ITEA Journal 2010; 31: 284–290
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Electromagnetic Spectrum Test and Evaluation Process

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With today's challenges of evolutionary acquisitions compounded by the dictates of balancing mission needs, Joint interoperability concerns, and decreasing budgets, the combat materiel developer faces increasingly complex acquisition decisions and is besieged with a multitude of requirements when developing and fielding systems. These factors often overshadow the need to address spectrum supportability and electromagnetic environmental effects control when procuring many of our military systems and during test and evaluation. However, by not assessing spectrum supportability and electromagnetic environmental effects during test and evaluation, the probability of systems experiencing electromagnetic interference (EMI), safety hazards, and/or denied operation/deployments increase dramatically. This article outlines the Department of Defense's approach to address and mitigate electromagnetic spectrum concerns throughout the system's acquisition life cycle.

Key words: Electromagnetic Environmental Effects (E3), electromagnetic spectrum, Spectrum-Dependent (S-D), Spectrum Supportability (SS), Spectrum Supportability Risk Assessment (SSRA).

Over the past several decades, the military has documented hundreds of electromagnetic interference (EMI) problems between blue forces that have resulted in diminished mission effectiveness, system failure, and even loss of life. Significant investments have been forfeited or lost due to a failure to address electromagnetic environmental effects (E3) control and spectrum management (SM) during test and evaluation (T&E). In addition, many fielded systems operate with limited capabilities and mission constraints due to vulnerabilities that would have been discovered if spectrum supportability (SS) and E3 controls had been addressed early during acquisition, as recently reported in General Accounting Office Report, GAO-03-617R, "Defense Spectrum Management."

In addition, the demand for electromagnetic (EM) spectrum, both nationally and internationally, coupled with increased worldwide implementation of emerging spectrum technologies, has resulted in new and challenging operational problems not previously encountered by our military. Our military now must compete for the use of the EM spectrum in an environment primarily driven by economic factors of the commercial marketplace. To overcome these challenges and reduce the potential for EMI and other ills associated with noncompliance, SS and E3 control needs to be designated as a mandatory critical operational issue (COI) during developmental and operational test and evaluation (DT&E/OT&E) processes.

Background

The operation of the Defense Acquisition System (DAS) is delineated in Department of Defense (DoD) Instruction 5000.02. The operation of the Joint Capabilities Integration and Development System (JCIDS) process is established by CJCSM 3170.01C. Procedures for certifying JCIDS programs are established in CJCSI 6212.01E. SS and E3 control requirements are required throughout the DAS beginning with the preparation of JCIDS documentation and validated through DT&E and OT&E. The relationship between the JCIDS, DAS, E3, and SS processes is depicted in *Figure 1*.

To ensure that these major concerns are addressed, DoD has issued the following policies:

- *DoD Instruction 4650.01 (Policy for Management and Use of the Electromagnetic Spectrum)*. This instruction establishes policy for management

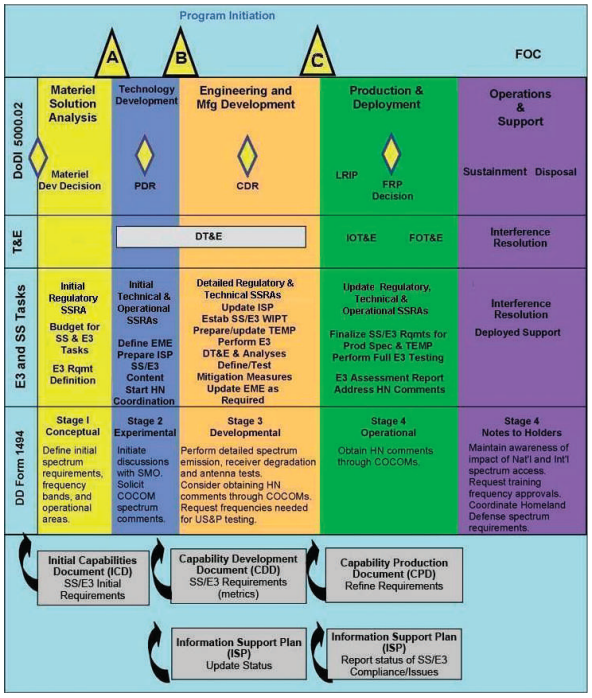

Figure 1. Electromagnetic environmental effects / Spectrum supportability implementation in the DoDI 5000.02 acquisition process.

and use of the EM spectrum within DoD and requires the DoD Components developing or acquiring spectrum-dependent (S-D) equipment or systems to perform a series of spectrum supportability risk assessments (SSRAs). SM is the planning, coordinating, and managing Joint use of the EM spectrum through operational, engineering, and administrative procedures, with the objective of enabling electronic systems to perform their functions in the intended environment without causing or suffering unacceptable interference.

- *DoD Directive 3222.3 (DoD E3 Program)*. This directive requires all electrical and electronic systems, subsystems, and equipment, including ordnance containing electrically initiated devices, to be mutually compatible in their intended electromagnetic environment (EME) without causing or suffering unacceptable mission degradation due to E3. E3 is defined as the impact of the EME on the operational capability of military forces; equipment; systems; and platforms and encompasses the disciplines of electromagnetic compatibility (EMC); EMI; electromagnetic vulnerability (EMV); electromagnetic pulse (EMP); electronic protection; electrostatic discharge (ESD); hazards of electromagnetic radiation to personnel (HERP), ordnance (HERO), and fuels or volatile materials (HERF); lightning; and precipitation static (p-static). E3 also addresses the impact from directed energy weapons and high-powered microwave devices.

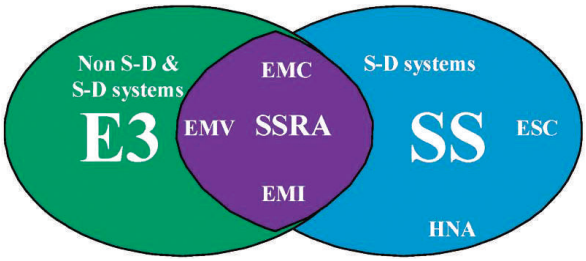

Figure 2. Interrelationship between electromagnetic environmental effects and spectrum supportability.

Together, these policies establish requirements for implementing SS and E3 control throughout the acquisition life cycle including design, development, T&E, and ultimately deployment and sustainment of military platforms, systems, equipment, and forces. These requirements must be addressed early in the program and enforced during milestone reviews by Milestone Decision Authorities. Operational impact assessments of SS and E3 control must be accomplished during both DT&E and OT&E. Doing so has proven to be cost-effective and greatly reduces risks associated with system deployment and supportability. The interrelationship between E3 and SS is depicted in *Figure 2*. The primary overlap occurs during the mutual concern for achieving EMC and preventing EMI for S-D systems and equipment.

Defense Spectrum Organization (DSO)

The DSO is situated strategically in the Defense Information Systems Agency (DISA) to provide leadership in addressing EM spectrum challenges facing the DoD. DSO comprises the Joint Spectrum Center (JSC), the Strategic Planning Office, the Global Electromagnetic Spectrum Information System Program Management Office, and the Business Management Office. Among these divisions, DSO promotes efficient, compatible use of the EM spectrum among our military forces and Allies. DSO's primary missions are to promote effective and efficient use of the EM spectrum to ensure interoperability, reliability, and survivability of military platforms, systems and equipment, and to ensure that system limitations and vulnerabilities are mitigated and documented for the warfighter. The DSO concept of operations also includes provisions to provide support to the Director, Operational Test and Evaluation (DOT&E) and the Services' Operational Test Authorities (OTAs).

Integrated approach for implementing SS and E3 T&E tasks

The following guidance was developed by DSO for program managers (PMs), Materiel Developers (MATDEVs), and OTAs for assessing E3 and SS during the T&E process:

1. Determine the spectrum required to support the mission and define the intended EME in which the system will operate.
2. Ensure E3 control and SS requirements are addressed in acquisition and procurement documentation including JCIDS documents such as the Initial Capabilities Document (ICD), the Capability Development Document (CDD), the Capability Production Document (CPD), Information Support Plan (ISP), and acquisition documents including the Test and Evaluation Master Plan (TEMP), Requests-for-Proposals, Contract Specifications, and other pertinent documents. Additional guidance for implementation of E3/SS during acquisition is provided in MIL-HDBK-237 and the Defense Acquisition Guidebook (DAG).
3. Apply interface standards such as MIL-STD-464 and MIL-STD-461 to ensure that the system and its subsystems and equipment will operate compatibly in the mission EME. The system must meet its performance requirements when exposed to the operational EME.
4. Define E3/SS test objectives in the TEMP and allocate sufficient resources to conduct test objectives.
5. Verify and document SS and E3 control issues during DT&E and OT&E.
6. Conduct early E3 and SS operational assessments that consider the intended mission including single Service, Joint, and international deployments.
7. Provide E3 assessments during operational test readiness reviews. Report the operational impact, system limitations, and vulnerabilities from unresolved E3 and SS problems.

Defining the EME

Fundamental to the process is defining the intended operational EME. MIL-STD-464 establishes maximum external EMEs for shipboard operations, space and launch vehicles, ground systems, fixed wing and rotary wing aircraft, and ordnance. MIL-HDBK-235 provides the assumptions, scenarios, and rationale used to derive the levels in MIL-STD-464. The following steps are provided to further refine and tailor these EMEs based on specific mission scenarios:

- Step 1. Identify the mission scenarios in which the system or equipment is targeted and the associated platforms and systems supporting the missions.
- Step 2. Determine the major geographic regions and countries in which the system or equipment is expected to operate.
- Step 3. Conduct engineering analyses to identify EMI source/victim pairs with the proposed system or equipment during these missions.
- Step 4. Run Joint E3 Evaluation Tool (JEET)[1] analysis based on mission profile to identify all systems contributing to the operational EME.
- Step 5. Use MIL-HDBK-235 to verify spectral characteristics of systems and equipment identified in the above steps.

The EME should include intentional and unintentional electromagnetic radiation (EMR) from DoD systems, as well as from civil and foreign systems. Specific mission-oriented EME profiles are defined in MIL-HDBK-235 and are composed of a combination of measured and calculated data.

Equipment Spectrum Certification (ESC)

ESC is required in accordance with Office of Management & Budget (OMB) Circular A-11 and DoD Instructions 5000.02 and 4650.01 for all S-D systems and equipment. OMB Circular A-11 requires ESC by the National Telecommunications and Information Administration (NTIA) prior to submitting budget estimates for program development. Furthermore, all military S-D systems must conform to the spectrum regulations delineated in the "NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management." ESC requests must be submitted by the PM, MATDEV, or other acquisition authority via the appropriate Service frequency management office (FMO) using procedures in DoDI 4650.01 and the NTIA Manual. As indicated in *Figure 1*, ESC is required at each phase of the acquisition process. Prior to operating S-D systems during DT&E and/or OT&E, the PM/MATDEV must obtain a frequency allocation and, in most cases, a frequency assignment to radiate.

Spectrum Supportability Risk Assessment (SSRA)

The SSRA is used to identify and assess regulatory, technical, and operational EM spectrum and E3 issues with the potential to affect the required operational performance of the overall system. As shown in *Figure 1*, SSRAs are required throughout the acquisition process with the level of detail in the SSRAs increasing as the item's design matures. Specifically

- Initial SSRAs evaluate the system's spectrum needs versus national and international spectrum regulatory requirements, availability of spectrum, and the potential for E3 problems:
  - The Initial Regulatory SSRA addresses the relative regulatory status of the candidate system with respect to host nation spectrum policy governing projected deployments and operational frequencies.
  - The Initial Technical SSRA focuses on candidate technologies and required technical parameters, such as system type, platform type, bandwidth requirements, etc. Preliminary EMC analyses are appropriate at this point to identify potential interactions that will require further study.
  - The Initial Operational SSRA takes into account the full complement of S-D systems anticipated to be in the operational environment and requires a more extensive EMC analysis to identify in operational terms (e.g., frequency-distance separations, steps that may be needed to preclude interference).
- Detailed Regulatory and Technical SSRAs, performed prior to Milestone C, provide increased specifics based on the findings of the initial assessments as the program matures. Developmental data are reviewed for impact to systems operation, and potential risks and mitigation measures are discussed.
- Updated SSRAs in each area are required prior to Production and Deployment, with mature Spectrum and EMC sections. Operational environments should be refined and spectrum and EMC risks reduced to acceptable levels through mitigation measures and/or tactical procedures. At this point the system is ready for deployment.

When evaluating SS, operational restrictions, availability of frequencies, host nation approval (HNA), and known incidents of EMI need to be considered. S-D systems and equipment cannot be operated legally until they have been granted ESC by National and DoD authorities; in addition, a frequency assignment must be obtained from the appropriate area frequency manager. For systems that will operate outside the United States and Possessions, an HNA also is required prior to operation in each foreign country designated for use.

Developers of S-D systems and equipment shall identify and mitigate regulatory, technical, and operational SS risks using the suggested tasks in DoDI 4650.01. System developers shall increase the detail of these risk assessments as the item's design matures. Developers shall assess the risk for harmful EMI with other S-D systems and manage it with other developmental risks. SSRAs should be initiated concurrently with the appropriate stage of certification of spectrum support. Complex "family of systems" (FoS) or "system-of-systems" (SoS) acquisition programs may require more than one SSRA.

DT&E E3 considerations

DT&E will demonstrate that the system design sufficiently mitigates E3 risks and that the system is in compliance with its contractual E3 specifications, based on tailored military standards or commercial standards. Developmental testing (DT) usually is conducted in a test laboratory or open area test site. These tests include production acceptance tests and evaluation and first article E3 testing after an item has been approved for full-rate production. Compliance with E3 control requirements provides a high degree of confidence in achieving platform/system compatibility upon integration but does not guarantee it. However, it is known that noncompliance often leads to operational EMI problems; the greater the noncompliance, the higher the probability that an operational EMI problem will occur.

Equipment and subsystem E3 design requirements must be specified early in the program to avoid costly fixes and ensure mission effectiveness. MIL-STD-461 provides detailed performance and verification requirements for emissions and susceptibility characteristics of equipment and subsystems. MIL-STD-464 provides system-level E3 requirements for airborne, sea, space, and ground platforms and systems, including associated ordnance. The design characteristics, as well as the intended mission, installation, shielding integrity, choice of components, and use of filtering should be considered when performing developmental tests.

OT&E E3 considerations

OT&E assessments are required to validate unresolved E3 problems and to document mission limitations and/or vulnerabilities. During OT&E, E3 testing should be structured to identify and resolve issues that impact mission effectiveness. The assessment should evaluate the impact to other key performance parameters described in the TEMP. These evaluations, which may include both tests and analyses, also may be used to formulate operational procedures and tactics for the item. OT&E assessments should be accomplished in as realistic an operational EME as possible. It is important that resources and assets required for

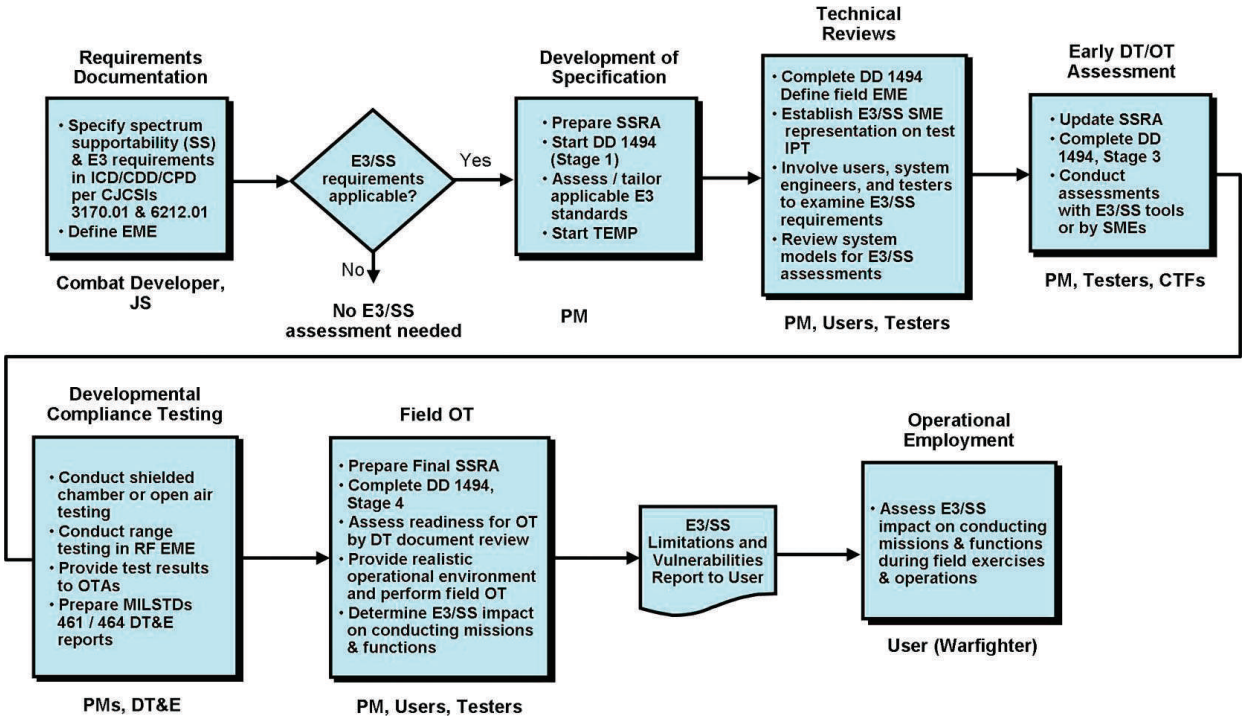

Figure 3. Spectrum supportability and electromagnetic environmental effects assessment process.

verification of E3 requirements be identified early in the program to ensure their availability when needed.

During operational testing (OT), potential EMI source versus victim pairs corresponding to the susceptibilities observed during DT should be identified and systematically evaluated by exercising the subsystem and equipment onboard the platform or system through the various modes and functions while monitoring the remaining items on the platform or system for degradation. Both "one source versus one victim" and "multiple sources versus one victim" conditions should be evaluated. The most common approach is to monitor performance through visual and aural displays and outputs. The need to evaluate antenna-connected receivers across their operating frequency ranges is important for proper assessment. In addition, detection of undesired responses during EMI testing may necessitate an EMV analysis during OT&E to determine the impact on operational performance. EMV analyses require identification of both friendly and hostile emitters that the item may encounter during its life cycle and a determination of the likelihood that the source system will be encountered during operation.

Assessment process for SS and E3 control

Figure 3 depicts the assessment process for SS and E3 control during acquisition. It highlights key objectives from the initial development of requirements to operational fielding. After requirements have been validated by the Joint Requirements Oversight Council, a decision must be made by the PM/MATDEV to determine whether the materiel solution will require SS and E3 control (i.e., is it electrical/electronic and/or S-D). If either SS or E3 control is required, then the subsequent technical reviews, assessments, and testing are mandatory throughout the remainder of the acquisition process. Early involvement from testers and the user community is recommended. Test events should be planned and resourced appropriately to achieve test objectives. SS and E3 control tests should be incorporated into the TEMP. Once DT and OT are completed, a system limitations and vulnerabilities report should be produced and updated periodically if SS and E3 control issues are discovered during operations.

The SSRA is discussed in detail above. The E3 assessment should document and examine compliance with tailored E3 requirements based on the mission needs defined by the combat developer and/or Joint Staff and required by the ICD, CDD, and CPD. In addition, the PM/MATDEV should ensure that the TEMP outlines the specific COIs aimed at verifying EMC. Any additional problems uncovered by verification testing need to be documented and the mission and design of the system may need to be reevaluated. Once all E3 concerns have been identified, an E3

Table 1. Data requirements for spectrum supportability and electromagnetic environmental effects assessments.

Objective: To identify, to the best extent possible, the E3 and SS limitations and vulnerabilities of the subject system.	
Information as appropriate to program development	**Responsibility**
1. DD Form 1494 submitted to the Service Frequency Management Office (FPO)	PM
2. Spectrum Supportability Risk Assessment (SSRA)	PM
a. Regulatory SSRA	
b. Technical SSRA	
c. Operational SSRA	
3. Description of operational electromagnetic environment (EME) (e.g., operational environment, theater, mission in the OPLAN)	PM
4. Latest program documentation (e.g., ICD, CDD, CPD, ISP, TISP, Specification)	PM
5. TEMP, which contains	PM
a. E3 within the scope of a critical operational issue (COI)	
b. list of tests and analyses used to determine the equipment effectiveness/suitability/survivability performance in the operational EME	
6. Copy of the following analyses and/or test and evaluation data	PM
a. intra-platform/system analyses	
(1) antenna coupling and blockage analyses and/or test data	
(2) subsystem/equipment EMC analyses and/or test data	
(3) CI/NDI/GFE EMC analyses and/or test data	
b. inter-platform/systems EMC analyses and/or test date for spectrum-dependent and non-spectrum-dependent equipment	
c. special E3 analyses and/or test data (i.e., HERO, HERP, HERF, EMP, Lightning, and P-Static), if required by the CDD, CPD, or TEMP	
7. E3 and SS impact assessments that identify and define operational limitations and vulnerabilities (i.e., lessons learned)	PM
8. DT&E Test Plans and results/reports	PM
9. OT&E Test Plan and results	OTA
10. User-initiated test results	OTA

E3, electromagnetic environmental effects; SS, spectrum supportability; PM, program manager; OPLAN, operation plan; ICD, initial capabilities document; CDD, capability development document; CPD, capability production document; ISP. information support plan; TISP, tailored information support plan; TEMP, test and evaluation master plan; EMC, electromagnetic compatibility; CI, commercial item; NDI, non-developmental item; GFE, government furnished equipment; HERO, hazards of electromagnetic radiation to ordnance; HERP, hazards of electromagnetic radiation to personnel; HERF, hazards of electromagnetic radiation to fuel; EMP, electromagnetic pulse; DT&E, developmental test and evaluation; OT&E, operational test and evaluation; OTA, operational test authority.

Assessment Report stating any anticipated operational issues can be prepared and incorporated into the SSRA, where applicable. In cases where these concerns were not identified during DT, it will be necessary to conduct further assessments as part of field OT prior to preparation of the final E3 Assessment Report and final regulatory, technical, and operational SSRAs.

Supporting documentation

Documentation including DD Form 1494, HN agreements, EMC control plans, EMI test plans and reports, etc., is the foundation for developing E3 and SS test events during OT&E. DT&E test data must be captured and documented. The core elements of the T&E effort are the test procedures and data collection. Faithful execution of the test procedures and explicit data collection will lead to meaningful evaluations during the assessment process. Test reports should summarize the results into viable conclusions and recommendations, thus finalizing the process. To aid in this process, the data item descriptions associated with MIL-STD-461 and MIL-STD-464 should be invoked through the contract specification by the PM/MATDEV.

SS/E3 assessment data requirements checklist

Table 1 presents the data requirements checklist to be used as a guide for the information needed by an SS/E3 assessor. All items except items 9 and 10 should be provided by the PM or MATDEV; items 9 and 10 should be provided by the OTA.

Summary

To overcome the difficult challenges discussed in this article, verification of SS and E3 control during T&E should be mandatory for DoD procurements. System limitations and vulnerabilities must be identified, documented, and provided to the warfighter.

Compliance must be enforced by the DOT&E, milestone decision authority (MDA), PM/MATDEV, and the various Service OTAs. Experience has shown that addressing and mitigating SS and E3 issues early during the acquisition process and verifying that these critical issues are achieved through the T&E process increases both cost and mission effectiveness. In support, DSO can provide the necessary T&E tools that allow for an acquisition to have a successful life cycle from cradle to grave. ❑

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Endnote

[1]Joint E3 Evaluation Tool (JEET). Request a copy from j5@jsc.mil.

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Acknowledgments

The author extends his appreciation to Mr. Jose Blanco (DISA/DSO) and to Mr. Stephen Caine, Mr. Michael Duncanson, and Mr. Joseph Snyder from the staff of EG&G Technical Services, a division of United Research Services (URS), for their support during the preparation of this article.