to operate effectively in both arenas.

A high-resolution radar designed to observe high-altitude engagements would operate at X-band (8.5 - 10.55 gigahertz) with up to 1500 MHz of bandwidth providing 10-centimeter resolution. It would be transportable, monostatic, and solid-state; it would digitally generate an LFM chirp waveform and then use stretch processing and pulse compression on the received signal. It would operate at 15- to 140-kilometer (km) ranges (but easily extendible to 280 km), using 2^o to 5^o adjustable beam width. The cost can be reduced by not requiring it to track in real time; it can be set up to collect high-resolution data and then pointed toward the target using track data from other radars.

A high-resolution radar designed to observe low-altitude dispenses would be very similar to the high-altitude version. Here the radar would operate at ranges of 2 to 20 km and would use an adjustable beam width between 5^o and 50^o. The cost of this radar can be reduced either by using other radars to point it toward the test arena or by operating with a stationary antenna and collecting data only within its illuminated angular extent.

The radars would be nearly identical except that the high-altitude version would use narrower beam widths and higher transmitter power than the low-altitude version. The radars would share C2 software, transport trailers, and many electronic subsystems. They would use the same digital waveform generator so that either one could generate variable-length LFM pulses for long-range use or frequency modulated continuous wave (FMCW) waveforms for tests at shorter distances. Test ranges that require both high-and low-altitude capabilities should plan on procuring a single radar design that can be used for both types of tests.

Some test ranges will require the high-resolution radars to track objects in real time. Here the radar may need to resolve and detect hundreds to thousands of objects in a cluster, track all of them, identify the targets, and then provide real-time cueing data to optical or other instrumentation on selected targets of interest. Most of this development work has already been done, so providing this capability will require only straightforward engineering.

3.4 Continuous Wave Radars

In many tests, the customer needs to know what happened and when it happened to identify and characterize events. Often these events occur early in the launch of a missile but they also occur frequently in the terminal period when munitions of one type or another are dispensed by either missiles or projectiles. These events often can be adequately characterized by their Doppler, provided the Doppler ambiguity interval is sufficiently wide. Although coherent pulsed radars can obtain Doppler on the tracked objects, the ambiguity interval is usually too small to allow the various Dopplers to be sorted out. The CW radars, by contrast, have a theoretically infinite ambiguity interval that can be digitized at a rate high enough to preserve the necessary Doppler interval. The CW radars are also excellent for providing TSPI on direct-fire weapons and mortars. Small transportable, solid-state CW radars are inexpensive, and also very reliable. Each range should buy CW radars and incorporate advanced technologies as needed.

Of course CW, FMCW, and LFM modulation can all be accomplished in the same small, reliable, inexpensive, high-resolution radar.

3.5 Remote Operations Capability

The test and training ranges will use a variety of different classes and combinations of radar instrumentation. The ROC is the key element in transforming these radars into an integrated SoS. It provides a set of standard services so that radars can be operated individually, in several small independent enclaves, or in a centralized C2 environment. A ROC also insures interoperability among all the range radars, thus facilitating resource sharing among the ranges.

The ROC uses network equipment and servers hosted on the test range's communication backbone to form a virtual radar network. It links radars, calibration towers, operator stations, and various software-based services into an integrated whole.

The ROC must be flexible. Each ROC will be tailored to use a mix of available services. It may be almost transparent when operating with one or two radars or it may require a large facility and many services when controlling many radars from a single location. Some services that the ROC may provide include:

3.5.1 Auto Discovery

A radar that has been connected to a range's communication backbone should be able to seek and find the servers associated with a ROC without manual intervention. Once it finds the server, it should then locate the appropriate configuration services and automatically join the ROC radar network.

3.5.2 Remote Startup and Shutdown

The ROC should provide services such that the radar can be fully operated remotely through the network. The ROC should provide a service to start the radars from a powered-down status and also be able to shut down and secure the radar without requiring a technician to visit the radar site.

3.5.3 Assignment of Operator Stations

The ROC must provide services to assign operator stations to radars. Relationships between radars and operator stations (i.e. control consoles) should be selectable as one-to-one, one-to-many, many-to-one, and many-to-many.

3.5.4 Mission Planning Software

The ROC should provide mission planning services to prepare the network of radars for a test. The capability should include the creation and playback of representative target trajectories. It may also include software to determine optimum radar placement, predict terrain masking, avoid potential radio frequency (RF) interference, and select the proper waveforms for the test.

3.5.5 Simulation

The ROC should provide real-time playback of mission planning data through a radar simulator. The simulator can be used for operator training, planning validation, and mission rehearsal. The simulator should provide all operator controls and displays and a simulated radar return. It should also support the automated development of RCL scripts.

3.5.6 Radar Control Language

The ROC should provide an RCL to assist the operators in controlling radars. The RCL should have simple if-then-else and loop capabilities and be able to access the same status and controls as the operator. Ideally, the RCL should be provided through an open-architecture plug-in to provide for third-party development and maximum flexibility.

3.5.7 Network Bandwidth Management

The ROC should provide a network bandwidth management service to help the operator adjust the network demands of the radars to accommodate the available bandwidth. The software should provide safeguards so that the operator can maintain full control of the radar as the highest priority.

3.5.8 Frequency Spectrum Management

The ROC should provide all the services needed to manage the RF emissions of the networked radars in a crowded RF spectrum. This may include automatic phasing for pulse radars or automatic interleaving of LFM waveforms to avoid interference between the radars.

3.5.9 Software Services

The ROC should provide push and pull software updating services. Push updates load new software into the radar processors from a central archive. Pull services check the attached radar to see if its software is more current than the archive and then update the archive if it is.

3.5.10 External Data Management

The ROC will often provide the real-time data interface between the radar network and the range control center(s). The ROC should provide services to manage the various protocols and data rates for the track and cueing information flowing between the range and the radars.

3.5.11 Central Data Logging

The ROC should provide a central data logging service for TSPI data sent by each radar on the network. Each data record should be time-stamped.

3.5.12 Data Fusion

The ROC is the logical location to ingest track data from all of the radars, perform object association, and then fuse individual radar tracks of the same object into a combined trajectory estimate.

3.5.13 Voice over Internet Protocol

The ROC should provide Voice over Internet Protocol (VoIP) services so that operators can communicate with each other, other ROCs, Range Control, and field technicians. The VoIP service should include an optional recording capability.

3.5.14 Data Retrieval

In many cases the radar data will outstrip the real-time network bandwidth and any overflow data will have to be recorded at the radar. The ROC should provide services to retrieve the recorded data after the test when the network load may be less, the data can be compressed, or longer transmit times can be accommodated.

3.5.15 Post-Mission Data Products

The ROC is the logical location where post-mission radar data products can be produced. In most cases post-mission editing, smoothing, data fusion, test assessment, and calculation of derivative flight information can best be performed by skilled radar operators and data analysts located within the ROC.

3.6 Miscellaneous

First, specialized uses of instrumentation radars should be considered as particular circumstances of the test/training ranges dictate. These include fine-line Doppler tracking, multiple-object tracking in the single beam of a dish antenna (e.g., the tracking of incoming multiple warheads/decoys or dispensed submunitions), and increased angle resolution through the use of multiple mutually coherent radars. Second, study should continue into alternative technologies, such as impulse radar and multiple-object bistatic radars. The former allows high resolution without the use of pulse compression techniques and the latter promises cheaper systems by using a single transmitter to illuminate the target for multiple receivers.

CHAPTER 4

Additional Remarks

The DoD test and training ranges are configured for a variety of different missions, and therefore require a variety of different combinations of radar instrumentation. A few ranges are making extensive use of GPS, particularly where manned aircraft testing is involved, but even among these ranges, some radar coverage is needed. Some ranges have the need for multiple-object trackers, particularly where multiple objects are dispensed or many objects are in the air at the same time. Other ranges are doing just fine with single-object trackers, although several radars may be used. Still other ranges need a mix of multiple- and single-object trackers. Several ranges are now expressing a need for high-resolution radars to make precise measurements and to detect and characterize events at long ranges or high altitudes, whereas other ranges are doing just fine with TSPI data only, not even using available coherent information. A few ranges need a modest increase in loop gain (e.g., for improved space object tracking), and the two ranges involved in space lift operations need a large increase. Finally, many ranges are combining radar data with optics, GPS, on-board signals, and other types of data to produce a more complete data product.

Whatever the mission or whatever the configuration of radars, most ranges expressed similar concerns. They need periodic updates of equipment to replace antiquated, insupportable, or inadequate components. They need higher reliability, reduced operating costs, more reliable components, more standardization of components and data products, reduced crew size, more automation, and remote operation. They also need to be able to leverage off each other’s developments. In this age of tight budgets, tri-Service development is essential, and coordination and information interchange through the ETMG are more important than ever.

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